



The effect of irrigation on soil and groundwater quality in the Huntley Irrigation District, Montana
by John Frazeur Moncrief

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Soil Science

Montana State University

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Abstract:

A study of the salt status of the soil, groundwater, and irrigation water was carried out at the Huntley Irrigation District in southcentral Montana. Evidence is presented which suggests that salt flux is dependent on: (1) local site characteristics such as soil texture, structure, and depth to groundwater, (2) the special site position relative to its location on the piezometric surface of the underlying gravel aquifer (salt concentrations increase from high to low piezometric head). Evidence is also presented which demonstrates that there is leakage of the main irrigation canal.

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IN THE HUNTLEY IRRIGATION DISTRICT, MONTANA

by

JOHN FRAZEUR MONCRIEF

A thesis submitted in partial fulfillment
of the requirements for the degree

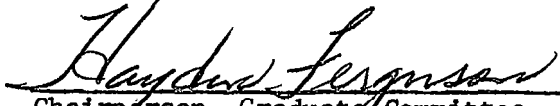
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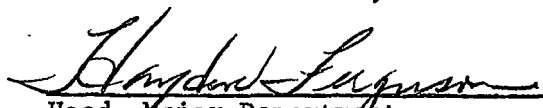
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ABSTRACT

A study of the salt status of the soil, groundwater, and irrigation water was carried out at the Huntley Irrigation District in southcentral Montana. Evidence is presented which suggests that salt flux is dependent on: (1) local site characteristics such as soil texture, structure, and depth to groundwater, (2) the spacial site position relative to its location on the piezometric surface of the underlying gravel aquifer (salt concentrations increase from high to low piezometric head). Evidence is also presented which demonstrates that there is leakage of the main irrigation canal.

CHAPTER I

INTRODUCTION

Study Area Description

The Huntley Reclamation (Irrigation) Project was begun at the turn of the century by the Bureau of Reclamation. The main irrigation canal diverted Yellowstone River water at Huntley, Montana, and brought an area about 24 kilometers long and 5 kilometers wide under irrigation.

Soils of the project were developed in generally fine textured alluvial fans (clays and clay loams) that originated from shale and sandstone hills to the south and more recent alluvium in proximity to the Yellowstone River. The soil material varies in depth from approximately 1 meter to greater than 5 meters and is underlain by coarse gravel. Many of the soils are saline and/or sodic; it is estimated that nearly one-third of the project is adversely affected by these factors.

Since the project opened for settlement in 1907, there has been concern for how irrigation was affecting groundwater and soil salinity and sodicity. Evidence of seepage from the main canal and elevated groundwater levels was documented early (Hansen, 1914; Hastings and Hansen, 1945).

The work described here was undertaken in an attempt to determine any relationship between the salt status of soils at various sites and underlying groundwater and the canal water and the degree to which seepage from the canal influences the water table level.

Methods and Materials

The Study Area

Size

The study area is confined within the limits of the irrigated land by that portion of the Huntley Reclamation Project that is fed by the main irrigation canal. It is bordered by the main irrigation canal and the Yellowstone River. The main canal is diverted from the Yellowstone River at Huntley, Montana and re-enters at Pompeys Pillar, Montana (see Fig. I-1).

Geology

The soil of the entire study area is underlain by Bearpaw Shale (see Fig. I-2). This is an upper Cretaceous, dark marine shale that generally bears no water or yields very small quantities of poor water (Hall and Howard, 1929). Except for the very outer fringe of the Custer Coulee-Arrow Creek-Fly Creek drainage basin, the entire drainage is underlain by Bearpaw Shale. Hem (1959) illustrates a Na_2SO_4 dominated water of Bixby River, South Dakota which drains an area of Pierre Shale. The Pierre Shale is lithologically similar to the Bearpaw Shale (Campbell et al., 1915). Since most of the soils of the study area have developed in a drainage basin dominated by Bearpaw Shale, this is the probable source of salts within these soils.

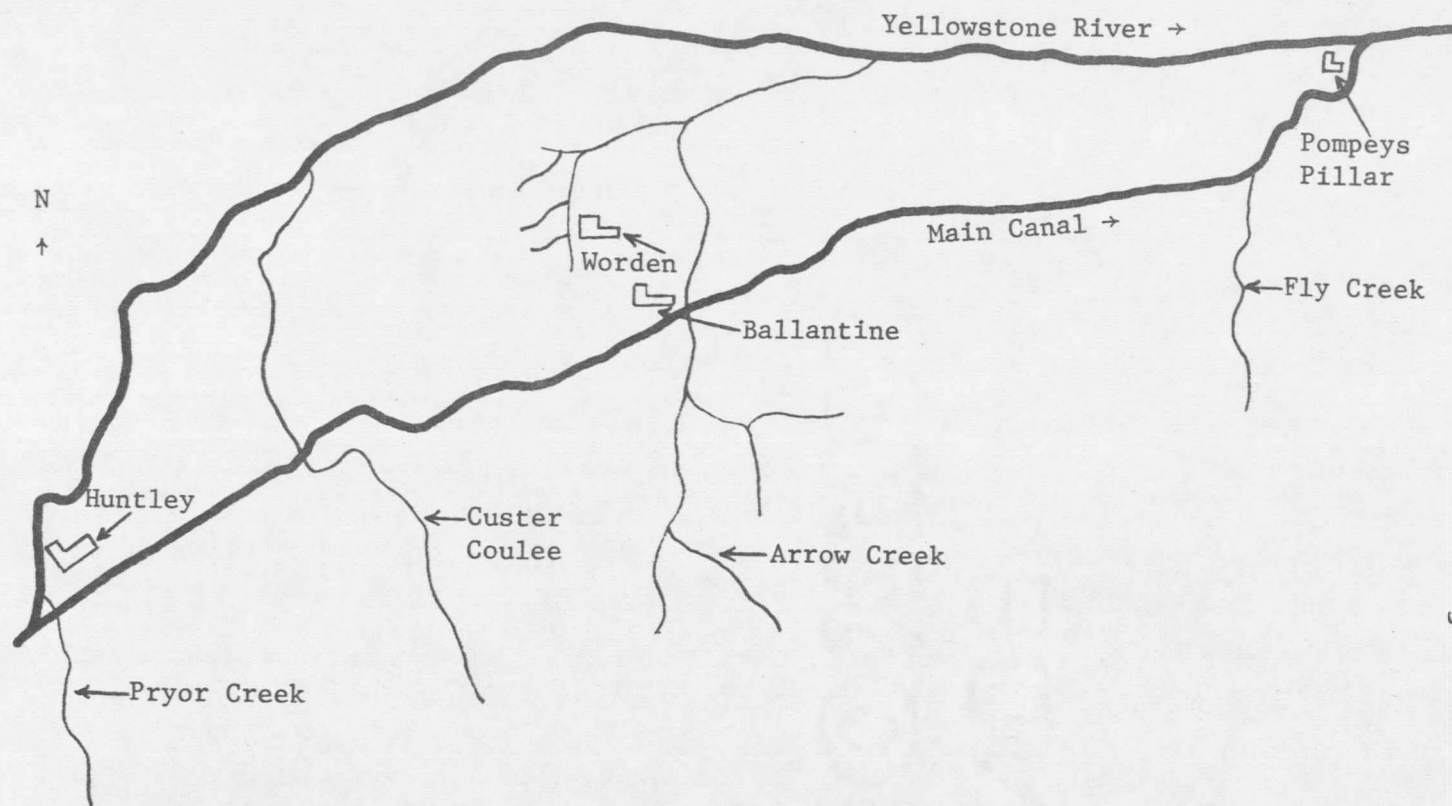


Fig. I-1. Surface hydrology and cultural features of study area.

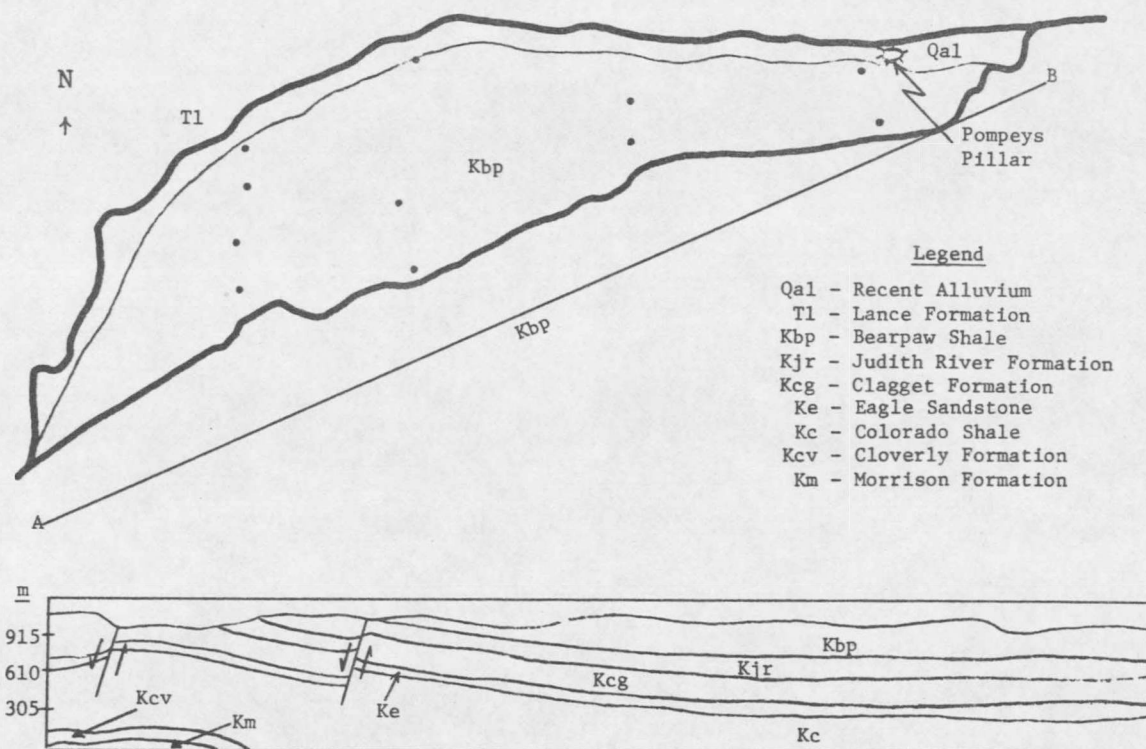


Fig. I-2. Geologic map and cross-section of source area of groundwater and alluvial soils of study area.

Beneath the Bearpaw Shale lies the Judith River Formation which Hall and Howard (1929) describe as "alternating sandstone and shales of fresh or brackish water origin which generally yield supplies of potable water." Smith (1972) cautions that water of poorer quality is obtained where wells are drilled through the Bearpaw Shale because mineralized water from the shale can enter the sandstone at outcrops and along faults and fractures. Above the Bearpaw Shale lies the Lance Formation of Tertiary age. According to Smith, "sandstones in this formation usually yield small to moderate supplies of potable water." The base of the Lance Formation forms the sandstone cap of Pompeys Pillar (a prominent butte at the eastern end of the study area on the Yellowstone River). The Lance formation makes up the steep cliffs on the north side of the river. Renich (1923) found that water percolating through the Lance Formation became Na-dominated because of base exchange of Mg and Ca for Na by Leverrierite now recognized as Kaolinite (Grim, 1968). The strata in the study area dip to the NNE at about 7° .

There is a fringe of Quaternary alluvium about .8 to 1.2 kilometers wide along the south side of the Yellowstone River within the study area (Fig. I-2). Evidence of a period of uplift and stability is shown by a high gravel terrace about 183 to 335 meters above the Yellowstone River. This terrace occurs south of Huntley and Ballantine and along the entire length of Pryor Creek. It has been dissected and drained

but localized seeps and springs which provide a source of potable water. A map by Hancock (1920) shows the extent of this gravel terrace.

Surface Hydrology

The surface flow in the study area is from south to north except for the eastern one-third of the project where the general flow is east. Four main creeks cross the study area: Pryor Creek, Custer Coulee, Arrow Creek, and Fly Creek. Pryor Creek flows out of the Pryor Mountains to the south and crosses the study area on the west end. Custer Coulee, an intermittent stream, flows across the west one-fourth to the area. The main stream draining the hills to the south and crossing the middle of the study area is Arrow Creek. Fly Creek is at the east end of the study area. The main canal is isolated from Pryor, Custer, Fly, and Arrow Creeks by aqueducts. See Fig. I-1 for surface drainage patterns.

Topography

The study area is relatively level with a slope of about 2 meters per kilometer of .2% within about 3 kilometers of the river (Fig. I-3). Along the central portion of the study area within 1.5 kilometers of the canal the slope is about 8 meters per kilometer of .8%. The steeper slope in this area is due to the closer proximity of the alluvial fans

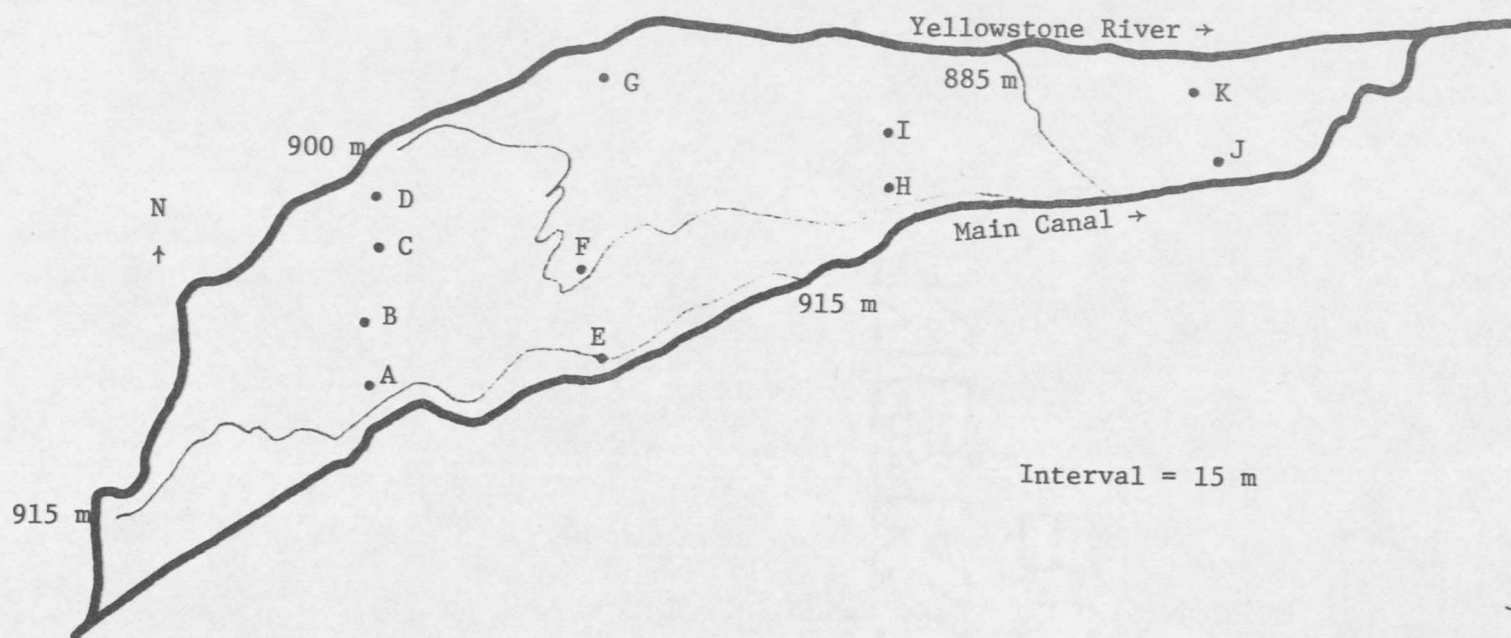


Fig. I-3. Topography of study area and location of groundwater monitoring stations labelled A-K.*

*Constructed from USGS 7.5' quadrangle.

emanating from the hills to the south. The prominent bow to the north at the western end of the canal is the Custer Coulee fan.

