ENVIRONMENTAL IMPACTS OF SALINE SEEP IN MONTANA

by

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ABSTRACT

Saline seeps are recently developed saline soils in nonirrigated areas that are wet some or all of the time, often with a white salt crust, and where crop or grass production is reduced or eliminated. Saline seep has already affected about 140,000 acres (about 220 square miles) of cropland in Montana, and could potentially affect a total of 17,000 square miles of land in the state. This report examines the geologic, climatic, and land use situations which have combined to produce saline seep. Saline seep systems have four components: recharge, subsurface, discharge, and overland drainage. The last two components affect the biosphere via the soil and surface water systems. The report first examines impacts of saline seep on ecosystems both at the discharge site and downstream. Alternatives for mitigation of saline seep are then discussed and examined for their own environmental impacts. Research for this report consisted of: A review of literature pertaining to saline seep and toxicology of substances found in saline seeps; and field and telephone interviews with research personnel, veterinarians, farmers, stockmen, and others knowledgeable about this problem.

New material (Appendix C) by ecologist Loren Bahls reports recent developments in saline seep monitoring and control. New data on the extent of the problem, current research in control strategies, and activities of the 1975 Montana Legislature on saline seep are summarized.

This report was prepared as a Resources Development Internship Project under the sponsorship of Western Interstate Commission for Higher Education (WICHE) and the Montana Environmental Quality Council (EQC). Project advisers were drawn from EQC, Montana Department of Fish and Game, Bureau of Mines and Geology, Department of Health and Environmental Sciences, and the Department of State Lands.

PREFACE

The Environmental Quality Council (EQC) began its coverage of saline seep in its First Annual Report dated October 1972. This came at a time when few people in Montana, other than those directly affected, had heard of the problem.

The following spring the Governor assembled an emergency committee on saline seep to gather resources and to make recommendations for prevention and control. A representative of the EQC was appointed to that committee.

The EQC Second Annual Report contained an article by Marvin Miller of the Montana Bureau of Mines and Geology and Loren Bahls of EQC, which was an attempt to relate the structural causative components of saline seep to real and potential environmental impacts and to environmentally sound control strategies.

This report by Michael Harlow is the latest in EQC's efforts toward maintaining a legislative overview of the saline seep problem. The report is technical enough to be of some value to professional workers in the field, and hopefully readable and understandable enough to assist farmers, legislators, and government officials in understanding the problem and in applying appropriate control measures. Mr. Harlow's report is written from an environmental perspective and from this standpoint it is easily the most comprehensive treatise yet assembled on the subject of saline seep in Montana. Hopefully, it will generate additional information and data, for the report is intended as an outline of possibilities, a first step toward delineation of the environmental scope of the saline seep problem.

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LAND SURFACE SYSTEMS

Geologic Setting

Saline seeps originating in Montana's valuable dryland agricultural areas have created growing concern, primarily because of the alarming acreages of previously highly productive grainland which have been rendered useless for cropping. All of the 28 counties in Montana which reported saline seep damage during the year 1973 (52)* are located east of the Rocky Mountains in the Great Plains (See Table 1, p. 11.) The most extensive outbreaks are found in the northern part of this region in areas underlain by glacial till of Pleistocene age (152, 33, 219), but saline seeps also occur in non-glaciated portions of the state, and in other regions of the northern Great Plains in neighboring states and provinces.

Occurrence and characteristics of saline seeps are intimately connected with the geologic structures near the surface; these in turn are largely determined by major geologic events of the past.

Inland marine shales of the Colorado Group, deposited in Lower Cretaceous time in an inland sea which covered Montana, were uplifted in the west during Upper Cretaceous and Early Tertiary periods. Erosion, keeping pace with uplift, leveled these first Rocky Mountains into a broad, nearly level peneplain. The sediments, transported eastward as sands and mud by the ancestral Missouri and Yellowstone Rivers, were spread above the marine shales in central and eastern Montana. These sedimentary strata became the sandstones and shales of the Lance Formation of Upper Cretaceous age, and the Fort Union Formation of Early Tertiary age. Great laccolith intrusions formed next, blistering the level plains and forming the island mountains of central Montana. Alluvial deposits from dissection of these highlands soon blanketed the surrounding plains, forming the Flaxville Gravels now found atop the uppermost members of the Fort Union Formation (152).

The pre-glacial Missouri and Yellowstone Rivers and their many tributaries began the dissection of these relatively level sedimentary lands, cutting broad channels into the plains. The down-cutting rivers left behind upland benches complete with discontinuous lenses of alluvial sands and gravels. The great rivers eventually drained into Hudson's Bay. Then great structural warps formed in eastern and central Montana, creating broad domes and arches. Erosion truncated these highlands, exposing the salty shales of the Colorado Group and other older strata (33, 152) (See Figure 1).

The Quaternary Period brought the glacial ice of the Keewatin Continental Sheet southward from Canada in at least four major advances and retreats. Only the last two left their mark upon Montana (See Figure 2). The Illinoian thrust blocked the ancient Missouri River,

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*Footnotes begin on p. 71.

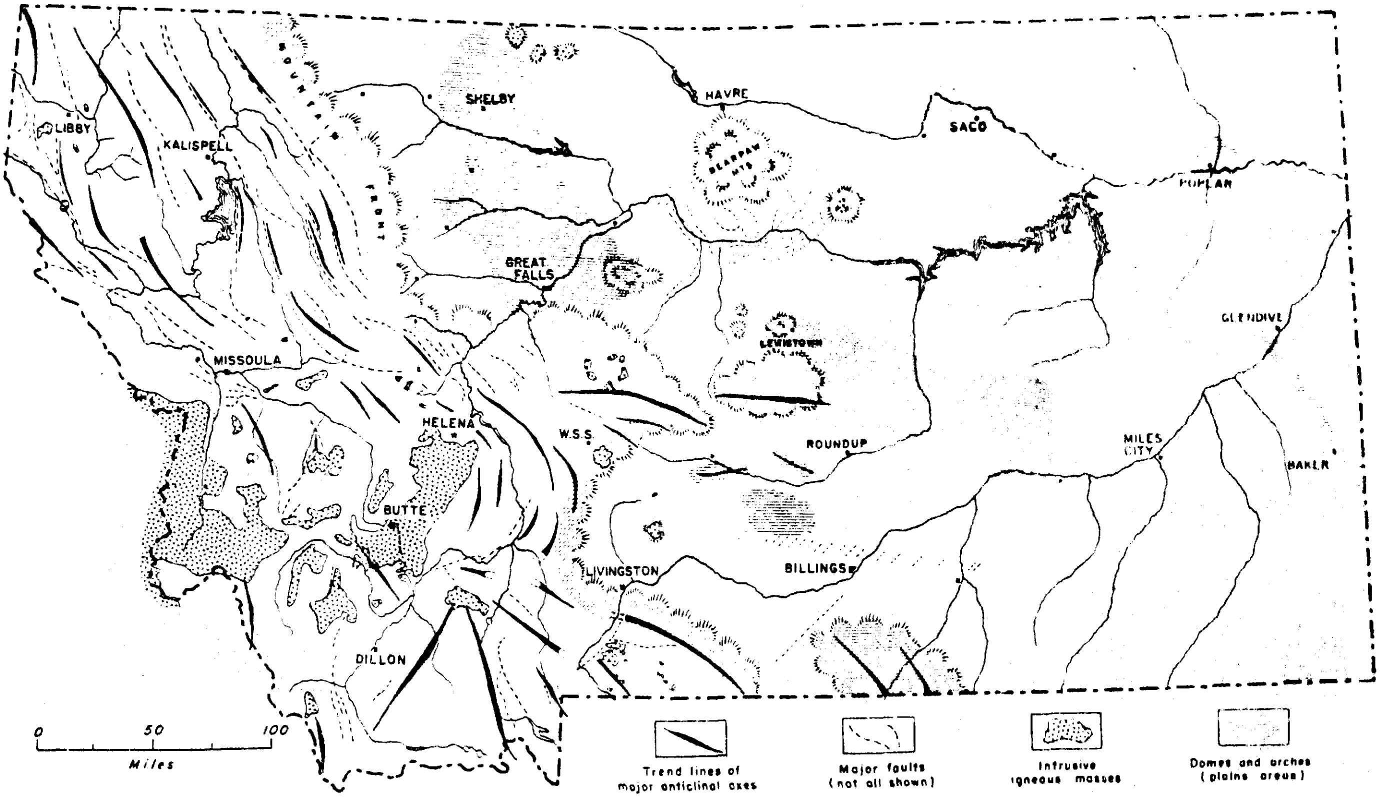


Figure 1. Map Showing Structural Trends in Montana. Deformation in western Montana during the making of the Rocky Mountains resulted in wrinkling and breaking (folding and faulting) of once nearly horizontal strata on an enormous scale. Geologic time was latest Cretaceous and early Tertiary. North of Missoula folds and faults show a northwesterly trend, but southeast of Butte major structural trends show a roughly radial pattern. Granitic igneous intrusions, mainly in southwestern Montana, are early Tertiary in age and later than much or most of the intense folding. In eastern and central Montana early Tertiary and older strata were warped into broad domes and arches with structural basins lying between. This region was then truncated to a nearly level plain. (152).

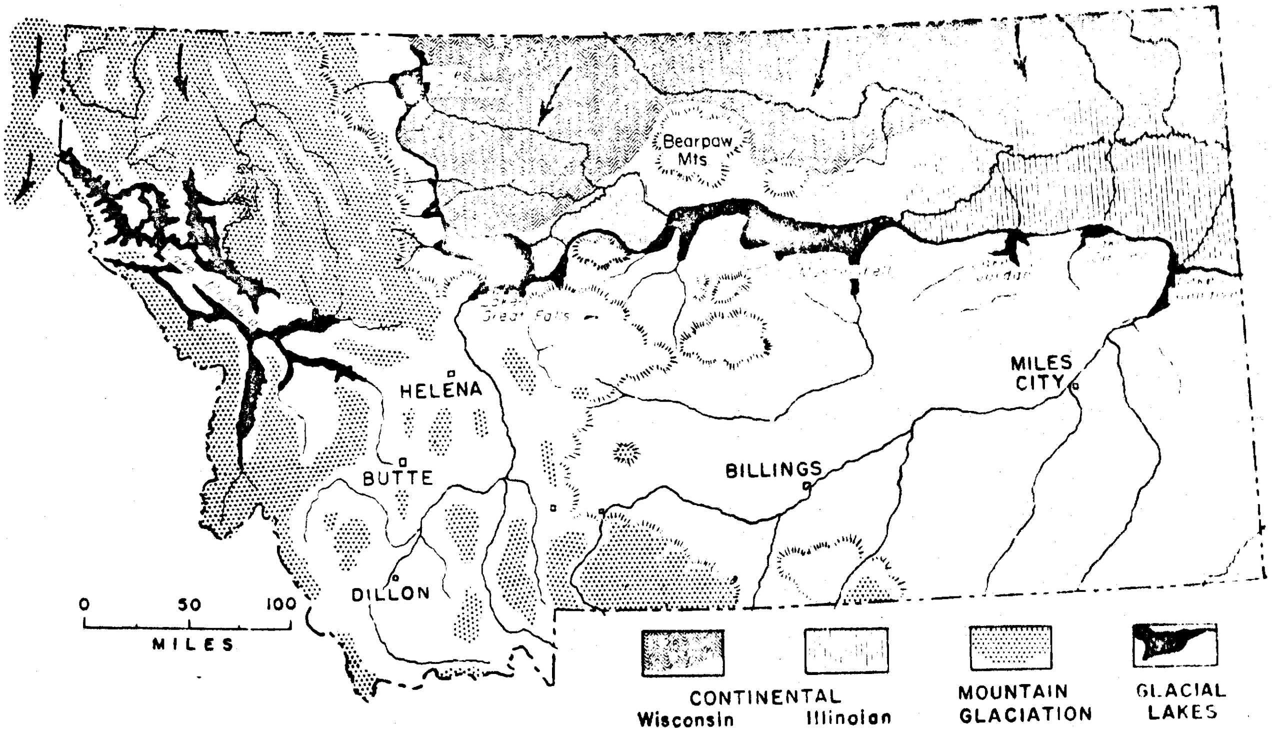


Figure 2. Areas of Glaciation in Montana. A general composite map showing areas where glaciation occurred. Glacial ice in the northern Rockies was both Cordilleran ice which moved in from Canada, and mountain glaciers. They merged together. Ice developed in both Illinoian (?) stage and Wisconsin stage in the mountains as well as on the plains. Ice from the mountain glaciers flowed down creek valleys to lower elevations where it melted, even in Yellowstone River valley south of Livingston. Where continental ice moved across valleys, such the Missouri River, Yellowstone River, and the Clark Fork of Columbia River, large lakes developed in front of the ice. (152).

forcing it to flow eastward, cutting the Shonkin Sag and intercepting the Yellowstone near Glendive. The Wisconsin stage, which was the last major southward thrust of the ice age, erased most traces of the Illinoian glaciation, and laid a nearly level blanket of ground moraine across the northern third of the state. This moraine filled and obscured the ancient valleys of the pre-glacial drainage system, created the basis of the present landscape and topography of the state north of the Missouri River, and formed the parent material for the rich dryland soils which today blanket the region (152, 219).

Entrenched in its present channel, the Missouri River system was joined by tributary streams draining southward across the mantle of glacial till. To the south in the areas untouched by glacial activity, the topography continued to roughen as the rivers enlarged their "breaks" by cutting back along coulees into highland benches and plateaus. On the nearly level upland till, depressions and irregularities hindered the establishment of overland drainage in many areas, and landlocked pothole lakes were common (33).

Native Prairie Ecosystems

Evolution. The glacial tills, generally derived from marine sediments, contained a large variety and quantity of soluble salts and trace elements. Eventually the salts were leached out of the uppermost layers and primary vegetative succession began. After over 15,000 years of succession, climax mixed prairies came to occupy the glaciated lands (7, 148). In their inventory study of the soil and vegetation of near-pristine rangeland prairie sites in Montana, Ross *et al*. (163) found that tall, highly productive grasses such as rough fescue (*Festuca scabrella*) dominated the communities, with only a small percentage of short grasses, forbs, and shrubs. The climax prairie communities evolved as an integrated response to the complex of environmental factors making up their habitat (217). On the Great Plains, the two most important factors controlling vegetative communities are the water content of the soil, and the humidity (217). Through development of a dynamic equilibrium among these facets of the water cycle and the interrelated cycles of nutrients, flow of solar energy, and spatial distribution of plants, the biotic and the abiotic resources of the Great Plains evolved into a diverse ecosystem which was highly resilient, yet at the same time possessed great long term stability.

Climate and Soils. The parent rock became deepening soil under the active biota which lived upon it. Dr. J. E. Weaver, a lifelong student of the American prairie, wrote:

> Soils and vegetation are closely related, intimately mixed, and highly interdependent upon each other and upon the climate. The grassland vegetation has exerted a powerful influence as a soil builder. Plants, which introduce the living, biological factor into soil formation, return much more to the soil than they take from it. In fact, their role in soil genesis is of such far-reaching effect that it is generally conceded that there could be no soil without

> vegetation. The great stability of the prairie, resulting in part from the long lifespan of many species, denotes a high degree of equilibrium between vegetation, soil, and climate (212).

Annual precipitation averages about 10 to 15 inches in the glaciated regions of central Montana, and slightly higher in the eastern sections and at higher elevations on the plains. Annual Class A pan evaporation potential is 40 to 50 inches (81). The climate is true continental (124), with wide temperature extremes and a seasonal distribution of precipitation. Most of the annual precipitation falls during May, June, and July, following shortly behind (or coinciding with) the melting of the snowpack. Snow contributes about 20 percent of the annual precipitation. Climax prairie communities responded to the demanding local climatic conditions through various strategies, such as spatial relationships in rooting habit, temporal distribution of reproductive activities, and emergency dormancy capabilities (217). But the plant community was not merely a passive respondent to environmental conditions imposed by the microclimate. Through time and the processes of growth, natural selection, decay, and soil formation, striking modifications of microclimatic factors were brought about. These modifications gradually changed the barren tills into highly productive grassland ecosystems, able to maintain themselves through both drought and cloudburst, and support the great abundance of wildlife which evolved to occupy the plains before the coming of the white man.

The soils which evolved along with the biota of the northern Great Plains are predominantly Pedocals (148) of the order Mollisols (82). The Brown soils (now Xerolls), underlain by clay at 3 to 8 inches, occur on the drier sites and have a lime layer below the subsoil; darker-hued Chestnut soils (now Ustolls) occupy areas of higher precipitation and are underlain at greater depth by clay and lime layers; Chernozem soils (now Borolls), with their thick dark surfaces, are found on the higher sites (24). Organic content of the topsoil generally decreases westward and the soils become lighter in color. Other major soil types in the northern Great Plains include the Lithosols which have developed over bedrock, slowly deepening to as much as 30 inches, and generally characterized by poorly defined horizons (104).

Leaching of the soluble salts from the surface and subsoil has been incomplete in certain regions of Chestnut and Brown soils. When poor drainage is combined with low rainfall and high evaporation rates, the soils accumulate high concentrations of gypsum (calcium sulfate), epsom salts (magnesium sulfate), Glauber's salt (sodium sulfate), or potassium sulfate (123). These soils then become saline, alkali, or saline-alkali soils. Naturally occurring soils of these types are called "residual alkali soils." It is important to distinguish them from formerly well-leached, productive soils which have become "salty" due to recent saline seep.

The residual alkali soils, which are found among Brown and Chestnut soils in the glaciated till region north of the Missouri River, are classed as Solodized-Solonetz soils by the Montana Agricultural Experiment Station in their survey of the state's soils (124). Alkali soils have an excess of sodium cations on the exchange complex and are diagnosed by exchangeable sodium percentage (ESP) of greater than 15 and specific conductance (EC_{25}) of less than 4 millimhos cm^{-1} at 25C (206). The Solonetz soils are also known as Black Alkali due to the dispersed and dissolved organic matter present on the surface. Sodium-saturated clays, leached into the subsoil, effectively curtail drainage, and the sodium on the humus exchange sites causes deflocculation and degradation of soil structure. This loss of physical structure, more than any chemical or nutrient effects, results in severe restrictions upon the vegetative composition of Solonetz sites. Greasewood (Sarcobatus vermiculatus) is frequently the only cover found. Where crops manage to take root, growth and yields are depressed (206). Such soils have an alkaline reaction (pH=8.5 to 10) (206) due to presence of sodium hydroxide (NaOH) (148).

The second type of salty soils are the Solonchaks, or saline soils, which do not have a high sodium tie-up of exchange sites (ESP less than 15 percent), but do have high contents of other soluble salts, yielding electrical conductivities greater than 4 mmhos cm^{-1} at 25C (206). The salts, primarily sulfates and chlorides of sodium, calcium, and magnesium (76, 206), are transported to the surface by evaporating groundwater, and are characteristically left as a white crystalline crust on the surface. Deflocculation is not usually a severe problem for the magnesium and calcium cations continue to maintain their dominance on the cation-exchange sites. Saline soils are thus reclaimable if the excess salts can be leached below the active root zone of plants (76, 85, 47).

A third type of soil may be found which is a combination of these two. Termed saline-alkali soils and characterized by both high electrical conductivity (greater than 4 mmhos cm^{-1} at 25C) and high exchangeable sodium (ESP greater than 15 percent), such soils generally become strongly alkaline when leached, and then deflocculate due to high sodium content. These soils require extensive treatment to replace the sodium with calcium or other more desirable cations on the exchange complex, and to restore suitable structure to the profile (206).

Water Use. There were substantial amounts of naturally saline, alkali, and saline-alkali soils present on the northern Great Plains when Lewis and Clark passed through Montana in 1805 (33), but the native prairie ecosystems effectively limited these soils to a small percentage of the total land surface. Biotic evolution is a response to the available resources of an environment, and is strongly influenced by "limiting factors." Water was a prime limiting factor on the northern Great Plains, with its semi-arid climate, scorching sun, desiccating winds, and highly erodible soils. The prairie had several mechanisms for maximizing the utility of the rainfall and for coping with the effects of these other stresses. By controlling the water budget of the prairie sod, these mechanisms helped prevent the spread of saline soils.

Protection of the soil from water erosion was accomplished through vegetative structures such as leaves and stalks, which shielded the mineral earth from mechanical forces of rain and hail through accumulation of a protective mulch of decomposing plant litter and through interception and evaporation of large quantities of precipitation. Weaver (217) discovered that "the amount of water intercepted by herbaceous plants is often surprisingly large." Wheat, alfalfa, needlegrass (Stipa spartea), and little bluestem (Andropogon scoparius) were all found to intercept and evaporate over 50 percent of a moderate application of water:

> Water is held upon plants in the form of thin films or as drops which form on the surface, at the tips, or along the margins of the leaves. Water also adheres to the stems. The extent of the leaf surface and the number of levels at which water may be held are important factors in determining the percentage of interception. Prairie vegetation has a foliage surface that is three to twenty times as great as the soil surface beneath it; leaves are displayed at many different levels (217).

Infiltration of precipitation precludes overland runoff and surface erosion. In addition, the prairie ecosystem controlled erosion through other means:

> The same cover of vegetation that intercepts the rainfall exerts a profound effect upon the force with which the raindrops strike the soil and upon their entrance into the soil by absorption. In prairie where there is a cover of grass, the force of the rain is broken by the foliage of the grass and other herbs and by the litter of fallen leaves and stems beneath...The lodgement of the undecayed materials among the stems of the grasses forms an intricate series of minute dams and terraces which tend to hold the water until it can percolate into the soil. Abundant humus creates a sponge-like condition in the topsoil, and this increases its capacity to absorb and hold water. Hence runoff in the prairie is usually slight unless the rains are heavy. Even during a heavy rainfall, the water that runs off is usually clear since the soil is firmly held in place by the bases of the plants, by their widely spreading and much-branched rhizomes, and by their widely and deeply spreading root systems. (217)

Soluble salts that remained in the soil profile of the prairie as it was formed generally were insufficiently concentrated to form a saline soil (206). Only where salts and other soluble contaminants have been transported and concentrated in an area by movement of water, either surface or subsurface, can soils become sufficiently altered to cause marked response in the biotic sector. In the native prairie ecosystem, surface water runoff was effectively reduced, slowing erosion and retarding development of dissected drainage systems. Limited by the sparse precipitation, the prairie evolved mechanisms to utilize all water which infiltrated into the soil.

After fifty years' study of the prairies of the Great Plains, Weaver (217) wrote at length about the vast biotic systems which lie unseen and even unsuspected beneath the surface of the land:

> The most obvious conclusion...is that prairie species are provided with well-developed, deep-seated and extensive root systems. On the basis of root depth, the...species...may be divided into three groups. The first groups includes plants with shallow roots that seldom extend below the first two feet of soil. This group, consisting entirely of grasses, makes up only fourteen percent of the total. The second group, of intermediate depth, is composed of grasses and forbs with roots that extend well below the second foot but seldom deeper than five feet. [This group composes] twenty-one percent of prairie species. The third and largest group is composed of plants whose roots extend beyond a depth of five feet (some to twelve, even twenty-three, feet), and this groups includes sixty-five percent of the species selected as typical of the prairie flora. Examination of the deeply rooted species shows that only about one-fifth rely to any marked degree upon the shallow soil for water or nutrients, and that many species, when mature, carry on relatively little absorption in the first, second, or third foot. Layering of the roots reduces competition and permits the growth of a larger number of species.

Excess water percolates downward as gravitational water after the available soil pore spaces in the profile have been filled. Mature prairie soils, interlaced with water-thirsty rootlets to great depths, allow little if any of the percolating water to pass beyond reach of the root zone (43). Plants remove water from the soil as a function of the heat load, the rooting depth, and the amount of plant-available water present in the root zone (76). The prairies served their vital function in the hydrologic cycle of the Great Plains by presenting an active root system at the time of the year when the soil profile was filled with water--during the spring and early summer. Perennial vegetation, with deep, well-established root systems, stood ready to suck this water from the soil. Seepage downward into subsurface water tables was normally minimal. The net result was that percolating groundwater leached soluble salts in only one direction: downward into subsoils. Lateral movement of salt-laden water was thus very limited and transportation to other locations and possible concentration of salts were restricted to special circumstances. Some leakage below the root zone did occur during years of abnormally high precipitation, or in areas where the topography offered depressions. These areas remained essentially static except for seasonal fluctuations. For the most part, the prairies protected themselves from the threat of spreading salinization of soils.

In addition to its efficiency, the native prairie ecosystem had evolved another advantage--durability:

> Plant parts in prairie sod are protected from sudden and extreme changes in temperature. They are scarcely harmed by frost or severe cold of winter, driving hail, tornadoes, or prairie fires. They endure ravages by grasshoppers and greatly prolonged drought. To prairie sod, only the plow or long-continued close grazing are lethal (217).

