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# Chemical and Physical Characteristics of Saline Soils in Grand Forks county North Dakota

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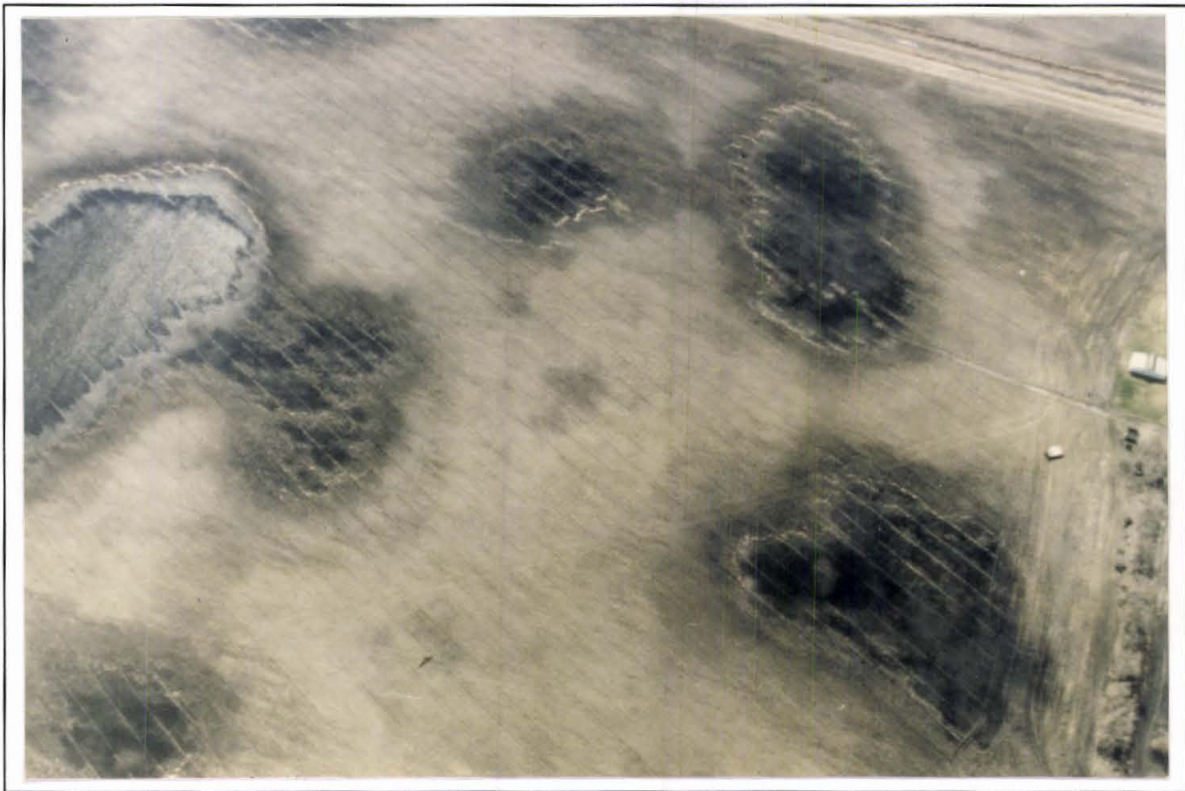
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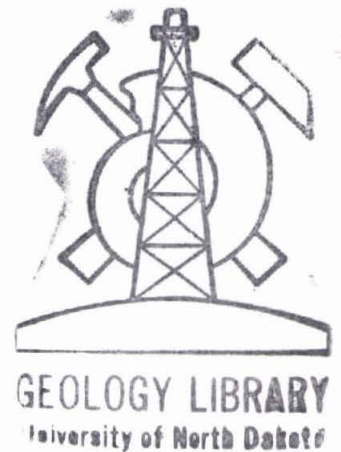
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## **Chemical and Physical Characteristics of Saline Soils in Grand Forks County, ND**



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## ABSTRACT

Saline soils reduce the productivity of over 80,000 hectares, or 23% of the land area, in Grand Forks County, an agricultural county in eastern North Dakota. A geochemical analysis was completed on soils from two salt-affected areas to determine if the salinity is depression-focused in saline spring areas and dominated by ground-water discharge, or landscape-wide and controlled by saline flushing and evapotranspiration. The areas chosen for study were an ephemerally wet, cultivated farm field and Kellys Slough, a perennial wetland. Two soil borings were completed at each site with samples taken in 15-cm increments to a depth of approximately 1 m. Samples were analyzed using laboratory procedures advocated by the National Soil Survey Center including reaction to dilute HCl, pH, particle-size analysis, carbonate and gypsum content, electrical conductivity, and soluble cations and anions. The results of the geochemical analyses indicate that soils from the farm site and Kellys Slough are quite different. pH values were mildly to moderately alkaline with the most alkaline soils at the farm. The slough soils appeared to have a higher clay content than the farm soils. Concentrations of carbonate generally increased with depth at the slough and were concentrated in the upper horizons at the farm. The slough soils were more saline than the farm soils. Sodium and chloride were the dominant ions in the slough soils, and calcium and sulfate dominated the farm soils suggesting that different salinization processes are taking place at the two sites; the salinity at the slough appears to be depression-focused and dominated by ground-water discharge while the salinity at the farm site appears to be controlled by precipitation and evapotranspiration.

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Saline soils reduce the productivity of over 80,000 hectares, or 23% of the land area, in Grand Forks County, an agricultural county in eastern North Dakota. Saline soils are those containing soluble salts in amounts sufficient to be harmful to plants, most frequently sulfates and chlorides of calcium, magnesium, and/or sodium (Johnsgard, 1967). Few areas accumulate sufficient salts from weathering in place to form saline soils. Most commonly, salts are received from other locations and surface and ground waters are the direct source (U.S. Salinity Laboratory Staff, 1954). Saline soils in North Dakota commonly occur in "nearly level or low-lying areas with imperfect or poor drainage and with seasonally high watertables or in areas with groundwater seepage" (Johnsgard, 1967. p. 3), along roadside drainage ditches (Skarie et al.,