Establishing Groundwater Monitoring Stations

Site Selection

Site selection for groundwater monitoring stations was done from aerial photographs of the study area. Establishment of the groundwater monitoring stations was accomplished in late June 1975. Four transects running north and south were established about 5 to 6 kilometers apart. The individual monitoring stations within each transect were about 1.5 kilometers apart. The sites have been labelled A-K (see Fig. I-3).

Groundwater Access Tubes

At each monitoring station a groundwater access tube and a series of from three to four piezometers were installed. The groundwater access tube enabled groundwater samples to be taken throughout the study period. The access tubes used are polyvinyl chloride with an inside diameter of 6 cm and are 3 m long. The bottom 1.5 m of the tube is perforated with 2 mm holes in 4 vertical lines 90° apart with holes about 15 cm apart within lines. The soil hole to accommodate the tube was drilled with a hydraulic soil auger slightly larger in diameter than the tubes. A rubber stopper was placed in the bottom of the tube to prevent entry of soil material during tube installation.

The access tubes were inserted to 3.0 m unless gravel was encountered (the auger was unable to penetrate gravel horizons). In this instance the tube above the ground was cut off appropriately. The tubes were allowed to protrude about 8 to 10 cm above the ground to prevent irrigation water from flowing in and then capped with a can to keep out debris but allow equilibrium pressure with the atmosphere to be maintained. The tubes were sampled about every 2 weeks during the summers of 1975 and 1976. The samples were frozen until lab analysis in the fall.

Piezometers

The piezometers used were 1.3 cm inside diameter steel pipe. The piezometers were installed using the driving method (35a) described by the U. S. Salinity Laboratory Staff (1954). The piezometers were not tested for responsiveness.

The Soil

At each monitoring station the soil was sampled to a depth of 1.8 m (unless impeded by gravel) at four modal locations within 6 m of the groundwater access tube. All sites were sampled during a 2-week period beginning the third week of June and ending the first week in July 1975. The samples were taken with a hydraulic soil sampler using a steel sampling tube 3.8 cm in diameter. Each .3 m increment soil sample

was hand textured as it was withdrawn from the sampler tube. The results of the textural horizonation are found in individual site discussion. Each of the depth increments were combined with the corresponding increments to make up a composite sample. The samples were then bagged and kept in a cooler until facilities were available for freezing (less than 4 hours). The samples were kept frozen to halt microbial activity until lab analysis in late summer.

Chemical Analysis

At the time of analysis the soil samples were thawed and oven dried at 60°C. They were then ground to pass a 2 mm screen. For chemical methods of analysis and references, see Table I-1.

The water samples were thawed and analyzed for $\text{NO}_3\text{-N}$ immediately. The samples were kept refrigerated until the remaining analysis was completed. See Table I-2 for summary of analyses run for the 2-year study period.

TABLE I-1. METHODS USED FOR CHEMICAL ANALYSIS.

Analysis	Method	Reference
NO ₃ -N	Phenoldisulfonic acid method analyzed with Bausch and Lomb Spectronic 20 spectrophotometer	Bremner (1965)
Available K		
Water soluble Ca-Mg-Na-K	Saturated paste extracts analyzed by atomic absorption spectrophotometry	U. S. Salinity Lab Staff (1954)
pH	Saturated paste extracts analyzed by potentiometric (calomel electrode) means	U. S. Salinity Lab Staff (1954)
Electrical Conductivity	Saturated paste extracts analyzed by wheatstone bridge type conductivity meter	U. S. Salinity Lab Staff (1954)
Saturation moisture percent	Saturation percentage from volume of water added	U. S. Salinity Lab Staff (1954)
Ca-Mg-Na-K (water samples)	Atomic absorption spectrophotometry <u>1/</u>	
SO ₄	Turbidimetric method	Amer. Public Health Assoc., Inc. (1965)
Cl	Argentometric method	Amer. Public Health Assoc., Inc. (1965)

1/ Atomic absorption spectrophotometer Perkin-Elmer model 290-B; solutions in a .5% Sr. matrix to minimize anion interference.

TABLE I-2. SUMMARY OF ANALYSES ON WATER AND SOIL SAMPLES.

	Ca	Mg	Na	K	pH	EC	SO ₄	Cl	NO ₃	NH ₄ OAc Extractable K	Saturated Moisture
<u>Water</u>											
1975	x	x	x	x		x	x		x	x	
1976	x	x	x	x	x	x			x		
<u>Soil 1/</u>											
1975	x	x	x	x	x	x			x	x	x

1/ Except for NO₃ and NH₄OAc extractable K all other determinations are of the saturated extract.

CHAPTER II

REVIEW OF LITERATURE

Early Research-Huntley Project Groundwater Fluctuations and Quality

Soon after the Huntley project was established there was a recognized need for agricultural research. The main problem was a seasonally high water table and accumulation of salts due to a combination of canal leakage and irrigation. In 1910, the United States Department of Agriculture founded an experimental farm on the project. This was primarily to deal with the problems of irrigated agriculture with the specific set of circumstances inherent to this project. In 1910, a saline soil reclamation study was initiated near Worden, Montana (Hansen, 1914). The soil in this area is a heavy clay overlying stratified sands and gravel at a depth of 1.5-2.4 m. The groundwater level at the site fluctuated from a low in January of 1.14 m below the ground surface to a high in late September of .61 m with the sharpest increase during the latter part of the irrigation season. The major cation was Na with moderate amounts of Ca and Mg. The major anion was SO_4 with only trace amounts of Cl and HCO_3 . The soil at this site had about five times greater concentration of salts than the groundwater below.

In 1923, a series of observation wells were established on the Huntley Experiment Station (Hastings and Hansen, 1945). The averaged data from 1924 to 1936 show a gradient in groundwater level from the

main canal to the Custer Coulee drain, about 366 m away. The gradient paralleled the topography and decreased in the direction of Custer Coulee. The seasonal fluctuations in groundwater level increased in the direction of the canal. In 1936, the observation wells were relocated to yield more information. The observation wells covered a greater area and some were located on non-irrigated land. In the summarized data from 1938-42 the same conclusion that the seasonal water level change increased in the direction of the main canal was obtained. More convincing data were presented, illustrating the effect of canal leakage on the groundwater level.

In the time lag from water entering the main irrigation canal and the beginning of irrigation, several sites exhibited a sharp rise in groundwater level. Also, the seasonal fluctuations were similar for both irrigated and non-irrigated fields. It is argued that the fluctuations in groundwater level are mainly due to canal leakage and not irrigation.

The groundwater quality was unaffected by irrigation. That is, the salt content was similar at irrigated and non-irrigated sites. The salt generally increased with increasing distance from the main canal. The salts of the groundwater in the study area did not change appreciably in the 19-year study period.

Ion and Water Movement Through Soils

The soil-water-plant continuum is a dynamic system which is rarely at equilibrium. Water flux is analogous to electrical flux. That is, the flux is proportional to the resistance and potential difference in a given circuit or soil. In a soil situation there are many interacting factors influencing potential gradients and resistance to flow. These include aggregate size and stability, clay type and amount, ionic species and concentration, pore size distribution, swelling, temperature and salt gradients, and biological activity.

Swelling leads to a reduction in size of the larger pores and in some cases total blocking. This results in a reduction of hydraulic conductivity. If clay particles are moved far enough apart in swelling to reach a situation where forces of attraction are less than those of repulsion, dispersion occurs. This can also block larger pores. Both of these processes can result in structural changes and reduction in large pore sizes. This has been shown by Chen and Banin (1975) with the aid of a scanning electron microscope. Shainberg and Caiserman (1971) found that Na moving to the external surfaces of tactoids resulted in blocking of large pores. McNeal and Coleman (1966) also found that the "domain" model of Na-Ca areas in clay influence swelling. Kissel and Ritchie (1974) found that overburden pressure decreased water and Cl flow in a swelling clay soil

and speculated that it was due to a reduction in pore size and the negative charge of clays. Ritchie et al. (1972) demonstrated that water contained in soil structure units is inactive in flow processes.

Early reports in the literature show gypsum can improve the physical properties of soils with high sodium adsorption ratios (SAR) (Antipov-Karataev and Filippova, 1936 and Mozheiko, 1936). The solubility of gypsum is so low that in some cases it is ineffective in a soil in which the permeability is initially low (Reeve and Tamoddoni, 1965). The anionic species present will influence the exchange equilibria of cationic species. Babcock and Schuly (1963) found that with soils leached with either Na_2SO_4 or NaCl , more exchangeable Na resulted with SO_4 , probably due to differences in activities. Dutt and Doneen (1963) salinized a Ca soil with a solution of Na_2SO_4 and NaCl which resulted in precipitation of gypsum. Rao et al. (1968) found that apparent equilibria by batch equilibration (in terms of concentration) of Na-Ca and Na-Mg, was explained better when solution phase activities and ion association of Ca and Mg with SO_4 was considered in comparing Cl and SO_4 systems. Dutt (1964) found that Mg in leachate was less than that of leaching solution when gypsum was present whereas Na was unaffected. Several researchers have assessed the effect of biological influences. Phytocycling of salts resulted in an estimated 20-60 kg/ha of salts (Kovda, 1944). Ogata and Bower (1965) showed the reduction of SO_4 results in formation of CaCO_3 , raising the SAR.

The velocity and concentration of leaching solution influence movement of salt. Abrol and Bhumbra (1973) found that pore size distribution and velocity distribution of water flowing through small pores influenced salt leaching in a saline-sodic soil. Biggar and Nielsen (1960), Dutt and Doneen (1963), and Biggar et al. (1966), showed that as the velocity of a solution moving through a soil is reduced, the point of inflection of the break through curve for a solute occurs with a smaller volume of solution owing to diffusion of the solute. Krupp et al. (1972) combined Gouy theory for ion distribution in soil pores and a hydrodynamic equation for mixing of two miscible solutions in a porous medium and described movement of ions related to charge and zones of mobile and immobile solution. Gardner et al. (1959) found that on a Pachappa sandy loam soil there was a tenfold increase in water diffusivity under K saturation compared to Na saturation. Quirk and Scholfield (1955) found that the threshold values for ion concentrations below which a decrease in soil permeability resulted were ranked: $\text{Na} < \text{K} < \text{Mg} < \text{Ca}$. Clay type and ionic species and concentration affect hydraulic conductivity. Montmorillonite and micaceous type clays disperse more at low SAR's, reducing hydraulic conductivity and high salt concentration increases permeability (Velasco-Molina et al., 1971; Christenson and Ferguson, 1966; and McNeal and Coleman, 1966).

Groundwater Quality vs. Soil Quality:
Cause and Effect

The effect of irrigation and groundwater on soil salinization has been given much consideration in the literature. The reverse situation (effect of soil formation on groundwaters) has received less attention until the recent coming of environmental awareness. Zonn (1944) cites only one reference to the fact that the degree and nature of salinity of groundwaters may be dependent on the type of soil above them. It becomes a question of, "Is salinity of groundwater an effect of the soil above or vice versa?" The answer is both, depending on the situation. The direction of net salt flux is, in most instances, dependent on the time frame in which it is viewed. The system is highly dynamic with daily fluctuations superimposed on seasonal changes, and those, on trends of the order of decades. Salts, in most cases, are carried upward into soil by water movement. Concentration gradients become important in instances where water velocity is small.

Upward movement of groundwater depends on pressure head, soil structure and texture, and depth to groundwater. The capillary fringe advances upward ahead of the saturated zone.

Davis and DeWiest (1966) class water-level fluctuations into four basic types: (1) fluctuations due to changes in groundwater storage, (2) fluctuations caused by direct fluctuations of atmospheric pressure in contact with the water surface in wells, (3) fluctuations

caused by deformation of aquifers, and (4) fluctuations caused by disturbances within the wells. Long term fluctuations are usually the result of gradual depletion or recharge of water stored in an aquifer (Hutchinson, 1957). Water level change maps are useful in determining local effects of recharge and discharge as a result of irrigation (Davis and DeWiest, 1966).

Ivanova (1939), found that zonal soil types of Russia were associated with the anionic character of the groundwater. Deserts were characterized by groundwater anionic composition of HCO_3 , SO_4 , and Cl ; still waters of all zones were dominantly Cl and SO_4 ; forest-steppe soils had groundwater dominated by HCO_3 . He cited sources of soil salts as being due to capillary rise, surface water, or soil forming rocks. Ivanova considered biologic factors the most important consideration of groundwater salts. Gatewood et al. (195) concluded that as groundwater moved through a vegetated area, increased Cl content reflected evapotranspiration. Zonn (1945) attacked the problem of assessing the influence of soil formation on groundwater composition and found the following:

1. An increase in soil salinity was associated with an increase in soil Na and a decrease in Ca , Mg , Cl , and SO_4 which are leached out of soil solution.
2. A solonetz soil with a high degree of salinity had more relative amounts of Na and less Ca in the groundwater

than a chestnut solonetz indicating that the groundwater under the solonetz soil was influenced by the soil profile above.

3. In another chestnut solonetz soil the groundwater had much more Na and less Mg and Ca than the soil indicating a leaching condition.
4. In a comparison of groundwater of slightly and moderately leached solonetz soils, the soil with more leaching resulted in higher groundwater concentrations of Na and less Ca and Mg.
5. He cited a source stating that alkaline groundwater is related to alkaline igneous rocks and suggested that his data show it was also related to the soil above the groundwater.
6. Concluded that each soil type of the alluvial series such as podzolized chernozem and chestnut solonetz, may be supplying soil solutions of widely different character which affects the chemical composition of the groundwaters.