Breaking the Plains

First the miners, then the cattlemen, and finally the dryland homesteaders flocked to the bountiful promise of the Treasure State. The homesteaders tilled the plains during the first two decades of this century. With a cycle of high-yielding wet years, homesteaders pushed even marginal agricultural land into production. This boom soon burst as a dry cycle sent production plummeting. The prairie winds lifted naked soils and squalls churned the dust, and more than half the homesteaders went bust. Then, in an historic inspiration, a desperate farmer noticed that the wind did not take the soil immediately leeward of his struggling stand of wheat. He put his crops in strips perpendicular to the prevailing winds, and discovered that he had virtually solved the problem of wind erosion. Later it was realized that cropping in alternate strips could be adapted to conserve moisture in the soil. Thus evolved the cropping system known as "summer fallow," characterized as:

> a farming practice wherein no crop is grown and all plant growth is controlled by cultivation or chemicals during a season when a crop might normally be grown. Thus production for one season is forfeited in anticipation that there will be at least partial compensation by increased crop production the next season (82).

Summer fallow began with the Mormons in Utah and was later introduced into Canada and Montana as they moved northward. It became almost universal in northern Montana's dryland regions (See Figure 3). Extensively studied, (43, 47, 82) it remains a highly controversial solution to the environmental demands of agriculture on the northern Great Plains. Haas *et al*. (82) reviewed summer fallow and compared it with annual cropping for spring wheat production in the northern plains. He summarized the advantages and disadvantages of summer fallow as follows:

Advantages:

1. Higher yield per planted acre.
2. More stable production.
3. Higher soil water content.
4. Greater supply of available nitrogen in the soil.
5. Aids in the control of weeds.
6. Aids in distributing the work load of the farmer.
7. Reduces insect and disease problems.

Disadvantages:

1. Greatly increased wind and water erosion of soil.
2. Increased air and water pollution.
3. Lower soil water storage efficiency.
4. Lower water-use efficiency.
5. Greater soil fertility decline.
6. Promotes development of saline seep areas under certain soil and management conditions.

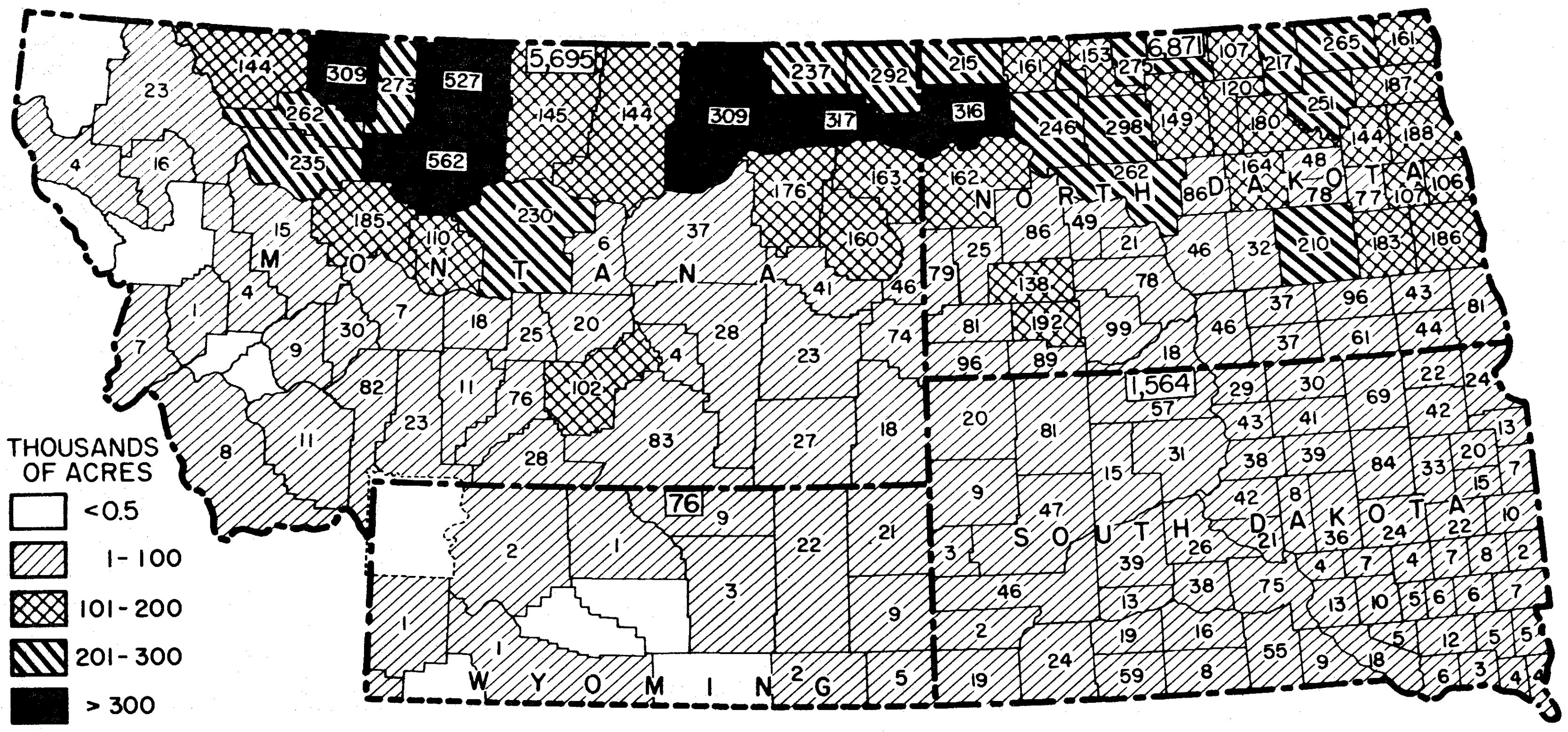


Figure 3. **Thousands of acres of summer fallow in each county of the northern Great Plains (counties with 500 acres or less of fallow are blank)** (82).

Saline Seep Outbreaks

Historically, saline seeps are a recent development on the northern Great Plains. To distinguish saline seep from residual alkali soils and from superficially similar (but causally distinct) saline problems resulting from irrigation mismanagement and leakage (214, 224, 219), saline seeps are defined as follows:

> Saline seeps are recently developed saline soils in nonirrigated areas that are wet some or all of the time, often with white salt crusts, and where crop or grass production is reduced or eliminated (33). (Emphasis added)

The beginning of saline seep outbreaks during the 1940s followed shortly after the establishment of the alternate crop-fallow (summer fallow) farming system. Wholesale adoption of the summer fallow system was heralded by introduction of large, high-powered farm machinery which made it practical and profitable to strip-farm extensive acreages. The efficiency of water storage was greatly improved due to cultivation of large areas of fallow land to control weeds. Efficient herbicides for weed control became widely available during this period, augmenting the water storage capability of the summer fallow method. Acreage of summer fallow tripled in the 17 western states between 1910 and 1940 (82). In Montana, 2.7 million acres were summer fallowed in 1930, 4.2 million acres in 1950, and 6.2 million acres in 1964 (87). Bahls and Miller (33) reviewed the history of saline seep in Montana. They confirmed that most of the prairie was plowed during the second decade of this century; however, the state did not experience saline seep problems until the late 1940s. This was less than a decade after summer fallow had become widely established in the state. Additional refinements in soil and water conservation added to the storage problem: contour cropping, stubble mulching, and snow interception by vegetative barriers (87).

The first field investigations of saline seep by the Montana Cooperative Extension Service culminated with a report published in 1947 (33). This report estimated that saline seeps were growing at a rate of about 1 percent per year. By the 1950s, the estimated seep growth rate was up slightly, with an annual 5 percent increase in acreage of newly formed saline soils in dryland farming areas.

By the 1960s, estimated damage was growing at a rate of between 5 and 10 percent each year. A series of wet years in the late '60s and early 1970s sent the estimate of newly ruined cropland soaring to over 10 percent annually (224).

These estimates indicate that the saline seep problem has increased dramatically over the past three decades. However, in spite of widespread recognition of the seriousness of the problem (7, 15, 38, 51, 160), a reliable and accurate surface inventory of saline seep land does not yet exist. The Soil Conservation Service (SCS) polled District Conservationists in Montana in 1969, 1971, and 1973 and published acreages of saline seep on cropland in 28 counties (54). Table 1 summarizes these estimates.

Table 1. Estimates of saline seep in Montana, 1969, 1971, and 1973 (52).

County	Acres		
	1969	1971	1973
Blaine	400	1,000	2,000
Cascade	3,000	7,000	7,000
Chouteau	9,000	11,000	12,000
Custer		250	250
Daniels	500	5,800	5,800
Dawson			2,000
Fallon		2,000	5,000
Fergus	5,000	5,500	5,600
Glacier	2,000	3,000	3,000
Golden Valley		250	5,000
Hill	900	1,000	1,200
Judith Basin	1,800	4,000	4,300
Lewis & Clark	100	100	100
Liberty	200	220	4,300
McCone	800	800	1,200
Musselshell		250	3,000
Phillips	300	360	400
Pondera	1,500	1,600	2,500
Prairie			100
Richland	1,500	1,500	3,000
Roosevelt	12,000	12,000	12,500
Sheridan	10,000	10,000	10,000
Stillwater		10,000	51,550
Teton	450	500	4,000
Toole	1,500	1,800	2,000
Valley	250	800	3,000
Wibaux		500	1,000
Yellowstone			600
TOTALS	51,200	81,230	152,400

Like the earlier estimates of saline seep increases, the SCS figures can only be used as a general guideline. They were not based on field data (except in a very few cases) and represented only the "best guess" of the District Conservationist. Other estimates of saline seep damage put the figure at between 150,000 and 250,000 acres of cropland; inclusion of saline damaged non-crop land (such as stockponds, coulees, drainage systems, and rangeland) undoubtedly would push the numbers higher (33).

The Highwood Bench, located between the Missouri River and the Highwood Mountains near Great Falls, was one of the first areas in Montana to experience a saline seep problem. Developing in highly salt-permeated glacial till derived primarily from the marine shales of the Colorado Group, saline seeps on the Bench have been more extensively studie~~s~~d than in any other area in Montana. The farmers on the Bench, alarmed over salinity spreading in formerly highly productive soils, organized the Highwood Bench Alkali Control Association in 1969 under the 1969 revision of Montana's Soil and Water Conservation Law (208). They taxed themselves to support research into the problem and its solution. A work-study student spent the entire summer of 1969 mapping seeps on the Bench (54). Miller (120) reconstructed the spread of seeps in one watershed on the Bench (Nine Mile Creek) by analysis of aerial photographs taken in 1941, 1951, and 1966. Based upon this analysis and his continuing extensive hydrologic investigation of water table conditions in the Nine Mile watershed, Miller (121) postulated a three-phase sigmiod growth curve for seeps in the Bench area (See Figure 4). In simplified terms, the Bench seeps are occurring due to saturation of the till above the impermeable Colorado Shale bedrock after years of summer fallow operations. Water in excess of plant requirements has been stored during fallow, and that which is not transpired eventually percolates downward, adding to the water table perched above the shale. Miller found that saline seeps occurred when this accumulated water table flowed laterally along a hydrostatic gradient, and contacted the capillary zone, where evaporative forces drew the salt-laden water to the surface. There the water evaporated, leaving the salts behind on the surface and in the soil profile (See Figure 5). Based upon the known water content of the till, the capacity of the system to store water, and experimental responses of the system to water input, Miller (121) constructed his projection curve (Figure 4) to estimate possible saline-nonsaline acreage ratios over time. The period of accumulation of water in the till, followed by the current period of seep outbreaks and growth, would theoretically be followed by a reestablishment of hydrologic stability at which time from 25 to 30 percent of the cropland on the Highwood Bench would have been rendered useless for cropping of small grains. If peripheral areas are included, such as coulees unsuited for cropland, damage could total 30 to 35 percent of the land.

Miller (33) speculated about the potential for saline seep damage in the entire state of Montana and the northern Great Plains. Observing that saline seeps usually occur only where relatively thin soil or till is underlain by impermeable shales or by layers of dense clay (See Figure 6), and where dryland strip-cropping is practiced, Miller calculated that a staggering 228,000 square miles in Montana, the Dakotas, and Canada could possibly become affected by saline seeps unless current trends are reversed (See Figure 7). Within Montana, Miller (33, 120) found saline seep potential on 12,500 square miles underlain by shales of Cretaceous age, and on 4,500 square miles underlain by Tertiary strata of the Fort Union Formation. Montana's total thus came to 17,000 square miles, or 10,880,000 acres. As its official estimate the USDA Montana Committee for Rural Development subsequently adopted a figure of 8,000,000 acres (208).

It is unlikely that these immense figures will be reached, although it is widely thought that another series of wet years could have a severe impact on already saturated groundwater systems (2). One problem with Miller's figures is that there are several distinct saline seep systems

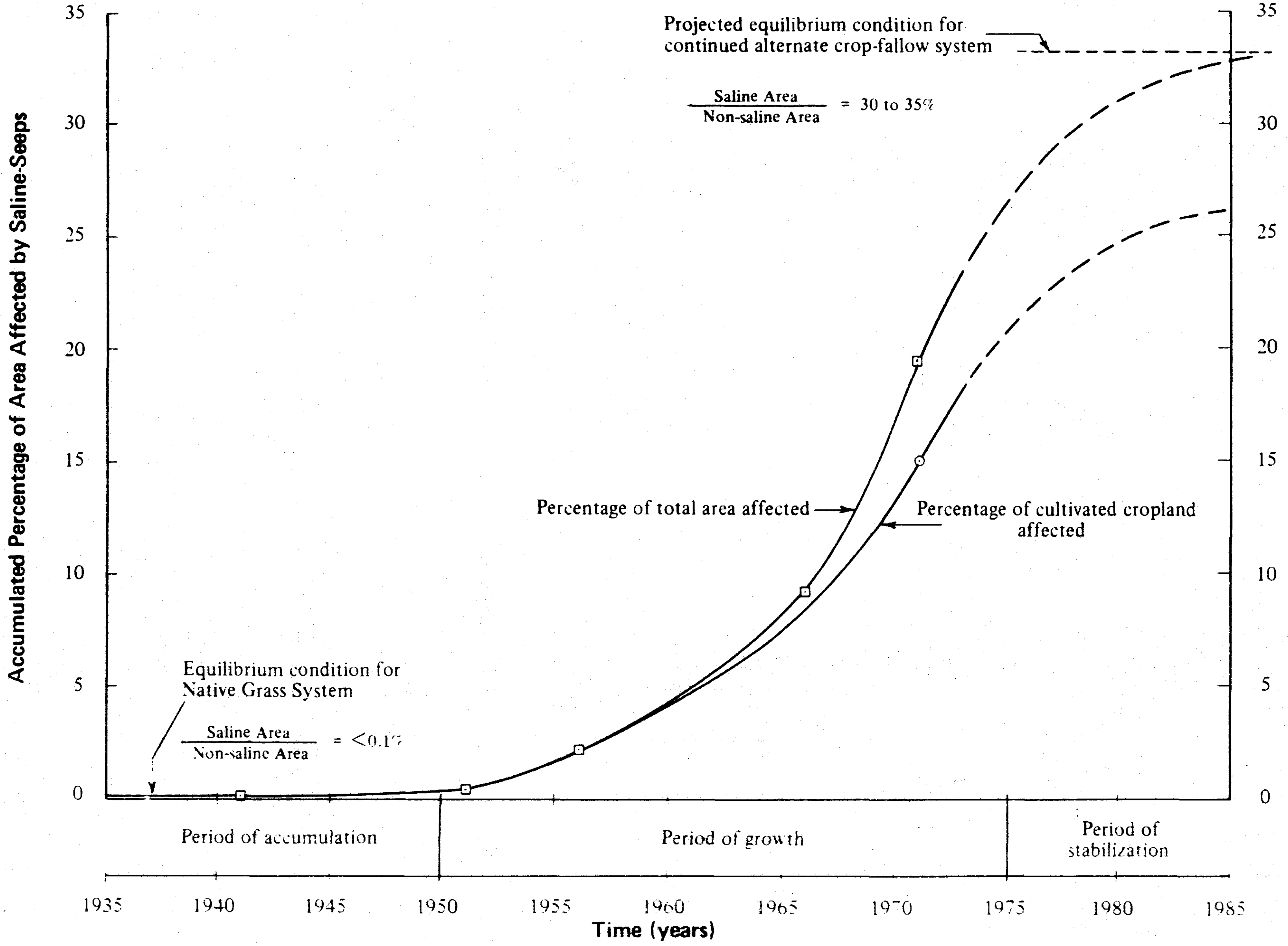


Figure 4. Rate of saline-seep development. Nine Mile Watershed. Highwood Bench. Montana (121).

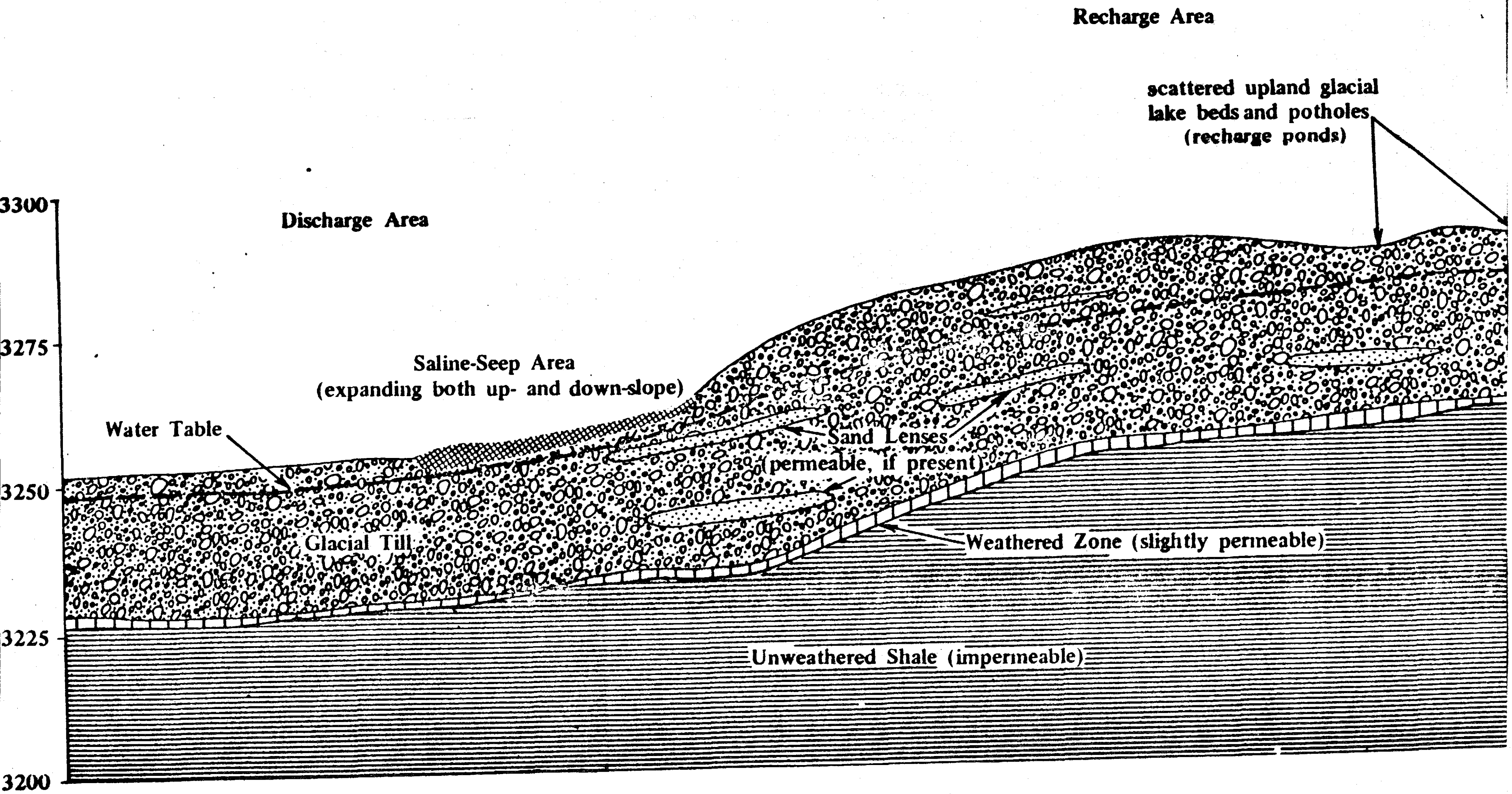


Figure 5. **Cross-sectional schematic diagram of a typical saline-seep complex** (121).

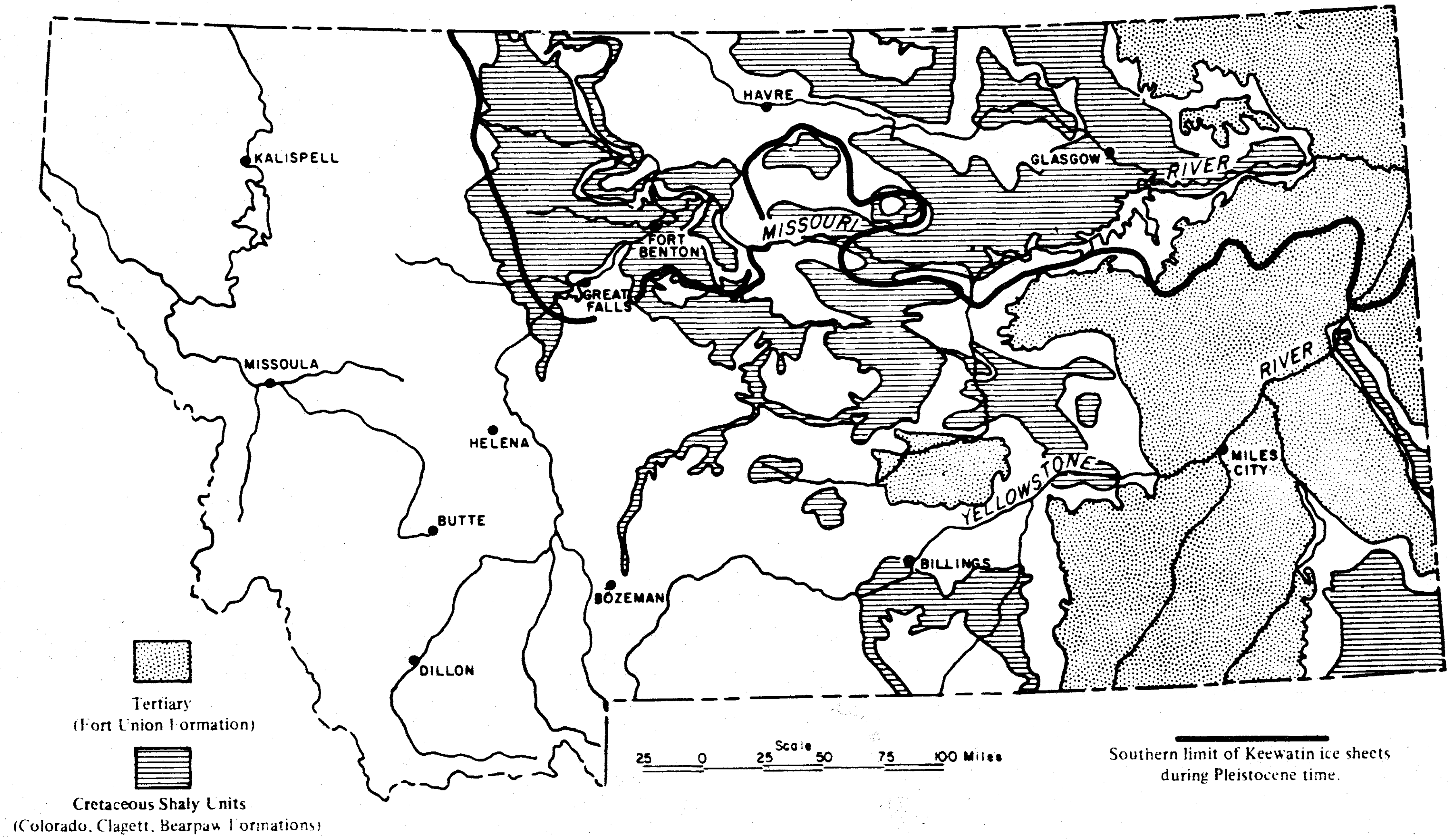


Figure 6. Map of Montana showing areas underlain by thick shale units (121).