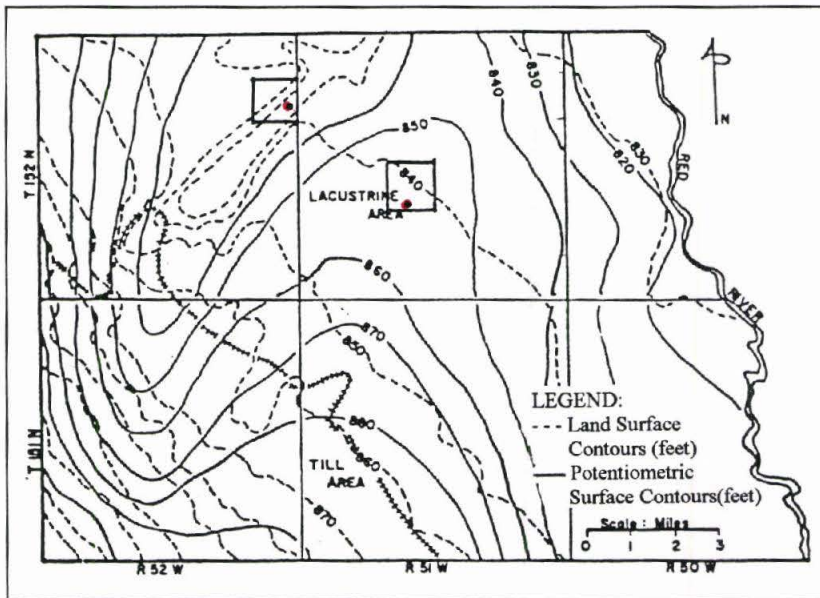


1986), and adjacent to flowing wells (Strobel et al., 1994). Regionally, areas of saline wetlands and high soil salinity coincide with bedrock topographic highs (Strobel, oral communication), while locally, the most extensive saline areas possibly overlie coarse-textured glacial tills with relatively large hydraulic conductivities (Strobel et al., 1993). Strongly saline areas may be used as pasture, grasslands, or wetlands. Moderately saline areas are typically cultivated, however, appropriate management strategies are required. These include lowering the water table through the use of drainage systems, selecting moderately salt-tolerant crops, and/or periodically planting crops that will prevent the accumulation of salts in the upper horizons, such as alfalfa or sweetclover, which are deep-rooted, moderately salt-tolerant, and require large quantities of water (Johnsgard, 1967).

The objective of this study was to determine if the salinity in the study area is depression-focused in saline spring areas and dominated by ground-water discharge or landscape-wide and controlled by saline flushing and evapotranspiration. A geochemical analysis was completed on soils from two salt-affected areas: an ephemerally wet, cultivated field and Kellys Slough, a perennial wetland. This study describes the basic geochemistry of the two sites.

### **Description of Study Area**

The study area consisted of Rye and Blooming townships in east central Grand Forks County, North Dakota (T152N, R51W and T152N, R52W, respectively). The two sites selected for geochemical analysis are located in the Red River of the North Valley, and exhibit similar topographic, hydrogeologic, and geologic characteristics. The land surface and potentiometric surface contours slope to the northeast with similar gradients of 2 to 3 feet per mile (0.4 to 0.6 meters per kilometer) in the study area (Figure 1). Land surface slopes at the western edge of the valley average 15 to 20 feet per mile (3 to 4 meters per kilometer). (Benz et al., 1961)

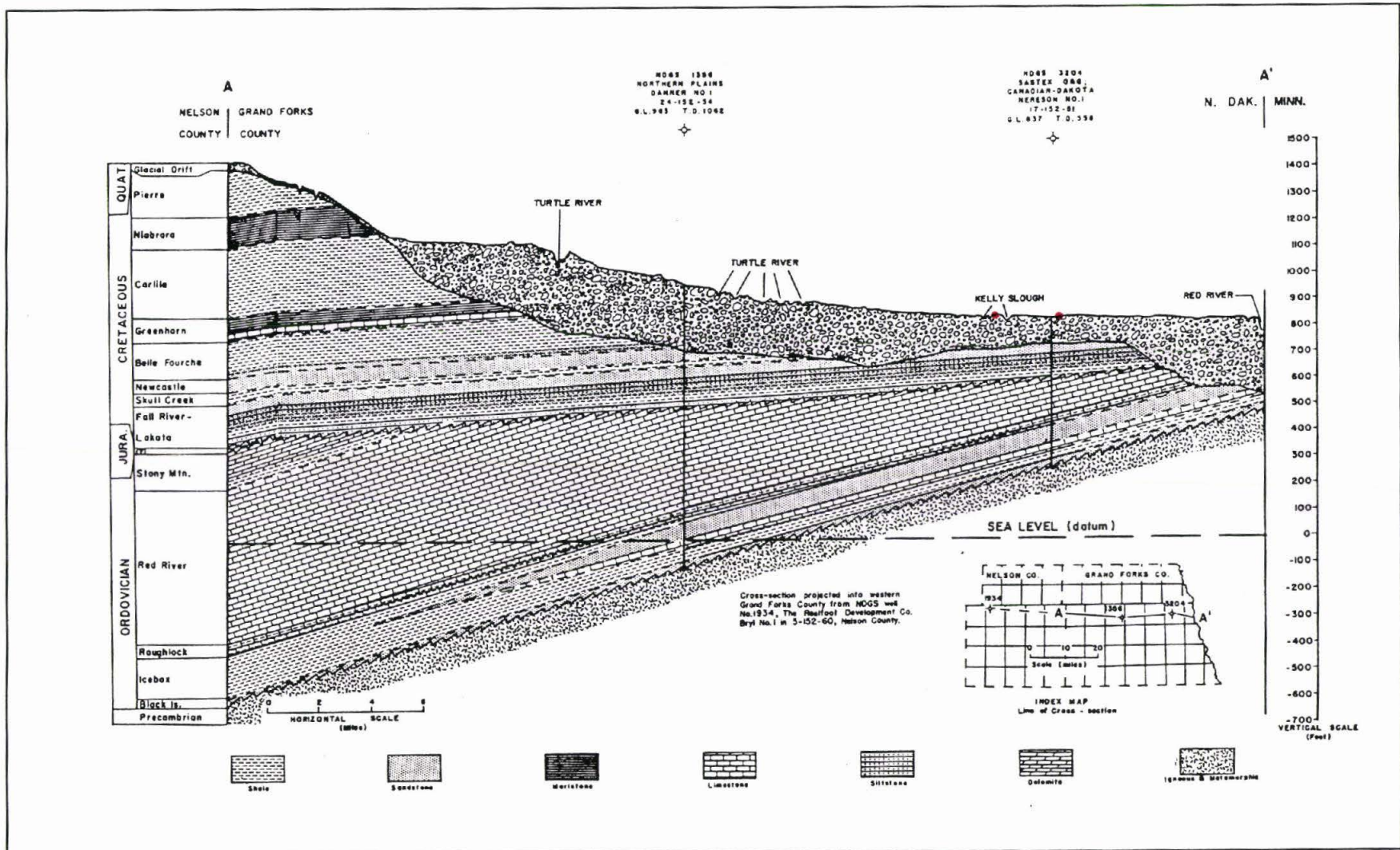


**Figure 1.** Land surface and potentiometric surface contours. The hatched line separates the glacial till and lacustrine areas. The sections containing the sampling sites are outlined and the sampling sites themselves are indicated by dots within the sections. The farm site is located in R51W (the easternmost site) and the slough site is located in R52W (the westernmost site). (From Benz et al., 1961)

The study area has a subhumid, continental climate and annual precipitation averages 50 cm, most falling in the spring through fall (Sandoval et al., 1964a). Rainfall and snowmelt are the most significant factors controlling the water table (Benz et al., 1961).