More recently environmental awareness has focused attention to groundwater pollutants, such as NO_3 , in addition to total salts. Nightingale (1972) found a correlation with crop species and NO_3 level in the groundwater and also soil NO_3 level with groundwater NO_3

level. In a paper 2 years later he reported a similar correlation with crop classes and groundwater salinity on a large irrigated area near Fresno, California. However, he also found groundwater salinity was poorly correlated with soil salinity nearby. Nightingale and Bianchi (1974) showed that irrigation with groundwater resulted in an increase in the electrical conductivity (EC), NO_3 , and Cl of groundwater whereas these decreased when good quality surface water was used for irrigation.

Brigham et al. (1971) found that no appreciable salinization of a study area occurred even though the irrigation water had an EC of 1.2 mmhos/cm. Salts accumulating in the soil profile were CaSO_4 and CaSO_3 . Nitrate losses were 45% of that applied.

Critical Depth to Water Table

Soil salinization can result from evaporation from a shallow water table and will be accelerated if there is substantial salt in the groundwater (Gardner and Fireman, 1958). There are several related factors that determine the magnitude of the salt and water flux. Gardner (1958) found that the evaporation rate can be limited by the atmospheric conditions at the soil surface or the hydraulic conductivity of the soil. If the depth to the saturated zone is shallow, atmospheric conditions were more important. Conversely, if the depth is great, transmission properties of the soil dominate evaporation rate (Wind, 1959 and Talsma, 1963).

When salts are a problem, it is desirable to maintain the capillary fringe below the root zone. If the existing water table during the growing period is too high to accomplish this, drainage is an available option. Of course the crop would have little water available from below. Russian investigators suggest that a layer of fresh water above saline groundwater would allow crops to use water from below (Krimgold, 1945; Kovda, 1961; and Legostaev, 1958).

The critical depth to groundwater is related to soil salt concentration, gradients opposite to upward water flux (Quazzum and Kemper, 1962), soil texture and structure, temperature gradients, and atmospheric conditions. Hence, many different "critical depths" have been offered in the literature. Burgess (1928) found that water tables must be at about 3 m in order to not have salinization with fine grained soils in an arid environment. Krimgold (1945) suggested water table depths in saline areas of Russia to be 1.5 to 2.5 m. Shoonover et al. (1957) found salt accumulations when water depths were less than 1 m. Groenewegen (1959) found salting was no problem on fine textured soils with groundwater at 1-1.5 m. Talsma (1963) found the critical depth was that which corresponded to a net surface evaporation of 1 mm/day. This was approximately 1.2 m below bare soil or below the root zone of crops.

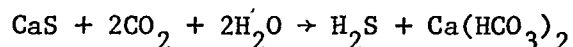
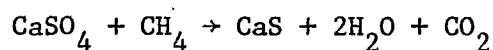
More recently, attention has been focused on soil horizonation and critical depth to groundwater. Hassan and Ghaibch (1977) found

that 1) the salt peak near the soil surface was probably due to the polyphasic nature of upward moisture flow, 2) ionic dispersion moved salt down and water flux up, 3) the theoretical predictions of salt flux are good for homogeneous soils by higher than the measured rates for heterogeneous soils. Willis (1960) evaluated upward movement of water and depth to the water table with various combinations of stratified sand and loam. It was concluded that the difference in evaporation rate of a fine textured soil overlying a coarse soil is similar to a homogeneous situation. The reverse situation can result in a large reduction in evaporation rate. When the water table is greater than 2.8 m, soil horizonation is of little influence. Hadas and Hillel (1972) found similarly that evaporation is reduced 1) when a coarse layer is over a fine layer, 2) when a tillage-induced coarse structured layer overlies a fine structured layer. They also speculated that 3) an interlayer contact zone may impede water flow.

Hydrochemical Facies

Hydrochemical facies is defined by Maksimovich (1949) as that part of a groundwater basin or stream having the same hydrochemical characteristics. Among the zones of soil types observed in Russia, steppes have groundwater which is predominantly $\text{SO}_4\text{-Na}$ and $\text{HCO}_3\text{-Na}$ in chemical makeup. Maksimovich (1949) also noted that facies change as one goes deeper and encounters different geologic strata. Several hydrochemical facies in close proximity to the Huntley Irrigation

District study area have been identified in the literature (Renich, 1923) and likely serve as a source of ionic species present in both soil and groundwater. Maksimovich (1950) presented data showing the composition of rivers, lakes, and groundwaters are related to soil solutions of different zonal type soils. Riffenburg (1925) showed chemical analysis of the Moreau River at Bixby, South Dakota which has a high concentration of Na and HCO_3 . This river drains an outcropping of Pierre shale which is the same geologic formation as the Bearpaw shale outcropping of the Huntley Irrigation District. This undoubtedly serves as an important source of these ions to the soils and groundwater at Huntley. White et al. (1963) offered a well water analysis of Pierre shale, Langdon, North Dakota with a SO_4 -Cl ratio of 45:1, well in excess of the Moreau River ratio of 1:10 of Riffenburg (1925). Hem (1959) suggested that the dominance of Na and HCO_3 may be the result of reduction of the sulfur in original anhydrite or gypsum present.



The dominant ions of the Huntley Irrigation District groundwater are Na- SO_4 suggesting the Bearpaw shale as the primary source in the absence of reducing conditions. Hem (1959) also illustrated a well water analysis from the Fort Union (sandstone and shale) formation at Rosebud County, Montana with Na and HCO_3 as the two major ions, and

suggests SO_4 reduction and cation exchange are responsible for its makeup. Torrey and Swensen (1951) showed a well analysis of the lower member of the Fort Union formation having Na, Mg, and Ca in equal proportions with SO_4 , the dominant anion. This formation could serve as a source of ions from outcroppings upstream from the Huntley Irrigation District, although there would be considerable dilution. Table II-1 shows ion concentrations at the Yellowstone River at the source of the main irrigation canal and also at the mouth of Fly Creek which drains the hills to the north. The Fly Creek analysis has a higher SAR and ion concentration than the Yellowstone River. Although the dominant anion is SO_4 in both analyses the ratio of $\text{SO}_4:\text{Cl}$ is higher in Fly Creek.

Water Flow Through a Gravel Aquifer

The soils of the Huntley Irrigation District vary in depth from 1 to 5 meters and are underlain by coarse gravel. It will be shown in the streamline discussion that the hydraulic gradient decreases from the west to east in the study area from .28 to .15%. The length of streamline increases in the same direction from about 5 to 15 kilometers. Several investigators have measured groundwater velocity in coarse gravel aquifers similar to the study area aquifer. Tolman (1937) published a value of 33 m/day average velocity in coarse gravel for a 1% hydraulic gradient. Sugisake (1961) used dissolved gases to deter-

mine the effective velocity in a coarse gravel aquifer ranging from 36 to 58 m/day along a similar 1% hydraulic gradient. If we assume an average velocity of 45 m/day, given the range in hydraulic gradient of the study area and length of streamlines, groundwater could move from the main irrigation canal to the Yellowstone River in 1.1 years in the west and 6.1 years along eastern streamlines.

TABLE II-1. ION CONCENTRATIONS OF THE YELLOWSTONE RIVER AT THE SOURCE OF THE HUNTLEY MAIN IRRIGATION CANAL AND AT THE MOUTH OF FLY CREEK (USGS, 1975).

Date (1975)	Dissolved Ions							pH
	Ca	Mg	Na	K	SO ₄	Cl	SAR	
-----meq/l-----								
<u>Yellowstone River</u>								
June 25	.95	.49	.39	.038	.416	.056	.5	8.2
July 29	1.05	.53	.56	.054	.707	.028	.6	7.2
Aug. 28	1.85	1.07	.96	.066	1.25	.144	.8	8.0
Sept. 18	2.00	1.23	1.26	.082	1.91	.183	1.0	8.3
<u>Fly Creek</u>								
June 2	2.54	2.39	3.61	.077	5.20	.228	2.3	--
July 14	5.99	6.00	10.00	.120	17.06	.423	4.1	--
Aug. 27	4.29	4.28	5.22	.102	8.73	.276	2.5	--
Sept. 18	2.94	2.39	2.96	.098	4.78	.248	1.8	--

CHAPTER III

RESULTS AND DISCUSSION

Main Canal

Ion concentrations of salt constituents in the canal are shown in Figures III-1 through III-3. The curves of individual cations were of similar magnitude and shape with the exception of Ca. The canal water varied between summers in total salt.

The cation fractions as a function of EC are shown in Figure III-4. The Mg percentage varied about the same magnitude both years but was higher the second year. The Ca percentage was lower the second year.

Gregorian and Julian dates of piezometer readings and sampling of groundwater during study period are given in Table III-1. Summary statistics for canal variables are given in Tables III-2 and III-3. The Na and Mg mean concentrations are close to being equal and slightly larger than Ca. Calcium varies the least. Changes in canal EC are correlated with Mg. The Mg percentage is the most stable.

With an average SAR of .8 and EC of .1 mmhos/cm, the sodium and salinity hazard is extremely low. According to the classification of irrigation water developed by the United States Salinity Laboratory Staff (1954), this water would be classified Cl-S1. This classification is the optimum for irrigation use.

If small amounts of net leaching are maintained there is little chance of "problem soil" development. In the case of the saline-sodic sites the combined effects of heavy texture, expanding type clays, and high SAR severely restrict downward water movement.

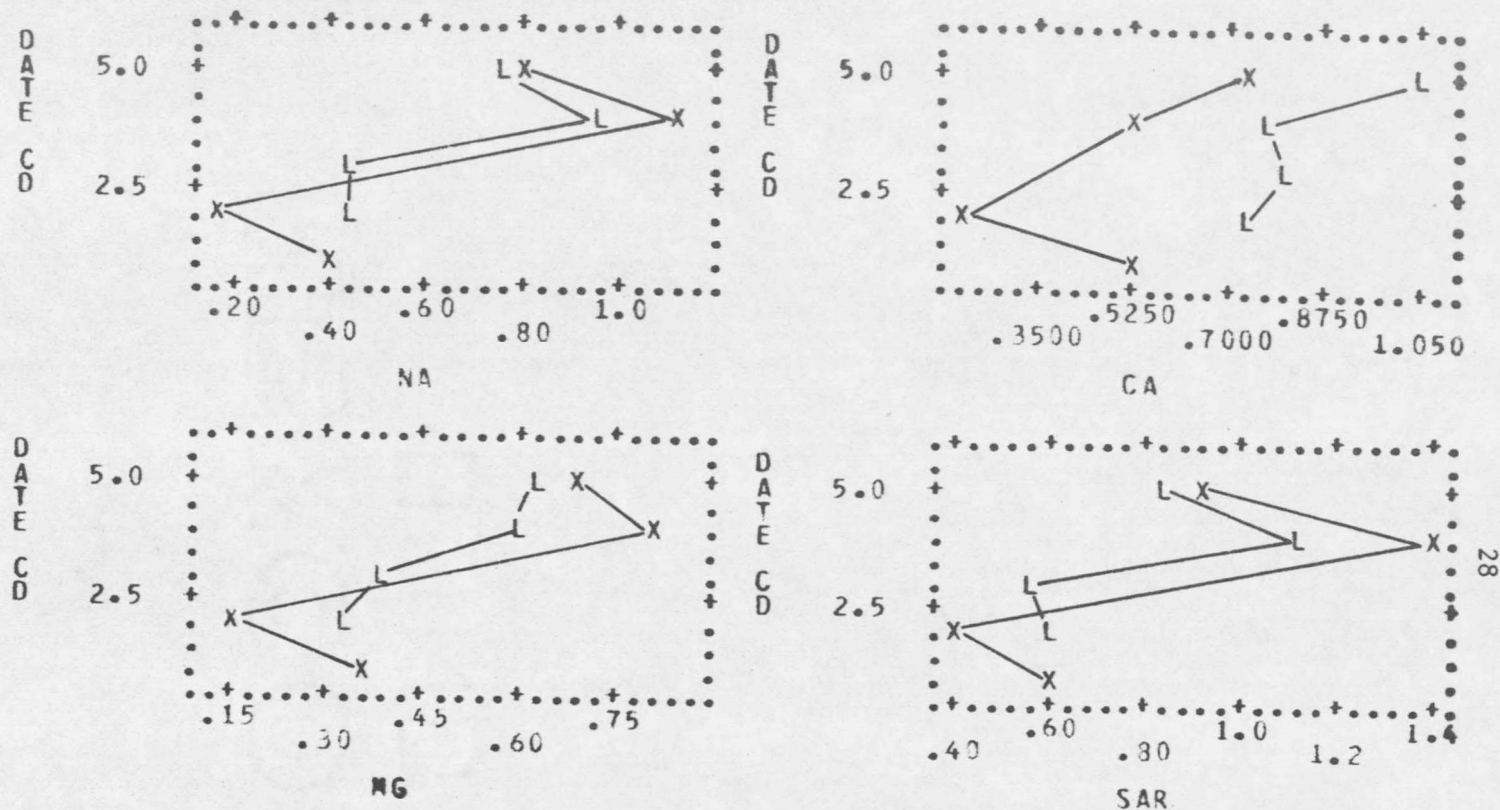


Fig. III-1. Concentrations of major cations (meq/l) and sodium adsorption ratio of canal water vs. time. The L and X data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Table III-L1; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