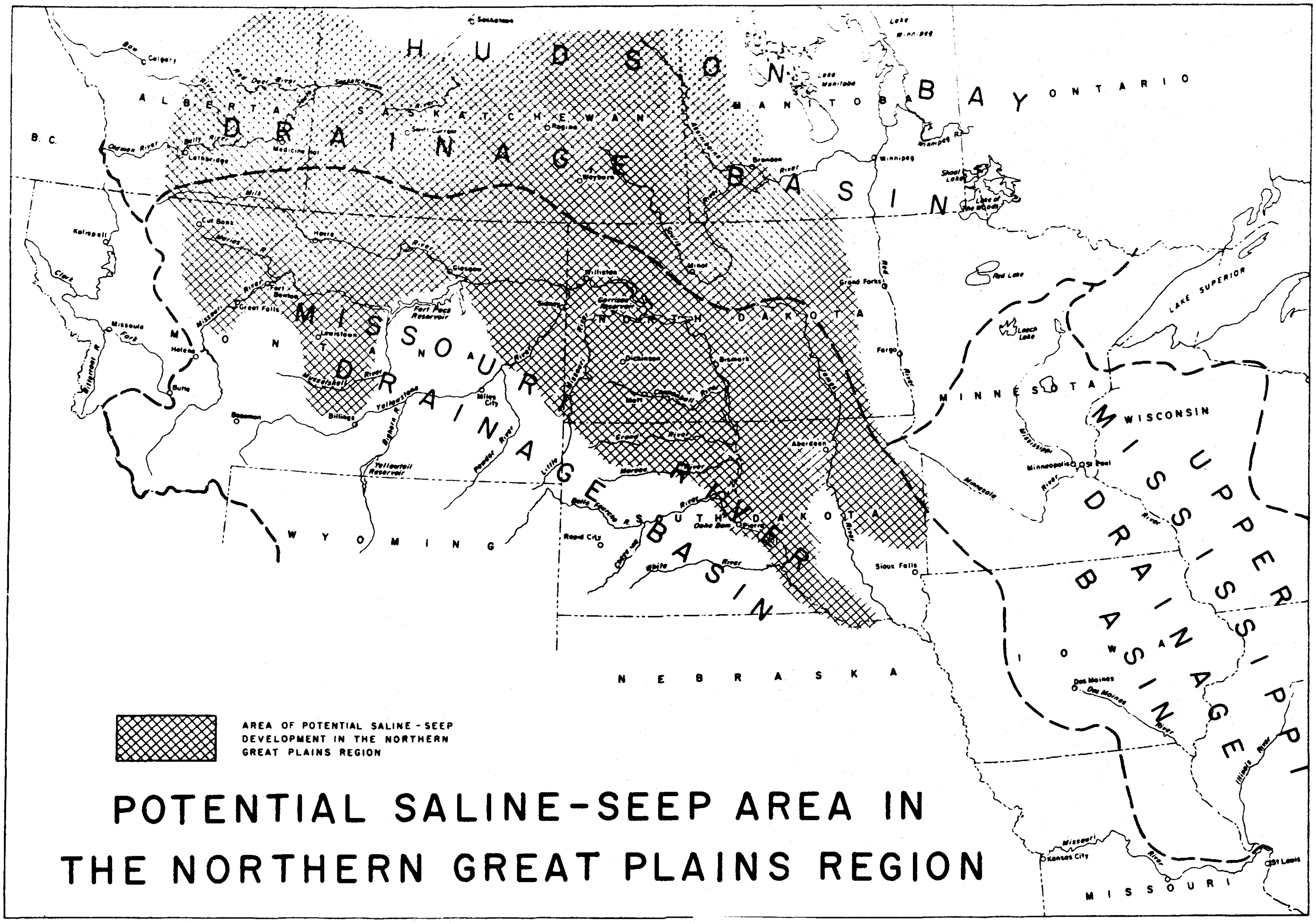

POTENTIAL SALINE-SEEP AREA IN THE NORTHERN GREAT PLAINS REGION
AREA OF POTENTIAL SALINE-SEEP DEVELOPMENT IN THE NORTHERN GREAT PLAINS REGION
HUDSON BAY DRAINAGE BASIN
MISSOURI RIVER DRAINAGE BASIN
UPPER MISSISSIPPI DRAINAGE BASIN
B. C.
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
MONTANA
WYOMING
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
MINNESOTA
WISCONSIN
IOWA
MISSOURI
Calgary
Lethbridge
Medicine Hat
Regina
Weyburn
Brandon
Winnipeg
Lake Winnipeg
Lake Manitoba
Lake of the Woods
Kalispell
Cut Bank
Havre
Glasgow
Fort Benton
Great Falls
Fort Peck Reservoir
Lewistown
Missoula
Helena
Butte
Bozeman
Billings
Miles City
Yellowtail Reservoir
Williston
Sidney
Garrison Reservoir
Minot
Grand Forks
Fargo
Dickinson
Bismarck
Aberdeen
Oahe Dam
Pierre
Rapid City
Sioux Falls
Red Lake
Leech Lake
Lake Superior
Minneapolis
St Paul
Des Moines
Kansas City
St Louis

Figure 7. (121).

besides the one found on the Highwood Bench. Halvorson (85) has studied saline seeps in the Fort Union area of eastern Montana, and asserts that Miller's curve does not apply in these strata, since the problem stems from both long-term storage of water in the soil profile, and from shorter term overloading of subsurface drainage capacity.

Halvorson and Black (87) studied a representative saline seep on the Tveit farm northwest of Sidney, Montana. They found that:

> When precipitation exceeded the amount needed to recharge the soil profile, water percolated below the crop root zone and accumulated above a layer of nearly impermeable, dense clay. Permeable layers of degraded sandstone, siltstone, and lignite conducted the perched groundwater laterally to a point where the water-conducting layers are truncated by glacial till of lower permeability. By capillarity, water moved upward in the till to the soil surface where it evaporated, leaving precipitated salts (Na, Mg, and Ca sulfates) on the soil surface in the seep area. Factors that enchanced deep percolation of water below the root zone included (a) above-average annual precipitation from 1962 to 1972, (b) unusually high fall and spring precipitation when evapotranspiration potentials were low, (c) increased use of summer fallow, and (d) improved soil water storage efficiency and conservation practices during fallow.

A stratigraphic profile from this study is reproduced as Figure 8. Halvorson (85) feels that the height of the asymptote would be much lower if a saline seep "growth curve" were hypothesized for eastern Montana. Ferguson (76) agrees that Miller's figures are probably unrealistically high. However, no one is willing to offer a figure in lieu of Miller's projection. In spite of the climbing SCS acreage estimates (which probably represent a "learning curve" as much as an increase in saline seep), many seeps in both areas have remained nearly static during the past year. However, data from the Highwood Bench indicate, at least in one research watershed, that the groundwater levels have not subsided appreciably during recent dry periods except in areas where specific attempts have been made to dry up the profile (120). It can be concluded that any prolonged periods of excess precipitation will probably cause a rapid increase in the size of many seeps, and widespread appearance of new ones. This response could well be analogous to the steep slope of Miller's curve in its second phase. Limited data indicate that the water table in eastern Montana seems to be rising at an annual rate of 4 to 10 inches per year (120). It remains a question at what point the systems will reestablish hydrologic equilibrium.

Assessment of the saline seep problem, then, must frequently rely on educated guesswork as to the current and potential scope of the situation. Even such basic information as the total affected cropland acreage is not yet known with accuracy. Given the fact that nearly all of the past research has focused rather strictly upon the agricultural

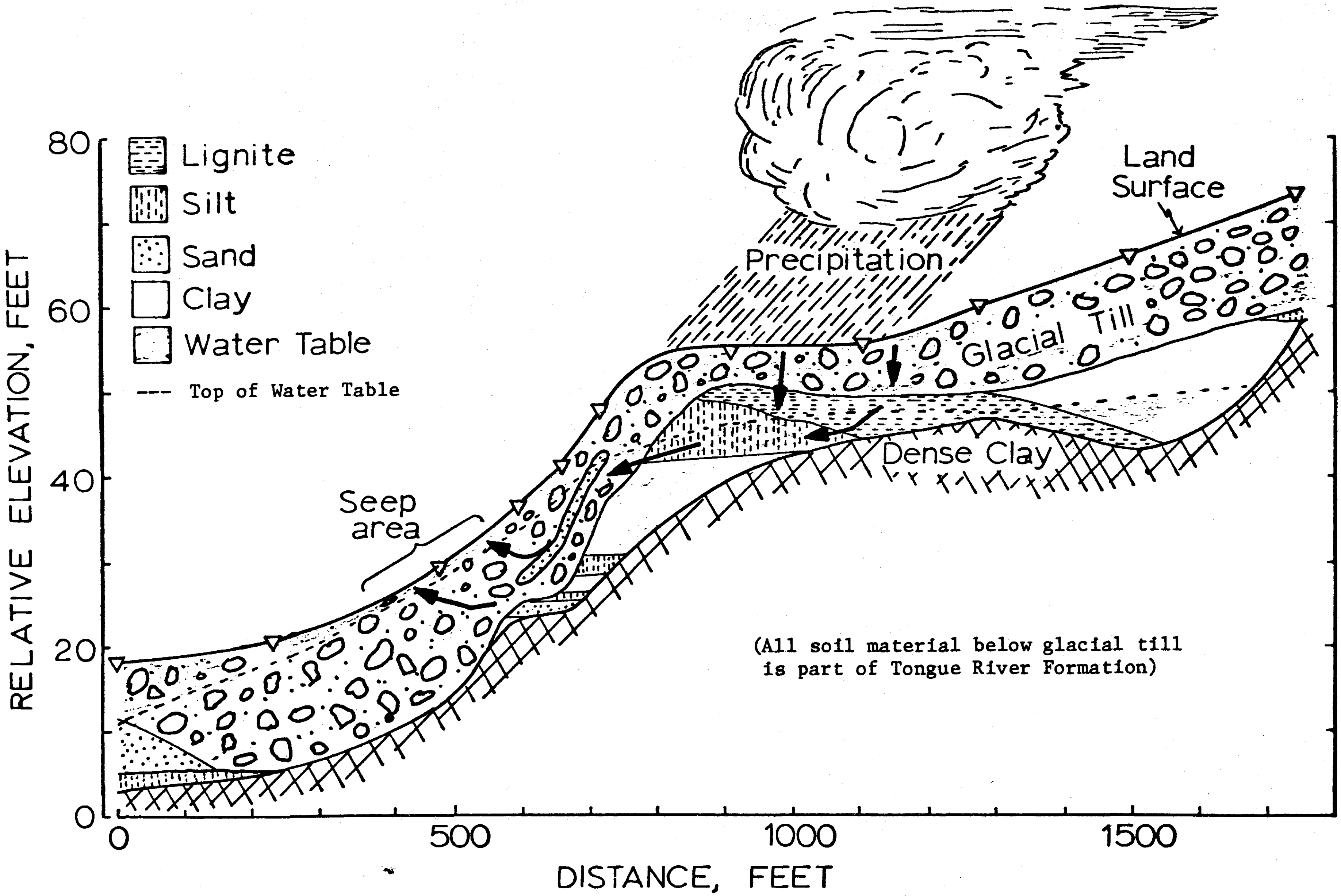


Figure 8. Stratigraphic profile of a typical Fort Union area saline seep (87).

impacts of saline seep, and given the lack of adequate data even in this sphere, Bahls and Miller (33) may well have understated their conclusion that "...the true extent of its adverse environmental effects is only guesswork." However, this very serious lack of data has not precluded speculation and even conclusions about the environmental impacts of saline seep.

GROUNDWATER SYSTEMS

Basically, saline seeps are caused by an imbalance in the hydrologic cycle. It is through this imbalance that the major effects of saline seeps will be displayed in the local and regional ecosystems. We have broadly described the combinations of climate, drainage, and land use which have upset the hydrologic balance of the plains, causing outbreaks and growth of saline seeps. Impacts of saline seep begin in the groundwater systems; from there, chemical and hydrologic changes reach upward into the surface systems, affecting land, surface water, and biotic communities. To the extent that he is involved in these systems, or dependent upon them, man will be impacted by saline seep.

Every saline seep is an individual and distinctly local system (33, 85). Each seep system has three, and occasionally four, components:
1) the recharge area; 2) the soil profile and groundwater aquifer;
3) the seepage or discharge area; and 4) overland drainage.

Recharge

The first component, the recharge area, collects and infiltrates precipitation. Quite frequently, recharge areas have pothole topography, with severely restricted overland drainage (33, 44, 76). Water ponding tends to concentrate recharge into small areas. Depending upon the particular circumstances, this ponding can overload the local subsurface drainage systems, creating hydraulic seeps (as described by Halvorson in eastern Montana); or they can cause rapid buildup of perched water tables due to introduction of excess water in the profile. These ponds may aggravate the high percolation rates (33, 120, 76) found in tills on the Highwood Bench, or compensate for slow rates (85, 87) found in tills in eastern Montana.

Recharge areas on the Highwood Bench have an additional feature: an extensive interconnected vertical jointing system, possibly created by swelling and shrinking of the high clay soils in response to repeated wetting and drying. These cracks act like a series of drainage pipes (76) conducting water quickly downward. It is not known if such cracks appear in eastern Montana (85).

Saline seep recharge areas are almost always strip-farmed cropland. The critical factor characterizing recharge areas is the failure of plant communities to fully transpire all or nearly all gravitational water from the profile. Native prairies rarely fail to exhaust this water. Analysis of hydrologic budgets in native prairie ecosystems is incomplete, and the mechanisms by which water is prevented from escaping below the root zone are not fully understood. It is known that infiltration rates on fallow and sod soils are essentially identical, but that sod induces much greater horizontal spreading of the water in the upper soil horizons. This may be due to the presence of the humus mulch which stores water for delayed release into the subsoils (33). Ferguson (76) found vertical cracks beneath native sod on the Highwood Bench, giving credence to the mulch storage theory. Miller (120) reports that the transpiration variable is the key difference, hydrologically, between fallow and native prairie sod, thus underscoring the critical importance of an active root system at considerable depth beneath the surface.

Rangelands are usually capable of preventing saline seep. However, rangelands can become recharge areas if conditions are such that water infiltrates faster than the plants can transpire it, and several saline seeps formed below native rangelands in very sandy soils were visited by the author (105, 112). Such seeps are quite rare and generally should fall into the category of "residual alkali" areas; generally one can expect to find poorly drained cropland above saline seepage areas.

Other common sources of recharge of saline seepage are leaky irrigation ditches and stockpond reservoirs. Saline damaged soils beside ditches and below reservoirs are common throughout the state of Montana. Unlike "classic" dryland saline seep, however, the mechanisms of recharge and the technologies for correcting the leakage are well known (75). No further specific discussion of irrigation or stockpond seepage is presented here, but environmental impacts ascribed to dryland saline seep may be applicable to these types of saline seep as well.

Profile

The second component of the saline seep system is the soil profile through which the water percolates, collects, and moves laterally prior to reaching a depth shallow enough to be pulled from the soil by the forces of evaporation. We have briefly described the geologic heritage of the soil profiles, stressing that they contain high concentrations of soluble salts and trace minerals. It is important to recognize that, just as all seeps are individual entities, unconnected to any regional groundwater systems (120), so also are the chemical contents of the particular seep system unique. Chemical characteristics of groundwater, while extremely complex due to mixing, dilution, and absorption factors, are generally closely related to availability of soluble materials within the host aquifer (213).

Only limited data have been published concerning the chemical composition of soils and groundwaters in saline seep systems. Miller (121) compiled extensive information on several seeps on the Highwood Bench, and Halvorson and Black (87) analyzed soil and water from seeps in Richland County. Table 2 summarizes their findings, along with existing water quality standards set for various uses. A comparison of the groundwater values with these standards indicates that the sampled groundwaters had become extremely polluted during passage through the profile. The extremely high total dissolved solids (TDS) value (45,773 mg/l) found in seep groundwater on the Highwood Bench exceeds the level (36,000 mg/l) for seawater. To set the specific conductance values in perspective, consider that the United States Department of Agriculture (206) has published the following scale interpreting the general effects of salinity on crops:

EC_{25}	Effects on Crops
0 - 2	Salinity effects mostly negligible
2 - 4	Yields of very sensitive crops may be restricted
4 - 8	Yields of many crops restricted
8 - 16	Only tolerant crops yield satisfactorily
16 +	Only a few very tolerant crops yield satisfactorily

Potentially dangerous nitrate contents and TDS are found in these seepage ground waters. For example, Montana Department of Livestock laboratories (131) use the following rating scales in evaluating water quality for stock:

Nitrates (mg/l)	Rating
0 to 44	Not harmful
45 to 132	Slight possibility of harm
133 to 220	Risky, especially over a long period of time
221 to 440	Interference syndrome likely
441 to 660	More serious; possible acute losses
661 to 880	Increased acute losses, secondary diseases
881 to +++	Heavy acute losses

TDS (mg/l)	Rating
0 to 1,000	Good
1,000 to 2,500	Fair
2,500 to 4,000	Poor
Over 4,000	Unsatisfactory
Over 10,000	Immediate toxic effects can be expected

The origin of the high nitrate concentrations in the groundwater is somewhat problematical. Nitrate (NO_3^-) is an oxidation product of ammonium (NH_4^+). NH_4^+ is oxidized to nitrite (NO_2^-) by Nitrosomonas spp., and NO_2^- is oxidized to nitrate by Nitrobacter spp.. Oxygen, moisture, and temperature must be favorable, or incomplete oxidation may occur. Under some alkali conditions, Nitrobacter spp. may be absent, causing accumulations of the more toxic nitrate in the soil (213). Nitrate levels in most ecosystems are unstable and may vary widely as the anion is assimilated by plants or algae, or denitrified to elemental nitrogen (N_2) under anaerobic conditions. Nitrate data are consequently difficult to interpret in isolation from knowledge about other factors within the environment.

TABLE 2. Chemical analysis of typical soils and groundwaters in saline seep systems in Montana. General water quality standards. (Data in mg/l unless noted)

Parameter	Salt	HIGHWOOD BENCH (121) Recharge Profile	HIGHWOOD BENCH (121) Groundwater*	RICHLAND COUNTY* (87) Recharge Area		RICHLAND COUNTY* (87) Seep Area		WATER QUALITY LIMITS (202)		
				Soil	Groundwater	Soil	Groundwater	Drinking	Stock	Irrigation
Sulfate (SO_4)	536,000	-	32,068	96	2,017	16,124	6,316	250	-	-
Nitrate (NO_3)	12,800	77	1,353	6	267	518	927	45	133	-
Chloride (Cl)	10,200	-	234	4	37	564	60	250	-	-
Bicarbonate (HCO_3)	4,000	-	570	165	186	276	516	-	-	-
Sodium (Na)	110,000	291	5,822	22	965	5,098	2,010	-	-	-
Magnesium (Mg)	72,000	224	5,149	12	438	1,646	705	-	-	-
Calcium (Ca)	8,200	439	460	60	341	462	351	-	-	-
Potassium (K)	-	31	30	-	-	-	-	-	-	-
Carbonate (CO_3)	-	-	-	9	21	19	53	-	-	-
Strontium (Sr)	-	-	12	-	-	-	-	-	-	-
Lithium (Li)	-	-	1.6	-	-	-	-	-	-	-
Iron (Fe)	3,340	-	4.8	-	-	-	-	0.30	-	-
Manganese (Mn)	112	-	0.9	-	-	-	-	0.05	-	-
Aluminum (Al)	1,108	-	6.1	-	-	-	-	-	-	-
Copper (Cu)	5.2	-	0.13	-	-	-	-	1.0	-	-
Lead (Pb)	28.0	-	0.95	-	-	-	-	0.05	-	-
Zinc (Zn)	22.0	-	0.70	-	-	-	-	5.0	-	-
Nickel (Ni)	9.6	-	0.43	-	-	-	-	-	-	-
Cobalt (Co)	-	-	0.28	-	-	-	-	-	-	-
Cadmium (Cd)	-	-	0.09	-	-	-	-	0.01	-	-
Chromium (Cr)	-	-	0.15	-	-	-	-	0.05	-	-
Silver (Ag)	1.5	-	0.09	-	-	-	-	0.05	-	-
Specific Conductance (EC_{25}) (mmhos cm^{-1} at 25°C)	-	4	30	< 1	5	20	12	-	-	2.2
Total Dissolved Solids (TDS)	-	-	45,773	-	-	-	-	500	4,000	-

* Averaged

\- Not established or not available

Marine sediments, such as those underlying north-central Montana, concentrated nitrates. Soil profiles in semi-arid environments frequently show high concentrations of nitrates in the leach zone (caliche). Excessive accumulation of nitrates in underground waters "is generally associated with a salinity problem" (213). Water is the only method for transport of nitrates, so they concentrate in evaporation areas.

Nitrates were released for leaching when the prairie was turned under; cultivation under fallow systems also returns organics to the soil. According to Ferguson (76) these sources plus known storage within the till are sufficient to explain nitrate levels found on the Highwood Bench. Halvorson et al. (88) account for high nitrate levels in eastern Montana in much the same way. However, Ferguson (76) contends that the extraordinarily high ammonium and nitrate levels found in some regions of till over Fort Union strata cannot be explained solely as decomposition products of organics added to the soil by agriculture. He postulates additional nitrates enter the perched groundwater from coal strata, natural gas, and fertilizers leached from the surface.

The quantity of water which reaches the water table and subsequently flows laterally into a seepage or discharge area is dependent upon the size of the recharge area, precipitation received by the recharge area, ambient soil moisture, evapotranspiration losses, and flow rates through the aquifer (76). Quantities of soluble salts and minerals carried into a seepage area can be estimated for a given seep system if these factors and the chemical quality of the water are known. Halvorson and Black (87) give an example of such a calculation:

> To illustrate the magnitude of the saline-seep problem, assume that 1 inch of precipitation was lost to deep percolation over a recharge area of 10 acres. Assume further that this water was channeled into a seep area of 1 acre. Then, 271,583 gallons of water would become available for evaporation from the soil surface in the seep area. If the total dissolved salt concentration of the seep water was 13,000 ppm, then 14.7 tons of salt would be concentrated in the seep area. With such potential quantities of water and salts reaching the seep area bound by geologic conditions outlined herein, it is not difficult to visualize why a seep area becomes extremely wet and saline so rapidly.

Discharge

The discharge area is the third and most easily recognized segment of this long and rather complex chain of events. This part of the saline seep system has all too often been mistaken for the disease itself, rather than its principal symptom. Seeps typically evolve over several years. During the first year, as the water table is building up, crop yields are commonly far above normal due to the presence of plant-available moisture (76). Then, perhaps after fallowing, the farmer notices that the area remains wet long after the rest of the fallow strip has dried and become workable. Those who ignore the condition quickly learn the truth of the old saw, "Spin yer wheels twice, and she's in up to the axle." Since the ground cannot be worked, salt-tolerant weeds invade the soggy cropland. Kochia (Kochia scoparia) usually appears first, followed by foxtail barley (Hordeum jubatum). When the ground does finally dry out enough to be worked with farm equipment, it exhibits the whitish surface bloom that heralds a growing crust of magnesium, calcium, and sodium sulfate crystals. If the ground is seeded to wheat or barley the next year, few of the plants appear, and those that do struggle forth are stunted and shrivel with the first dry spell. Usually, these doomed grain plants are quickly crowded out by the ubiquitous Kochia and foxtail. As the water continues to flow into the seep, depositing higher and higher concentrations of salts, even these hardy species fail. Saltgrass (Distichlis stricta) sometimes attempts an invasion of the barren white crust, and occasionally a tuft will survive long enough to add its dull green to the colorless tableau. After several years, if the recharge is still feeding the brackish water into the seep, a classic saline soil will have formed, complete with dispersed organics lying black and wet beneath the layered crust. Once emerged, saline seeps can and do spread--up slope, down slope, across slope, or any combination.

Overland Drainage

Although the hydrologic imbalance which drives the seep system usually reaches stability with the evaporation of the excess water from the soil, a fourth component of the system may exist. Some seeps, due to the very shallow depth to the impermeable layer and/or high recharge, actually flow as springs during certain periods of the year. In other cases, the salts continue their inevitable journey back to the sea, carried by snowmelt runoff and overland flow resulting from cloudbursts. Many seeps occur near or within coulees, which collect surface drainage. Precipitation may flush the salts downstream several times each year. Once the salts enter the surface water systems of the state of Montana, their environmental impacts become increasingly diverse, and difficult to trace and document. The following section will examine in some detail the environmental impact of saline seep on the surface systems of the land and water. Much of this inquiry must culminate not in conclusions, but in questions--questions which will grow in urgency as the problem of saline seep increases.

ENVIRONMENTAL IMPACTS

Concern For Environmental Impacts of Saline Seep

Although research on saline seeps continues to be directed exclusively toward the problem faced by farmers losing valuable cropland, many have recognized (34, 103, 120, 141, 144) that off-site resources, such as surface water quality, livestock, and wildlife are being threatened by the salts, nitrates, and heavy metals transported to the land surface by the seeps. The popular press, responding to incidents of damage purportedly caused by saline seeps, has poured out many articles describing the environmental hazard represented by the growing seep problem in the dryland regions (15, 38, 60, 179, 188, 189, 194, 195, 197).