The sampling sites are on the lake plain of glacial Lake Agassiz near the eastern edge of the Williston Basin. Near the city of Grand Forks on the eastern border of Grand Forks County, lacustrine sediments are more than 30 meters thick and thin to the west. Deltaic sediments overlie the western edge of the valley. Underlying glacial drift crops out at the surface between the deltaic and lacustrine sediments and overlies Precambrian, Ordovician, and Cretaceous bedrock (Figure 2). The Lower Cretaceous units include the Dakota Group, part of the locally highly saline Dakota aquifer. The Cretaceous shale thins toward the east and, where it is very thin or absent, direct contact between the drift and the Dakota sandstones occurs. Upward migration of saline water from the lower Cretaceous and Paleozoic bedrock aquifers has been attributed to diffusion (Remenda et al., 1992), advection (Goebel et al., 1992), preferential flow along zones of relatively large vertical hydraulic conductivity within glacial sediments (Laird, 1944; Downey, 1973), and flow from wells (Strobel, 1992). Saline soils, wetlands, and flowing wells characterize areas where ground water is discharged to the surface (Strobel, 1992; Strobel et al., 1992). Soil





**Figure 2.** Geologic cross section, Grand Forks County, North Dakota. The Dakota Group includes the following formations: Belle Fourche, Newcastle, Skull Creek, and Fall River-Lakota. The approximate positions of the sampling sites are indicated in red. (From Hansen et al., 1970)

salinity in the study area has been attributed to these saline artesian conditions, a high water table, and poor drainage conditions (Benz et al., 1961; Sandoval et al., 1964a). Anthropogenic causes for soil salinity include roadside drainage ditches (Skarie et al., 1986), the crop-fallow system of dryland farming (Ferguson et al., 1982; Halvorson et al., 1974), and flowing wells (Strobel et al., 1994).

Saline soils are generally not found on the east side of the Red River in western Minnesota although similar topography exists, including a high water table and poor drainage conditions. There appears to be a ground-water discharge divide near the Red River (Gerla, 1992) and there are few artesian wells on the east side and only small concentrations of dissolved solids in ground water (National Uranium Resource Evaluation Program, 1981a and 1981b, as cited by Gerla, 1992). An extensive drilling program on the eastern side of the river, extending from the Canadian border to near Hillsboro, North Dakota, was recently completed and resulted in no flowing wells (Harris<sup>1</sup>, oral communication). A relation between the development of saline soils and the presence of ground-water discharge from the bedrock aquifers appears to exist and supports the hypothesis that salinity on the western side of the Red River is due to ground-water discharge from the saline Dakota aquifer.

The two sites chosen for study included the farm site, an ephemerally wet, cultivated field (SE 1/4, SW 1/4, section 21, T152N, R51W), and Kellys Slough, a perennial wetland (NE 1/4, SE 1/4, section 12, T152N, R52W). The cultivated field was selected and identified on the basis of salt efflorescences visible in aerial photographs taken in the spring of 1994 (cover photo). The crusted layers of light gray or white salt crystals fringing areas of ponded water are typically indicative of saline soils while the light gray soil color on shallow rises may be due to saline and/or calcareous conditions. The wetland area was selected based on its proximity to the cultivated field and its known salinity.

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<sup>1</sup> Ken Harris, Minnesota Geological Survey, St. Paul, MN



The soils at the farm site are frigid Aeric Calciaquolls, consisting of fine-silty Bearden silty clay loam. The soils at the slough are frigid Typic Fluvaquents, consisting of fine, montmorillonitic, calcareous, Lallie silty clay loam (Doolittle et al., 1981).

### **Field Methods**

At each site, one boring was completed at a point near the intersection of the land surface and the water table, and a second boring was completed at a topographically higher point as previous investigations have indicated a relation between salinity and relief (Benz et al., 1961). Soil borings were completed with samples taken in 15-cm increments to a depth of approximately 1 m with an 8.0 cm bucket auger. At the farm site, one boring was completed in a swale at the edge of an area of standing water with a visible salt efflorescence. A second boring was completed approximately 50 meters away in a topographically high area referred to as the farm rise. At the slough, one boring was completed near open water at the center of an area referred to as the slough crust that earlier in the spring appeared to be salt-encrusted. A second boring was completed approximately 9 meters away in an area referred to as the slough margin that was clearly outside the crust as evidenced by a change in vegetation. Standard soil descriptions and reaction to dilute HCl are included in appendices A and B.

### **Laboratory Methods**

Soil samples were analyzed using laboratory procedures advocated by the National Soil Survey Center, described in the Soil Survey Laboratory Methods Manual (U.S.D.A. Soil Survey Laboratory Staff, 1992), including reaction to dilute HCl, pH, particle-size analysis, carbonate and gypsum content, electrical conductivity, and soluble cations and anions. Field-moist samples were air-dried, crushed to < 2 mm, and checked for the presence of carbonate with 1 N HCl. Upon air-drying, the soils from the farm site were friable and easily crushed to < 2 mm with a metal rolling pin. The soils from the slough became cemented upon drying and it was necessary



to use a rock crusher to reduce the samples to the desired size. Saturated soil pastes were prepared and soil saturation extracts obtained (U.S. Salinity Laboratory Staff, 1954). Soil salinity is conventionally defined and measured on aqueous extracts of saturated soil pastes (U.S. Salinity Laboratory Staff, 1954). "This soil/water ratio is used because it is the lowest reproducible ratio for which enough extract for analysis can be readily removed from the soil with pressure or vacuum and because it is often related in a predictable manner to field soil water contents<sup>2</sup>." (Rhoades, 1982, p. 168)

Three pH readings were taken: one of the saturated paste and two of the dry soil sample. For the first reading the sample was dissolved in distilled, deionized water, and the second reading was taken following the addition of a 1 M CaCl<sub>2</sub> solution. Particle size was determined by the hydrometer method with preliminary soluble salt extraction. Dry samples were dissolved in distilled, deionized water, shaken for 30 minutes with a mechanical shaker, centrifuged, and the supernatant decanted (Kaddah, 1975). A total of three washings was performed on each sample. Flocculation of the clay minerals was a significant problem (see Results).

Carbonate content was determined by manometric measure of CO<sub>2</sub> released when the soil sample reacted with phosphoric acid in a water/carbonate vacuum-line U-tube manometer such as used in stable isotope geochemistry. Gypsum (CaSO<sub>4</sub>·2H<sub>2</sub>O) was determined indirectly by precipitation in acetone. The preferred method for gypsum would have been direct determination by X-ray diffraction, but a diffractometer was not available.

The electrical conductivity of the saturation extracts was determined using a pH/conductivity/temperature meter. Readings were done on dilute solutions since full strength solutions were outside the calibration range.

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<sup>2</sup> At the upper and lower ends of the field moisture range, the salt concentration of the soil solution is about 4 times and 2 times the concentration in the saturation extract, respectively (U.S.D.A. Soil Survey Laboratory Staff, 1992, p. 260).

Analyses were performed to determine the soluble cations Ca, Mg, Na, and K. The anions determined were those normally found in the greatest abundance in saline and alkali soils, namely, carbonate, bicarbonate, sulfate, and chloride. Concentrations of the cations in the saturation extracts were determined by atomic absorption spectroscopy. Initial determinations were made using a primary stock mixed standards solution (PSMSS). Subsequent analyses for Ca, Mg, and Na on a subsample of 12 intervals were performed with certified standards rather than the PSMSS. Because of the high concentrations of dissolved solids, it was necessary to use very dilute solutions to obtain readings within the calibration range of the instrument. In some cases, samples were diluted as much as 1 part in 6,250. For magnesium, calcium, and sodium at the farm, the dilutions ranged from 1:312.5 to 1:625; for sodium at the slough, dilutions were 1:3,125 for the slough margin and 1:6,250 for the slough crust. Anions were determined by the following methods: carbonate and bicarbonate by acid titration with  $H_2SO_4$ , sulfate by turbidimetric analysis using  $BaCl_2$ , and chloride by Mohr titration with  $AgNO_3$ . A subsample of 12 intervals was also analyzed for chloride by titration with  $Hg(NO_3)_2$ .