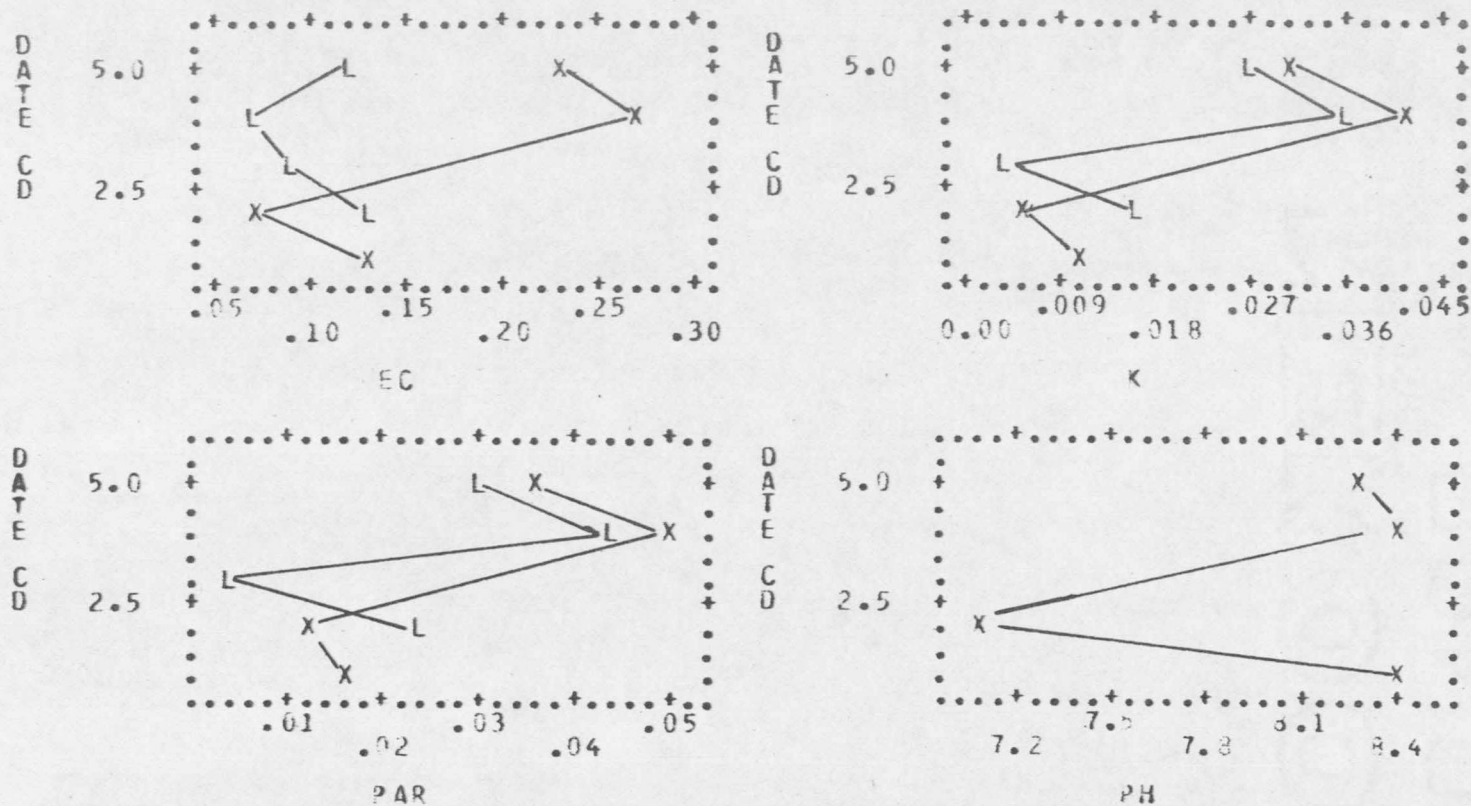


Fig. III-2. Electrical conductivity (mmhos/cm), K (meq/l), potassium adsorption ratio (PAR), and pH of canal water vs. time. The L and X data points are for 1975 and 1976 respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Table III-L1; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

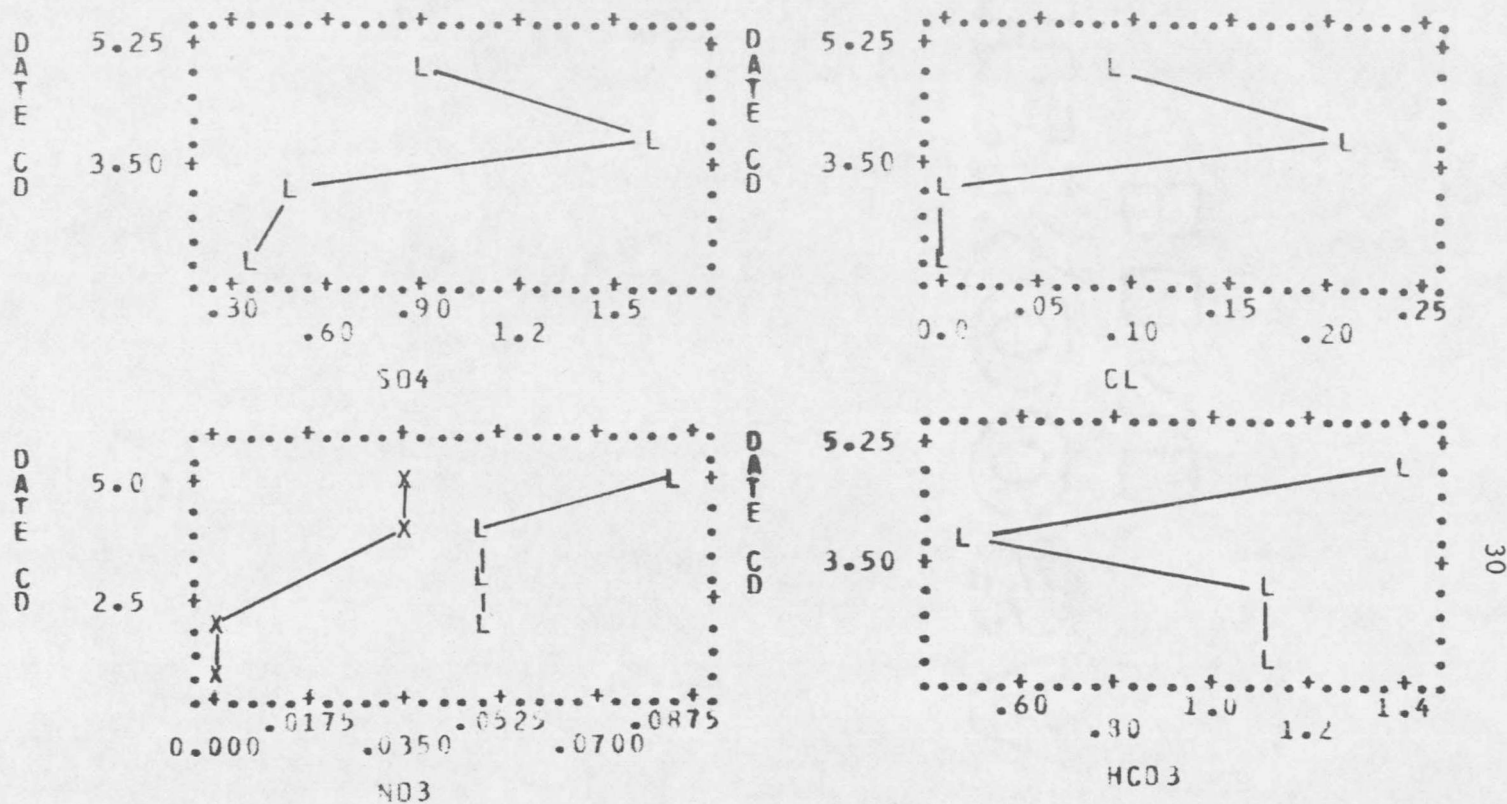


Fig. III-3. Anion concentrations of canal water (meq/l) vs. time. These data are for 1975 only. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Table III-L1; The second date of 1975 is Julian day 224, the first date of 1976 is Julian Day 207, etc.

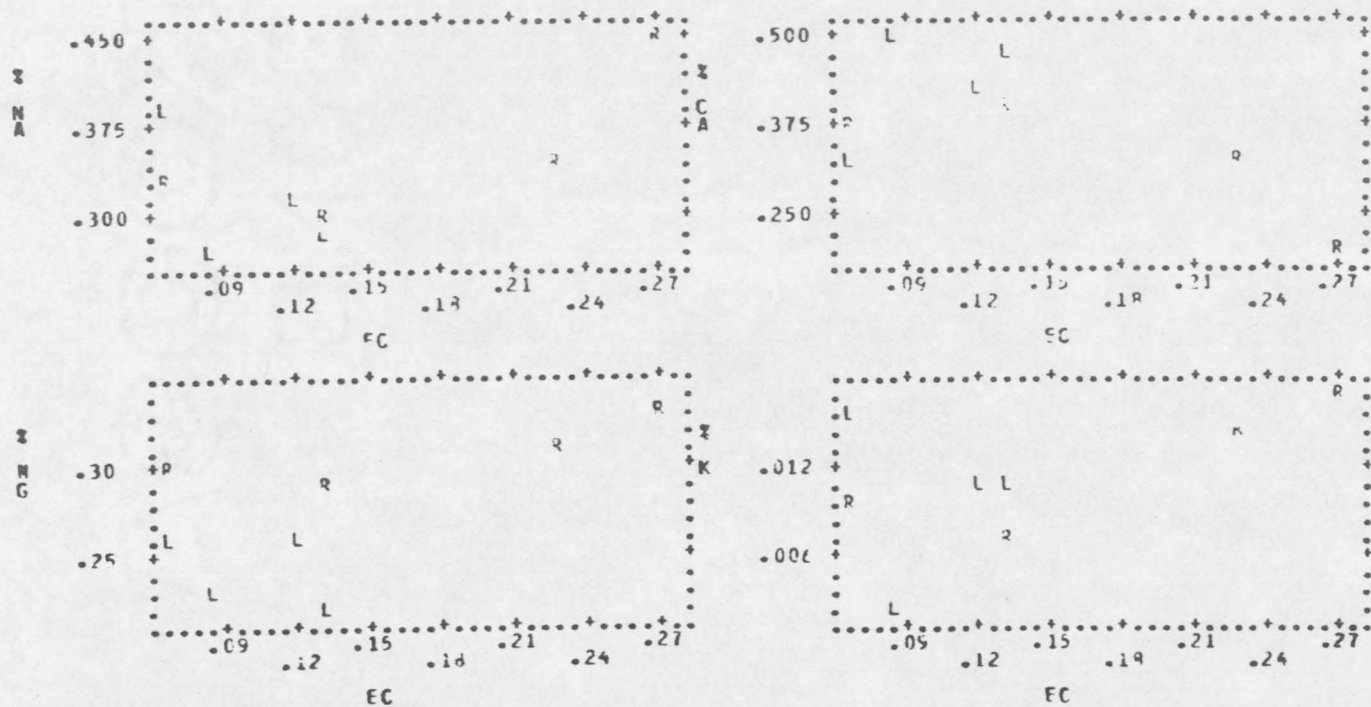


Fig. III-4. Individual cation fractions (cation/total cations) as a function of EC for groundwater and soil. Data points L and R represent 1975 and 1976 groundwater, respectively.

TABLE III-1. GREGORIAN AND JULIAN DATES OF PIEZOMETER READINGS AND SAMPLING OF GROUNDWATER DURING STUDY PERIOD. GROUND-WATER SAMPLING DATES ARE INDICATED BY *.

Date Code 1/	Gregorian Date	Julian Date
1	*7/3/75	184
2	*7/21/75	202
3	*8/11/75	223
	8/20/75	232
4	*9/1/75	244
5	*9/11/75	254
	10/31/75	304
	11/10/75	314
	11/24/75	328
1	*7/12/76	193
2	*7/26/76	207
3	*8/10/76	222
4	*8/26/76	238
5	*9/14/76	257
	10/3/76	276
	10/15/76	288
	2/23/77	54
	4/25/77	115
	5/4/77	124
	5/12/77	132

1/ Groundwater sampling dates have been numbered sequentially during each summer from 1 to 5. This is called Date Code and is the vertical axis on groundwater graphs in the individual site discussions.

TABLE III- 2. CANAL WATER CORRELATIONS WITH EC, AND MEANS AND STANDARD DEVIATIONS OF CONCENTRATIONS (meq/l) AND PERCENTAGES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.602	.631	.324	51.3
Mg	.710*	.502	.221	44.0
Ca	-.004	.670	.251	26.7
K	.604	.0213	.0145	68.1
<u>Cation Fraction</u>				
Na	.540	33.5	.0614	18.3
Mg	.614	27.4	.0371	13.5
Ca	-.620	38.0	.0942	24.8
K	.525	1.08	.00465	43.1
SAR	.625	.803	.331	41.2
EC		.137	.0738	53.9

1/ N = 8, $r_{.95} = .621$, and $r_{.99} = .789$.

TABLE III- 3. CANAL WATER CATION RATIO CORRELATIONS WITH EC, AND
MEANS AND STANDARD DEVIATIONS OF CONCENTRATIONS
(meq/l). 1/

<u>Correlation Coeff. w/EC</u>			<u>Mean</u>		
	<u>Mg</u>	<u>Ca</u>		<u>Mg</u>	<u>Ca</u>
Na	.062	.682*	Na	1.22	.986
Ca	-.572		Ca	1.45	
N = 8			<u>Std. Dev.</u>		
	<u>r_{.95}</u>	<u>= .621</u>		<u>Mg</u>	<u>Ca</u>
	<u>r_{.99}</u>	<u>= .789</u>	Na	.165	.578
			Ca	.527	

1/ The vertical numbers of the tables are numerators and the horizontal numbers are denominators. For example, the mean Na/Ca value is .986.

Carbonate Precipitation

The anion compliment of the canal water rank as follows: $\text{HCO}_3^- > \text{SO}_4 > \text{Cl}^- > \text{NO}_3^-$. Sulfate and HCO_3^- are about equal and are the most abundant anions. As the soil solution carbonates become more concentrated Mg and Ca precipitate. This results in a higher sodium percentage. The United States Salinity Laboratory included the following three equations to assess the effect of carbonate precipitation of Ca and Mg.

1. Soluble sodium percentage "found" =

$$(\text{Na} \times 100) / \text{Ca} + \text{Mg} + \text{Na}$$

substituting mean canal values yields:

$$(.63 \times 100) / .67 + .50 + .63 = 35$$

2. Soluble sodium percentage "possible" =

$$(\text{Na} \times 100) / \text{Ca} + \text{Mg} + \text{Na} - (\text{CO}_3 + \text{HCO}_3)$$

where the $\text{CO}_3 + \text{HCO}_3$ deduction does not exceed Ca + Mg.

Substituting mean canal values yields:

$$(.63 \times 100) / .67 + .50 + .63 - 1.0 = 81$$

3. Residual Na_2CO_3 =

$$\text{CO}_3 + \text{HCO}_3 - \text{Ca} + \text{Mg}$$

substituting mean canal values yields:

$$1.0 - (.67 + .50) = 0.$$

The soluble sodium percentage of the mean canal cation concentrations is 35 whereas after precipitated carbonates there is a possible percentage of 81. This is about that of the groundwater in some of the sites with elevated sodium percentages (Fig. III-22, p. 257).

Individual Site Discussion

Introduction

The discussion of individual sites is divided into three sections: (1) site description, (2) soil-groundwater relationships, and (3) site summary. The location of individual sites is shown in Figure I-3.

The sites have been assigned one of the four following productivity ratings from high to low: (1) excellent, (2) good, (3) fair, (4) poor. The productivity evaluation was made by visually assessing the relative crop growth at each site. The site location, productivity rating, and unusual features observed at the site are included in the "site description" section.

The "soil-groundwater relationships" section is divided into three subsections. These are presented in the following order within the prose of this section: (1) profile horizonation and soil chemical properties, (2) piezometer data, and (3) groundwater-chemical properties.

At the end of each site discussion a summary is presented for that individual site. The sites are discussed by transects as they occur from west to east and from south to north within transects. They have been assigned identification letters from A to K (Fig. I-3).