In 1973, State Senators Gordon Bollinger and Gordon McOmber introduced legislation

> ...requesting the Governor of the State of Montana immediately to marshal all resources of the State and to seek emergency aid from the Federal government to halt further destruction of Montana's natural resources in soil, water and wildlife and further damage to Montana's ecology and economy by saline seep caused by agricultural practices and geologic conditions (137).

In addition to agricultural losses the bill cited damage to water supplies in several Valley County communities, loss of fisheries in stockwater ponds in northeastern Montana, and the effect of increasing pollution of Montana's waters on downstream users. The bill, which passed as Senate Joint Resolution No. 33, prompted Governor Thomas L. Judge to set up an Emergency Committee on Saline Seep. In announcing the formation of this select study committee, the Governor issued a news release on April 25, 1973, in which he reported:

> Estimates of saline-alkali damage in Montana range from 150,000 to 250,000 acres of nonirrigated cropland. And these destructive conditions are spreading rapidly.
>
> Saline-alkali conditions are ruining our croplands, polluting our water, destroying wildlife habitat and killing livestock. Crop production has been reduced in many saline areas, many streams are becoming unfit for irrigation, some stockwater ponds cannot support fish and deposits around bogs have killed livestock.
>
> The extent of saline-alkali damage and its adverse effect on the economy and ecology of this state has created a problem of near-crisis proportions, and we cannot allow this to continue (58).

Formed to assemble all available knowledge about the causes and effects of Montana's seeps and possible alternatives for control and reclamation, the Emergency Committee gave only peripheral attention to the broader, non-agricultural environmental impacts of saline seep. Although Bahls' (27) report to the Committee reviewed the ecological implications and set the suspected impacts in clear perspective, most of these impacts have remained in the realm of speculation or supposition. A more comprehensive survey of the ecological aspects and implications (33) appeared in the 1973 Second Annual Report of the Montana Environmental Quality Council (EQC). The survey concluded that "soil and water pollution are the two most severe environmental impacts of saline seep; little is known about its impact on wildlife populations." More than anything else, the EQC report revealed the scope of present ignorance about the extent (much less the details) of these environmental impacts. A number of very basic questions could not then (1973) be answered, even with regard to more obvious foreseeable off-site damages of saline seep. For example, the EQC report posed the following questions concerning water quality degradation:

1. What components of seep water are causing the damage?
2. How severe is the damage?
3. What is the potential for spread?
4. How may damaged waters be restored?

It is not yet possible to answer these questions, or the many other questions related to them, in sufficient detail to fully justify the sweeping general statements which have heretofore constituted popular notions of the environmental impacts of saline seep.

Current Research

Since publication of the EQC report, the state legislature has appropriated $255,000 to be administered by the Department of State Lands for studies of saline seep. Some field research (64, 65, 67, 68) has begun which will begin to shed light upon the unknowns. Although most of the time and money are focused on the agricultural plight, some data for assessment of the ecological variables are now beginning to be collected.

As part of a contract with the Department of State Lands, the Water Quality Bureau of the Department of Health and Environmental Sciences has begun establishing a baseline water quality inventory and sampling network for waters possibly affected by saline seep runoff (39, 80, 103). As one phase of this inventory, the Bureau has begun analysis of historic domestic water quality in communities near known saline seep infestation (81). Preliminary findings from this analysis will be discussed below in the section on domestic water supplies. Duncan, heading the Department of State Lands Saline-Alkali Advisory Commission's current study of saline seep and related problems (the successor to the Governor's Emergency Committee), has requested that all federal Committees for Rural Development (CRD) prepare detailed maps outlining saline affected areas in their respective counties (68). This mapping should at least allow assessment of the problem for individual watersheds. Other inventory projects, such as the use of Earth Resources Technology Satellite (ERTS) capability and computer mapping, have been proposed (118, 153), and Duncan

(68) reports that necessary support within NASA for such an effort appears to be growing. The Department of State Lands has contracted for experimental photographic infrared mapping at a scale of 1:80,000. Black and white photographic reconnaissance at this scale has proven effective in Canada (2).

In June, 1974, at the urgent request of the Environmental Quality Council and the Governor's Emergency Saline Seep Committee (4), the Environmental Protection Agency's National Field Investigations Center--Cincinnati--sent a team of aquatic biologists to Montana. Concentrating on four stockponds and reservoirs on the Highwood Bench, this team sampled fish, zooplankton, benthos, and phytoplankton, as well as making detailed analyses of water quality (40).

Degraded surface waters in the Highwood Bench area have been the basis for most of the reports of fisheries losses due to saline seep. Data from these studies are not yet available.

On-Site Environmental Impacts

Wells. Saturation of aquifers with highly polluted water is reported to have contributed to declining water quality in shallow domestic wells (88). Miller (120) noted hearing farmers in the area say that shallow wells on the Highwood Bench became undrinkable during the 1940s, and that formerly palatable springs (2 to 3 mmhos EC_{25}) have become too high in TDS and nitrates for safe use. Data to support these reports should be collected. As far as can be determined, the declines coincide with outbreaks of saline seep on the Bench. Halvorson (85) is currently preparing a publication on water quality in saline seeps, but his data are not yet available.

Halvorson et al. (88) found up to 1,829 ppm nitrates in shallow groundwater in seep discharge areas. There are many reports of wells in eastern Montana becoming unsafe due to nitrates (33, 36, 56, 57, 76, 194, 224). Declining quality of municipal wells along the Milk River has been prominently cited as evidence of saline seep pollution (137). While it is certain that saline seep can be directly implicated in the loss of shallow wells, it is premature to specify which wells, and in which areas. Well water in much of Montana, especially water from shallow aquifers, is historically notorious for poor quality due to alkalinity (76).

Watson and Heider (216) investigated the feasibility of desalting municipal water supplies in ten Montana communities (See Figure 9). Selection of the communities was done on the basis of population and on condition of the municipal water supply in terms of TDS, hardness, and sulfates. A thorough study was made of the groundwater sources used by each community, as well as the chemical characteristics of the water. Table 3 summarizes the chemical analysis of the water for study communities that are in saline seep areas.

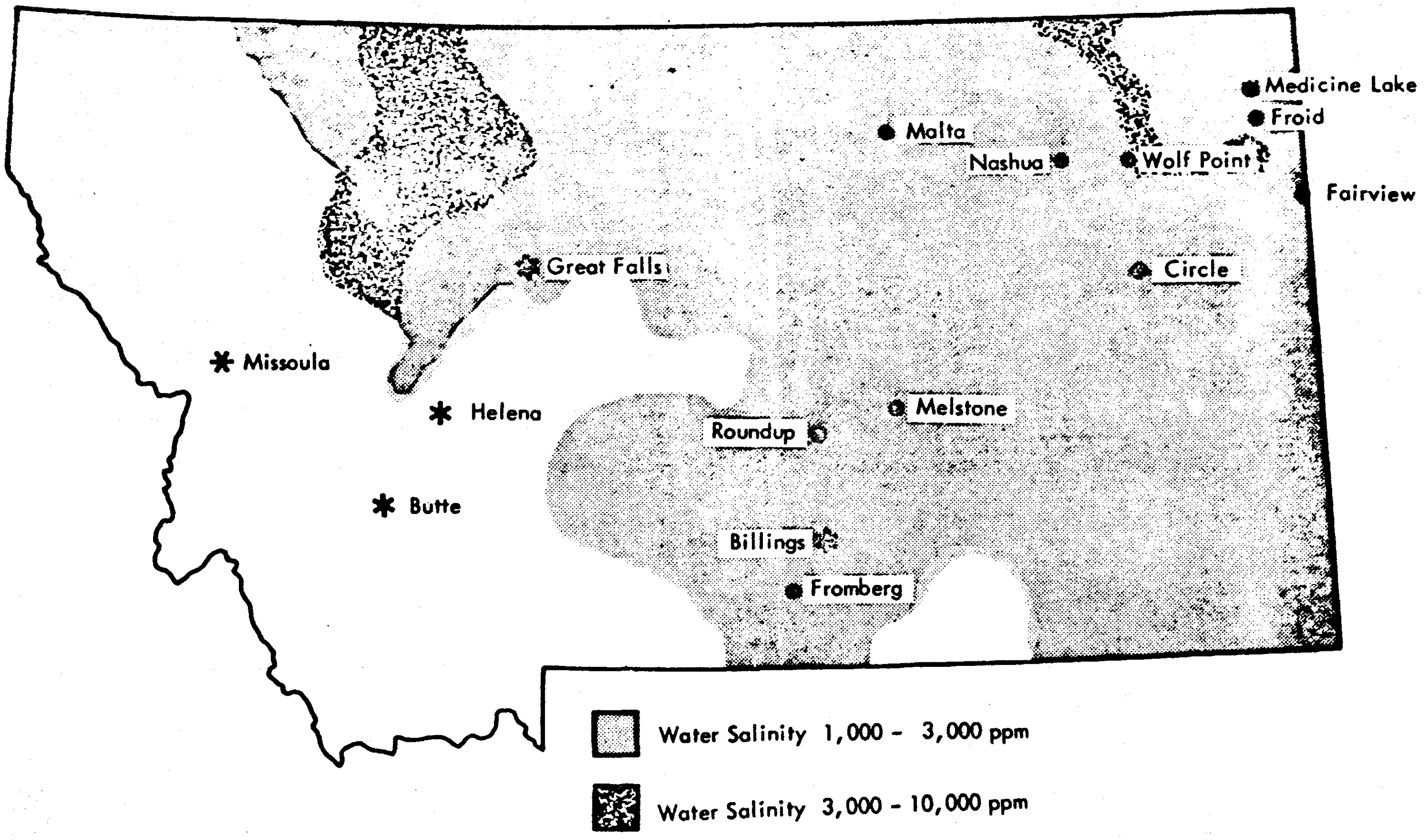


Figure 9. Map of Montana showing location of desalinization study communities (216).

Table 3. Composite chemical analysis of selected community water supplies. Underlined figures exceed USPHS limits for drinking water (216). All figures in ppm.

Parameter	Wolf Point	Malta	Nashua	Medicine Lake	Circle	Fairview
TDS	1100	960	2190	1380	2260	898
Hardness ($CaCO_3$)		350	710	690	130	306
Calcium	57	66	140	92	24	69
Magnesium	45	40	90	110	17	32
Sodium	293	167	440	260	750	235
Iron	0.9	1.0	1.3	0.1	0.0	2.4
Carbonate		0	0	0	0	0
Bicarbonate	602	432	480	560	950	662
Sulfate	410	490	1250	690	910	243
Chloride	30	21	46	38	17	11
Nitrate		2	0.1	5	0	1.0
Fluoride		0.7	1.0	0.7	4.2	4.3
pH			8.3	8.5	9.2	9.0

Several of these communities derive at least a portion of their water from relatively shallow aquifers which might conceivably be receiving pollution from saline seep groundwater. No mention is made of such problems by Watson and Heider, and they make no effort to document historical values for any of the parameters, other than to indicate that these regions have never enjoyed non-alkaline water supplies.

In general, records documenting changes in water quality over time are spotty and questionable at best, and confusing or missing at worst. Gormann (80, 81) has begun compilation and analysis of well records for communities in saline seep areas. To date, he has been able to establish no clearly defined long-term trends in water quality, and no deterioration that can be linked specifically to growth of saline seep. Nitrates in the Denton community water system have increased slightly since 1959, and exhibit a marked seasonal dip during the early summer months. Coming during the high flow period, the dip may indicate a dilution of pollutants within the aquifer. In his survey of the literature on nitrate accumulation in plants, soil, and water, Viets (213) concluded that the nitrate composition of well waters fluctuates "seasonally and often erratically." Nitrates in the Denton domestic water are frequently above 80 mg/l making the water questionable for human consumption, but the residents apparently have experienced no noticeable ill effects (36). The town has recently tapped four higher quality springs, and levels of nitrates in Denton municipal water have declined since 1972.

Further complicating the analysis of seep effects is the fact that many of the so-called saline seep affected wells are located in areas subject to extensive irrigation seepage. Leakage from irrigation structures has created extensive saline seepage in a manner entirely analogous to the classic dryland seeps; hence it is frequently impossible to evaluate reports of well pollution without first-hand observation of the source.

And in many cases, such as Nashua, Frazer, Malta, Wiota and other communities along the Milk River, a combination of both types of seepage may well prove to be the culprit.

Barber (36) reports the death of several cattle in his herd from suspected nitrate poisoning several years ago. This herd, most of which showed no ill effects, was limited to water from a shallow well in the Denton area. The well was subsequently abandoned, and no known water samples were taken to confirm the diagnosis. Dr. Connell of the Glasgow Veterinary Clinic indicated (56) that very few cattle in his area are watered off shallow wells due to very poor quality. It is known that the dryland acreages have been hard hit by saline seep in both of these areas, but without extensive monitoring of wells in these locations, it is impossible to state how much of the problem is related to saline seep.

Halvorson (85) put the problem of monitoring in a realistic perspective. Referring to his intensive monitoring of a single seep (87), he stated that the chemical quality of groundwater is complex and highly variable even over short distances. It would take many closely spaced wells to determine beyond question how a given well had gone sour. Such a monitoring system would be unrealistic or of very little practical value in most cases.

Halvorson and his co-workers are currently experimenting with a device which may make monitoring of seep-prone areas more practicable. Originally developed many years ago for geologic research, the 4-probe method of assessing field soil resistance has recently been applied to the study of saline seep in the northern Great Plains. Miller (121) used a 4-probe in some of his work on the Highwood Bench, and found that it allowed him to locate certain features such as the shale layer and the top of the water table. Halvorson and Rhoades (89) have been refining the equipment and interpretation of results, and are currently attempting to calibrate the device and to compile a field manual for Montana (85). Miller, Brown, and Ferguson are also involved in this promising research.

The 4-probe device consists of 4 stainless steel electrodes (1.3 by 51 cm.) set in the earth equally spaced in a straight line, and connected to a geophysical Megger-type earth resistance meter. An electrical charge is generated between the paired sets of electrodes, and resistivity (the inverse of conductivity) is read from the meter. The electrodes are then moved a specific distance apart, and the procedure is repeated. After taking a number of such readings, the values are adjusted (to correct for the geometric characteristics of the subsurface electrical field) by using equation (1),

$$EC_a = \frac{1}{2\,\underline{a}\,R} \qquad (1)$$

where $\underline{a}$ is the inter-electrode spacing in cm and R is the measured soil resistance in ohms (89). When plotted as EC_a vs. $\underline{a}$, distinctively shaped curves are found for recharge areas, saline seep (discharge) areas, non-seep sites, and intermediate sites. Figure 10 is reproduced from the forthcoming publication by Halvorson and Rhoades (89), illustrating the clear differences

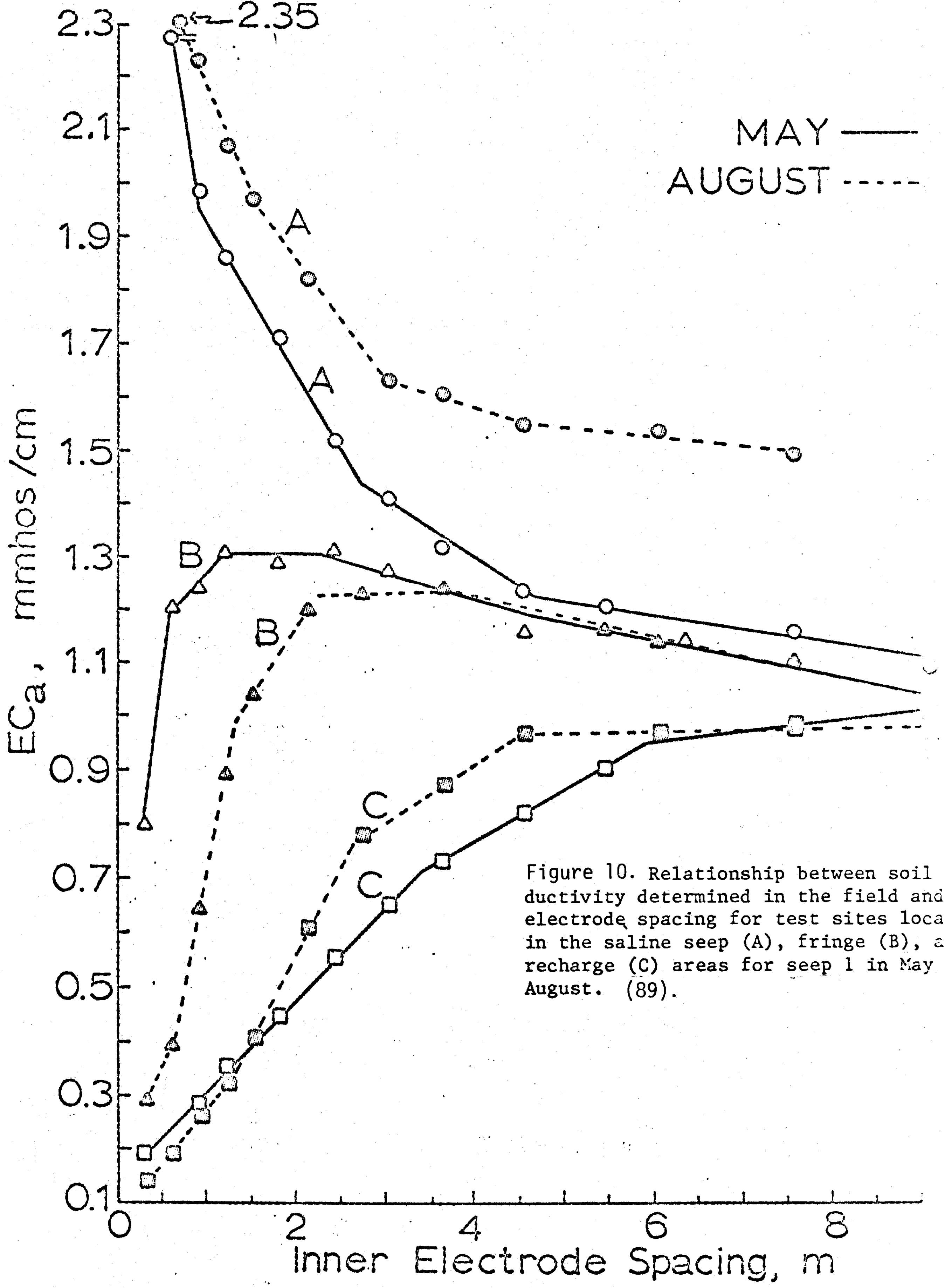


Figure 10. Relationship between soil conductivity determined in the field and electrode spacing for test sites located in the saline seep (A), fringe (B), and recharge (C) areas for seep 1 in May and August. (89).

Area: Davis Test Area (P. 5-1) **Location:** T. 22 N., R. 8 E., sec.4, D
Survey Crew: Rhoades, Halvorson, Miller, Ferguson **Reference No.:** EC13, 14, 15
Equipment: "Megger" Null Balance Earth Tester **Date:** 8-17-73
Electrode Set-up: Expanding Wenner configuration at Test Holes F120-D9, F184-D36, and F117-D6
Remarks: See Appendix E, for additional geophysical data, Appendix A, Part 3, for detailed lithologic description, and Appendix B for fluctuation in static water level.

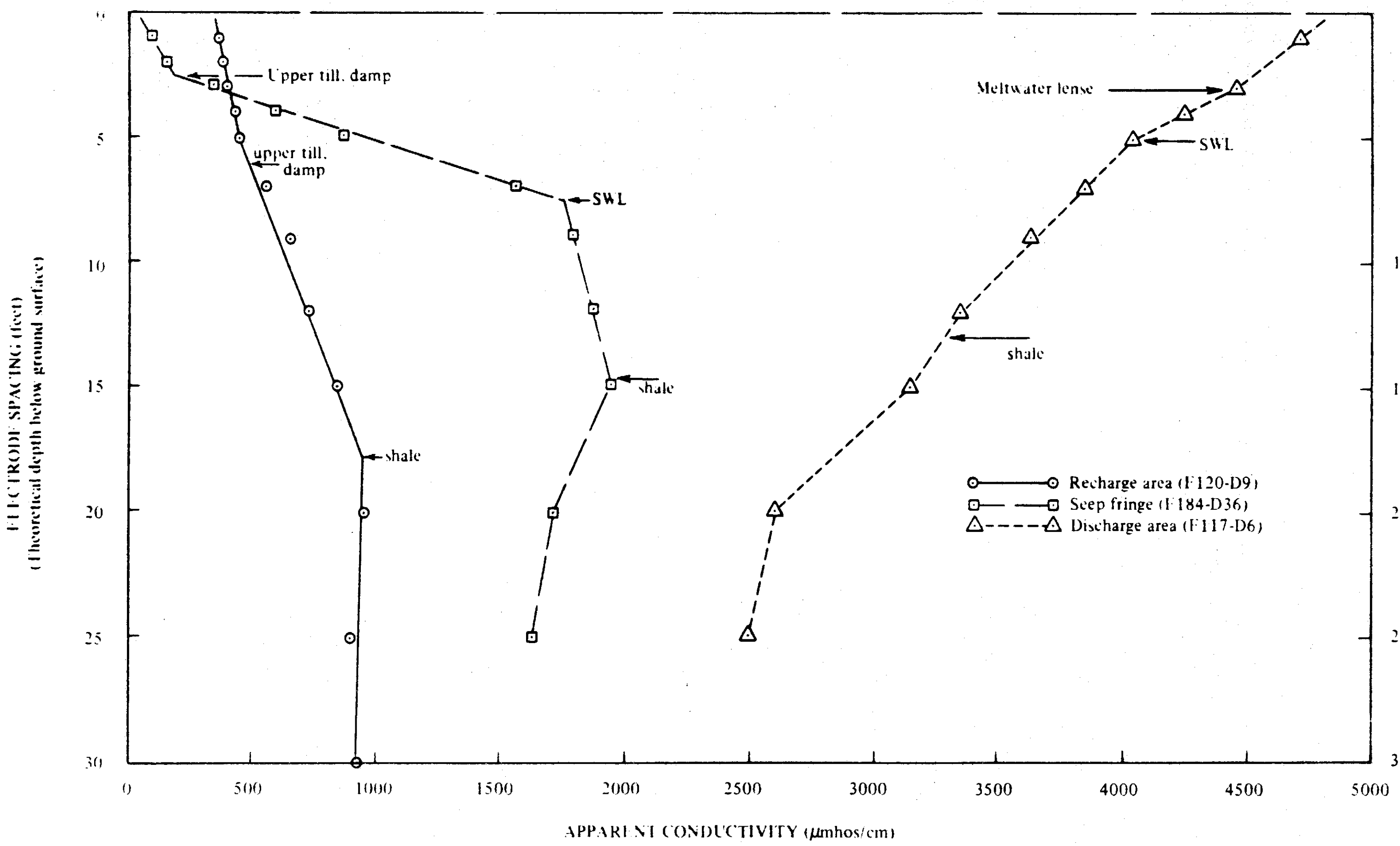


Figure 11. Comparison of 4-probe curves for recharge, seep fringe, and discharge areas on the Highwood Bench. Breaks in slope indicate subsurface features. (121).

between curves for the three types of sites. Subsurface "events," such as the top of the water table, impermeable layers, and salt-bearing aquifers, can be associated with changes in slope of the curves. The depth beneath the surface which is being sampled in a given resistivity reading is roughly equal to the inter-electrode spacing (166). This is illustrated in Figure 11, which shows plots of EC_a vs. a for a recharge, seep fringe, and discharge area on the Highwood Bench. At present, drilling is still required to confirm the meaning of these indicators. The 4-probe is a simple and accurate means of determining EC_{25} in the field without complicated soil extraction procedures. The device promises to become a major tool for diagnosis and monitoring of saline seeps and their subsurface activities.