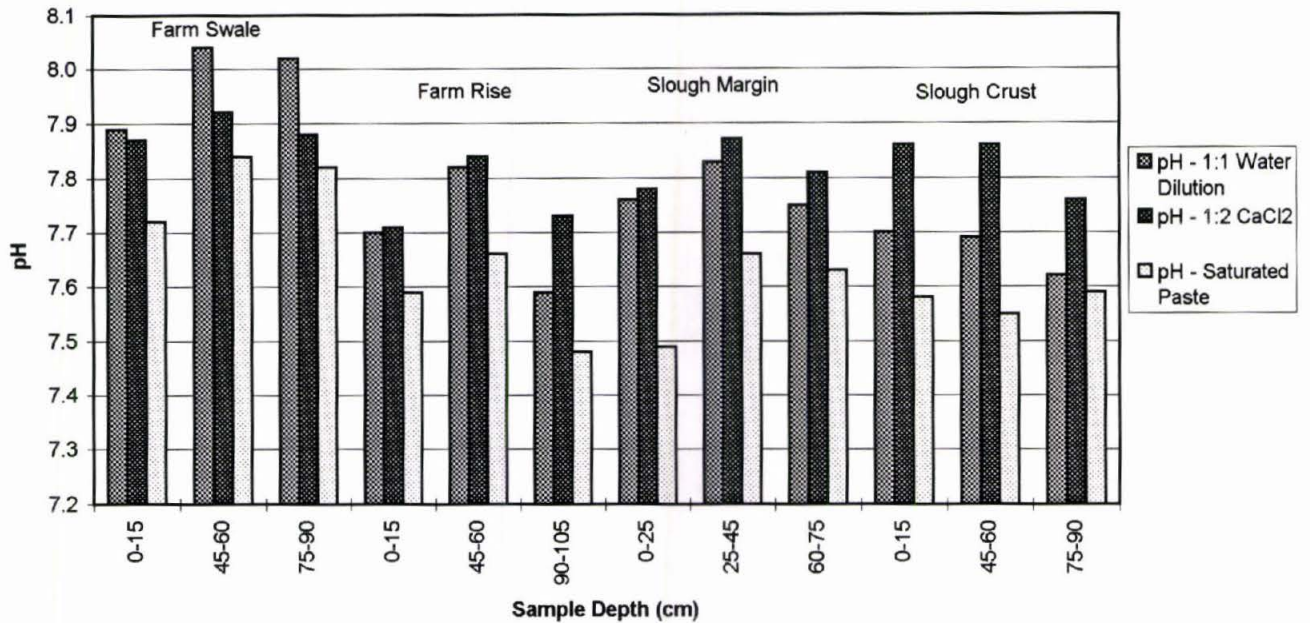
## Results

The results of the geochemical analyses indicate that soils from the farm site and Kellys Slough are quite different.

pH values were mildly to moderately alkaline, ranging from 7.59 to 8.04 (Figure 3). The most alkaline soils were at the farm swale. The usual pH sequence is 1:1 soil/water pH > 1:2  $CaCl_2$  pH > saturated paste pH (U.S.D.A. Soil Survey Laboratory Staff, 1992, p. 267-268). In the study area, the farm swale followed this pattern, but in the other borings, the  $CaCl_2$  readings were slightly higher than the 1:1 soil/water readings except in the case of the slough crust where the difference was 0.2.



Figure 3. pH



The slough soils appeared to have a higher clay content than the farm soils. The paste saturation percentage, an indication of the water retentiveness of the soil, ranged from 42.1% to 70.8% for the farm soils and from 86.7% to 98.4% for the slough soils. This indicates the possibility of swelling clays at the slough. Reliable particle-size distributions for silt and clay were not obtained, however, due to flocculation of the clay minerals. Soluble salts were extracted from dry soil samples prior to particle-size analysis in an attempt to prevent flocculation. Data from a preliminary assessment of the effectiveness of this method are summarized in Table 1. Representative samples from a slightly saline site (the 60-75 cm increment of the farm swale) and a strongly saline site (the 30-45 cm increment of the slough crust) were analyzed. Four samples from each of the two intervals were analyzed by the hydrometer method. Three of the four samples were washed. The effect of the washings on the farm swale samples was negligible, with the calculated percentage of clay increasing from 1.9% to 2.9% after three washings. However, in the slough crust sample, the difference was significant. The calculated clay content increased from 7.9% with no pretreatment to 94.7% after three washings.

Table 1. Effects of Preliminary Soluble Salt Extraction on Particle-Size Analysis

Sampling Site	Sample Depth (cm)	Number of Washings	Sample Weight (g)	Hydrometer Reading (g)	Calgon Reading (g)	Weight of Clay (g)	Weight of Sand (g)	% Clay	% Silt	% Sand
Farm Swale	60-75	0	52	6.0	5.0	1.0	*0.9	1.9%	96.3%	1.8%
		1	52	6.0	5.0	1.0	*0.9	1.9%	96.3%	1.8%
		2	52	6.0	5.0	1.0	*0.9	1.9%	96.3%	1.8%
		3	52	6.5	5.0	1.5	*0.9	2.9%	95.3%	1.8%
Slough Crust	30-45	0	57	9.5	5.0	4.5	**	7.9%	**	**
		1	57	12.0	5.0	7.0	0.6	12.3%	86.7%	1.0%
		2	57	52.0	5.0	47.0	0.5	82.5%	16.7%	0.8%
		3	57	59.0	5.0	54.0	0.6	94.7%	4.2%	1.0%

\*This represents an average for the four samples as the sand fractions were combined for a total weight of 3.6g.

\*\*Data for sand and silt for this sample are not available as the sand fraction was not weighed.

Based upon these initial findings, samples from an additional six intervals were washed three times and then analyzed by the hydrometer method (Table 2). However, there was significant flocculation, particularly with the samples from the slough crust.