To aid in the interpretation of soil and groundwater data nine figures and three tables are included with each site discussion. The

textural horization of individual samples of the composite at each site is diagrammatically represented in the first figure. The next three figures show the distribution with depth of the measured soil constituents. The piezometric head at various depths over time is shown in the next figure.

The depth of piezometers was dictated by how deep the gravel was at each site. A series of from 3 to 5 piezometers which were distributed through the saturated zone above the gravel layer were installed as close to the groundwater access tube as possible.

The next three figures show the change in concentration of groundwater chemistry over time. Groundwater samples and piezometer readings were taken concurrently at about 2-week intervals throughout the summer. The last figure shows the cation fraction vs. EC for groundwater and soil data. Cation percentage and cation fraction are used synonymously throughout the discussion. The cation fraction equals the cation in question over the sum of cations.

Following the site figures are three tables. The first two show site summary statistics for the following groundwater and soil (of the saturated extract) chemical properties: Na, Mg, Ca, K, SAR, and EC. The cation concentrations are evaluated as absolute values and as a fraction of the total cation concentration. Correlation coefficients of cations and cation fractions with EC are given. This is provided to show the relationship between changes in individual cation concen-

trations and cation fractions with changes in EC. If an individual cation is chiefly responsible for changes in soil or groundwater EC it will have a significant positive correlation. The means and standard deviations are also given. The coefficient of variation is used to evaluate the variability of the measured variables within the soil profile or over time in the case of groundwater values.

Site A

Site Description

This site is located on the Southern Montana Agricultural Experiment Station in Field 0 several hundred yards from the main irrigation canal (Fig. I-3). The productivity is estimated as being good. Small grain was grown both years of the study. This field was irrigated only once the second year.

Soil-Groundwater Relationships

The texture of the soil profile at Site A is predominately silty clay loam with interstratified lenses of coarser material (Fig. III-A1). Figures III-A2, A3, and A4 show the value of the measured variables in a saturated extract from a composite by depth increment of the four profiles taken at the site. The sand-sandy loam lens at about 0.9 m had a major influence on most of the measured variables, especially EC, saturated water content, pH, and $\text{NO}_3\text{-N}$. Soluble Ca generally decreased with depth, with a minimum below the sandy lens. Magnesium changed little with depth except for a strong maximum at 1.2 m just below the sandy zone. Sodium and SAR increased significantly with depth and were not affected by the sandy zone. The solubilities of the cations are generally $\text{Na} > \text{Mg} > \text{Ca}$. Thus, under the normal leaching process, the distribution of the cations in the soil is as

would be expected; however, the sandy lens may have, in some way, affected both Ca and Mg distribution. The sandy lens would be expected to modify the unsaturated water flow process of the site. The potassium distribution in the profile seems to be consistent with its mobility in a soil system (Fig. III-A4). Ammonium acetate extractable K, potassium adsorption ratio (PAR), and water soluble K have about the same shape with a maximum at the surface.

Soil groundwater levels in both the water access tube and the piezometer tubes are shown in Figure III-A5. The water level in the access tube reached a maximum height of about 1 m below the ground surface. In general, groundwater levels and piezometric heads increased when water was in the main canal. Since this site was only irrigated once during 1976, it appears that the groundwater level at this site is influenced by canal leakage. The rapid response of the 5 m piezometer after emptying of the canal indicates high hydraulic association between the site and the canal. However, the significant rise of piezometer heads in the 3.6 and 5 m tubes and the general fall in the 2.3 m tube indicates that some external water source, other than canal leakage, influenced the lower depths.

On each date that the groundwater height was read in the access tube and the piezometers, a sample of water was removed from the access tube and analyzed for various constituents. These data are shown in Figures III-A6, A7, and A8. The dates correspond to the

dates of Figure III-A5; that is, date one 1976 was sampled on Julian date 194. In 1976 the samples were not analyzed for HCO_3 , Cl , and SO_4 .

The water constituents measured varied greatly, both at dates within years and between years. The between-year variations in the more soluble constituents (Mg , Na , NO_3) are especially striking; they tend to be mirror images between years at specific dates. This may be associated with the fact that the site received less irrigation due to above normal precipitation in 1976. The concentration of the less soluble constituents (Ca and K) varied considerable between years but had the same general shape as a function of date. We can explain neither the difference between dates nor years.

Sodium and Mg are the major cations of the groundwater, making up 72.7% and 18.5%, respectively, and largely control the EC and SAR. The pH curve is similar in shape to Na and SAR suggesting interdependence. The Na in the soil is similar in magnitude to that in the groundwater at the lower depths. The calcium concentration is generally much higher in the soil than in the groundwater. Groundwater Mg concentrations are twice that of the lower soil profile.

The major anion of the groundwater is SO_4 with about half as much HCO_3 and small amounts of Cl and NO_3 . The relative amounts of anions are about constant over time as indicated by the similar shape of the curves.

The percentage of the cations in the groundwater and saturated extracts (henceforth referred to as the soil) as a function of the EC of the sample is shown in Figure III-A9. The percentage of Na and Mg in the groundwater was less than the soil in 1975 and higher than the soil in 1976. This difference may be associated with the difference in irrigation.

Summary statistics of these data are presented in Tables III-A1 and A2. The EC of the groundwater is largely a function of Na. This is indicated by a significant positive correlation of Na concentration and EC. The variability of the major cations are about equal, indicated by similar coefficients of variation (CV).

The ratio of specific cations can be used to evaluate their relative concentrations. Cation ratios are dependent on soil and aquifer chemistry. Summary statistics for cation ratios are shown in Table III-A3. There is more than twice as much Mg as Ca in the groundwater (Ca/Mg ratio = .451). This can be contrasted with a Ca/Mg ratio of 3.28 in the soil. This ratio is much less variable in the soil than in the groundwater indicated by the size of the standard deviation relative to the mean.

Summary

It seems that the lower part of the soil profile is being influenced by the elevated levels of Na and Mg in the groundwater.

The EC of the groundwater is mainly a function of Na and to a lesser degree Mg. The salt of the groundwater is generally slightly higher than the soil profile. It appears that the upper meter is being leached of the more mobile cations (Na and Mg) while the next meter seems to be leached of Na but an accumulation of Mg is found below the sand layer and above the seasonal high water depth. Na and Mg concentrations in the groundwater graph appear as mirror images for the two years of the study. The changes of Ca and K in the groundwater produced the same shape curve both summers and although the salt increased the second year, the levels of these cations decreased.

Potassium is concentrated at the surface and water soluble K is correlated with ammonium acetate extractable K. The major anion present is SO_4 with lesser amounts of HCO_3 , Cl, and NO_3 .

SITE A

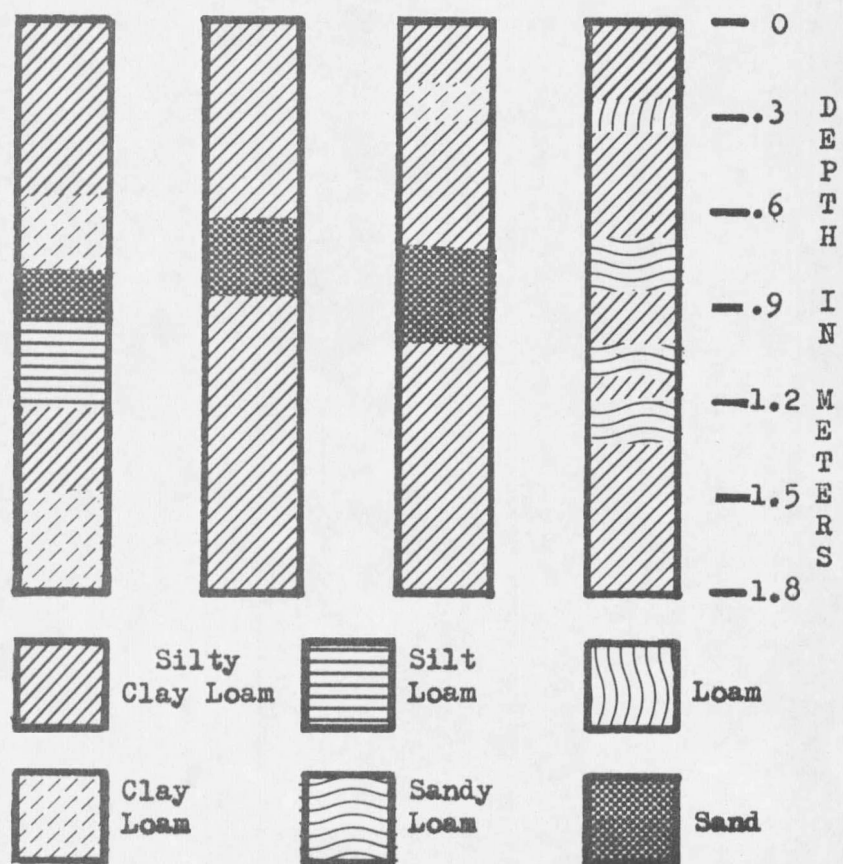


Fig. III-A1. Horizationation of soil profile at four sampling sites adjacent to groundwater access tube.

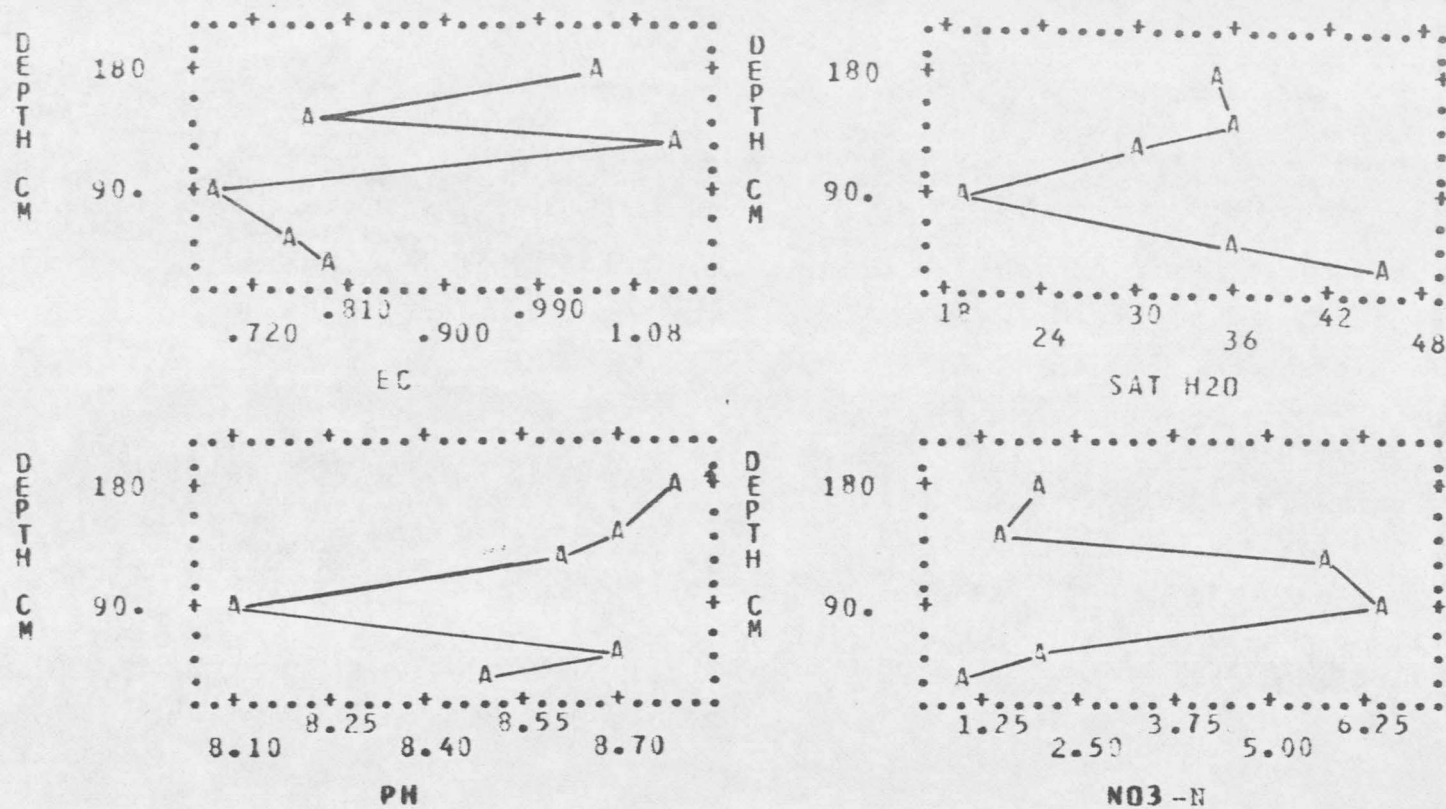


Fig. III-A2. Distribution of electrical conductivity (mmhos/cm), NO₃-N (ppm), pH, and saturated water percentage of the soil with depth. The pH and EC are of the saturated paste extract.

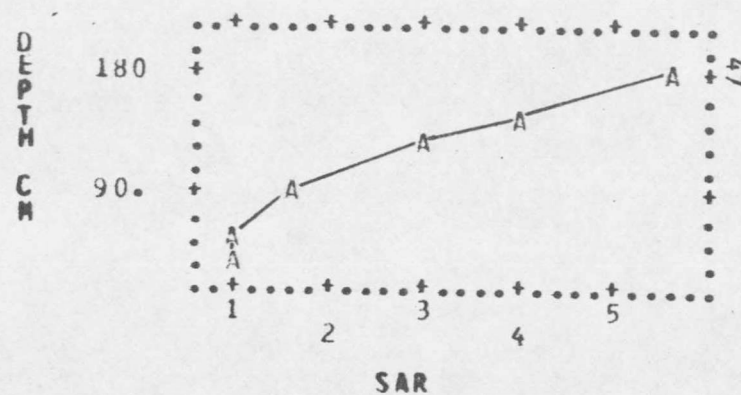
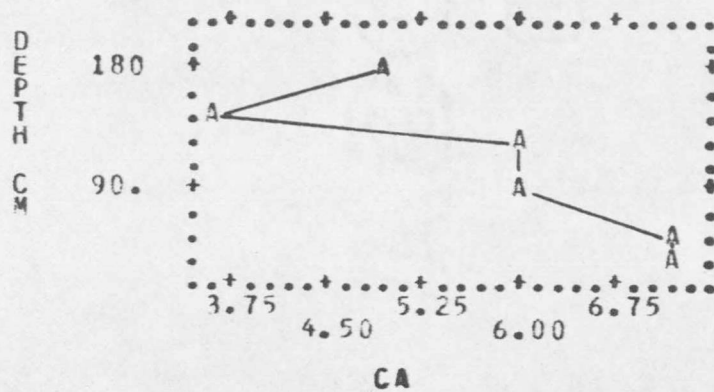
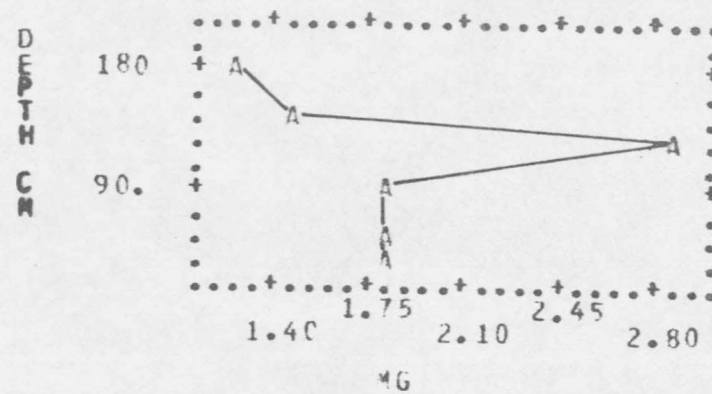
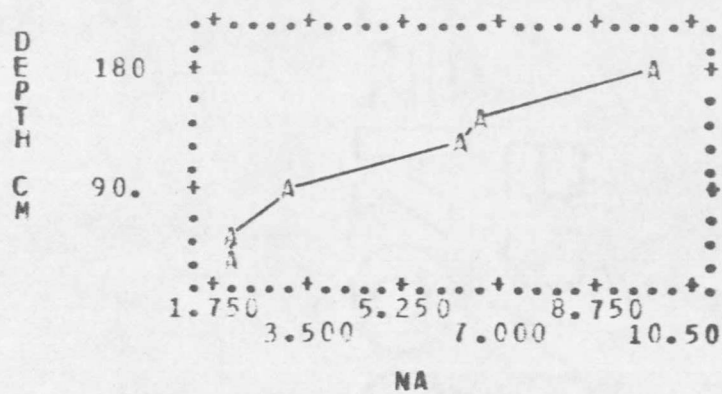


Fig. III-A3. Distribution of major cations (meq/l) of saturated extract and sodium adsorption ratio (SAR) with soil depth.