Soils. Soils in discharge areas generally remain wet throughout the year, and may discharge water during the spring and early summer. The surface is usually encrusted with the white crystalline deposit that characterizes saline soils, composed of heavy metals, and crystals of sodium, magnesium, and calcium sulfates and chlorides. Data from Halvorson and Black (87) indicate that soils in discharge areas of their study seeps should be classified as saline-alkali soils. EC_{25} ranged from 9 to 38 mmho cm^{-1}, indicating high salinity. The sodium absorption ratio (SAR), which is nearly analogous to the exchangeable sodium percentage (ESP), ranged from 9 to 74. This indicates a very high level of sodium cation tie-up of available exchange sites. Comparable data are not yet available for seeps on the Highwood Bench. Brown (47), Ferguson (76), and Miller (120) agree that sodium buildups occur on the cation exchange sites. USDA figures (206) for SAR values follow:

Type of Soil	Typical SAR Analysis
Nonsaline-nonalkaline	0.8 to 7.5
Nonsaline-alkaline	13.9 to 35.0
Saline	10.5 to 17.4
Saline-alkaline	24.4 to 67.6

For many years, it was presumed that saline seep damage to the soils was "nearly irreversible" (33), since high sodium ratios usually cause major structural degradation following leaching of calcium and magnesium cations from the profile. Investigators now report, however, that discharge area soils usually recover once the water level is lowered below the root zone (47, 76, 85). Due to the low rainfall, this recovery takes two to three years. This allows time for normal cation exchange ratios to be reestablished, which protects the soil from deflocculation. Leaching the profile suddenly, as with flooding, would cause severe problems with sodium remaining on the exchange complex, even if the undesirable salts were otherwise removed. Brown (166) reports "self-reclaimed" fields now recovered to nearly their original productivity. He cautions, however, that after more than three years as a saline-alkali soil, recovery may not be as rapid or complete.

In this respect, it is perhaps fortunate that the three alkali metals tend to occur together in saline seeps. The magnesium and calcium cations compete with sodium for exchange sites, and help to retain soil aggregation.

Application of organic materials may also be beneficial:

> The available data indicate that organic matter improves and prevents deterioration of the physical condition of the soil by its interaction with the inorganic cation exchange material, by serving as energy material for microorganisms which promote the stable aggregation of soil particles, and by decreasing the bulk density of soils (206).

Soil Microorganisms. Soil microorganisms in discharge areas probably experience drastic changes in diversity and community composition when their environment is flooded with highly saline groundwater. No biological studies concerning these impacts of saline seep were located during the present investigation. Consequently, no specific data can be reported here. Although Ferguson (76) confirms that the spectrum of subsoil organisms must change when the soil is wetted, he feels that once the area is dried out and reclaimed, the communities will become reestablished. This conclusion is open to investigation.

Rodents. Ground-dwelling rodents, including gophers and field mice, are displaced by saline seep. Food sources in the discharge area are also lost, and several farmers (115, 173) observed that rodents rarely venture across the open salt barrens. Large seeps may temporarily increase rodent densities in adjacent fields, but the population will quickly stabilize at or near the former densities.

Vegetation. The response of the vegetation to saline soils is dependent upon a variety of factors: 1) soil texture; 2) distribution of salt in the profile; 3) composition of the salt; and 4) the species of plant (206). Soils with high ESP (above 15) may become dispersed and less permeable to air and water. This is a major restrictive factor in plant growth (37, 214). Salt-tolerant plants, or halophytes, are not all equally salt tolerant. The depth of the salty water beneath the soil surface will make a major difference in the composition of native communities on residual sites (206). Saline seeps, when saturated throughout the root zone, present an additional hazard. Plant roots must carry on respiration continuously, which means that oxygen must be present in the soil (148). Most field crops are not adapted to long-term submersion of their root systems.

Vegetative response to the soil's salt composition may include reduced growth of the plant or plant parts, nutritional imbalances due to osmotic stresses preventing water and food uptake by the roots, or toxic reactions to specific salts or combinations of salts (140). These impacts are extremely complex and difficult to distinguish:

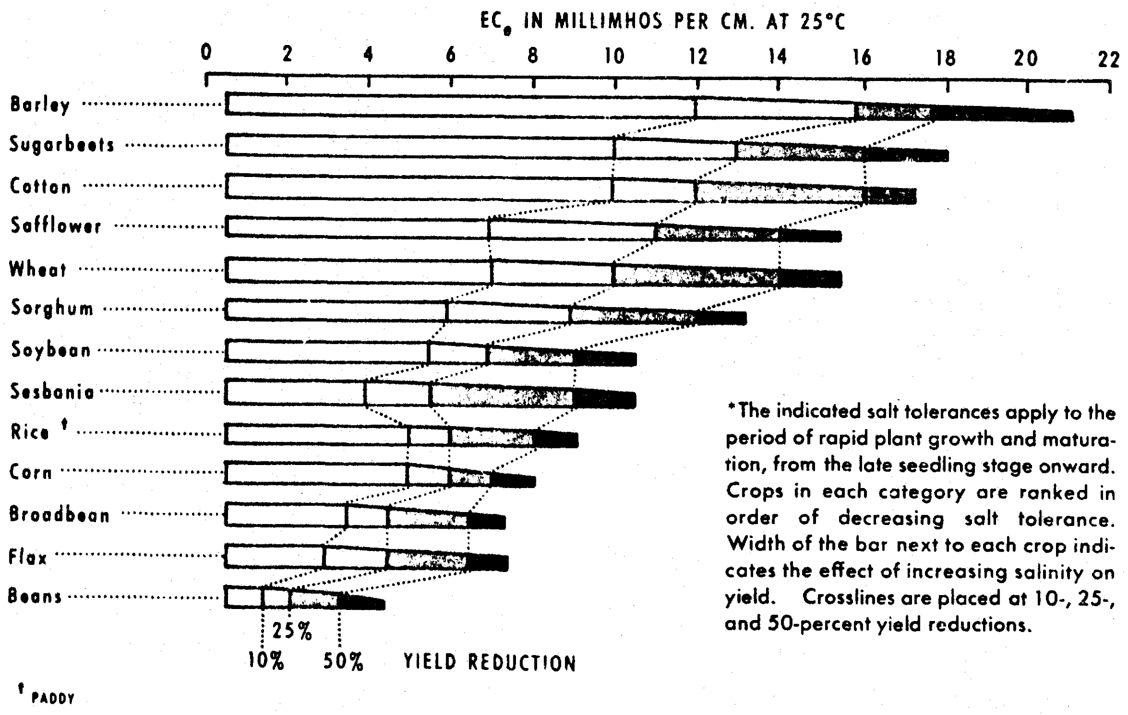
> It appears...that differences in plant tolerance to excessive concentrations of ions in the substrate are related, in some degree, to specific selectivity in ion absorption and nutrient

> requirements of the plants. In addition to these factors, there is also a marked difference among species in the amounts of such ions as sodium and chloride that can be accumulated without toxic effects (206).

Salts also reduce the availability of certain soil micronutrients by displacing them on the exchange complex of the soil (123). Figure 12 shows general salt tolerance of field crops.

A typical chronology of vegetative response to the incursion of a saline seep has been presented above. After the seep is well established, Kochia and foxtail barley frequently dominate whatever vegetative cover is found on the site. Kochia grows extremely well on fringe areas of seeps, while foxtail will invade the wetter interior. If the seep is on cropland, generally the farmer will make every effort to work the soil if it dries enough to support the weight of his machinery. Thus it is often the case that, although the seep is not cured, it will remain in this early state of disturbed succession for many years. Kochia and foxtail, opportunistic annuals, will be joined by a few other halophytes if the stand is left undisturbed for a year or more. Studies of natural succession on saline seeps have not been done (47, 76), nor have there been any known data published on diversity, structure, or productivity of saline seep successional communities.

Figure 12. SALT TOLERANCE OF FIELD CROPS* (37).



*The indicated salt tolerances apply to the period of rapid plant growth and maturation, from the late seedling stage onward. Crops in each category are ranked in order of decreasing salt tolerance. Width of the bar next to each crop indicates the effect of increasing salinity on yield. Crosslines are placed at 10-, 25-, and 50-percent yield reductions.

Informal observations made during the course of the current project suggest that, when left undisturbed, vegetative species diversity greatly increases after the first several years as additional halophytic pioneers find their way onto the site. Productivity (rate of biomass conversion) probably decreases as Kochia is joined by slower-growing woody species. Schneit (173) has a five year old seep which occupies 15 acres. Flowing water is available near the center, and a dense community of sedges (*Carex spp.*) and cattail (*Typha latifolia*) occupies this site. On the drier fringes, saltgrass (*Distichlis stricta*), several species of the mustard (*Cruciferae*) family, pigweed (*Amaranthus sp.*), lamb's quarter (*Chenopodium sp.*), wild oats (*Avena fatua*), bindweed (*Convolvulus arvensis*) and cheatgrass (*Bromus sp.*) are well established, along with the ever-present Kochia and foxtail. Quack grass (*Agropyron repens*) and several species of wheatgrass (*Agropyron spp.*) have begun to crowd out the foxtail in the driest sections of the seep. Alfalfa, seeded in an attempt to dry up the site, has fared poorly except on the extreme fringes where it struggles along without much vigor. Schneit was able to plow the site several years ago when he seeded the alfalfa and some tall wheatgrass. Kochia and foxtail were the first plants to grow, and the present community soon followed.

If left undisturbed long enough, the sites would probably evolve into salt shrub communities. Branson *et al*. (41) reviewed salt desert shrub vegetation in the western United States and classified communities in terms of maximum tolerances to osmotic stress. Table 4 summarizes shrub community occurrence in the intermountain area along osmotic stress and conductivity (EC$_{25}$) gradients. EC$_{25}$ in saline seep soils ranges upwards from 8 mmhos cm^{-1}, indicating that shrub communities which might be expected to develop on saline sites, depending on distribution and availability of seed, would include desert molly (*Kochia americana*), greasewood, saltbush, alkali sacaton, saltgrass, seepweed, glasswort, and pickleweed. The salt marsh zone communities occur in playa bottoms in the Great Basin, and the wettest seeps would probably evolve to this type of vegetation if left undisturbed.

Many coulees are affected by saline seep, and where these coulees have not been farmed (due to steepness or inaccessibility), native shrub and deciduous vegetation may be affected by the encroaching salty water. Dusek (69) studied range vegetation in central Montana in relation to the feeding habits of mule deer. His survey of coulee range indicated that the floodplains of the major drainageways and side coulees were typically inhabited by silver sage (*Artemisia cana*), wildrose (*Rosa spp.*), cottonwood (*Populus deltoides*), and abandoned floodplain meadow subtypes. Impacts of saline seep in these communities should be quite marked, with decreased diversity and productivity due to complete or partial loss of vegetative cover. Secondary succession would favor one or more of the above halophytic types (after the usual Kochia-foxtail phase).

Slopes above floodplains and in the lower sections of some side coulees are occupied by the big sage type. Subtypes include the big sage-*Agropyron*, big sage-greasewood, greasewood, deciduous shrub, and *Juniperus spp.* communities. Big sage is not especially salt tolerant; hence greasewood could be expected to increase markedly on salinized sites. Greasewood is found near the lower end of the gradient of EC$_{25}$ values found in seepage soils, however, and stability of this community might be upset by fluctuations in salt concentrations.

Table 4. Community distribution in intermountain shrub zones along gradients of osmotic stress and EC_{25} (41, 206).

Osmotic Stress at Field Capacity (Atmospheres)	Specific Conductance (mmhos/cm at 25°C)	Vegetation Community
		SAGEBRUSH ZONE
0.01	1	Little rabbitbrush (*Chrysothamnus viscidiflorus*)
0.1	1	Big sagebrush (*Artemisia tridentata*)
0.2	1	Black sagebrush (*Artemisia nova*)
		SALT DESERT SHRUB ZONE
0.6	2	Bud sagebrush (*Artemisia spinescens*)
0.6	2	Winterfat (*Eunotia lanata*)
2.2	6	Shadscale (*Atriplex confertifolia*)
3.2	10	Desert Molly (*Kochia americana*)
5.0	13	Greasewood (*Sarcobatus vermiculatus*)
5.0	13	Nuttall saltbush (*Atriplex Nuttallii*)
		Mat saltbush (*Atriplex corrugata*)
Osmotic Stress at Saturation (Atmospheres)		SALT MARSH ZONE
1.5	4	Rabbitbrush (*Chrysothamnus nauseosus*)
2.8	8	Alkali sacaton (*Sporobolus airoides*)
16	36	Saltgrass (*Distichlis stricta*)
23	52	Seepweed (*Suaeda torreyana*)
35	>60	Glasswort (*Salicornia utahensis* and *S. rubra*)
35	>60	Pickleweed (*Allenrolfea occidentalis*)

Dusek (69) found a grassland type of tablelands above major drainages and in shallow upper coulees. Subtype communities were dominated by needlegrasses (*Stipa spp.*) on rangelands, cash grains on agricultural lands, deciduous shrubs (*Rhus trilobata*, *Rosa spp.*, *Symphoricarpos spp.*) on mesic sites such as heads of coulees and depressions in sides of coulees, and the *Juniperus spp.* subtype on sloping sides of coulees. It is difficult to predict the impacts of saline seep on these communities, beyond the certain knowledge that most of them would be severely changed.

Little effort will probably be made to reclaim coulees and non-cropped land so there will be ample opportunity for definitive studies of secondary succession after saline seep invasion. Such studies will be necessary to determine changes in species, cover, general carrying capacity, and a host of ecological variables such as microclimate, moisture regime, and symbiotic and synergistic relationships between soils, plants, and microfauna and macrofauna.

Noxious and Poisonous Plants. Rangeland vegetation in Montana is sometimes rendered less palatable by noxious, or undesirable species. Common noxious plants are Russian thistle (*Salsola kali*), knapweed (*Centaurea maculosa*), fringed sage (*Artemisia frigida*), broom snakeweed (*Gutierrezia sarothrae*), prickly pear (*Opuntia polyacantha*), Canadian thistle (*Cirsium arvense*), and field bindweed (*Convolvulus arvensis*) (132).

No data were found on the salt tolerance of these species, but Russian thistle is frequently seen in or near seeps in northern Montana, and field bindweed was collected, along with knapweed, from an old seep in Fallon County. The extent to which these less desirable species will invade saline seeps is not known at present.

Poisonous plants contain or produce "substances that cause sickness, death or a deviation from normal state of health of animals" (132). Black greasewood (_Sarcobatus vermiculatus_), chokecherry (_Prunus virginiana_), arrowgrass (_Triglochin maritima_), cockleburr (_Xanthium strumarium_), death camas (_Zygadenus venenosus_), lupine (_Lupinus candatus_), locoweed (_Astragalus spp._), and leafy spurge (_Euphorbia esula_) are common poisonous species on Montana ranges (132). Arrowgrass and chokecherry contain cyanides and are particularly dangerous during droughts. Greasewood, the most common poisonous plant on Montana ranges, contains substantial quantities of oxalic acid, which causes severe imbalances in calcium regulation in the body. Cockleburr seedlings contain a highly toxic glucoside, xanthostrumarin. Death camas, a vernal perennial, contains steroid alkaloids of veratrum, a powerful nerve toxin. Locoweeds are particularly favored as forage by horses, and losses may be severe. Lupines are responsible for some livestock losses in northeastern Montana each year, and contain complex alkaloids which are most toxic in late summer (158). Most of the other species are also dangerous only at certain times of the year, and to certain species of animals.

Spread of these species to saline seep successional communities may occur, although authorities consulted during the present project deny that it is a problem (1, 19, 26, 36, 47, 50, 56, 63, 76, 78, 85, 94, 97, 99, 115, 116, 157, 170, 172, 200, 205, 222). Less severely affected sites may support greasewood after a few years, as discussed above, but the importance of this eventuality from the standpoint of livestock management is not yet documented.

Domestic Livestock. Livestock problems connected with saline seeps, although widely reported in the popular press (e.g., 179-198) and elsewhere (33, 58), are exceedlingly difficult to link to saline seep in an irrefutable manner. No known research, outside of the informal survey conducted as part of the present project, has been done to document the reported incidents; most claims rely on circumstantial evidence. However, it is entirely reasonable to expect that livestock, along with all other biota in seep areas, will be impacted. On-site impacts affecting livestock are discussed in this section; problems connected with polluted surface waters are deferred until a later section. There are three major areas of concern with regard to on-site impacts on livestock.

We have discussed the vegetative changes which can be expected when a rangeland is invaded by saline seep. Loss of stable grassland ecosystems and replacement by Kochia and foxtail will reduce the carrying capacity of the pastureland. Kochia is highly palatable and protein rich (45, 72) during the spring and early summer, and provides excellent forage. However, as summer advances, the mature plant toughens to the consistency of wood, and livestock cease to graze it. Foxtail is useless as forage, primarily due to its heavy beard. Consequently, saline seep discharge areas can be used only seasonally, and the productivity of the sites is thereby lowered. This lower productivity and subsequent reduction in carrying capacity may force heavier grazing on adjacent rangeland, and subsequent damage to the quality of those pastures.

Stripping the soil bare invites invasion by all types of opportunistic annual weeds. Although little evidence is found of extensive invasion of discharge areas by noxious or poisonous species, this is still a possibility.

The saturated soils may present physical difficulties which, although probably of little significance, deserve mention. One farmer (116) reports that a few range livestock have been lost when they became stuck in the deep mucky soils near residual alkali playas. If not discovered and rescued, the cattle and horses die from lack of water. Another interesting question is whether quicksand might be formed in discharge areas in rare instances.

Saturated saline soils might have metabolic impacts if livestock lick the salts in an attempt to obtain sodium and trace nutrients. Veterinarians consulted during this project consider this to be unlikely (1, 26, 56, 63, 83, 94, 115). Another possible impact which has been mentioned by Dr. Halver, State Veterinarian, is the harboring of diseases whose vectors find the moist, salty soil an ideal habitat. Dr. Halver (83) indicated that tetanus, malignant edema, blackleg, and other diseases produced by organisms of genus Clostridium may be propagated on highly alkaline soils. Anthrax was one of these diseases mentioned as needing an alkali medium for reproduction. Dr. Halver's concern was not seconded by any other veterinarians contacted during the present investigation, although it was confirmed (57) that stagnant alkali waters or saturated alkali soil, along with other highly specific environmental conditions, are involved in the life-cycle of these disease organisms. This possible impact definitely should be kept in mind for future research efforts.

Livestock may incorporate salts and metals into their tissues through plant consumption. Metabolic or toxic impacts to these livestock conceivably could be expected if they consume excessive amounts of plants which have taken up certain salts or heavy metals from the soil. None of the experts contacted about this possibility thought that it would be of any significance (1, 26, 56, 63, 83, 94, 115). Plant uptake of these substances is highly species-specific; herbivore consumption of food plants is highly species-specific, as is animal reaction to salts and heavy metals. The possibility of this indirect metabolic impact is hidden behind a triple set of relatively unknown variables. It is much easier to isolate such impacts when uptake is direct as in the case of drinking water.

Big Game Mammals. Mule deer (Odocoileus hemionus), white-tail deer (O. virginianus) and antelope (Antilocapra americana) are found throughout the northern Great Plains. The deer generally inhabit the coulees, while antelope prefer the upland plateaus where agricultural land predominates. The herds are not considered migratory (132). Saline seep is detrimental to big game animals because of disruption of cover and forage, primarily in the coulees. The extent or seriousness of this disruption is not yet known.

Mule deer are distributed through the areas affected by saline seep. They graze croplands and browse the sides of coulees during summer and winter. They also utilize the bottoms and heads of the coulees at all times except when snow accumulation prevents access. During the summer, grassland forbs dominate in the diet, followed by browse: rubber rabbitbrush (Chrysothamnus viscidiflorus), green rabbitbrush (C. nauseosus), skunkbush sumac (Rhus trilobata), big sagebrush (Artemisia tridentata), silver sagebrush (A. cana), chokecherry (Prunus virginiana), and snowberry (Symphoricarpos alba) (69, 132). During the fall, browse becomes the primary food as the forbs decline, and during winter, rubber rabbitbrush and Juniperus spp. make up the major part of the mule deer's diet. As springtime brings back the herbs and forbs, their importance in the diet grows. Mule deer food preferences probably would not exclude Kochia if it were the only edible plant available on a saline seep site. It is likely that deer would leave a saline area in favor of sites containing their preferred foods. Species types making up the bulk of mule deer food are not very salt tolerant and would be eliminated on seepage sites.

Displacement of mule deer would compound the problems of limited habitat and overpopulation, problems which the species already face (209). Most of the uplands have been preempted for agriculture, and all wildlife species have been relegated to leftover land parcels (74). Extensive spread of saline seep, to the extent that it makes present habitat unattractive to mule deer (or any other species), would put additional stresses on the animal and its competitors.

As an example of this competition, Dusek (69) found that cattle and mule deer do not seriously compete for food on healthy ranges. If the grasses decline due to over-grazing (or are destroyed by saline seep), cattle are forced to use more of the deciduous shrubs which form the most important part of the mule deer diet during late summer and early fall. Thus, loss of cattle pasture, where deer and cattle are dependent upon the same vegetative community, could adversely affect the condition of mule deer as winter approaches. This is a time of high mortality under the best of circumstances.

White-tail deer inhabit the river bottoms and eat mainly deciduous riparian vegetation such as chokecherry, serviceberry, skunkbush sumac, western snowberry (Symphoricarpos occidentalis), cottonwood, and dogwood (Cornus spp.). They are more dependent upon drinking water than mule deer, and prefer dense brush rather than the open habitat favored by mule deer (210). White-tail deer would thus seem to be less susceptible to severe disruption of upland habitat and cover than mule deer, since on-site impacts of saline seep would probably be confined to areas well upland from the riparian bottomlands. Irrigation seepage would be a greater threat in these areas. The white-tail deer's preferred food species are not known to be salt tolerant.

Pronghorn antelope may frequently be seen in the wheat fields of eastern Montana. Unless blocked by poorly designed fences, these animals roam the upland benches, inhabiting open sagebrush and grassland. Principal forage items include sagebrush and forbs, all highly susceptible to eradication by saline seep. The principal impact upon antelope would be crowding due to exclusion from the barren and uninviting discharge areas, and loss of browsing areas.

Ruminants change their diets in spring and fall, and at these times they may need salt licks (74). Apparently the salt helps convert bacterial content of the rumen during the changeover from dry to succulent foods in the spring, and from succulents to dry foods in the fall. Although it is known that big game animals frequent salt licks during these periods, it is not known to what extent they might use salts in saline seep discharge areas.

Upland Game Birds. Four species of upland game birds are common in the prairies affected by saline seep. Sharp-tail grouse (Pedioecetes phasianellus) live in tree-shrub-grasslands on the upland prairies and are distributed throughout the eastern two-thirds of the state (128, 132). Cover, food, nesting habitat, and winter survival require standing grasses and dense trees and shrubs (132). Most of the water needed by the sharp-tail grouse is derived from succulent plants. These species are displaced in barren saline seep discharge areas.

Sage grouse (Centrocercus urophasianus) also occupy grasslands and brushy draws of the upper coulees and upland plains, and are dependent upon sagebrush for their winter food (132). Strutting grounds, essential to reproductive behavior, are also in sagebrush lands. Grasslands and sagebrush communities cannot tolerate high salinity, and the sage grouse will be displaced to the extent that these communities are disrupted.

Hungarian partridge (Perdix perdix) are found nearly everywhere in the northern Great Plains, including croplands. This species needs a minimum of cover, and is able to inhabit even waste areas (51, 74). Impacts of saline seep should, therefore, be less severe, although it is expected that carrying capacity would decline as croplands and edible plants are lost during the initial stages of seepage outbreak.

Ring-necked pheasant (Phasianus colchicus) habitat includes lowland river bottoms, especially irrigated floodplain areas. Food is primarily commercial grain (132). Cover requirements are satisfied by brush or grass. Pheasants have disappeared from one coulee in Cascade County as a direct result of tile drainage from a saline seep being flowed overland through the coulee bottom (177). Impacts of saline seep on ring-necked pheasant are not expected to be severe in most habitat areas, although disruption of grain cropping would decrease food availability.

It is impossible to accurately predict at this time the ultimate impacts of saline seep on upland game birds. Although primary habitat will no doubt be adversely affected for all species, disruption of monocultural agriculture will allow establishment of a certain amount of weedy cover. This could provide additional habitat for some species. Grouse species, for example, are known to live in heavily overgrown seepage areas below stockpond dams (74). At present, most cropland is of very limited value as wildlife habitat, due to extensive manipulation of the vegetation. Thus removal of the land from this use, while it entails severe implications for soils, vegetation, and water quality, may actually benefit certain wildlife species (144). Disruption of the major components of the ecosystem, however, renders these benefits of dubious value for any but the immediate species involved. Loss of vegetative cover, which would be widespread, renders the land valueless for wildlife.

An additional consideration involves exploratory efforts to reclaim saline seeps by planting perennial cover on recharge areas. This could be considered a secondary or indirect beneficial impact of saline seep. There is no doubt that wildlife, especially upland game birds and other species able to capitalize on these habitats, will be generally benefited. Populations may be expected to fluctuate in response to all of these factors.