Table 2. Particle-Size Analysis

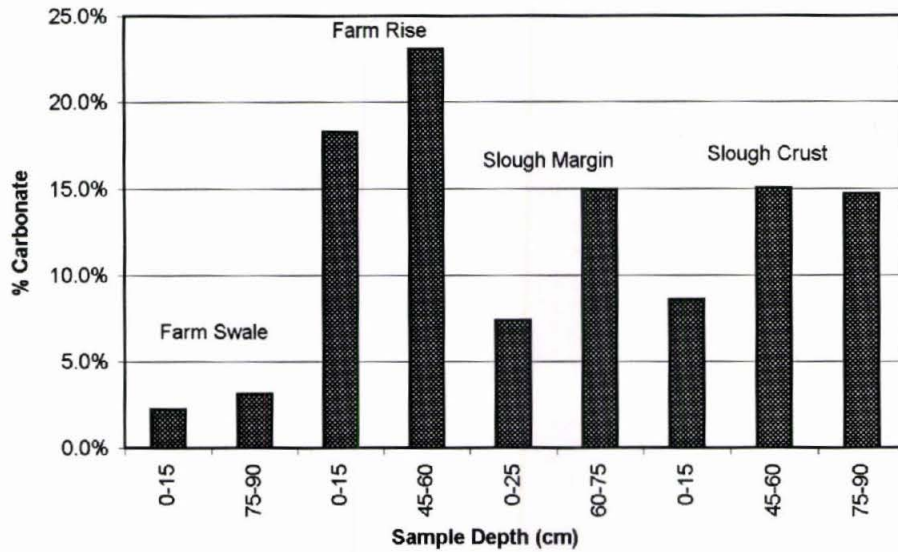
Sampling Site	Sample Depth (cm)	Number of Washings	Sample Weight (g)	Hydrometer Reading (g)	Calgon Reading (g)	Weight of Clay (g)	Weight of Sand (g)	% Clay	% Silt	% Sand
Farm Swale	0-15	3	51.46	17.0	7.0	10.0	0.19	*19.4%	80.2%	0.4%
Farm Swale	75-90	3	50.78	7.0	7.0	0	0.12	0	99.8%	0.2%
Farm Rise	45-60	3	51.49	7.0	7.0	0	0.66	0	98.7%	1.3%
Slough Margin	60-75	3	52.51	11.0	7.0	4.0	0.17	*7.6%	92.1%	0.3%
Slough Crust	0-15	3	52.93	23.0	7.0	16.0	0.12	*30.2%	69.6%	0.2%
Slough Crust	75-90	3	51.97	10.0	7.0	3.0	0.04	*5.8%	94.1%	0.1%

\*Clay balls up to 5 -10 mm in diameter were observed in these samples. Although the other two samples did not give any readings for clay, there did not appear to be any flocculation with these samples.

In the intervals analyzed, sand was a minor constituent, ranging from 0.1% to 1.8%.

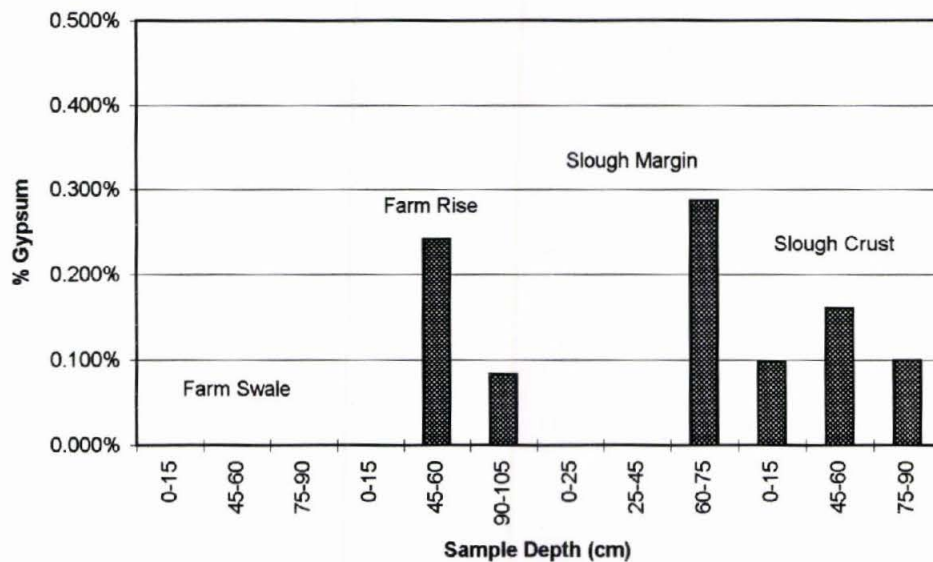


Figure 4. Percent Carbonate



Concentrations of carbonate (Figure 4) generally increased with depth for the intervals analyzed. Carbonate content was greatest at the farm rise. Due to problems encountered during analysis<sup>3</sup>, results are not available for three of the intervals. Gypsum (Figure 5) is absent from the farm swale and the surface horizons of the farm rise and slough margin. The greatest concentrations were at approximately 60 cm in depth in the farm rise and the slough margin.

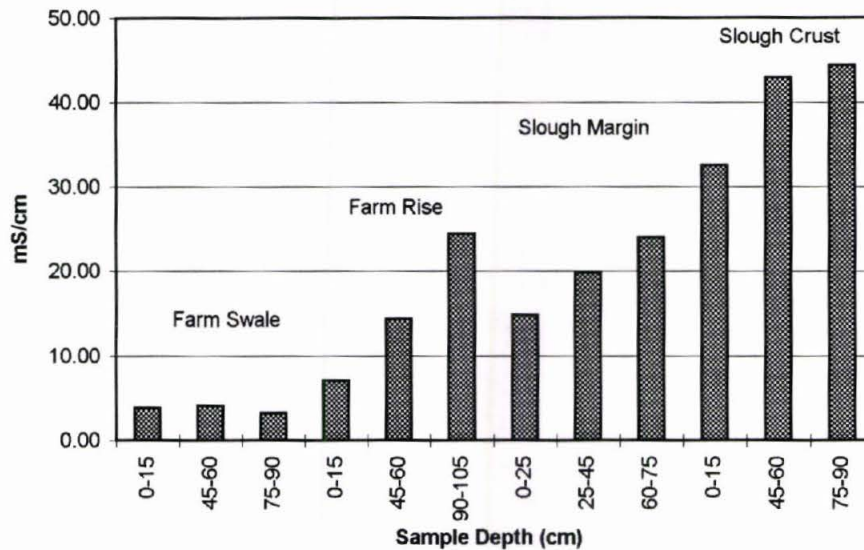
Figure 5. Percent Gypsum



<sup>3</sup> One flask was defective resulting in the escape of CO<sub>2</sub> and one sample was reacted with the phosphoric acid prematurely. With respect to the slough margin boring, the decision was made to analyze only the samples from the surface and the greatest depth omitting the interval within the section.

The slough soils were more saline than the farm soils (Figure 6). The farm swale was slightly saline (2-4 millisiemens/cm) and the farm rise, slough margin, and slough crust were strongly (8-16 millisiemens/cm) to very strongly (> 16 millisiemens/cm) saline. The electrical conductivity of the saturation extracts from the slough crust, slough margin, and farm rise increased with depth with a corresponding increase in ionic concentrations. The farm swale saturation extracts exhibited a similar pattern until the water table was reached and electrical conductivity and ionic concentrations declined. The electrical conductivities of the slough margin saturation extracts were less than those of the slough crust.