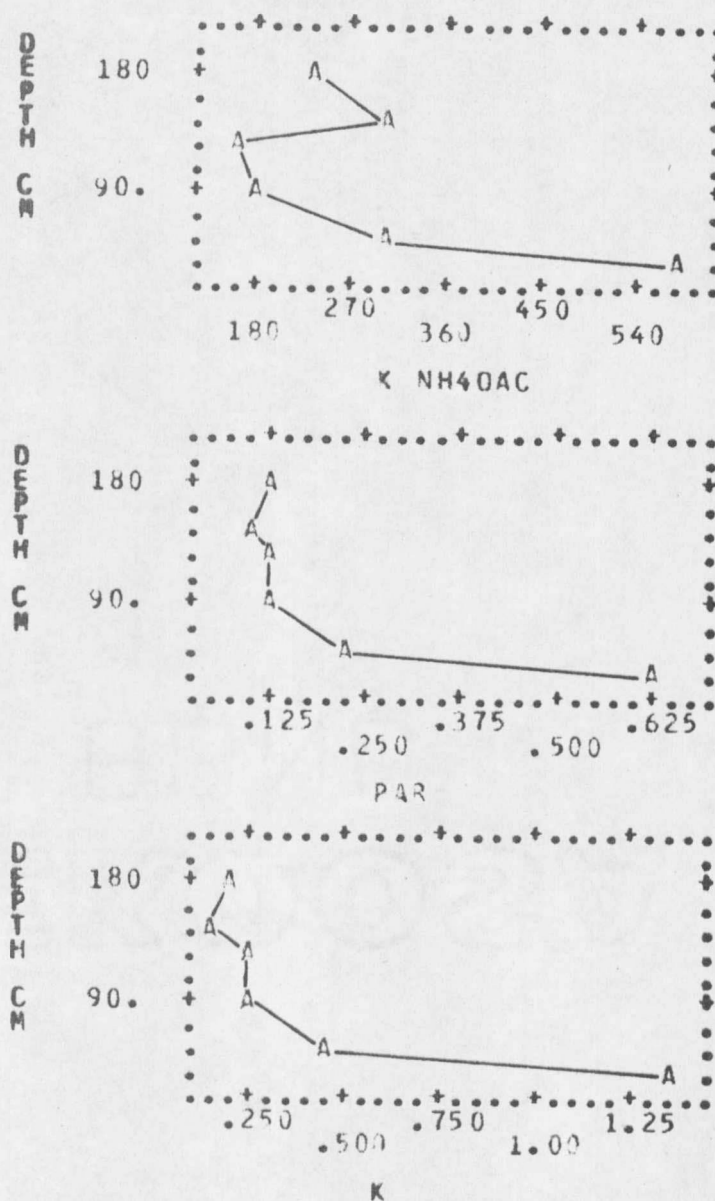


Fig. III-A4. Distribution of water soluble K (meq/l), ammonium acetate extractable K (ppm), and the potassium adsorption ratio with depth.

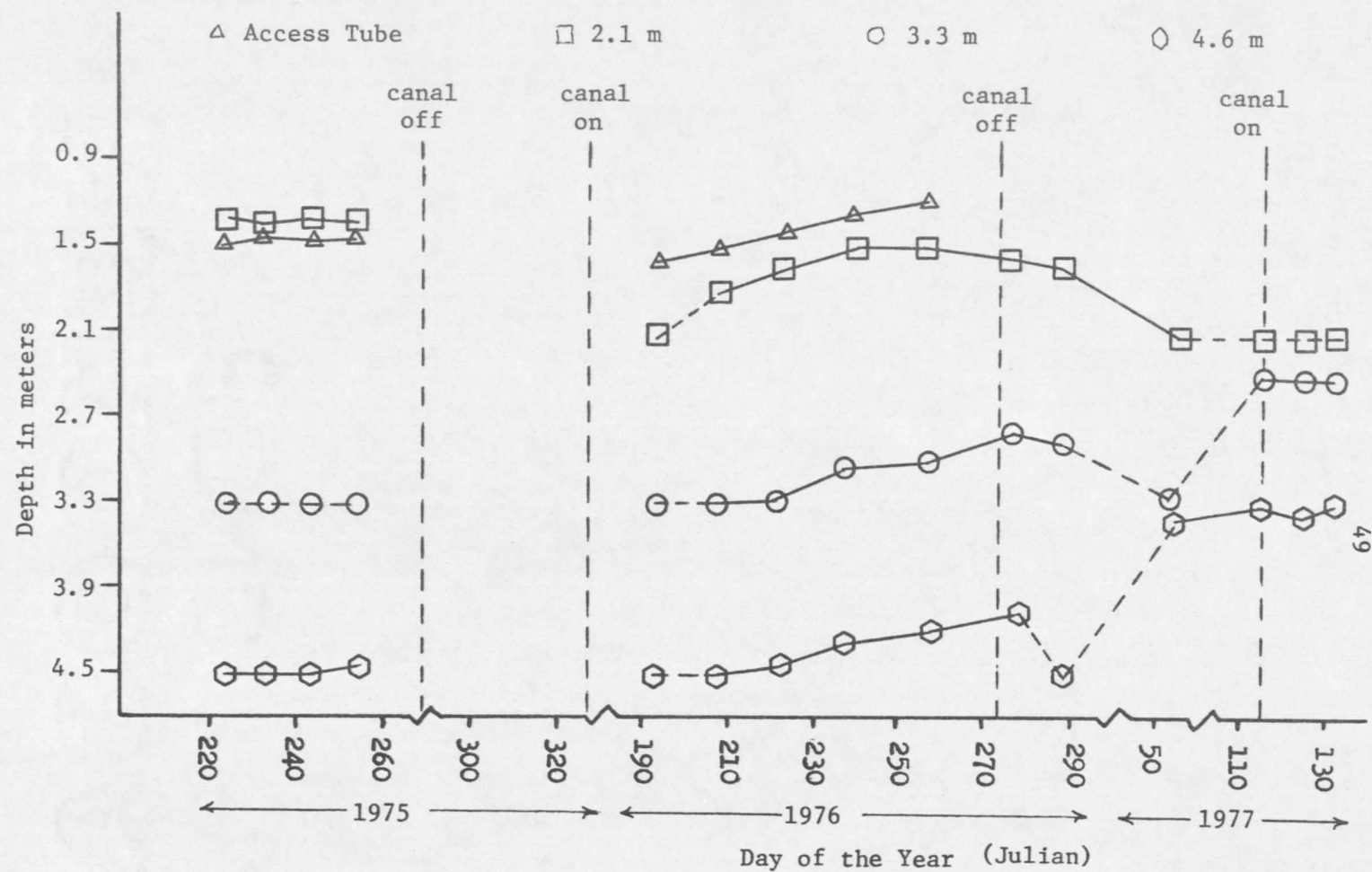


Figure III-A5. Changes in piezometric head with time. Data points connected by dashed lines represent unsaturated conditions at the depth sampled by the piezometer. Data are missing where there is no line.

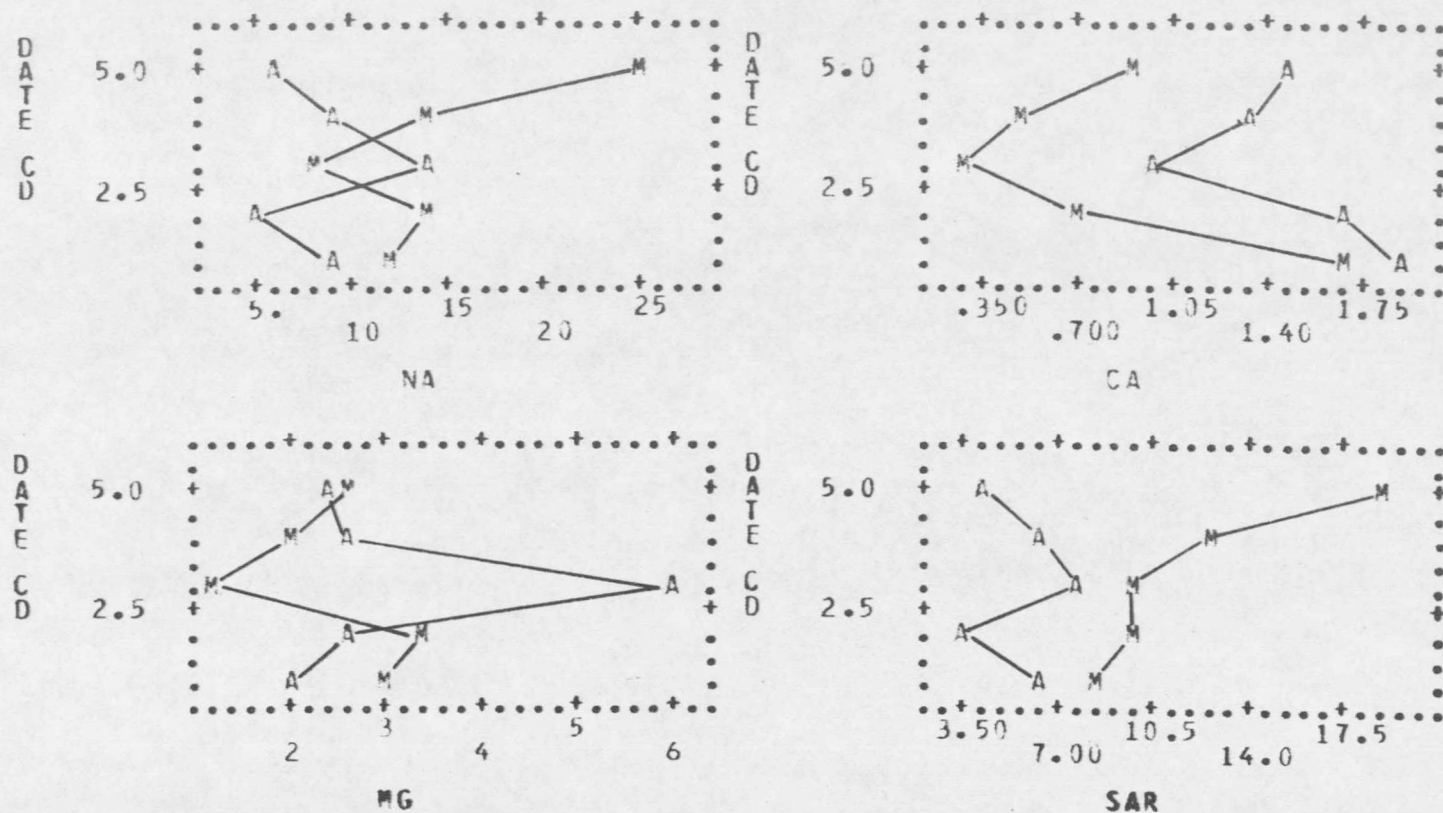


Fig. III-A6. Concentrations of major cations (meq/l) and sodium adsorption ratio of ground-water vs. time. The A and M data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-A5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

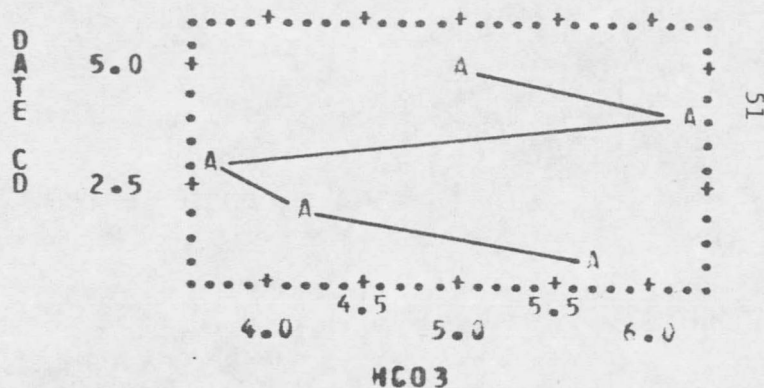
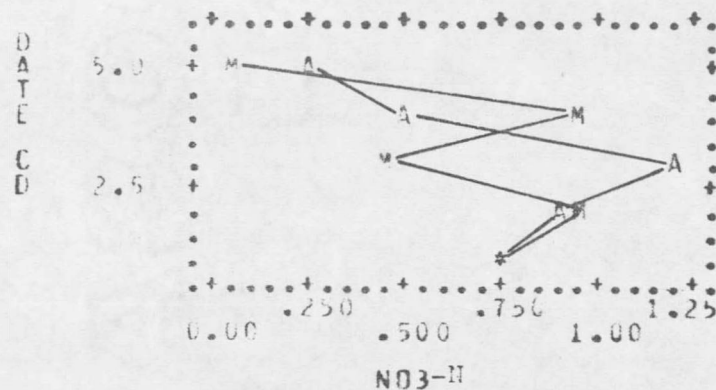
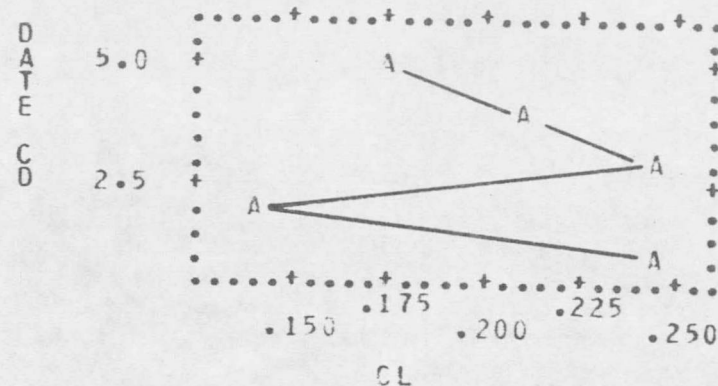
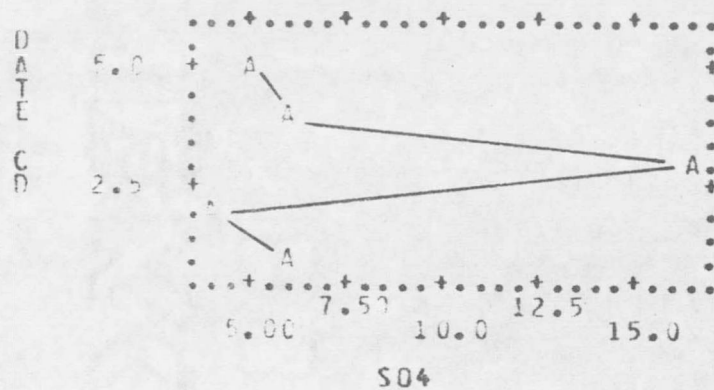