Other Wildlife. A wide spectrum of non-game species inhabits the northern Great Plains and utilizes areas potentially disruptable by saline seeps. Cottontail rabbits, badger (_Taxidea taxus_), fox (_Vulpes fulva_), coyote (_Canis latrans_), skunk (_Mephitis mephitis_), field mice, and ground squirrels are frequently encountered in agricultural areas and in the nearby coulees (74). Loss of food or cover on discharge sites might force changes in location for some species, with attendant impacts of crowding on adjacent non-seeped areas, disruption of territories, and other more subtle impacts. A more complete list of Montana wildlife is included on the following pages (Table 5) (127). Starred (*) species may be considered residents of areas affected by saline seeps.

Air Pollution. Wind erosion has always been a serious problem in the agricultural areas of the northern Great Plains (160). When saline seeps dry out, a white crust forms on the surface. It is composed of sulfate crystals of sodium, magnesium, and calcium, and although it is hard-packed and dense when moist, the crust becomes loose and fluffy when thoroughly dried (76). Several farmers report that white clouds of alkali dust occasionally issue from their larger seeps (116, 170), and "blowing" of residual alkali deposits is considered common (200). The Montana Agricultural Experiment Station's list of needed reclamation procedures (125) includes snow fence barriers, which would help prevent salt blowing by protecting discharge areas from wind.

Ferguson (76) and Halvorson (85) consider that salts blown from saline seeps probably do not present a serious air quality problem, because such blows serve mainly to dilute salt deposits by spreading insignificant amounts of salt over a wide area. No diseases are thought to be spread by blowing saline seep dust (40).

Most seeps, except those dry enough under the surface to be cultivated, are protected against wind by tall stands of Kochia and other weedy vegetation during most of the year (37). In addition, few seeps occur on ridgetops where the wind hazard is most prevalent; the great majority of seeps are found in relatively sheltered low places (170, 200). The relatively small size of unprotected barren areas also mitigates against significant air pollution problems (54). Dramatic increases in the size and extent of saline seeps, especially those too salty to support some form of protective vegetative cover, could make blowing of salt dust more frequent and serious.

Table 5. MONTANA MAMMALS (127).

Classified According to Montana Law

G - - - - Game Animal

P - - - - Predatory Animal

F - - - - Furbearer

Common Name	Scientific Name	Distribution and Occurrence
Masked Shrew	**Sorex cinereus**	Dry woods, throughout the state.
Vagrant Shrew	**Sorex vagrans**	Moist woods and meadows in western portion, common.
* Merriam Shrew	**Sorex merriami**	Sagebrush and grasslands in eastern counties, quite rare.
Dwarf Shrew	**Sorex nanus**	Known from several high mountain ranges in the center of the state.
Northern Water Shrew	**Sorex palustris**	Banks of fast streams and shores of high altitude lakes in mountains.
* Preble Shrew	**Sorex preblei**	Known from a few specimens in central and eastern Montana, very rare.
Pigmy Shrew	**Microsorex hoyi**	Dry woods of northwestern Montana only, rare.
* Little Brown Bat	**Myotis lucifugus**	Throughout the state, common.
* Yuma Bat	**Myotis yumanensis**	Throughout the state, less common than above.
* Little Long-eared Bat	**Myotis evotis**	Throughout the state, fairly common.
California Brown Bat	**Myotis californicus**	Known from Ravalli county.
Long-legged Bat	**Myotis volans**	Higher elevations in western half of the state.
* Say Bat	**Myotis leibii**	Most of the state.
Fringed Bat	**Myotis thysanodes**	Very rare; specimens from Lewis and Clark Caverns and Ravalli County.
Big Brown Bat	**Eptesicus fuscus**	Throughout the state, may hibernate in buildings during winter.
Hoary Bat	**Lasiurus cinereus**	Deep woods in summer, probably occurs throughout the state in migration.
Spotted Bat	**Euderma maculatum**	Known only from single specimen obtained at Billings.
Townsend's Big-eared Bat	**Plecotus townsendii**	Known from several caves and mines in central and western Montana.
Silver-haired Bat	**Lasionycteris noctivagans**	Wood areas, rather common.
G—Black Bear	**Ursus americanus**	Forested areas, rather common.
G—Grizzly Bear	**Ursus arctos**	Remote wilderness areas especially at high elevations, rare.
F—Fisher	**Martes pennanti**	Probably extinct, but successfully transplanted from British Columbia in 1958-59 near Holland Lake, Missoula County, and Pink Creek, Lincoln County.
F—Marten	**Martes americana**	Most higher mountain regions, common.
P—Short-tailed Weasel	**Mustela erminea**	Generally in forested areas, common.
* P—Long-tailed Weasel	**Mustela frenata**	Throughout the state, common.
* P—Least Weasel	**Mustela nivalis**	Eastern half of the state, rare.
* F—Mink	**Mustela vison**	Marsh areas and stream banks throughout the state, common.
* F—Black-footed Ferret	**Mustela nigripes**	Eastern part of the state in prairie dog colonies, extremely rare.
P—Wolverine	**Gulo gulo**	Wilder portions of western mountains, rather rare.
* P—Striped Skunk	**Mephitis mephitis**	Throughout the state in farm land and open country, common.
P—Spotted Skunk	**Spilogale putorius**	Known only from specimens obtained in Ravalli county, and in south central Montana.

* Badger	**Taxidea taxus**	Throughout the state, common.
F—River Otter	**Lutra canadenis**	On large streams, mostly in western portion, rare.
* Raccoon	**Procyon lotor**	Recent invader from both east and west, now common in large river valleys throughout the state.
* Red Fox	**Vulpes vulpes**	Formerly rare through the state but now fairly common in many areas.
Swift Fox	**Vulpes velox**	Originally common in eastern counties, now probably extinct.
* P—Coyote	**Canis latrans**	Throughout the state, common.
P—Wolf	**Canis lupus**	Originally present throughout the state, now confined to Glacier National Park and vicinity, rare.
G—Cougar	**Felis concolor**	Western counties, rare.
Canada Lynx	**Lynx canadensis**	Heavily forested areas in western part of state, rare.
* P—Bobcat	**Lynx rufus**	In many areas in state, common.
Yellow-bellied Marmot	**Marmota flaviventris**	Rocky areas and mountains of most of the western part of the state, common.
Hoary Marmot	**Marmota caligata**	Above timberline in Glacier National Park and neighboring high mountain ranges, rare.
Columbian Ground Squirrel	**Spermophilus columbianus**	Western one-third of the state, common.
* Richardson Ground Squirrel	**Spermophilus richardsonii**	Eastern two-thirds of the state, common.
Uinta Ground Squirrel	**Spermophilus armatus**	Yellowstone Park and surrounding areas, common.
* Thirteen-lined Ground Squirrel	**Spermophilus tridecemlineatus**	Grassland in eastern and central areas.
Golden-Mantled Ground Squirrel	**Spermophilus lateralis**	Rocky areas in the mountains of central and western regions, common.
* Black-tailed Prairie Dog	**Cynomys ludovicianus**	Formerly abundant in eastern Montana, now much reduced by poisoning.
White-tailed Prairie Dog	**Cynomys leucurus**	Known only in Carbon county.
* Least Chipmunk	**Eutamias minimus**	Primarily in sagebrush areas in eastern and central Montana, common.
Yellow Pine Chipmunk	**Eutamias amoenus**	Lower elevations in western Montana, common.
Rufous-tailed Chipmunk	**Eutamias ruficaudus**	Higher elevations in northwestern mountains, common.
Uinta Chipmunk	**Eutamias umbrinus**	Higher elevations in the vicinity of Yellowstone National Park.
Red or Pine Squirrel	**Tamiasciurus hudsonicus**	Coniferous forest in western counties, common.
Northern Flying Squirrel	**Glaucomys sabrinus**	Dense forest in western counties, common.
* Fox Squirrel	**Sciurus niger**	In towns and river bottoms along the Missouri and Yellowstone Rivers.
* Northern Pocket Gopher	**Thomomys talpoides**	Throughout the state, common.
* Wyoming Pocket Mouse	**Perognathus fasciatus**	Dry areas in eastern counties.
Great Basin Pocket Mouse	**Perognathus parvus**	Known only from Beaverhead county.
Hispid Pocket Mouse	**Perognathus hispidus**	Known only from extreme southeastern Carter county.
* F—Beaver	**Castor canadensis**	Along streams and lakes throughout the state, common.
* Ord Kangaroo Rat	**Dipodomys ordii**	Sandy soil and sagebrush in the eastern half of the state.
* Northern Grasshopper Mouse	**Onychomys leucogaster**	Grasslands of eastern Montana.
* Western Harvest Mouse	**Reithrodontomys megalotis**	Grasslands of eastern Montana.
* Western Deer Mouse	**Peromyscus maniculatus**	Throughout the state in virtually all habitats, common.
* White-footed Mouse	**Peromyscus leucopus**	Eastern Montana.
Bushy-tailed Wood Rat	**Neotoma cinerea**	Deserted cabins in Rocky Mountain areas, common.
Northern Bog Lemming	**Synaptomys borealis**	Only in wet meadows of west side of Glacier National Park, rare.
Mountain Phenacomys	**Phenacomys intermedius**	Mostly near timberline in high mountain ranges.
Red-backed Vole	**Clethrionomys gapperi**	Moist coniferous forests in western half of state, common.

Water Vole	**Arvicola richardsoni**	Stream banks at high elevations in the mountains.
Meadow Vole	**Microtus pennsylvanicus**	Wet meadows throughout the state, common.
Longtailed Vole	**Microtus longicaudus**	Wet woods of central and western Montana, common.
*Mountain Vole	**Microtus montanus**	Dry grasslands of western and central Montana, common.
*Prairie Vole	**Microtus ochrogaster**	Dry grasslands of eastern Montana, common.
*Sagebrush Mouse	**Lagurus curtatus**	Sagebrush areas in eastern and central mountains, rare.
*F—Muskrat	**Ondatra zibethicus**	Ponds and streams throughout the state, common.
Rocky Mountain Jumping Mouse	**Zapus princeps**	High mountain meadows and wet woods near water in the western half of the state.
*Meadow Jumping Mouse	**Zapus hudsonius**	Known only in eastern Montana.
*House Mouse	**Mus musculus**	Around human habitations throughout the state, common.
Norway Rat	**Rattus norvegicus**	Known only in some of the cities.
Porcupine	**Erethizon dorsatum**	Throughout the state, common.
Nutria	**Myocaster coypus**	Introduced; once found in the Bitterroot Valley; may still occur near Billings.
Pika	**Ochotona princeps**	Slide rock areas in mountains, common.
Snowshoe Rabbit	**Lepus americanus**	Forested areas in western half of the state, common.
*White-tailed Jack Rabbit	**Lepus townsendii**	Open areas throughout the state, common.
Black-tailed Jack Rabbit	**Lepus californicus**	Known only in Beaverhead County.
Mountain Cottontail	**Sylvilagus nuttallii**	Lower elevations in Montana, common.
*Eastern Cottontail	**Sylvilagus floidanus**	Found only along the extreme eastern border of the state.
*Desert Cottontail	**Sylvilagus audubonnii**	Eastern counties, common.
Pigmy Rabbit	**Sylvilagus idahoensis**	Known only in Grasshopper Drainage in Beaverhead County.
G—Elk	**Cervus canadensis**	Certain suitable areas in central and western Montana, common.
*G—White-tailed Deer	**Odocoileus virginianus**	Forested areas in western Montana and brushy river bottoms in eastern Montana, common.
*G—Mule Deer	**Odocoileus hemionus**	Suitable habitats throughout the state, common.
G—Moose	**Alces alces**	Suitable areas in western half of the state, fairly common.
G—Woodland Caribou	**Rangifer tarandus**	Formerly occurred in Lincoln County, now enter the state from British Columbia, but only rarely and in winter.
*G—Pronghorn Antelope	**Antilocapra americana**	Most of eastern and central Montana, common.
G—Bison	**Bison bison**	Formerly occurred throughout the state, now confined to Yellowstone National Park, the National Bison Range, and in scattered bands on private ranches.
G—Bighorn Sheep	**Ovis canadensis**	In scattered bands in the western half of the state, reintroduced into several mountain ranges.
G—Mountain Goat	**Oreamnos americanus**	High mountain ranges of northwestern Montana, successfully transplanted in several mountain ranges in central Montana.

*Species usually residing in areas affected by saline seep.

(Montana Mammals list originally compiled by Philip Wright, Professor of Zoology, University of Montana)

Off-Site Environmental Impacts

Introduction. Saline seeps affect far more than just crops, plants and animals on the discharge area. It is necessary to examine, in addition to the "on-site" impacts which occur within the discharge area, the "off-site" impacts possibly caused by the pollutants released by saline seeps. These other effects are frequently subtle. The off-site components include: 1) coulees--those leading from the seeps or from seep-infested fields, and those directly affected by seepage; 2) stockponds and reservoirs; 3) creeks and other small intermittent and perennial streams; 4) major streams, tributary to; 5) the Yellowstone and Missouri rivers.

Most of the concern over non-agricultural environmental impacts of saline seep has centered on the possibility of significant degradation of the quality of surface waters (33, 34, 64, 120). There is ample evidence that local surface waters leading from seepage areas have become highly polluted by the salts, heavy metals, and nutrients from the seeps (33, 224). The potential impacts from this pollution may be quite serious:

> The implications of seep-caused water pollution are clear. Montana is a headwater recharge area for downstream states in the Missouri River Basin, and any degradation of water quality here will affect downstream uses. Unless saline seep is checked, present water uses such as drinking, recreation, and fish and wildlife, will be seriously degraded and water treatment will become more expensive (33).

The process of data collection to substantiate and fully evaluate the severity of current water pollution by saline seep has only just begun. Like so many of the impacts already discussed, it is impossible to quantify present saline seep damage to water quality in most surface water systems. The present discussion of ecological impacts is consequently tentative.

Sources of Surface Water Pollution. Saline seep can potentially affect surface water quality through two mechanisms: 1) discharge of polluted groundwaters as a spring-like flow: and 2) transportation of sediment and saline solutes in overland flow, originating primarily outside the discharge area. In terms of the four-part saline seep system described earlier, these processes constitute the fourth component of the system: overland drainage.

Miller (58) reports that formerly intermittent or dry coulees on the Highwood Bench have become small perennial streams because of increasing discharge from stored groundwaters within the till. Flow data and water quality analyses for these discharges are not presently available. Miller hypothesizes that such flows will increase if the till continues to receive and store excess water, raising local water tables. Schneit (73), a farmer near Rapelje, has a perennially flowing seep in the middle of his horse pasture, and another in the middle of a wheat field. Both of these outflows reinfiltrate into the soil within fifty feet of their origins during most of the year, but they may occasionally flow into a nearby creekbed (itself normally intermittent) during heavy storms and spring snowmelt. A water sample was taken from the pasture flow, but analysis was unavailable (August 30, 1974). Barber (37) reports that several creeks in the Denton and Coffee Creek area flow later into the summer than most other creeks in that area, due to discharge from saline seeps along their banks. No water quality or flow data are available from these creeks. These three examples illustrate the major types of "natural" surface flows generated by saline seep discharges.

An additional source of direct overland discharge from saline seeps is outflow from artificial drainage systems. Fortunately, tile drainage systems for saline seep are very rare in this state. Three such systems, in widely separated locations around the state, were visited during the field investigation phase of the present project. Water samples were taken at all sites, but no chemical data are yet available. Flows varied, depending upon the size of the recharge area and on precipitation during the previous months, but all three drainage systems reportedly discharge year-round. One, flowing at a rate of .25 gallons per minute (gpm), flowed by pipe into a stock tank and was used to water cattle (99). A second, flowing several gpm, drained into a dry creekbed. This water was reportedly used by a downstream rancher for irrigation and stock water, since it was the only available surface water in the vicinity (170). As far as was known, no ill effects had occurred from this usage. A sample was collected for analysis. The third tile drainage system, outflowing into a stagnant pool which led eventually (via a ditch) into the Benton Lake Wildlife Refuge in Cascade County, could not be gauged, but appeared to be flowing about five gpm. The ditch was stagnant due to being choked with rushes and aquatic vegetation, and reportedly must be cleared by dredging each fall (177).

Transportation of solutes and sediments by overland flow occurs during the spring snowmelt and immediately following heavy precipitation events. The soil in many seeps is bare, exposed to the mechanical beating of the rain and to the erosive transport of runoff. Dislodged by rainfall impact, the soil is easily eroded, and the soluble salts on the surface are quickly leached and carried off the site. Monitoring of erosion and leaching during these events has apparently not been done; no data have been located. The salt loads could be calculated if the volume of runoff water, the salt composition of the soil, and the leaching and erosive potential of the soil were known (104). Accurate data could also be gathered by continuous monitoring systems, but these require frequent human attention, are rather expensive, and are vulnerable to vandals (104).

Miller (121) studied the water budget of the Nine Mile Creek watershed on the Highwood Bench. He calculated groundwater storage and surface runoff as percentages of the annual precipitation input, but did not separate out direct seepage flow or flow which had contacted discharge areas. If this could be done for a watershed, it would then be possible to evaluate salt contributions per unit of discharge area. Unit salt contributions could also be calculated by working backwards from chemical loads in catchment basins, or by leaching studies; so far as is known, this has not been done. Halvorson (85) cautions that each seep must be evaluated separately, and that the salt loads in Montana's seeps can vary from 55 mmhos cm^{-1} on the Highwood Bench to 7 mmhos cm^{-1} near Sidney.

Soil erosion (and subsequent siltation) is the most serious present water quality problem in Montana's streams (33):

> Erosion often leaves severely scarred landscapes with reduced productivity. Studies reveal that excess sedimentation destroys fish spawning beds; covers aquatic food supplies; fills in channels and reservoirs; increases the water treatment requirements before it can be used for municipal and industrial water supplies; reduces the recreation value of water; is aesthetically displeasing while suspended in water. Although the total economics of erosion and sediment damage has not been fully evaluated, significant costs have accrued to individuals and the general public of Montana (133).

Bare soils are extremely vulnerable to erosion, and many soils in seepage discharge areas are bare of vegetative cover. They are also frequently located in the lower, steeper sections of fields. Since the erosive power of water varies as the cube of its velocity, serious sediment pollution from both sheet and gully erosion could be expected to be generated, especially by saline seeps faced with this double disadvantage. When this sediment pollution is added to the chemical pollution carried away by water flowing out of saline seep discharge sites, it is no mystery why stockponds and other catchments below saline seep areas tend to have such poor quality water.

Miller (120) reports that saline seepage is increasing above the impermeable shale on the Highwood Bench. Where this saturated till-shale interface is exposed in coulees along the breaks of the Missouri River, major slumps have occurred. The soil is subsequently flushed into the river in the springtime and after heavy rains.

Although precise measurements of these several mechanisms for pollution of surface streams have not yet been made, it has generally been concluded that storm runoff is the major current vector for the salts reaching perennial streams (224). As far as can be ascertained, no data are available concerning the quantities of pollutants carried into surface water systems from saline seeps in Montana.

Stockponds: Livestock. Because surface water is usually not available on the Great Plains during late summer and fall, it is necessary to store water for domestic and farm use. The need to store water for livestock use is compounded by the general unsuitability of shallow aquifers for stock watering. The simplest storage method is erection of a shallow earth-fill dam across the mouth of coulees with enough flow early in the year to fill the resulting reservoir. In some places, storage is increased by excavation behind the dam. These small reservoirs fill during the spring and generally last until late into the year.

Saline seep pollution of stockponds can cause adverse impacts on livestock under certain circumstances. Throughout the state, there are stockponds with naturally alkaline waters which may cause livestock problems late in the year when evaporation has concentrated the salts.

Saline seep can intensify these problems. It can also cause salinity problems where none existed previously. Miller (121) has documented the deterioration of several stockponds on the Highwood Bench due to the growth of saline seeps in the drainage areas above them. His data are shown in Table 6. But for most of the state, firm data are not available at the present time to fully document the suspected degradation due to saline seep. A systematic monitoring program is needed. Most stockponds are rarely tested for water quality, and then only when losses have already occurred. It is important to document trends, especially in ponds which are downstream from growing saline seeps. Until this monitoring is begun, it is reasonable to assume that water quality in most stockponds below saline seep areas has deteriorated, and will continue to do so.

Although numerous incidents of alleged losses due to saline seep poisoning have been reported (171, 179, 180, 181, 188, 189, 194, 195, 197), very few verified cases can be cited at the present time. There are many variables which must be considered in determining the causes of livestock deaths or ill health. But saline seep has not been considered a serious enough problem in the state of Montana to warrant any systematic investigation of its possible impacts on livestock (76, 84, 157), nor the establishment of an organized information-gathering network to receive reports of suspected incidents from veterinarians and to dispatch teams of expert investigators into the field to fully evaluate all such incidents. In some areas where poor water quality is recognized, the stockmen and veterinarians consider saline seep to be a significant cause of livestock problems at this time (56, 115).

Analysis of the possible adverse impacts of saline seep-polluted water on livestock is not a simple matter. Tomlinson (202) compiled a survey of the literature on toxicity of substances present in saline seep, and in many cases found that the lethal doses of these substances varied over wide ranges even for individual species of livestock, fish, and other organisms. Although he listed many experimentally determined lethal doses for various substances and organisms, Tomlinson did not attempt to establish limits for the substances present in saline seep. Limits--essentially arbitrary--for a few of the elements found in saline seep have been set by various authorities, but there have not been any studies done to determine lethal properties of the combined salts, heavy metals, and nutrients found in saline seep water, nor studies of the concentrations or dosages at which adverse responses might be expected in the various species of livestock, fish, and wildlife exposed to such water (83, 157).

Stockwater suspected of causing livestock problems is usually sent to the Livestock Board Diagnostic Laboratory at Montana State University. Analysis is normally limited to TDS and nitrates, since these are the most commonly recognized sources of trouble (157). Several commercial laboratories also routinely receive samples of suspect water, and they frequently perform more complete analyses (50). Any monitoring setup should include these laboratories as primary data sources.

Table 6.

SELECTED CHEMICAL ANALYSES OF WATER SAMPLES FROM FORT BENTON REGION

MISCELLANEOUS ANALYSES – SELECTED RESERVOIRS

Values in mg/l except as indicated

REF. NO. SAMPLE NO. DATE SAMPLED	Hanford HRS-17 12-4-69	Birkeland BIR-85 7-1-71	Booth BOI-13 12-5-69	Booth BOR-133 8-4-72	Bramlette BRS-15 12-4-69	Bramlette BRS-79 5-14-71	Bramlette BR-132 8-4-72	Bramlette BR-147 5-9-73	Average	Minimum*	Maximum**
TDS (calc.)	15109	9200	4053	5058	5566	7201	8380	5332	7487	4053	15109
SC (µmhos)	13500	8740	4460	5380	5860	6190	8110	5230	7184	4460	13500
pH	7.92	7.89	7.59	7.58	8.0	7.51	7.63	8.29	7.80	7.51	8.29
Major Constituents											
SODIUM	2090	1390	676	790	720	814	950	580	1001	580	2090
MAGNESIUM	1479	831	219	290	498	631	908	549	676	219	1479
CALCIUM	363	207	225	307	215	444	273	192	278	192	444
POTASSIUM	17	28	13	16	16	36	28	59	27	13	59
SULFATE	10580	6195	2520	3473	3600	4846	5690	3600	5063	2520	10580
NITRATE	104	16	150	0	115	14	0	62	58	0	150
BICARBONATE	344	373	212	129	334	301	425	221	292	129	425
CHLORIDE	118	148	32	51	57	88	96	58	81	32	148
Minor Constituents											
STRONTIUM	5.3	2.0	2.3	2.4	2.0	2.1	2.4	1.8	2.5	1.8	5.3
LITHIUM	.9	.7	.2	.2	.3	.4	.4	.3	.4	.2	.9
IRON	.14	.07	.13	.06	.14	2.7	.20	.10	.44	.06	2.7
MANGANESE	.06	.33	.33	.06	.24	.86	.39	.05	.29	.05	.86
ALUMINUM	.2	.0	.0	.0	.0	2.4	.0	.0	.33	.0	2.4
COPPER	.04	.04	.01	.02	.02	.02	.03		.03	.01	.04
LEAD	.40	.23	.20	.11	.20	.10	.13		.20	.10	.40
ZINC	.06	.05	.03	.01	.03	.04	.02		.03	.01	.06
NICKEL	.14	.13	.02	.02	.05	.07	.03		.07	.02	.14
COBALT	.10	.03	<.05	.08	<.05	.03	.10		.06	.03	.10
CADMIUM	.02	.03	.01	.01	.01	.02	.01		.02	.01	.03
CHROMIUM	.07	.06	<.02	.02	<.02	.05	.02		.04	<.02	.07
PHOSPHATE	2.0	3.2	.05	.13	7.0	.60	.55	.0	1.69	.0	7.0

*Dotted lines represent minimum values
**Solid lines represent maximum values

(121).