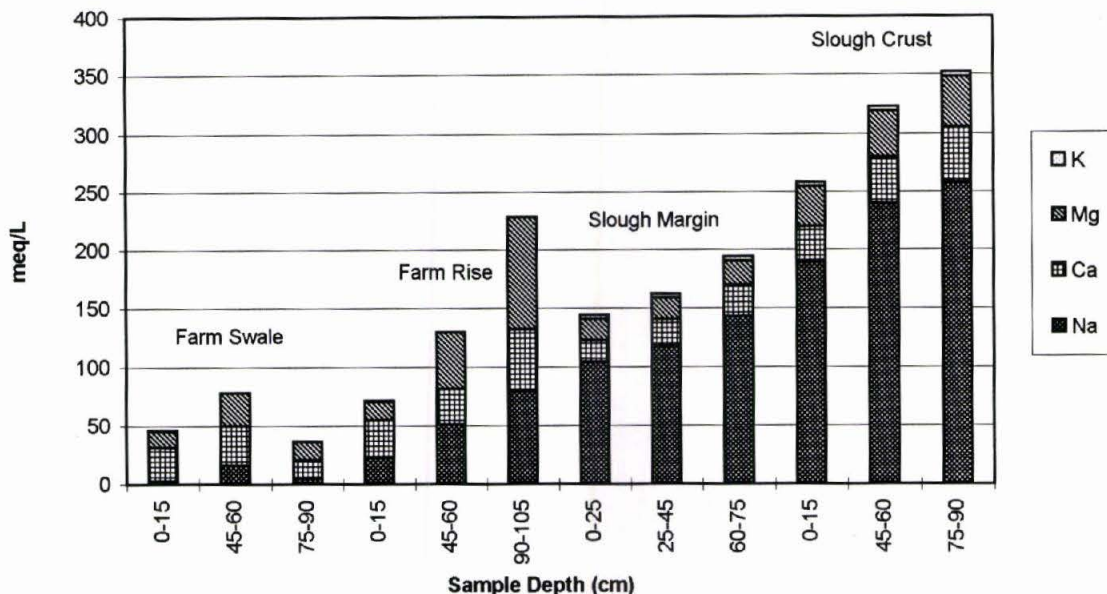
Figure 6. Electrical Conductivity (mS/cm)



Sodium was the most abundant cation in the slough soils (Figure 7). Calcium was the most abundant cation in the farm swale and the surface horizon of the farm rise. The largest concentrations of Mg were in the farm rise. Sulfate was the most abundant anion in the farm swale and the surface horizon of the farm rise (Figure 8). Chloride was the most abundant anion in the slough soils and the lower intervals of the farm rise.

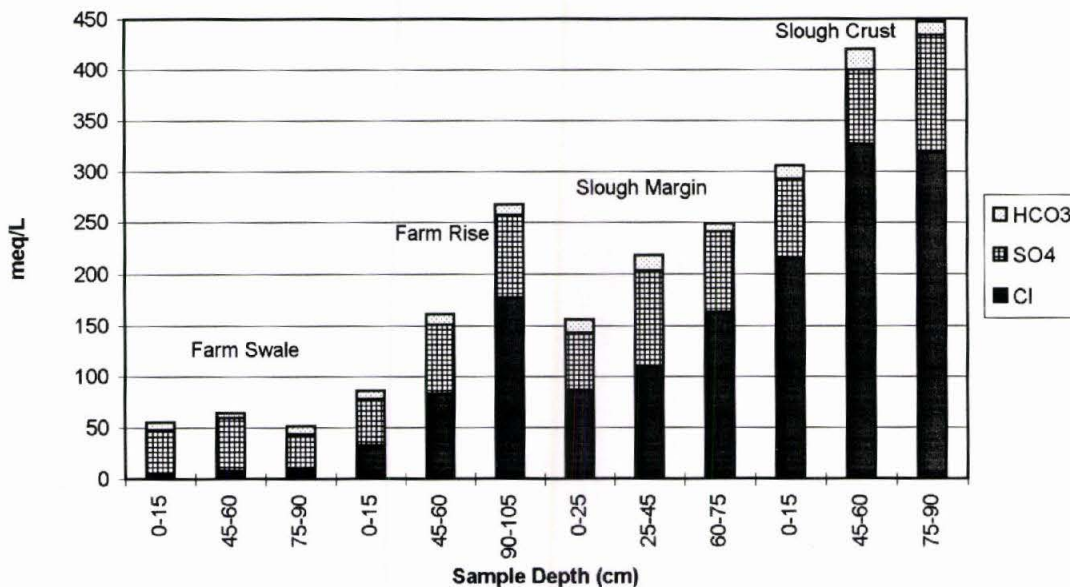


Figure 7. Cation Concentrations (meq/L)



All intervals were originally analyzed, but there were significant imbalances in the cation/anion ratios and it was necessary to repeat the analyses. Due to time constraints and the availability of adequate amounts of sample, only 3 intervals from each boring were analyzed: the surface interval, the deepest interval, and one within the section. Note the imbalance of cations and anions persists, possibly the result of the use of dilute solutions.

Figure 8. Anion Concentrations (meq/L)



## Discussion

The lower pH readings at the slough and the farm rise relative to the farm swale are consistent with the observation that the presence of salts generally results in a decrease in the soil pH (U.S.D.A. Soil Survey Laboratory Staff, 1992, p. 267). The difference in the saturation percentages between the farm soils and the slough soils suggests a higher clay content in the slough soils and also the presence of swelling clays. Hansen et al. (1970, p. 58) describes an extensive, but perhaps discontinuous, bed of silt up to 2 meters thick directly underlying the glacial lake plain surface and overlying interlaminated clay and silt. This bed is about 1 meter deep in an exposure immediately adjacent to the farm site<sup>4</sup>. Given the proximity of this exposure, it is possible that the high readings for silt at the farm site are correct and are not the result of clay flocculation.

When salts of different solubilities are present, the positions of their maximum concentrations may be used to determine the direction of water movement. Using the Hardie-Eugster model of closed basin brine evolution (Hardie et al., 1970) which "interprets the chemistry of waters undergoing evaporation in terms of a succession of chemical divides," (Drever, 1988, p. 236), Timpson et al. (1986b) predicted the mineral sequence calcite-gypsum- and mixed Na-Mg-(SO<sub>4</sub>) minerals as saline waters migrate upward through the soil profile. At the slough, the carbonate concentrations increase with depth. The gypsum concentrations, however, also generally increase with depth. In the case of the slough margin and crust, the greatest concentrations of carbonate and gypsum occur within the same intervals, 60-75 cm and 45-60 cm, respectively. At the farm swale, the concentrations of carbonate are minimal with very little difference between the surface and the greatest depth. The 0-60 cm interval of the farm rise contains the highest concentrations of carbonate within the four profiles. Data are not available for the deepest interval; there was no reaction of the dry sample to dilute HCl, however, indicating the absence of carbonate at this depth. The relative distributions of carbonate in the soil profiles indicate possible upward movement of ground water at the slough and downward movement at

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<sup>4</sup> The described exposure is located in the NW 1/4, section 28, T152, R51W whereas the farm site is located in the SW 1/4, section 21, T152N, R51W. The two sections abut one another -- the southern boundary of section 21 is the northern boundary of section 28.



the farm. The gypsum concentrations do not appear to fit the model quite as well. An obvious limitation of the Hardie-Eugster model, however, is that "phase diagrams model relationships in the relatively closed system of an evaporating dish," (Skarie et al., 1987, p. 1377), and the soil system is not a closed system. Precipitation and subsequent infiltration may temporarily alter the usual evaporite sequence. There is little or no gypsum in the surface horizons of each of the four borings and this may be due to leaching during spring recharge.