Fig. III-A7. Anion concentrations of groundwater (meq/l) vs. time. These data are for 1975 only. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-A5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

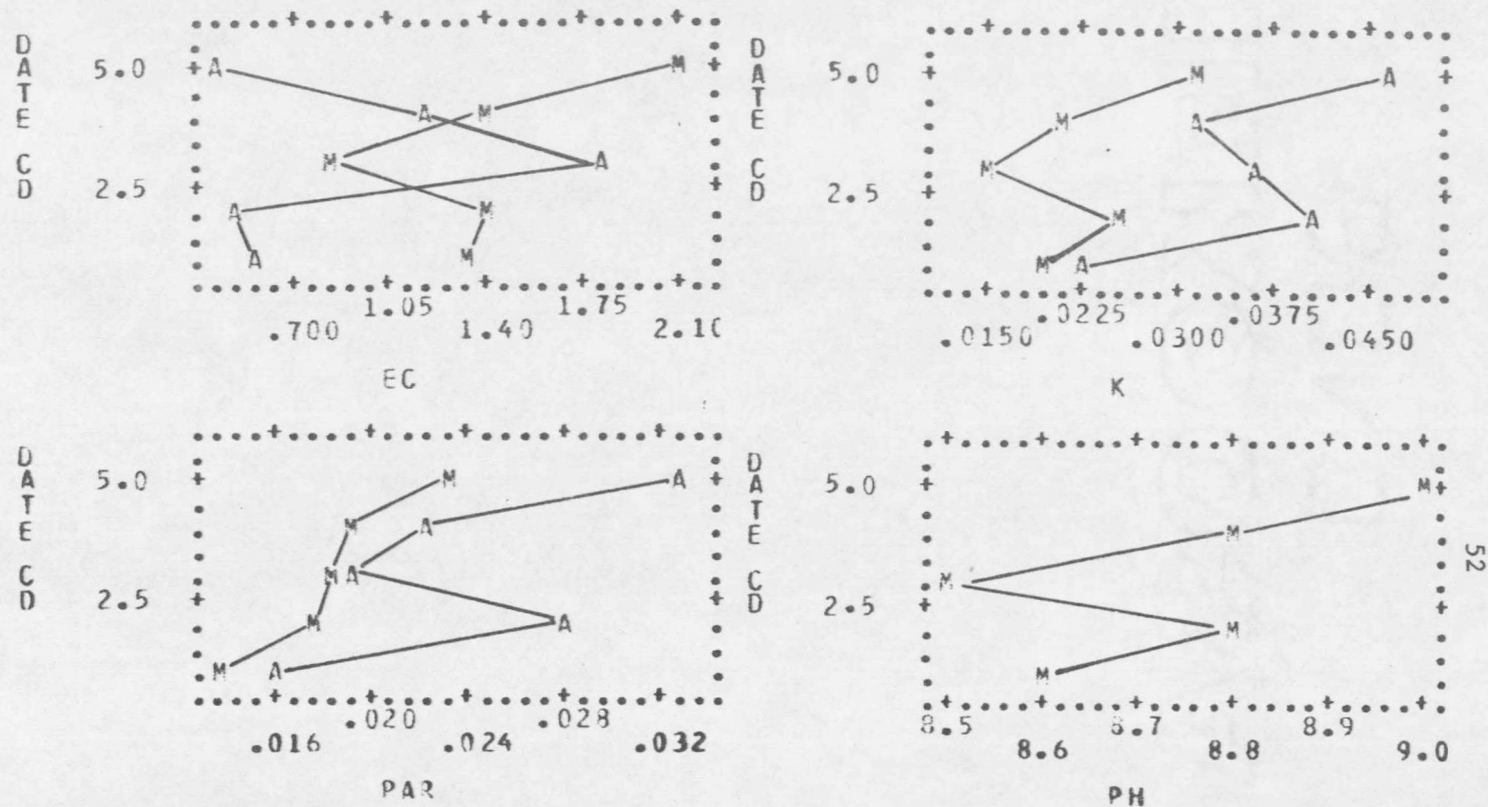


Fig. III-A8. Electrical conductivity (mmhos/cm), K (meq/l), potassium adsorption ratio (PAR), and pH of groundwater vs. time. The A and M data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-A5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

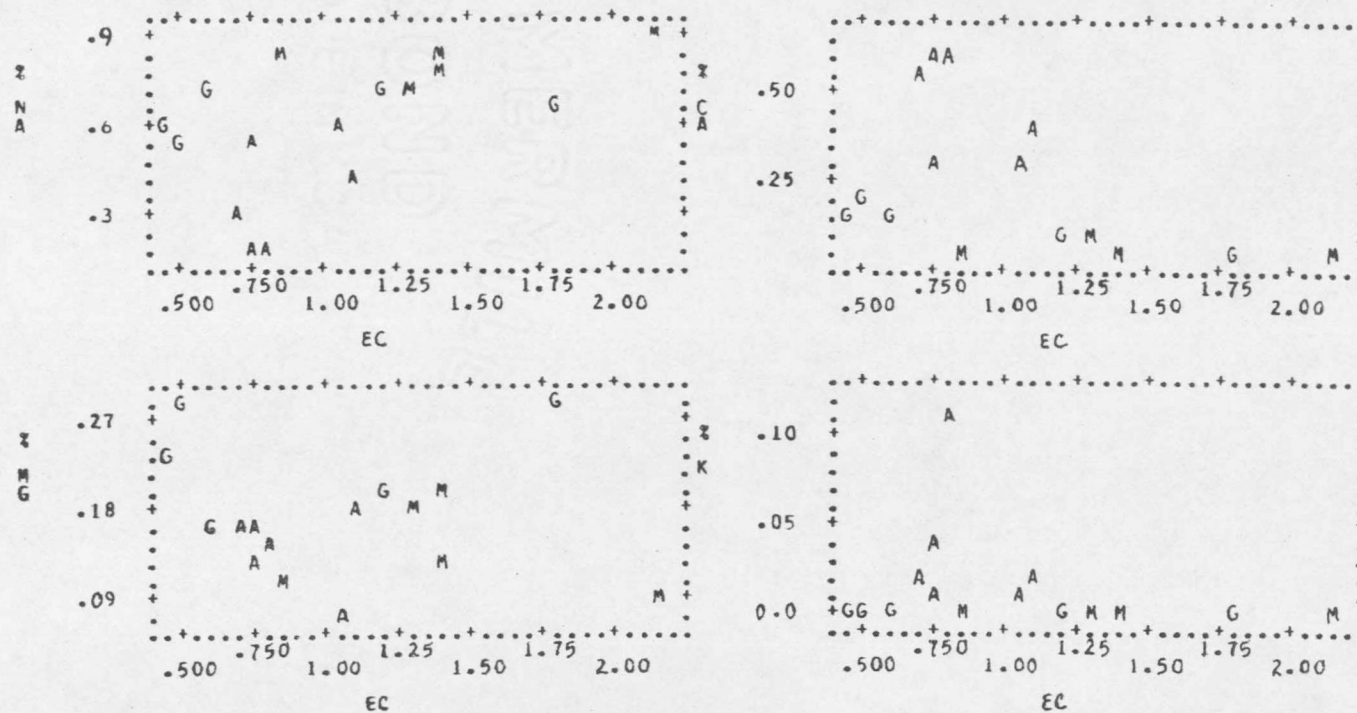


Fig. III-A9. Individual cation fractions (cation/total cations) as a function of EC for groundwater and soil. Data points A, G, and M represent soil, groundwater 1975 and groundwater 1976, respectively.

TABLE III-A1. SUMMARY STATISTICS OF SOIL VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.714	4.98	3.11	62.4
Mg	.362	1.85	.564	30.5
Ca	-.185	5.83	1.40	24.0
K	-.261	.443	.447	101.0
<u>Cation Fraction</u>				
Na	.540	.365	.189	51.8
Mg	-.157	.143	.0394	27.6
Ca	-.597	.457	.140	30.6
K	-.333	.0351	.0360	103.0
SAR	.605	2.70	1.90	70.4
EC		.860	.179	20.8

1/ All values for cations are expressed in meq/l of the saturated extract. Percentages are calculate as follows: cation (x)/Na + Mg + Ca + K. N = 6, $r_{.95} = .729$, and $r_{.99} = .782$.

TABLE III-A2. SUMMARY STATISTICS OF GROUNDWATER VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.914**	11.7	5.84	49.9
Mg	.496	2.78	1.32	47.4
Ca	-.461	1.14	.552	48.4
K	-.181	.0289	.00994	34.4
<u>Cation Fraction</u>				
Na	.599*	72.7	11.2	15.4
Mg	-.318	18.5	6.68	36.1
Ca	-.766**	8.59	5.87	68.3
K	-.705*	.213	.130	61.0
SAR	.781**	8.73	4.52	51.8
EC		1.16	.565	48.7

1/ All values are expressed in meq/l. Percentages are calculated as follows: cation (x)/Mg + Na + K + Ca. N = 10, $r_{.95} = .549$, and $r_{.99} = .715$.

TABLE III-A3. SUMMARY STATISTICS OF CATION RATIOS. 1/

GROUNDWATER

Correlation Coeff. w/EC

	Mg	Ca
Na	.490	.618*
Ca	-.688*	

N = 10

 $r_{.95} = .549$ $r_{.99} = .715$ Means

	Mg	Ca
Na	4.69	14.5
Ca	.451	

Std. Dev.

	Mg	Ca
Na	2.51	10.9
Ca	.245	

SOIL

Correlation Coeff. w/EC

	Mg	Ca
Na	.487	.514
Ca	-.306	

N = 6

 $r_{.95} = .729$ $r_{.99} = .882$ Means

	Mg	Ca
Na	3.11	.990
Ca	3.28	

Std. Dev.

	Mg	Ca
Na	2.74	.766
Ca	.810	

1/ The vertical numbers of the tables are numerators and the horizontal numbers are denominators. For example, the mean Na/Ca value is 14.5.

Site B

Site Description

Site B is located on the west end of the study area about halfway between the Yellowstone River and the main canal (Fig. I-3). This field is in pasture and has a fair level of productivity. Strong angular blocky structure was found in the surface .6 m. Soil structure was unique to this site and Site F.

Soil-Groundwater Relationships

The soil texture is silty clay loam for about the first meter (Fig. III-B1). Gravel or loamy sand exists at 1.2 m. Figures III-B2, B3, and B4 show the value of the measured variables in a saturated extract from a composite by depth increment of the four profiles taken at the site. The EC (Fig. III-B2) is approximately 1.2 to the gravel-sand lens and then drops to about .75. The EC relative to the study area mean is below average. The range in pH of the soil profile is narrow. There is a small amount of $\text{NO}_3\text{-N}$ evenly distributed through the profile.

The concentrations of Ca, Mg, and Na with soil depth are shown in Figure III-B3. The concentrations of Ca and Mg are relatively high near the surface and decrease with depth to a low in the sand-gravel layer. The Ca and Mg have the same pattern of distribution in the profile with a maximum at about .6 m and .9 m, respectively. They both

then decrease until sandy textures are reached at 1.5 m where both seem to stabilize. The Na increases with depth to a maximum at about 1.5 m where it stabilizes. This distribution of Na, Ca, and Mg results in an SAR of about 2 at the surface that increases to about 4 at 1.2 m. The K distribution (Fig. III-B4) is similar to that of most sites with the maximum at the surface and decreasing with depth. The cation peaks occur with depth in the order K, Ca, Mg, Na.

The piezometer data are shown in Figure III-B5. The superimposition of all piezometer and access tube measurements suggest little vertical movement of groundwater. Changes in piezometric head at different depths between observations are realized throughout the entire aquifer resulting in equal piezometric head. There appears to be hydraulic association with the canal or irrigation. The water table reaches a peak in mid-summer at about 1 m below the surface, but for the most part is about 1.5 m below the soil surface.

Groundwater concentrations are shown in Figures B6, B7, and B8. The Na and Mg concentrations of the groundwater are about equal. The Ca levels are comparable although slightly less. The Na in the groundwater is about one-third the concentration of that in the saturation extract from the soil profile just above it. The Mg concentration in the groundwater is slightly more than the profile immediately above in the spring but equal to or less in the late summer (the soil samples were taken in the spring). The Mg and Ca concentrations are about

two-thirds of that in the profile directly above the water table (Figs. III-B3 and B6). Sodium, magnesium, calcium, and SAR of the groundwater all have the same gross shape with time over the two summers. The increase in SAR about mid-summer is probably due to a rise in the water table allowing Na of the lower profile to enter the groundwater. The anions at this site rank as follows: $\text{SO}_4 > \text{HCO}_3 > \text{Cl} > \text{NO}_3$.

The individual cation percentages of the groundwater and saturated extracts as a function of the EC of the sample is shown in Figure III-B9. The groundwater has a smaller percentage of Na, Ca, and K than the soil profile. The soil has about twice the total salts as the groundwater. Mg makes up a higher percentage of cations in the groundwater than in the soil.