During the present investigation, the writer was frequently driven to recall the following words of wisdom, quoted from a text on veterinary toxicology:

> It is disconcerting to call upon an expert in toxicology for a positive opinion concerning a certain dosage an individual may have consumed only to find he will rarely take a clear stand as to whether that dosage will or will not produce an undesirable effect...It is essential to keep in mind that factors such as age, sex, genetic background, and species differences all affect the responsiveness of an animal to a toxicant, as do the chemical and physical properties of the compound, the diet, and the animal's physical condition...
>
> The circumstances surrounding poisonings are highly variable and are often difficult to determine and to evaluate. Deductions must be made from a variety of occurrences and facts, most of them irrelevant...The presence and previous use of poisons on the premises should be determined. The premises should be carefully examined for rodenticides, insecticides, drugs, paints, disinfectants, fertilizers, herbicides, defoliants, desiccants, petroleum products and discarded equipment that contains chemicals....Other sources of poisons to be considered are fungi, gossypol, blue-green algae, and venoms. The possibility of poisonous plants must be considered in range animals (158).

Most veterinarians who were contacted were extremely reluctant to state positively that there had been bona fide cases of saline seep poisonings in their area. However, several cases of nitrate poisoning from seep-polluted ponds, and several other incidents of documented seep-related losses due to secondary stresses were investigated based upon information supplied by veterinarians and Soil Conservation Service agents.

Several common factors appeared in every case of nitrate poisoning investigated. There were no problems from seep-polluted waters except in the later part of the summer, when stockponds had evaporated down to higher concentrations (56). There were no ill effects noticed unless the stock were excluded from alternate sources of better quality water. If the animals have a choice, they never drink saline water above about 800 mg/l TDS. Only under heat stress will cattle become thirsty enough to tolerate stagnant, brackish, algae-encrusted water.

Owners of range cattle have experienced calf losses under a variation of this situation. Adult cows can go for several days without water under normal range conditions, but calves must have water more frequently. If a cow and calf quench their thirst at a good waterhole and then drift out onto the range to graze, the calf would be forced to drink whatever water was available long before its mother would be inclined to return to good water. It is not known whether such incidents have occurred on seep-affected rangelands.

Nitrates in water supplies may be additive to nitrates in oat hay or urea-based feeds (50, 201). Deaths from this combined poisoning are known in Montana, but unthriftiness and lack of weight gain are the more frequent impacts.

Nitrate poisoning is very difficult to diagnose with certainty in the field. Nitrates are reduced to nitrite in the rumen, and this reaction can cause over-oxidation of iron in hemoglobin, forming methemoglobin which is incapable of carrying oxygen. Death is due to anoxia. Non-fatal nitrate poisoning can result in dehydration syndrome and extreme susceptibility to diseases. If carcasses are not examined within minutes after death, the chocolate-colored blood which characterizes nitrate anoxia will not be found. Consequently, diagnoses of nitrate poisonings are often circumstantial, sometimes based upon analysis of the nearby water, and sometimes upon vague suspicions (78, 84). Most losses to nitrates are complicated by secondary stresses, such as lethal combinations of dehydration, heat, and a disease organism, such as Leptospirosis (56).

High nitrate levels have been implicated in abortions (56). However, Barber reports wintering his pregnant cows on 150 mg/l NO_3^- water without subsequent calving problems (36).

High levels of TDS appear to have two types of impacts on livestock. The first and most common is dehydration, since most stock refuse to drink highly saline water unless forced to by thirst.

Dehydration may render them vulnerable to the many other potentially harmful substances in the saline seep water, although this has not been proven. The second impact is called "waterbelly" or urolitosis. Although this condition can appear even when excellent water is available, it seems to be most prevalent in late summer when saline watering ponds have high concentrations of salts. Waterbelly begins with formation of stones in the kidney or penis, causing rupture of the organ. With no outlet, urine swells the belly region and will bring death unless surgery is prompt. Smaller calves are the usual victims. It must be stressed that the precise causes of waterbelly are not known, and that it is not possible to unequivocally implicate saline seep (26, 115).

The sulfates, especially magnesium sulfate, are powerful laxatives. Saline seep-polluted waters cause scours (diahrrea) in mammals of all sizes and shapes. Livestock eventually develop a tolerance for these compounds, but some losses may occur if newly-introduced individuals are not treated to alleviate the severe weakness and dehydration which may accompany scours. Juvenile animals are the most susceptible to this stress. Another problem time is right after newborn animals are weaned in the spring. Keller (105), for example, reports losing a newly-weaned calf to scours after prolonged consumption of seep-affected waters.

Eutrophication of stockponds is common following invasion of saline seep waters. Production of algal blooms during the summer and fall, particularly as the stockponds become shallower and more concentrated, frequently renders the water unacceptable to stock (26, 115). Dehydration may then become a problem. In addition, three species of toxic blue-green algae may be present in saline waters in Montana.

Prescott (156) reports that Microcystis aeruginosa, Anabaena flos-aquae, and Aphanizomenon flos-aquae occur in lakes and ponds across the northern United States. Gorham (79) found that Microcystis contains a potent liver toxin; it is known to be deadly to livestock after being mechanically disintegrated, or during decomposition. Anabaena is also highly toxic and thrives in shallow eutrophic waters. Aphanizomenon is regarded as being possibly toxic, although isolation of the toxin has not been successful. In their extensive biological studies of saline lakes in Saskatchewan, Rawson and Moore (159) found that Microcystis was common in lakes up to TDS levels of 10,000 ppm, and rare (but present) at 10,000 to 20,000 ppm TDS. Anabaena and Aphanizomenon were both common up to 5,000 ppm TDS, but were not present at higher levels of salinity. Miller's data for stockponds on the Highwood Bench (See Table 6) indicate that Microcystis would be right at home in these waters. The other two species of toxic blue-green algae are not as likely to be present in saline seep infested waters if TDS levels rise much above 5,000 ppm. Microcystis toxin is active only upon decomposition or mechanical destruction of the cells. This would suggest that the danger for livestock is in the period after the algal bloom has passed its peak. This is also the period of maximum potential danger from high concentrations of other components of saline seep. Non-toxic strains of all three blue-greens are known to exist, and it is necessary to conduct mortality tests to be sure that these organisms are responsible for any livestock problems. No livestock deaths from toxic algae were reported by the veterinarians contacted during this study.

Stockponds: Fisheries. In addition to providing drinking water for livestock, some of the larger ponds have been stocked with trout by the Montana Department of Fish and Game. Only the deeper ponds are normally stocked, to avoid fish-kills due to freezing, drying out, or excessively high summer temperatures. These ponds also provide feeding places and in some instances nesting habitat for waterfowl and shorebirds.

The trout fisheries have declined and eventually disappeared in a few stockpond reservoirs on the Highwood Bench in recent years. Saline seep has been definitely linked to increased levels of pollution in these stockponds (33, 120). Miller (120) tested water from four reservoirs (see Table 6), and in those whose fisheries had declined, he found potentially dangerous levels of TDS, heavy metals, and nutrients. In their 1973 report on the ecological implications of saline seep, Bahls and Miller (33) cite these three characteristics as possibly being responsible--"alone or in combination"--for fish mortalities in these reservoirs. In their request for research assistance from the Environmental Protection Agency (4), members of the Governor's Emergency Committee on Saline-Alkali Problems in Montana explained this theory in more detail:

> Detected levels of heavy metals were generally in excess of recommended water quality criteria for fish and aquatic life (McKee and Wolf, 1963). Total dissolved solids were likewise above recommended levels for freshwater biota. Nitrate and

> phosphate were extremely high in the one reservoir sampled. Nitrate is one of the major anions of the salt deposited by saline seep on the Bench and has been thought to be partly responsible for advancing eutrophication of area reservoirs. Increased aquatic plant growth may have resulted in depressed dissolved oxygen levels which alone may have been responsible for fish mortalities. On the other hand, stresses produced by possible sub-lethal levels of dissolved oxygen may have rendered fish more vulnerable to other toxic agencies, i.e., heavy metals and TDS.

A team of biologists from the Environmental Protection Agency's (EPA) National Field Investigation Center visited the Highwood Bench area in early June, 1974, to conduct biological sampling of seep-affected reservoirs. Their sampling was done as part of a project (224) with the following stated objectives:

1. Outline the severity of groundwater quality problems at this point in time and the potential for surface and groundwater degradation should the saline problem remain unchecked.
2. Define the agent or agents responsible for aquatic life mortality and their effective lethal concentrations, alone or in combination.
3. Suggest methods for restoration of water quality in affected areas and maintenance of existing water quality in those waters not appreciably affected to date.

The biological survey (40) for the EPA's saline seep project in Montana included a fish survey; a zooplankton collection; benthos transects; phytoplankton sampling; a profile analysis for dissolved oxygen (DO), conductivity, pH, temperature, and depth; and chemical analysis for nitrates, sulfides, metals, TDS, chlorides, nitrogen, and phosphorus. The EPA saline seep project (146) is also slated to include chemical analysis of water from farm ponds for background data and surface water studies to determine the TDS loads of coulees and streams entering the Missouri River.

Unfortunately, the results of this research will not be published due to dissolution in 1975 of the EPA office responsible for conducting the studies.

Waterfowl. Eastern Montana is on the Central Flyway, and is visited by numerous species of migratory waterfowl every year. Among the more common species to be found on lakes and refuges at various times of the year are the puddle ducks (mallard, pintail, blue-winged teal, green-winged teal, gadwall, shoveler, and widgeon), the diving ducks (lesser scaup, redhead, ruddy duck, canvasback), geese (Canada goose, snow goose), whistling swan, and many shorebirds (including lesser yellowlegs, avocets, sandpipers, and willet).

Saline seep is not likely to create much additional habitat for waterfowl (201), since the vast majority of seeps do not remain wet on the surface, do not create ponds, and do not support vegetation used by waterfowl. Saline seep pollution of existent ponds will change the floral and faunal structure of the water, but as long as high fertility is maintained, the carrying capacity of the lake or pond is not expected to be degraded (100, 199, 222). Many of Montana's most productive bird sanctuaries are highly saline, such as Medicine Lake (2,300 mg/l TDS) (144, 199, 222).

In saline environments, ducks are more susceptible to botulism. Clostridium botulinum is an anaerobic organism, and can become a problem when high productivity in waters exhausts the dissolved oxygen. Fluctuations in water level are especially conducive to growth of crustaceans which concentrate the toxin. Ducks subsequently pick up the toxin during feeding, and mortalities may be quite high. Although saline seep may conceivably contribute to increased salinity in certain bodies of water, Witt (222) concludes that there should be no appreciable increases in botulism attributable to this factor.

Stockponds: Wildlife. Creation of stockponds has been credited with greatly increasing the distribution of big game on the Great Plains of Montana (209). Availability of surface water has especially benefited the antelope, and has contributed to establishment of the large herds which are found on the plains today. There is some disagreement about the degree to which mule deer are dependent upon reliable sources of surface water during the summer. Trueblood (206) feels that deer can normally exist in these areas without surface water, subsisting upon moisture from succulent plants in their diet. Others (161) question the availability of sufficient moisture to sustain deer in the absence of drinking water, especially considering the amounts of water required for digestion in the rumen.

Both antelope and mule deer are known to utilize highly alkaline watering holes in the desert areas of the Southwest. There is no question that these animals can tolerate such waters after acclimatization, but it is very likely that salinization of surface waters will cause the herds to shift their range in favor of other, more palatable water. The extent of such probable shifts is not known. To the extent that these displaced animals increase congestion and pressure on limited non-polluted drinking holes, additional adverse stresses will be generated. The primary impact on big game will thus be displacement into areas not plagued by deteriorating surface water supplies. Secondary impacts will be related to stresses caused by increased densities in the receiving areas.

Salinization of ponds causes loss of willow vegetation, which serves as food for deer. This will further lower the carrying capacity of the area (205).

Many other species of wildlife benefit from the proximity of a source of drinkable surface water. This would include the smaller predators, such as coyote, fox, mink, badger, and skunk. If the water becomes too saline for drinking, these animals would be forced to locate alternate sources. Dislocation of predator species would cause oscillations in prey populations, a disruption of hunting territories, and other behavioral stresses. As the community became adjusted to the new situation, the oscillations would subside. The new equilibrium would most likely be at a lower level of productivity, due to reduction of a limiting ecosystem resource--fresh water.

ENVIRONMENTAL IMPACTS OF CONTROL ALTERNATIVES

Behind the Symptoms: A Fundamental Imbalance

Saline seeps are caused by overloading the water storage and drainage capacity of the subsurface of our land. When the prairie sod grew on the land, overloading generally did not occur because the climax prairie had evolved to the maximum sustainable productivity, diversity and stability within the chief limitation: the availability of water. Natural balance and maximum efficiency was achieved long ago. In a fundamental sense, then, any change by man almost guaranteed imbalance.

Now the prairie sod is gone, plowed under, and in its place is a system of agriculture which has a comparatively low efficiency of water use. Much soil moisture goes unused. This is a circumstance arising from human action that combines with a geologic fact to produce saline seeps.

The presence of an impermeable layer just beneath the surface of the northern Great Plains means the storage and subsurface drainage capacity of the soil profile above the impermeable layer is easily exhaustible. Water that is not evaporated, transpired by plants, stored on the surface, lock up as soil moisture, or drained off overland, must contribute to the growth of perched water tables. As the groundwater exceeds storage and drainage capacity underground (as it has done in many areas), the water, now highly charged with soluble chemicals inherited from the geologic past, must surface as saline seep.

The extreme imbalance that has resulted from these man-caused changes is indicated by the speed with which saline seeps appear and grow, often alarmingly so during wet cycles. During dry cycles, the seeps may dry up a little, but the groundwater, insulated from the drying forces which operate on the surface, does not dry up.

The present crop-fallow system of agriculture allows water to overload the system, producing serious and difficult side effects characteristic of any simplified technological response to a complex environmental situation. If the crop-fallow system is continued without modification, this overloading will continue, and saline seeps will inevitably be the result. The problem will not cure itself.

The need for action is made even more critical because saline seep systems ultimately extend outward, inescapably impacting many phases of ecosystems, including land and water resources on which we all depend.

Saline seeps are complex entities; each case is different, and must be considered with an open mind. Yet all saline seeps have at least three symptoms in common: recharge, subsurface storage and movement, and discharge. The impact of saline seeps lies in the discharge component, with its subsequent disruption of so many other phases of ecosystems. The control of saline seep is conceptually quite simple: 1) eliminate the recharge of moisture to the water table;

or 2) eliminate the flow of contaminated subsurface water into the discharge area. Achieving this control is not so simple, however.

The Range of Alternatives

The alternatives available to farmers for coping with saline seep present a wide spectrum of trade-offs in a complex hierarchy of values. In approaching the alternatives, it is imperative that farmers be aware of the broader implications of their choices, and recognize that simplistic technological stopgaps often further unbalance the natural functioning of the land. Summer fallow, though economically attractive in many cases, is itself a simplistic technological response to the ecological complexity of the Great Plains. Along with the bountiful harvest of grain, it has produced saline seep. Now it is clear that the present order must be changed toward a land use system which allows intelligent management of the water table as well as the surface soils; yet possible changes are fraught with difficulties.

Saline seep is a severe problem. It has already generated much thought and experimentation in search of ways to control and reclaim seeps. But ultimately, saline seep forces the individual--the landowner and farmer--to choose among a set of alternatives. Among the alternatives which may be chosen, the least promising--and the most environmentally damaging--is "no action." This alternative, in keeping with the adage that "to do nothing is to do something," is in reality a very likely response for some farmers. The problem of saline seep is not just the incursion of salts and salty water into croplands and coulees. The problem is ignorance of how saline seeps are formed, what they can do to the land and water, and how they can be controlled and possibly reclaimed.

The problem is economic: strip farming is an established, profitable, and reasonably reliable system. Many farmers are rather proud of their high yields, which are often not attainable when the land is recropped. Changing to other crops or to other systems may entail severe financial strain. Other systems may require more fuel, more time in the field at harvest. The farmer must compare the cost of the loss of seeped land to the costs of control and reclamation. This economic question is the most difficult aspect of the whole saline seep situation. It must be solved.

The problem is political, involving questions such as subsidies, land bank programs, allotments, and landowner's rights. There is the additional legal factor of water pollution, for saline seep pollution may be a violation of the Water Quality Act of the State of Montana and federal water pollution regulations (129, 130).

The problem is social, touching at the very heart of human interaction and community. The epitome of this complexity is reached in the case where the recharge area and the discharge area are separated by a property line.

It is beyond the scope of this report to delve into these interesting, and ultimately crucial topics. But if there was one thing upon which everybody contacted during the present inquiry agreed, it was the postulation that the key to the problem rests in the education of the farmers. The responses which solve the saline seep problem cannot come from the researchers, although they can help guide that response and provide an information-gathering and dissemination focus. It cannot come from the county agents and conservationists, who can only advise. Effective water table management must come for the landowners and farmers, who have control over the several components of the saline seep system. If they don't act, if they don't make changes, in an attempt to bring the saline seep system back under control, then saline seeps will continue to grow.

Assuming the choice is to take action, then, the farmer will find active control alternatives expensive and time consuming. There are two basic ways to approach the recharge, and discharge components of the saline seep system: 1) vegetative and 2) non-vegetative (85).

Vegetative approaches are based on the manipulation of transpiration rates in the recharge area. The idea, basically, is to use the water where it falls, emulating the native prairie's ability to prevent excess water percolation by transpiring as much water as possible. This must be consistent with good crop management techniques. There are several systems being tried in various parts of the state. Annual or intensive cropping is being attempted by some farmers on a large scale basis (86, 88). On a smaller scale, the Montana Agricultural Experiment Station has been conducting experiments for many years. With the uncertainties involved in annual dryland cropping, this method offers a high percentage chance of "bust" (yield of less than 10 bushels per acre), compared with summer fallow systems. However, "booms," or years when crop yields are equal to or greater than those obtained by summer fallow, occur 16 percent of the time under intensive farming. A variation uses snow barriers of tall or intermediate crested wheatgrass to trap and distribute snow across the fields. Siddoway and Black (58) report this system stores enough moisture to allow intensive cropping. The system may not, however, be effective in the "chinook belt," but only in the eastern part of the state.

The annual cropping systems have generally proven of limited value in correction of existing seeps. Where saline seeps have become established, it is necessary to thoroughly dry out the profile in the recharge area, to cut off percolation into the problematic water table. This has been done successfully by the use of deep-rooted plants, such as alfalfa (45, 47, 152). Alfalfa can dry out the profile to depths of thirty feet once it is established, and this is sufficient to allow return to small grain cropping and fallowing for a number of years until the water table begins to build up again (43, 166). Wheatgrasses can also be used, although their roots do not go as deep or transpire as much water as alfalfa.

A permanent solution has not been found in these various monocultural manipulations. The alfalfa, once it has dried the profile, declines and ceases to yield enough to pay its own way. Annual cropping is extremely vulnerable, economically, to dry years. Inclusion of deep-rooted, water-using plants such as alfalfa, safflower, or sainfoin in the rotation is currently hampered by marketing limitations. In short, these systems need a great deal of further study and experimentation--as well as changes in certain basic supply and demand relationships--for them to be considered proven methods for coping with saline seep. The biggest shortcoming for most of them is economic. In long-term economics, saline seep causes deflated land values, higher operative costs, lost crop income, lost tax money to the state, and lost wheat to the nation (61). But even if a control technique stands a good chance of controlling saline seep, the farmer will not implement it unless he stands at least an even chance of surviving economically. In short-run economics, the cost of control cannot exceed the cost of doing nothing.

With the current high wheat prices, some farmers will prefer to retain the proven fallow system, even though they lose land to seep, rather than attempting treatment of the recharge areas. There is one other vegetative technique for stopping saline seep at its source in the recharge area: grasslands. Seeding the recharge area to native or range grasses implies a complete change in the land use, from cropland to pasturage. The economics of this transition are complex in the extreme (33, 58), as are the impacts on marketing structures and all aspects of farm operations. In many areas, there is a problem with water supplies to support livestock on former dryland, and water would have to be hauled to meet this need (49). Bahls (30) has suggested that reversion to native grasslands may be most practical and beneficial in areas that are only marginally valuable for farming and where the saline seep problem is "beyond immediate control."

In many areas, poor surface drainage (ponding) is a major contributor to excessive recharge (44, 58). Non-vegetative approaches to this situation include land leveling and cutting of drainageways to allow the extra water to run off overland before it can infiltrate. In either case, this mechanical disturbance must include revegetation of drainageways to minimize erosion and to prevent gullying. Grassed drains are becoming more common in some areas of the plains, especially where the farmers are working in cooperation with the Soil Conservation Service to control erosion.

A second set of alternatives involves interception of the water table before it can surface and disrupt the productivity of the land. Vegetative methods involve the use, again, of deep-rooted, salt-tolerant perennial plants. The wheatgrasses are often used, because of their relatively halophytic characteristics. Perennial alfalfa is not as salt-tolerant, and often will not become established where the high water table is excessively salty. Vegetative control between the recharge and discharge areas has not proven particularly successful.

Mechanical methods include pumping and interceptor drains. Pumping has not been tried, as far as can be determined, because of the physical characteristics of the soils and saline seep recharge systems, and because of the economic disadvantages. Interceptor drainage systems have been installed in a few localities with mixed results. These systems cannot be used in many areas, due to economic impracticalities or the tight clay subsoils (77, 166). However, there are at least three interceptor drainage systems currently in operation which have very definitely "cured" the discharge area of its immediate symptoms. With current trends in grain prices, two of these systems have reportedly been a sound short-term economic investment (170, 177).

The Range of Impacts: Worst to Best

The range of alternative methods of control has a range of environmental impact too. The best alternative will vary from field to field, even on the same farm. And because of the environmental, economic, social and political nature of the problem, the farmer's choice is invariably a hard one.

In order of decreasing environmental impacts, the current known technologies for control of saline seep include:

1. No action
2. Artificial drainage with untreated surface disposal.
3. Artificial drainage with evaporative lagoon disposal.
4. Artificial drainage with fossil-fueled desalinization.
5. Intensive or annual cropping methods.
6. Intensive cropping with perennial barriers.
7. Artificial drainage with solar-powered desalinization.
8. Re-cropping with deep-rooted perennials in recharge area.
9. Native or reestablished grasslands in recharge area.

No Action. The environmental impacts of continued growth of saline seeps have been discussed at some length in this report. Although it is not possible to describe every detail of what will happen if seeps continue to spread over thousands of square miles, it is possible to describe the extent to which natural systems will be impacted.

Most of the impacts cannot fail to be adverse. Saline seep represents another disruption of a natural order which has already--in the case of the plowed field--been massively disrupted by man. Any saline seep will change vegetation completely in the areas it affects, and this will change the entire structure of the communities of animals which depend upon the existing environment for their nourishment, protection and reproduction. It will pollute the surface water, change the aquatic environment and possibly poison the animals which drink the water.

Environmental impacts of the remaining eight technologies fall into five groups:

Subsurface or Surface Drainage and Surface Disposal. Unless handled intelligently, alteration of landscapes to improve surface drainage may result in greatly increased erosion and sedimentation. This might fill in stockponds, necessitating dredging and consequent problems with spoils disposal. Sediment in surface waters is already at damaging levels immediately following heavy storms, and creation of exposed, disturbed soils would aggravate this condition.

Prompt and thorough revegetation of drainages would be absolutely necessary to prevent gully erosion. Rains in the northern Great Plains are not always frequent, but they are often intense. Grassed drains are known to be effective in preventing soil erosion, and their use is highly recommended if land leveling or cutting of surface drainages is contemplated.

Improvement of surface drainage would be beneficial to the quality of water in catchments downstream. Prompt collection and removal of the water would minimize leaching of soluble nutrients and salts, and the concentrations present in reservoirs and ponds would thus be diluted by the additional water.

Improved collection and removal of storm waters might create a flashflood hazard downstream.

The design of the leveling project and drainage systems should also give careful thought to the probability that disturbance of the surface soil layers could negate thousands of years of soil evolution which has leached the surface layers free of harmful quantities of salts by moving them downward through the profile. Provisions would have to be made to avoid burial of topsoil beneath highly mineralized subsurface soils.

Ordinary subsurface drainage of saline seeps is a technological short-circuit which, under certain circumstances, can be highly effective in by-passing the third component of the saline seep system--the discharge area--at the expense of the fourth component--the overland drainage system. Most seeps do not have this fourth component at the present time, because the water evaporates, leaving the salts relatively far from surface waters. But with subsurface drainage, entry of highly polluted water into the surface waters of Montana is virtually assured.

Subsurface drainage, using tile lines buried just above the impermeable layer and perpendicular to the groundwater gradient, provides a flow path of least resistance. The drainage tiles collect water from the soil and transport it to a surface outfall. There the water is dumped into a ditch or coulee, and no further responsibility is assumed by the landowner. Interception of the subsurface flow allows the saline seep discharge area to dry up and be recropped within a relatively short period of time.