Salinity is highest at the slough and is higher in the crust than in the margin consistent with the observation that salinity is highest within seeps and decreases with increasing distance from the seep (Timpson et al, 1986a). At the farm site, salinity is highest in the farm rise. This is consistent with a previous investigation of the microrelief of the study area which found salts concentrated on the ridges while the depressions were relatively salt-free (Sandoval et al., 1964b).

Benz et al. (1961) found sodium to be the dominant cation (70%-75%) in deep artesian waters, presumably originating in the Dakota aquifer, and chlorides were higher than sulfates. This pattern was observed in the samples from the slough -- sodium concentrations ranged from 72% to 74% and chlorides exceeded sulfates. This indicates that artesian waters are the principal source of salinity in the slough. At the farm site, calcium is the dominant cation and sulfate the dominant anion in the farm swale and the surface horizon of the farm rise. Magnesium, sodium, and chloride dominate the deeper intervals in the farm rise. Sandoval et al. (1964b) observed a similar pattern -- high quantities of Mg compared to Ca especially in the lower depth of the profile and chlorides increasing at lower depths, with sulfate the dominant anion throughout the profile. The increase in chlorides at the lower depths was attributed to the proximity of the glacial till because NaCl is the principal salt of till waters in the area. This indicates artesian waters are a source of salinity at the farm also.

Arndt et al. (1989) found recharge wetlands were nonsaline, free of calcite and gypsum, and sulfate was the dominant anion, followed by bicarbonate and then chloride; calcium was

consistently the dominant cation followed by Mg and then Na. This generally describes the observed chemistry at the farm swale and may indicate that it is a recharge area.

### **Suggestions for Future Research**

It would be interesting to do sampling in transects perpendicular to the ground-water gradient to determine the magnitude of salt transport from the glacial till area (Sandoval et al., 1964a). Timpson et al. (1986a) suggest that saline seeps in southwestern North Dakota will not only be maintained, but will increase in size with desertification in and around the seeps. It would be interesting to monitor the temporal and spatial changes in an area that is ephemerally wet such as the farm swale.

An additional objective of this study was to provide background information for clay mineralogical studies. Clay minerals are of interest because their properties of adsorption, swelling, water retention, low permeability, and cation exchange strongly influence the chemical and physical characteristics of soil. Also, most soils in the county are clayey with montmorillinite the principal clay mineral in the saline soils (Sandoval et al., 1964a). A subject for additional research would be how clay minerals affect the salinization process -- whether chemical properties or impermeability are more influential. With respect to particle-size analysis, further experimentation with pretreatment methods to prevent flocculation would be worthwhile. One approach would be to increase the Calgon<sup>5</sup>/soil ratio (Kaddah, 1975). Another, as Doner (1989, p. 302) suggests, is to eliminate the flocculating effect of gypsum by heating the sample to convert gypsum to bassanite<sup>6</sup> and then removing the more soluble bassanite (Rivers et al., 1982). An evaluation of the efficacy of the various methods with respect to Na-saturated clays vs. Ca-saturated clays would be helpful.

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<sup>5</sup> Sodium hexametaphosphate

<sup>6</sup> Intermediate form between gypsum and anhydrite

## Conclusions

This study looked at the sources of salinity in the study area and evaluated the geochemistry of soil samples from two salt-affected areas: an ephemeral wet, cultivated field, and a perennial wetland. The salinity of the farm site generally fits the model of landscape-wide salinity, controlled by precipitation and evapotranspiration, while the salinity of the slough generally conformed to the model of depression-focused salinity, dominated by ground-water discharge. Although only two sites were sampled, the trends are consistent with the models. A high water table, especially one that occurs at depths of 1.5 meters or less, is a major factor in the development of many saline soils (Johnsgard, 1967). Because of the generally high water table in the glacial lake plain, discharge of saline ground water from the Dakota aquifer, poor drainage conditions, and farming practices, it appears the potential for soil salinization is landscape-wide. The low permeability of the glacial sediments, however, impedes the upward flow of ground water in much of the study area (Remenda et al., 1992). Where there is a hydrologic connection with the Dakota Group, there is a significant source of salts and this dominates the geochemistry of the resulting seeps. In areas of lower hydraulic conductivities, although the bedrock ground water may be a source of salts, the salinization process appears to be dominated by precipitation and evapotranspiration.



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## **APPENDICES**

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**APPENDIX A**  
**Soil Data Summary**



## Soil Data Summary

Sample Number	Farm Swale			Farm Rise			Slough Margin			Slough Crust		
	MF2-0-15	MF2-45-60	MF2-75-90	MF1-0-15	MF1-45-60	MF1-90-105	KS2-0-25	KS2-25-45	KS2-60-75	KS1-0-15	KS1-45-60	KS1-75-90
Sample Depth (cm)	0-15	45-60	75-90	0-15	45-60	90-105	0-25	25-45	60-75	0-15	45-60	75-90
Reaction to HCl*	S	W	0	S	M	0	T	W	M	T	T	T
AD/OD Ratio**	1.08	1.07	1.05	1.05	1.04	1.05	1.14	1.12	1.11	1.15	1.09	1.09
% Water Content	8.5%	7.0%	5.4%	5.2%	3.9%	4.6%	14.4%	12.3%	10.9%	14.5%	9.2%	8.8%
pH - 1:1 Water Dilution	7.89	8.04	8.02	7.7	7.82	7.59	7.76	7.83	7.75	7.7	7.69	7.62
pH - 1:2 CaCl <sub>2</sub>	7.87	7.92	7.88	7.71	7.84	7.73	7.78	7.87	7.81	7.86	7.86	7.76
pH - Saturated Paste	7.72	7.84	7.82	7.59	7.66	7.48	7.49	7.66	7.63	7.58	7.55	7.59
Paste Saturation %	61.0%	44.9%	42.1%	70.8%	49.3%	61.8%	92.7%	95.2%	91.2%	98.4%	86.7%	86.9%
Extract EC - mS/cm	3.86	4.06	3.30	7.05	14.40	24.36	14.88	19.80	24.00	32.52	42.96	44.40
Ca <sup>2+</sup> (meq/L)	28	34	16	32	30	53	19	23	27	30	40	47
Ca <sup>2+</sup> (ppm)	561	681	321	641	601	1062	381	461	541	601	802	942
Mg <sup>2+</sup> (meq/L)	14	28	15	15	49	96	18	18	20	34	39	43
Mg <sup>2+</sup> (ppm)	170	340	182	182	595	1167	219	219	243	413	474	523
K <sup>+</sup> (meq/L)	1	0	0	1	0	0	3	3	4	4	4	4
K <sup>+</sup> (ppm)	39	0	0	39	0	0	117	117	156	156	156	156
Na <sup>+</sup> (meq/L)	3	16	5	23	51	79	104	118	143	190	240	258
Na <sup>+</sup> (ppm)	69	368	115	529	1172	1816	2391	2713	3288	4368	5518	5931
CO <sub>3</sub> <sup>2-</sup> (meq/L)	0	0	0	0	0	0	0	0	0	0	0	0
CO <sub>3</sub> <sup>2-</sup> (ppm)	0	0	0	0	0	0	0	0	0	0	0	0
HCO <sub>3</sub> <sup>-</sup> (meq/L)	7	5	7	8	10	10	13	15	8	13	20	13
HCO <sub>3</sub> <sup>-</sup> (ppm)	427	305	427	488	610	610	793	915	488	793	1220	793
Cl <sup>-</sup> (meq/L)	4	8	9	33	83	177	87	109	163	216	327	319
Cl <sup>-</sup> (ppm)	142	284	319	1170	2942	6275	3084	3864	5778	7657	11592	11309
SO <sub>4</sub> <sup>2-</sup> (meq/L)	44	51	35	45	68	81	56	94	78	77	73	115
SO <sub>4</sub> <sup>2-</sup> (ppm)	2113	2450	1681	2161	3266	3890	2690	4515	3746	3698	3506	5523
Total Cations (meq/L)	46	78	36	71	130	228	144	162	194	258	323	352
Total Anions (meq/L)	55	64	51	86	161	268	156	218	249	306	420	447
Ratio: Cations/Anions	84%	122%	71%	83%	81%	85%	92%	74%	78%	84%	77%	79%
% Carbonate	2.2%	***	3.1%	18.3%	23.1%	***	7.4%	***	15.0%	8.6%	15.1%	14.7%
% Gypsum	0.000%	0.000%	0.000%	0.000%	0.241%	0.084%	0.000%	0.000%	0.287%	0.098%	0.160%	0.100%