Many areas, including the Highwood Bench, are not suited to subsurface drainage (77, 166). The till there is thick and has very low permeability, necessitating extensive networks of interceptor lines, and greatly complicating the installation process. Presence of fine clays creates a high clogging hazard, and at least one experimental tile drainage on the Bench has been abandoned due to clogging, coupled with possible collapse of the pipe (90, 166).

We have discussed surface water pollution by saline seeps, indicating that the amounts and seriousness of pollutants have not been fully determined at the present time. With subsurface drainage and surface disposal, undiluted, highly saline groundwater is injected directly into the surface water system. While there are no data yet available on the specific impacts which the heavy metals, soluble salts, and nutrients may ultimately have on fish, other aquatic fauna, aquatic plants, streamside plants, and animals drinking the affected waters, it is certain that these impacts will be adverse.

The most drastically affected areas may be the coulees which carry the outflow. For example, below one outfall pipe from a saline seep drainage system, introduction of year-round surface water has stimulated growth of a variety of salt-marsh type plants. The coulee has become choked with vegetation near the outflow. This growth has completely stopped drainage, causing the water from the outflow to pond, and leaving downstream portions of the coulee bottoms caked with white crystals left when earlier water evaporated. The dead vegetation in the coulee excludes former animal residents, and the value of the land as wildlife habitat is greatly diminished. Where the water is temporarily ponded, awaiting the annual dredging, eutrophic productivity creates a community of frogs, waterbugs, and algae amidst the sedges and cattails. Ducks can use the ponds for limited feeding, and the surrounding Kochia growth will provide cover and food for smaller mammals. Below this wet growth zone, weedy vegetation lines the banks of the coulee or ditch as far downstream as the water lasts, then gives way to the encrusted desolation where only salt exists, coating the bottom. In perspective, the amount of land lost in coulee bottoms is far greater than the habitat produced by the availability of water just below the outfall. Also, the need to dredge the ditch or coulee annually to restore drainage flow obliterates much of the aquatic and streamside vegetation, and creates the problem of disposal of spoils which have long been saturated with the saline outflow waters. This dirt is usually piled along the streambanks, where it is susceptible to erosion. The salt prevents growth of most plants, and Kochia and foxtail comprise the majority of the cover. While juvenile Kochia makes good forage and will support cattle or big game, by midsummer the stems toughen and become useless for forage.

In the springtime, after the ditch has been cleared, the snowmelt and high drainage flows flush the salts out of the coulee and into whatever portion of the surface water system is next downstream. This may be a stockpond, a landlocked lake, or a creek leading to a tributary of the Missouri or Yellowstone River.

Disposal of saline seep waste waters by simple drainage into the surface waters of Montana may be a violation of the water pollution laws of the state (39). Consequently, in areas where artificial drainage is economically and physically feasible, alternative methods for disposal of the water must be developed. There are several possibilities. The most prominently mentioned method of protecting surface waters is to evaporate the waste water in specially lined lagoons. This method is, in effect, a trade-off which salvages cropland at the expense of other land. Untreated surface drainage impacts both the drainageway and the water quality downstream; evaporation lagoons impact only the land used for ponding. The amount of land which the evaporative lagoon method would need makes it prohibitive in most cases (77, 166). Further study is definitely needed to define the trade-offs involved. Since it is virtually certain that cropland will not be sacrificed for construction of lagoons, the land which is sacrificed will probably include wildlife habitat. The value of this habitat and the secondary costs to recreation should be considered in the trade-off calculations.

An interesting suggestion for reducing the size of evaporative lagoons by increasing evaporative efficiency comes from the Montana Agricultural Experiment Station (125), which has proposed additional research into the possible use of windmills to speed evaporation. The feasibility of this, or other methods, to increase the capacity of evaporative lagoons, remains to be demonstrated.

The most obvious solution for disposal of saline wastewater would be desalinization. This would provide usable water for farm needs, and allow possible commercial utilization of the substances recovered from the seep waters. A commercial evaporative process at Chaplin, Saskatchewan, recovers glaubers salts from saline Lake Chaplin. No water is recovered by this process. The capital and operating costs of such a process are probably prohibitive for even the largest farm operation. Costs of pooling seep water from several neighboring farms for treatment are also not encouraging.

Intensive Cropping. One big advantage of the summer fallow system is that it interrupts the life cycle of many of the common weeds which plague the small grain farmer. With partial abandonment of this system, weeds have once again become a major problem, both as a competitor for scarce water and nutrients, and as a complication at harvest time (166). Volunteer grain is often more of a problem than weeds. Control of weeds will be by means of increasing applications of various herbicides, including Paraquat, 2,4-D, and, if it is permitted by the Environmental Protection Agency, Roundup. There is high probability that some of these herbicides will find their way into surface waters, especially when unexpected precipitation follows application. The herbicides also will drift to lands and water adjacent to sprayed fields. Some adverse impacts may accrue from such accidents.

In addition to weed control, intensive cropping constitutes a tremendous drain on the nutrient resources of the soil. Usage of fertilizer must increase to maintain production competitive with levels achievable under summer fallow. Unfortunately, this increased usage coincides with general shortages and high prices of fertilizers. Environmental impacts of fertilizer manufacture may be considered germane to the evaluation of intensive cropping, although they will not be mentioned here. With increased application of fertilizers, there will be increased losses by leaching into surface and subsurface drainage systems. Saline seeps are already highly loaded with nitrates and phosphates, some of them probably from agricultural sources. Additional nutrients will speed eutrophication of ponds and reservoirs, impacting fisheries, recreation, and palatability of water for livestock use.

In many cases, intensive cropping will utilize the snow-management and wind-protection advantages of barrier strips of tall or intermediate wheatgrass. Since these barriers will be perennial cover, they may provide habitat for limited numbers of upland game birds. However, the strips are quite thin in width, and cannot be expected to provide extensive cover or nesting areas. They doubtless will be an improvement over the ephemeral stands of grain at least for some species of wildlife. Control of drifting snow may decrease depths in adjacent coulees. If so, deer and other coulee-dwelling widlife will find a beneficial increase in their winter habitat. This could mean increased access to food plants, and better winter survival rates. This in turn might result in improved hunting opportunities. From the farmer's point of view, perennial barriers may be troublesome, in that they harbor diseases and rodents which threaten crops (170). Finally, intensive cropping will amplify the farmer's dependence on available fossil fuel supplies and aggravate environmental impacts associated with exploration, drilling and refining.

Subsurface Drainage and Subsurface or Solar-Powered Disposal. In some areas of the world, solar stills are currently in use for desalinization of brackish water for domestic and irrigation use. The capital investment for a system large enough to handle waste waters from seep drainage is not known, but since the system operates on a free source of power, and requires little maintenance, further investigation seems warranted.

One Montana farmer (177) has developed a wholly different approach to disposal of waste waters drained from his saline seeps. The glacial till in his area has a dense clay layer at a depth ranging from about five to ten feet. Seeps, perched on this impermeable clay layer, are intercepted by standard tile laterals and piped to a central "junction box." This is a culvert-lined well dug down through the clay layer and resting on the bedrock shale below. Water from the seep recharge area is diverted into the junction box, which directs it downward past the clay layer, and allows it to infiltrate back into profile just above the impermeable shale. This system of "burying" the water has not been fully tested, and the capacity of the system has not been determined. However, if it does work, the immediate dangers of surface water pollution would be removed. The question which must then be faced is, where does that buried water go? The region is a high plateau, falling eventually as the breaks of the Missouri River begin to the south. Will the injection system cause eventual outbreaks along the exposed shale-till contact? How long can the till beneath the clay layer continue to absorb the injected water, and where (if at all) will it surface? Although this method is apparently far superior to surface disposal, it may lead to other complications, yet unforeseen. It seems to be a viable alternative only under quite special geologic circumstances.

Deep-rooted Perennials. Seeding of recharge areas to alfalfa or other deep-rooted perennials would have no significant adverse impacts on the environment. It is possible that the stands would provide additional cover and temporary habitat for many species of wildlife, especially rodents and their predators. Most of these areas would be cropped for hay or grazed, which would tend to eliminate their use as permanent nesting sites or homes. Establishment of cover would decrease soil erosion. Forage for domestic livestock and big game, especially antelope, would be increased, and the carrying capacity of the region for these animals would be increased. The use of alfalfa would also improve groundwater quality, since alfalfa is known to remove nitrates from the profile down to depths of over twenty feet (213). When plowed under, after drying out the profile, these plants would increase soil fertility and improve soil structure. If exotic phreatophytes are imported for the purpose of drying out the profile, there is the danger that these plants may escape. The tamarisk invasion of the southwest is a good example of what might happen if an unwise choice is made (17).

Native Grasslands. Environmentally, there is no question that reestablishment of a grassland ecosystem offers the greatest number of benefits. The advantages include: improved stability of all facets of the ecosystem: soil, water table, microclimate of the surface and subsurface, animal populations, sustained productivity, etc.; increased diversity of both flora and fauna; reintroduction of natural forces of selection and elimination (rather than energy-intensive maintenance of monoculture); elimination of problematic levels of soil erosion and nutrient leaching; and elimination of the dependence on fertilizers, herbicides, insecticides, and other unnatural and potentially damaging agents. On the other hand, reversion to grasslands would lower the efficiency of conversion of solar energy into foodstocks for human consumption, due to the introduction of a second trophic level of herbivores (cattle, big game) into the food production chain on those lands.

A Perspective

The task of choosing the saline seep control measures best suited for a particular farmer on his land will be a personal one, costly and probably thankless. In considering the trade-offs, in this new age of environmental and resource awareness, the farmer would do well to heed the spirit expressed by Bahls (27):

> As we work to mitigate the problems created by saline seeps let us avoid any grandiose technological schemes for reclamation that may be offered and strive instead to work more closely with the land within the ecological framework. Large scale drainage projects or even massive inputs of fertilizers, machinery, and fuel energy are not conducive to regenerating a healthy, functioning ecosystem. The alternatives are clear: We can once again pump up the system artificially and mask the symptoms for another decade or two or we can strive toward stewardship of our land resource, working within its basic limitations so that it may be passed along without further degradation to future generations. In the final analysis, the farmers of Montana will determine by their actions what the long-term environmental impacts of saline seep will be. Judging from the available evidence, control of saline seep is already a major environmental responsibility. The farmers need the continued understanding and support of the general citizenry and the government, for correction of this major ecological imbalance will not be cheap or easy.

CONCLUSIONS

1. Saline seeps constitute a severe threat to the land and water of Montana.

2. Saline seeps have increased greatly during past wet cycles, and the present high water tables and land use patterns virtually assure new growth and outbreaks during future normal and wet years.

3. Saline seeps have four components: recharge area, subsurface water table, discharge area, and surface drainage. Adverse environmental impacts occur as direct and secondary results of discharge and surface drainage.

4. Surface drainage is operative primarily during heavy rainstorms.

5. Surface drainage from saline seeps threatens water quality and all ecosystems in contact with waters polluted by this drainage. The damaging agents are currently under investigation; they are assumed to be a combination of heavy metals, high TDS, and high nutrient levels. Sediment from erosion of soils also degrades surface water quality.

6. Adverse on-site environmental impacts include: a) formation of saline soils due to saturation of exchange sites with sodium; b) loss of present vegetation due to soil saturation, osmotic disruption of plant processes, and specific ion toxicities; c) drastic changes in microclimate due to loss of cover and presence of a salt crust; d) invasion by halophytic annual weeds; e) virtually complete disruption of animal habitats; f) susceptibility to sheet and gully erosion and wind erosion; g) deterioration (to an unknown extent) of shallow aquifers, with possible effects on domestic and stock water wells.

7. Off-site impacts are not fully documented at this time. Known adverse off-site impacts include: a) leaching of salts, heavy metals, and nutrients into surface waters of the state; b) eutrophication and saline stratification of ponds and reservoirs, and loss of trout fisheries; c) poisoning of livestock under certain circumstances; d) loss of surface drinking water for big game and other wildlife, with consequent habitat disruption.

8. Control of saline seep is technically possible using known methods, although practical problems, especially agricultural economics, remain to be solved. A great deal of additional experimentation and demonstration work is needed.

9. The 4-probe technique offers a practical and economical method for diagnosing the features of individual saline seeps, and for monitoring treatment progress. Calibration of the technique in terms of the many geologic variables is proceeding, and a handbook is being prepared for use of the 4-probe on a wide-scale field basis.

10. Education of farmers, about the problem and the alternatives for controlling it, is sorely needed. Much has been done along this line by individuals but an organized and properly funded effort is needed. It is critical that this education effort include information about the environmental impacts of saline seep, and of the various alternatives. The present narrow focus on agricultural technology and economics is understandable, but unfortunate. This focus should be expanded to explain the broader implications of control alternatives to complete the farmer's information set during his inevitable decision-making effort with regard to saline seep.

11. Data, needed for a complete evaluation of the environmental impacts of saline seep, are not currently available. Some important new information is now being collected and evaluated, and this new information will modify and extend the interpretations expressed in the body of this report.

12. A well-publicized saline seep information clearinghouse is needed, especially for collection and investigation of reports of livestock, wildlife, and fisheries damage due to saline seep, and for coordination of research. The Department of State Lands is well-situated for such a function, and could incorporate it into its present saline seep program.

13. Specific information on the toxicity of saline seep to livestock, wildlife, and fishes is not now available. Research into this subject is essential for interpretation of impacts of existent or projected levels of surface water pollution.

14. The alternative methods for control of saline seep involve manipulation of the hydrologic factors of the recharge, and/or subsurface storage and drainage components. Saline seep cannot be cured by manipulations of the discharge area.

15. Ranked in order of decreasing adverse environmental impacts, the currently known control technologies include:

1. No action.
2. Artificial drainage with untreated surface disposal.
3. Artificial drainage with evaporative lagoon disposal.
4. Artificial drainage with fossil-fueled desalinization.
5. Intensive or annual cropping methods.
6. Intensive cropping with perennial barriers.
7. Artificial drainage with solar-powered desalinization.
8. Re-cropping with deep-rooted perennials in recharge area.
9. Native or reestablished grasslands on recharge area.

RECOMMENDATIONS

Education

A. Establish, fund, and staff a well-defined and adequately publicized central clearinghouse within the Department of State Lands for collection and dissemination of information on saline seep, generation and storage of data, reports, and research, coordination of research efforts, and investigation of incidents.

B. Continue to fund Cooperative Extension Service and Agricultural Research Service personnel for dissemination of current state-of-the-art information on farming economics and techniques, and the environmental consequences of these techniques.

C. Clarify and make public the legal implications of saline seep pollution, especially regarding artificial drainage into surface waters of the state of Montana.

D. Fund and provide expert technical assistance for frequent farm management seminars on saline seep, to provide a forum for exchange of ideas, experiences, and mutual aid.

Research

A. Involve the state's university system in disciplines other than agriculture. Much research is needed on the many unknown parameters of saline seep impacts on the environment. Much of this work could be accomplished by research projects at the graduate and undergraduate levels in the fields of terrestrial ecology, aquatic biology, limnology, water resources management, wildlife biology, rural economics, game management, sociology, land use planning, biochemistry, and toxicology. This potential source of manpower and expertise has not been adequately tapped in the past.

B. Continue to fund the establishment of a water quality monitoring network for saline seep. Expand this system to provide representative trend data for all areas of the state which are afflicted with saline seep.

C. Coordinate the various agency and commercial laboratories which test water samples originating from seep-polluted sources. This should be a task for the state clearinghouse.

D. Initiate formal research into the water budget of the native prairie ecosystem, to discover the precise mechanisms which allow it to fully utilize available water and prevent deep percolation. Apply this information to agricultural practices.

E. Expand the effort to calibrate the 4-probe resistivity technique: initiate a broad effort to fully evaluate its potential for diagnosis and monitoring of saline groundwaters. If the technique continues to look promising, the instrument should be widely distributed and field personnel should be trained to use it.

F. Considering the premature termination of the Environmental Protection Agency biological study on the Highwood Bench, additional research into the effects of saline seep on fisheries and water quality should be given top priority. The state clearinghouse should coordinate the efforts of Federal, State (Fish and Game, Water Quality Bureau, Department of Natural Resources and Conservation), and university research personnel in carrying out a broad investigation of the long-term impacts of saline seep on the surface waters of Montana.

G. Initiate bioassay studies on the toxicology of saline seep.

Control and Reclamation

A. Artificial drainage with untreated surface disposal should be discouraged. Techniques for disposal by injection should be studied further to evaluate the ultimate fate of the water.

B. Desalinization, especially techniques using solar distillation, should be evaluated for use in areas where artificial drainage is under consideration.

C. Ongoing agricultural research into intensive cropping, use of barriers, water-efficient crops, and deep-rooted perennials in the recharge area should be continued, as these techniques must ultimately be adopted in most areas. This research should be coordinated with efforts by the Montana Department of Fish and Game to reintroduce wildlife into these areas where feasible.

D. Marginal and submarginal agricultural land in recharge areas should be returned to grass cover, preferably native prairie species.

E. The Agricultural Stabilization and Conservation Service should recognize the serious consequences of uncontrolled saline seep. This agency should revise its national policy, to make saline seep control measures eligible for cost-sharing programs on an equal basis with soil erosion control measures.

F. The Federal Government and the State should give serious consideration to establishment of a "land bank" type program, to compensate farmers for loss of agricultural production due to recharge control and reclamation techniques, and to encourage cooperation among farmers with saline seep systems whose component parts are divided by a property line.

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Missouri River Basin Commission

10050 Regency Circle, Suite 403
Omaha, NB 68114

MRBC has voted to cooperate with state and federal agencies in helping to alleviate the saline seep problem. MRBC staff has reviewed the situation and issued a background report (224).

Mountain Plains Federal Regional Council

Federal Building, Room 14041
1961 Stout St.
Denver, Colorado 80202

MPFRC, together with MRBC, has expressed concern over potential problems generated by saline seep and may become more actively involved at a later date.

Soil Conservation Service (U.S.D.A.)

Director: A.B. Linford
P.O. Box 970
Bozeman, MT 59715

As primary advisory personnel in the field, SCS District Conservationists are invariably well acquainted with the saline seep problem in their counties. Many are actively encouraging control and mitigation procedures among their local constituents.

STATE

Department of Health and Environmental Sciences

Water Quality Bureau
Board of Health Building
Helena, MT 59601

The Water Quality Bureau is responsible for administering and enforcing the state's water pollution laws and regulations. Maxwell Botz, Jerry Kaiser (Billings), and Peter Gormann are currently involved with establishment of a water quality inventory network for saline seep.

Department of Livestock

Livestock Sanitary Board Diagnostic Laboratory
Bozeman, MT 59715

Department of State Lands

Robert Duncan
Administrator, Staff Services Division
Capitol
Helena, MT 59601

Bob Duncan and his technical coordinator, Les Pederson, are administering the state money appropriated to finance research on saline seep mitigation and control. Mr. Duncan is also affiliated with the Saline-Alkali Advisory Committee.

Environmental Quality Council

Loren Bahls
Box 215, Capitol Station
Helena, MT 59601

Dr. Bahls, a long-time advocate of ecological perspective in saline seep investigations, has been chief adviser for the current WICHE internship project, studying environmental impacts of saline seep.

Fish and Game Department

Mitchell Building
Helena, MT 59601

Fish and Game personnel around the state are beginning to watch for saline seep impacts on fish and wildlife. Robert Needum, Regional Fisheries Manager at Glasgow, is implementing a water quality monitoring system in his area.

Montana Bureau of Mines and Geology

Marvin Miller
Montana College of Mineral Science and Technology
Butte, MT 59701

Dr. Miller initiated and is continuing research into the hydrogeological mechanisms of saline seep.

Montana State University (Bozeman)

Hayden Ferguson
Plant and Soil Science Department

James Krall
Agricultural Experiment Station

Charles Smith
Cooperative Extension Service

Dr. Ferguson has been involved in research on the properties of soils affected by saline seep. Mr. Krall has assumed the responsibility of heading the Department of State Lands' saline seep research effort.

APPENDIX C: RECENT DEVELOPMENTS IN SALINE SEEP MONITORING AND CONTROL

Since the initial publication of this report in September 1974, and endorsement of its recommendations by the Environmental Quality Council on December 6, 1974, a number of significant events have marked progress in understanding and combating saline seep in Montana.

For example, new estimates of acres damaged have been released by the Department of State Lands for 1974:

County	Acres Affected
Stillwater	23,000
Chouteau	17,400
Fergus	13,848
Roosevelt	12,500
Sheridan	10,000 - 12,000
McCone	10,000
Cascade	7,000
Toole	6,000
Daniels	5,400
Liberty	4,600
Judith Basin	3,500
Richland	1,900 - 3,500
Pondera	3,088
Blaine	3,000
Glacier	3,000
Hill	2,000 - 2,500
Meagher	2,300
Madison	2,060
Teton	1,600
Phillips	1,500
Big Horn	1,000
Musselshell	924
Valley	800
Fallon	753
Golden Valley	715
Ravalli	701
Yellowstone	600
Lake	300
Wibaux	300
Prairie	250
Carbon	200
Dawson	106
Lewis & Clark	100
Custer	40
	140,485 - 144,585

These figures were compiled by the department from estimates supplied by County Committees for Rural Development. When the state total above is compared with the total for 1973 from Table 1 (p. 11), it would appear at first glance that the problem has stabilized, or indeed, that the situation has even improved! However, the almost 10,000-acre decline in damaged lands from 1973 to 1974 more likely reflects a different and more refined method of census rather than an actual improvement (6). Previous estimates in some counties were unduly high, especially for Stillwater County. In 1974, however, over 6,500 acres of damage were reported in counties where none had been reported before.

The 1975 Legislature passed--and the Governor signed--House Bill 33: "AN ACT ESTABLISHING A SALINE SEEP CONTROL PROGRAM WITHIN THE DEPARTMENT OF STATE LANDS; PROVIDING EFFECTIVE AND TERMINATION DATES." The act gives legislative direction to the broad research and education program initiated by the Department of State Lands under a $265,685 appropriation from the 1974 Legislature (5). The continuing program will be funded in the amount of $220,769 for FY 1976 and $235,794 for FY 1977. The act will terminate on July 1, 1977, reinforcing the expressed intention of the Department of State Lands to eventually "get out of the saline seep control business and turn it over to the farmers" (8). Also included in the act are guidelines for the Governor's appointment of an advisory council to assist the Department in the discharge of its responsibilities under the act.

A second saline seep bill--House Bill 66--would have added a new subsection to Sec. 84-202, R.C.M., 1947, to exempt from taxation agricultural lands adversely affected by saline seep. The bill was killed in the House Taxation Committee.

In addition to the saline seep research program established by the Montana legislature, another $226,000 has been allocated by the Old West Regional Commission for various projects related to saline seep. Of this amount, $100,000 is for saline seep water quality monitoring in Montana by the Bureau of Mines and Geology and by the Department of Health and Environmental Sciences. Also included in the Old West allocation is a grant of $60,000 to South Dakota State University for pre-emergence detection of saline seeps using aerial photography. Flights will be made over two major Montana saline seep areas: the Hailstone Basin between Rapelje and Broadview and the Highwood Bench northeast of Great Falls (1).

Significant advances are also being made in the area of cropping research to control saline seep. Alfalfa has proven more effective and less costly than either draining or pumping in lowering perched water tables and its use would solve rather than create water pollution problems (2). An economist at Montana State University is in the preliminary stages of designing a prototype cropping and marketing system for small acreages of alfalfa grown to regulate seep recharge in the Fort Benton area (7). Studies on tall wheatgrass barriers, functioning as snow fences in distributing moisture evenly across a field, are promising greater success at continuous cropping in northeastern Montana (9).

Prospects for federal financial assistance to farmers also appear somewhat brighter at this stage. Specifications for cost-sharing revegetation of seep areas are now being developed by the state Agricultural Stabilization and Conservation Service office as a special practice option available to counties under the Rural Environmental Conservation Program (10). And the Federal Crop Insurance Corporation is completing a report on the advisability of continuous cropping wheat and barley in Montana for purposes of saline seep control. An insurance program for Montana, if it is implemented, would only be for certain limited areas where re-cropping is a viable deterrent to saline seep and would probably not be effective prior to the 1977 crop year (3).

The outlook for saline seep control is not entirely promising, however. The "spring" of 1975 has been one of the wettest on record for several areas of Montana. Flooding has been reported along the Judith and Poplar Rivers, which drain areas already severely affected by saline seep. Saturated soils and rising groundwater levels in these areas would result in significant setbacks to progress already made in controlling Montana agriculture's most serious pollution problem (4, 6).

Loren L. Bahls
May 1, 1975
Montana Environmental Quality Council
Helena

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