\*S=Strong, M=Moderate, W=Weak, T=Trace, 0=None; Evaluation shown is qualitative, not quantitative, and is somewhat subjective, therefore, it does not necessarily correlate with the quantitative analysis for carbonate concentration.

\*\*Air Dry/Oven Dry Ratio

\*\*\*Due to problems encountered in the analytical process, results for these intervals are not available.

**APPENDIX B**

**Soil Borehole Logs**



<b>Soil Borehole Log:</b> Farm Rise	<b>Elevation:</b> 256 m (estimated)
<b>Logged by:</b> SDS	
	<b>Boring Depth:</b> 1.05 m
<b>Drilling Method:</b> Hand Auger	
<b>Sampling Method:</b> Macroscopic Analysis	<b>Start Date:</b> 6/17/94
	<b>Completion Date:</b> 6/17/94
	<b>Vegetation:</b> Sunflowers

**Depth from  
ground surface**

**DESCRIPTION OF MATERIAL**

0 to .15 m	silty clay loam, black 2.5/ Gley, organic material, rapid effervescence with dilute HCl
.15 m to .30 m	silty clay loam, light yellowish brown in color, 2.5 Y 6/4, calcareous throughout sample depth, rapid effervescence, white specks (about 1%) beginning at .18 m, small roots
.30 m to .45 m	silty clay, 2.5 Y 2.5/1, still calcareous, mottled, both light and dark areas effervesce although slightly less rapid on lighter areas, medium-grained sand increasing in quantity with depth, very small concretion, reddish grains
.45 m to .60 m	very silty lean clay, darker at top, color change to light olive brown 2.5 Y 5/4 and light yellowish brown 2.5 Y 6/4, mottled, root remains, organics, some larger concretions, redox features, still calcareous, rapid effervescence
.60 m to .75 m	2.5 Y 6/4, silty clay, one intact lens of medium-grained sand, persistent sand, still effervesces but more moderately
.75 m to .90 m	silty clay, 2.5 Y 5/3, gypsum, some sand, less calcareous material, only very minimal effervescence
.90 m to 1.05 m	red, 2.5 YR 4/8, silty clay, coarse-grained gypsum, cap zone of few mm, some calcite but small amount and only slight effervescence, some iron staining, laminations, concretions, some manganese
	end of boring



<b>Soil Borehole Log:</b> Farm Swale	<b>Elevation:</b> 255 m (estimated)
<b>Logged by:</b> SDS	
	<b>Boring Depth:</b> .90 m
<b>Drilling Method:</b> Hand Auger	
<b>Sampling Method:</b> Macroscopic Analysis	<b>Start Date:</b> 6/17/94
	<b>Completion Date:</b> 6/17/94
	<b>Vegetation:</b> Sunflowers

<b>Depth from ground surface</b>	<b>DESCRIPTION OF MATERIAL</b>
0 to .15 m	clay silt loam, 2.5/ Gley, black organic, moist, roots
.15 m to .30 m	silty clay, 2.5/ Gley, oxidized iron, moderate to rapid effervescence
.30 m to .45 m	silty clay, 2.5 Y 6/2, no gypsum or calcite crystals visible yet, slight upward gradient of water table
.45 m to .60 m	silty clay, saturated, 2.5 Y 4/2
.60 m to .75 m	silty clay, super saturated, water table at -.64 m
.75 m to .90 m	silty clay, same olive color
	end of boring

<b>Soil Borehole Log:</b> Slough Crust	<b>Elevation:</b>	253 m (estimated)
<b>Logged by:</b> SDS	<b>Boring Depth:</b>	.90 m
<b>Drilling Method:</b> Hand Auger	<b>Start Date:</b>	6/27/94
<b>Sampling Method:</b> Macroscopic Analysis	<b>Completion Date:</b>	6/27/94
	<b>Vegetation:</b>	Grasses

<b>Depth from ground surface</b>	<b>DESCRIPTION OF MATERIAL</b>
0 to .15 m	5 Y 2.5/1, black, saturated, roots, few small white grains
.15 m to .30 m	5 Y 2.5/1, black, saturated, roots, few white nodules
.30 m to .45 m	5 Y 3/1, very dark gray, saturated, roots
.45 m to .60 m	5 Y 3/2, dark olive gray, saturated, roots
.60 m to .75 m	5 Y 3/2, dark olive gray, saturated, trace of white nodules
.75 m to .90 m	5 Y 3/2, dark olive gray, saturated, roots, trace of white nodules
	end of boring

<b>Soil Borehole Log:</b> Slough Margin	<b>Elevation:</b>	253 m (estimated)
<b>Logged by:</b> SDS	<b>Boring Depth:</b>	.75 m
<b>Drilling Method:</b> Hand Auger	<b>Start Date:</b>	6/27/94
<b>Sampling Method:</b> Macroscopic Analysis	<b>Completion Date:</b>	6/27/94
	<b>Vegetation:</b>	Grasses

<b>Depth from ground surface</b>	<b>DESCRIPTION OF MATERIAL</b>
0 to .25 m	5 Y 2.5/1, black, saturated, roots
.25 m to .45 m	5 Y 3/1, very dark gray, saturated, roots, few white nodules
.45 m to .60 m	5 Y 3/1, very dark gray, saturated, roots, few white nodules
.60 m to .75 m	5 Y 3/2, dark olive gray, saturated, trace of white nodules
	end of boring

**APPENDIX C**

**Photos**





**Photo 1:** Dean Goebel, (left), Energy and Environmental Research Center, and Jon Folkedahl, (right), University of North Dakota graduate student, sampling at the farm rise, June 17, 1994.



**Photo 2:** Goebel, (left), and Folkedahl, (right), sampling at the farm swale, June 17, 1994.





**Photo 3:** Sampling at Kellys Slough, June 29, 1994. This area appeared to be salt-encrusted in April, 1994, and is the site referred to as the slough crust.



**Photo 4:** View of the Kellys Slough site, July 28, 1994. The sampling site is indicated by the arrow.