Summary statistics of groundwater and soil data are shown in Tables III-B1 and B2. There is a significant positive correlation of EC with Na in the groundwater. Profile means reveal that $\text{Na} > \text{Ca} > \text{Mg}$ whereas the ranking is $\text{Mg} > \text{Na} > \text{Ca}$ in the groundwater. The variation of Na, Mg, and Ca over time in the groundwater is about equal. The groundwater fractions of Na and Mg have about the same CV but Ca has about twice as much variability. The CV for K is about threefold higher than the other cations.

Cation ratios are summarized in Table III-B3. The Ca/Mg ratio in the soil is about twice that of the groundwater (.884 vs. 1.87). The Na/Ca ratio is only slightly higher in the soil than groundwater

whereas the Na/Mg ratio is three times as much in the soil as in the groundwater. This is because of the disproportionate increase of Na in the soil. This also accounts for an SAR in the soil that is twice that in the groundwater.

Summary

The textures of this site are silty clay loam over gravel or loamy sand. The piezometric head at the various depths measured were similar. The mean soil concentrations of major cations within the saturated extract are $\text{Na} > \text{Mg} > \text{Ca}$. The peak concentrations occur with depth in the reverse order. The K is most abundant at the surface. The Na concentration in the groundwater is about one-third that of the soil profile just above the water table; Mg and Ca concentrations are about two-thirds that of the soil. The major cation concentrations are ranked $\text{Mg} > \text{Na} > \text{Ca}$. They all have similar shape curves with time in both summers. The dominant anion is SO_4 . Changes in groundwater EC are associated with changes in Na concentrations.

SITE B

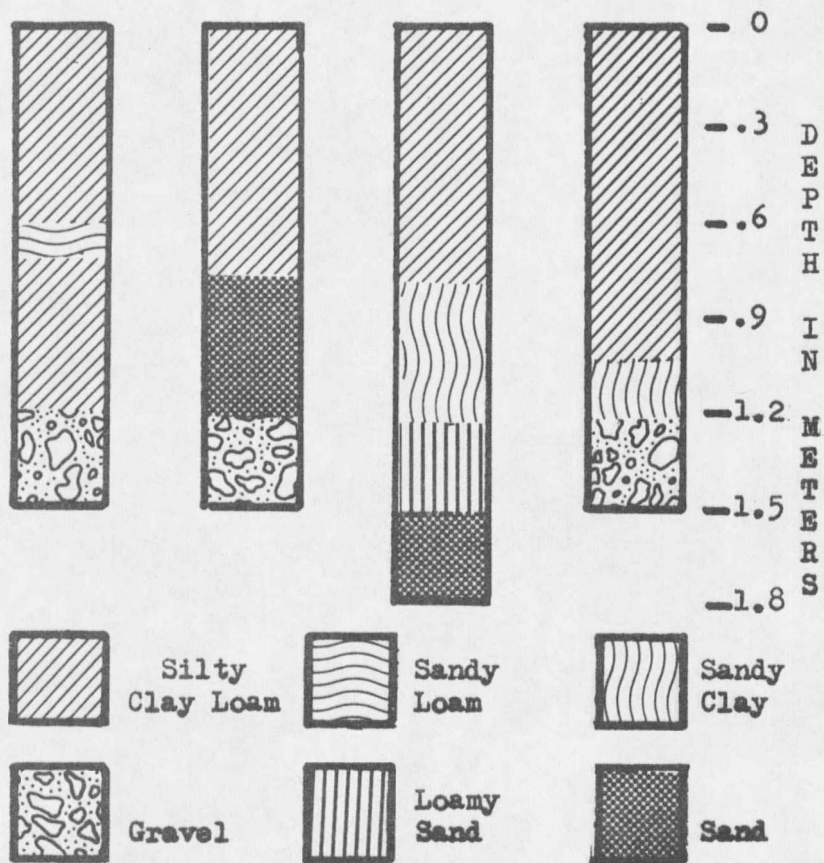


Fig. III-B1. Horizationation of soil profile at four sampling sites adjacent to groundwater access tube.

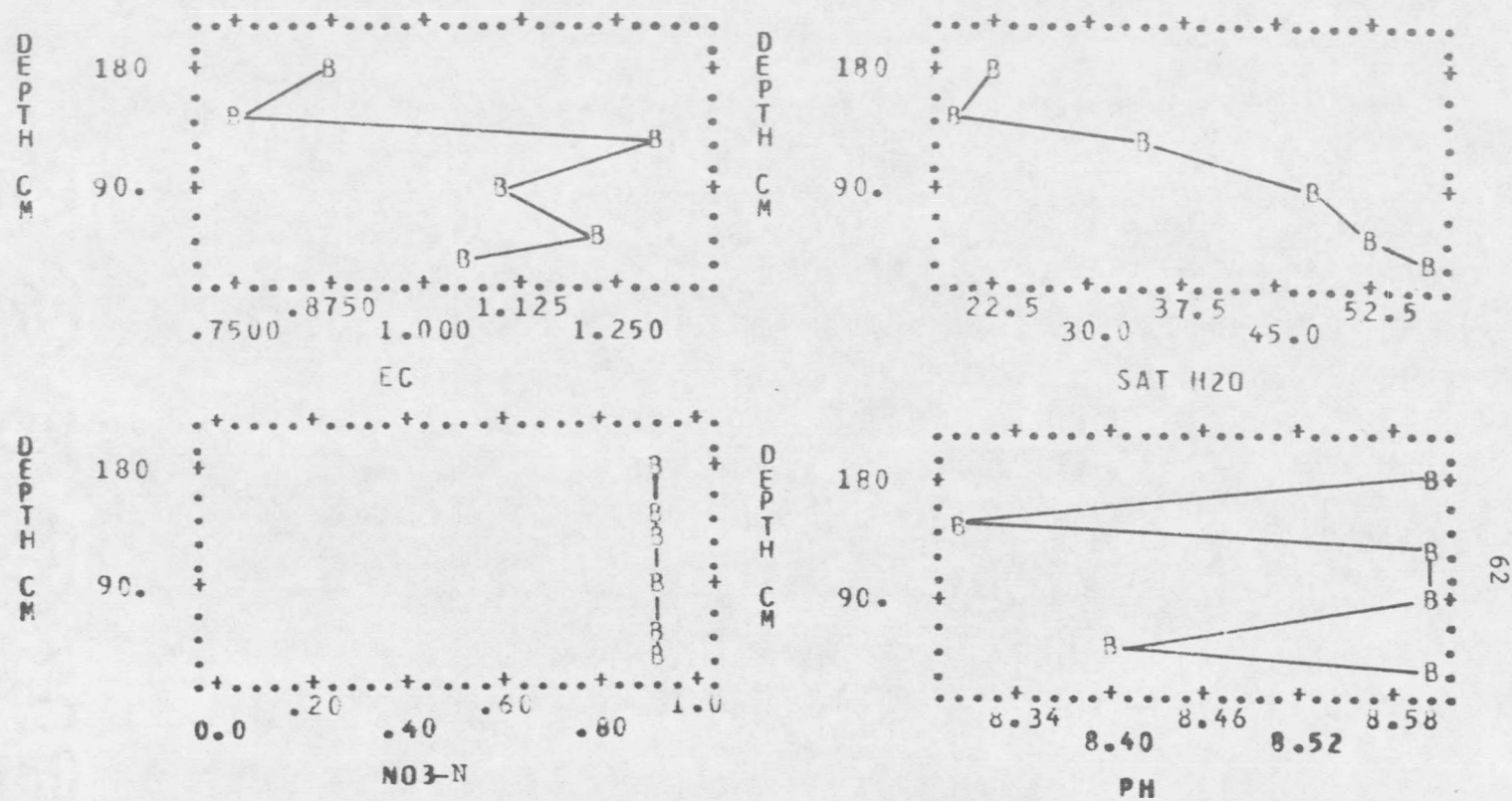


Fig. III-B2. Distribution of electrical conductivity (mmhos/cm), NO₃-N (ppm), pH, and saturated water percent of the soil with depth. The pH and EC are of the saturated extract.

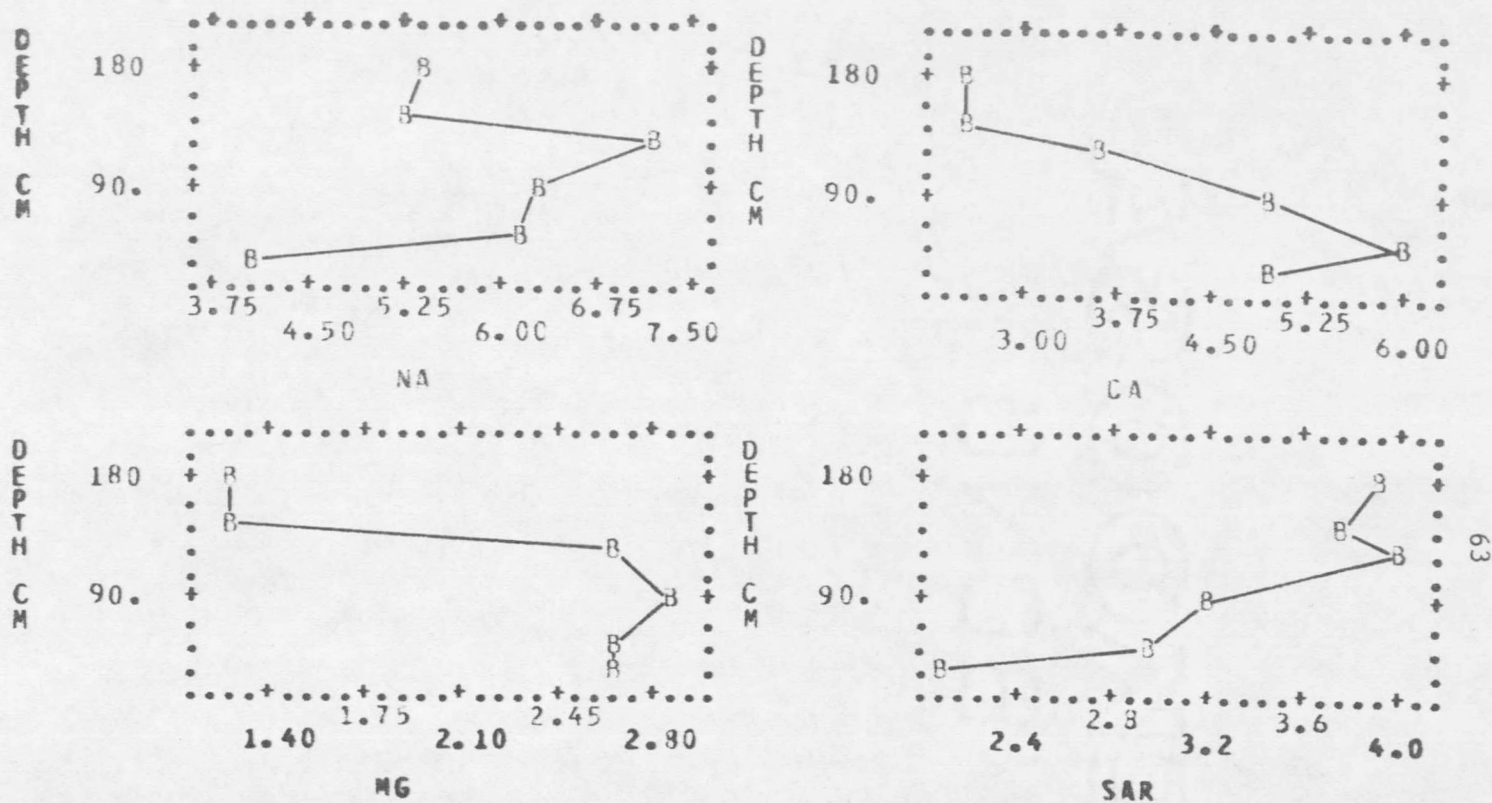


Fig. III-B 3. Distribution of major cations (meq/l) of saturated extract and sodium adsorption ratio (SAR) with soil depth.

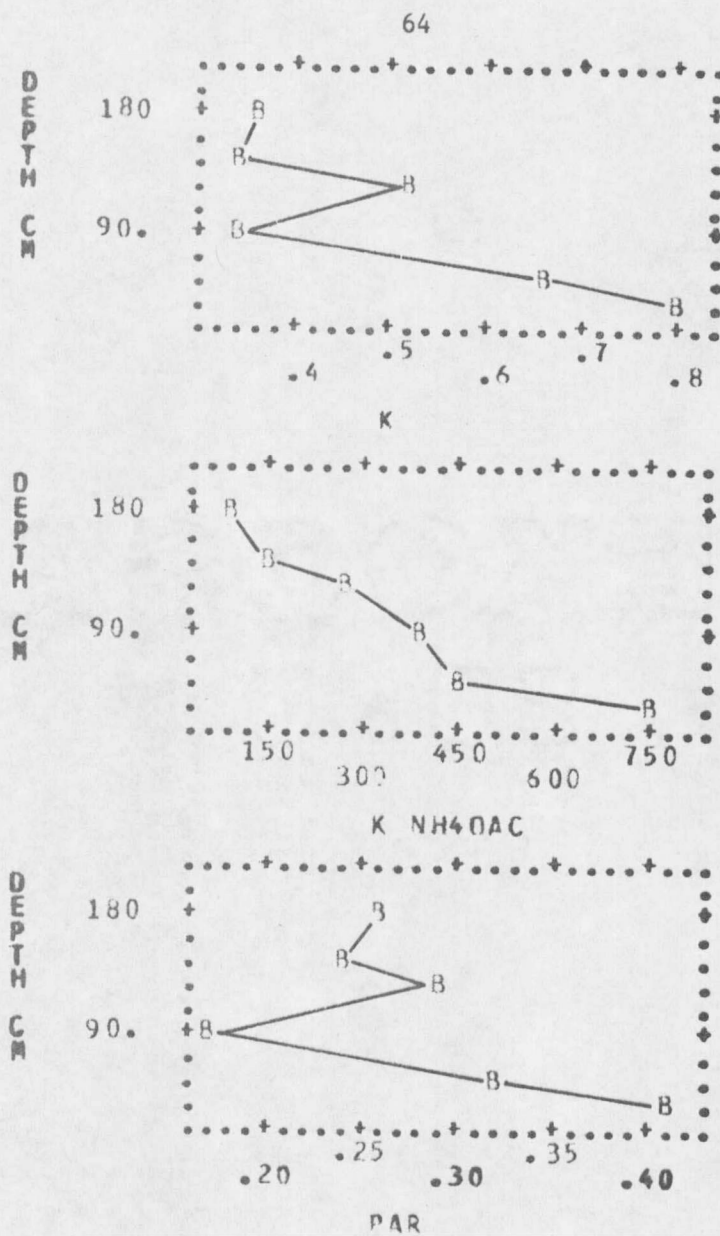


Fig. III-B4. Distribution of water soluble K (meq/l), ammonium acetate extractable K (ppm), and the potassium adsorption ratio with depth.

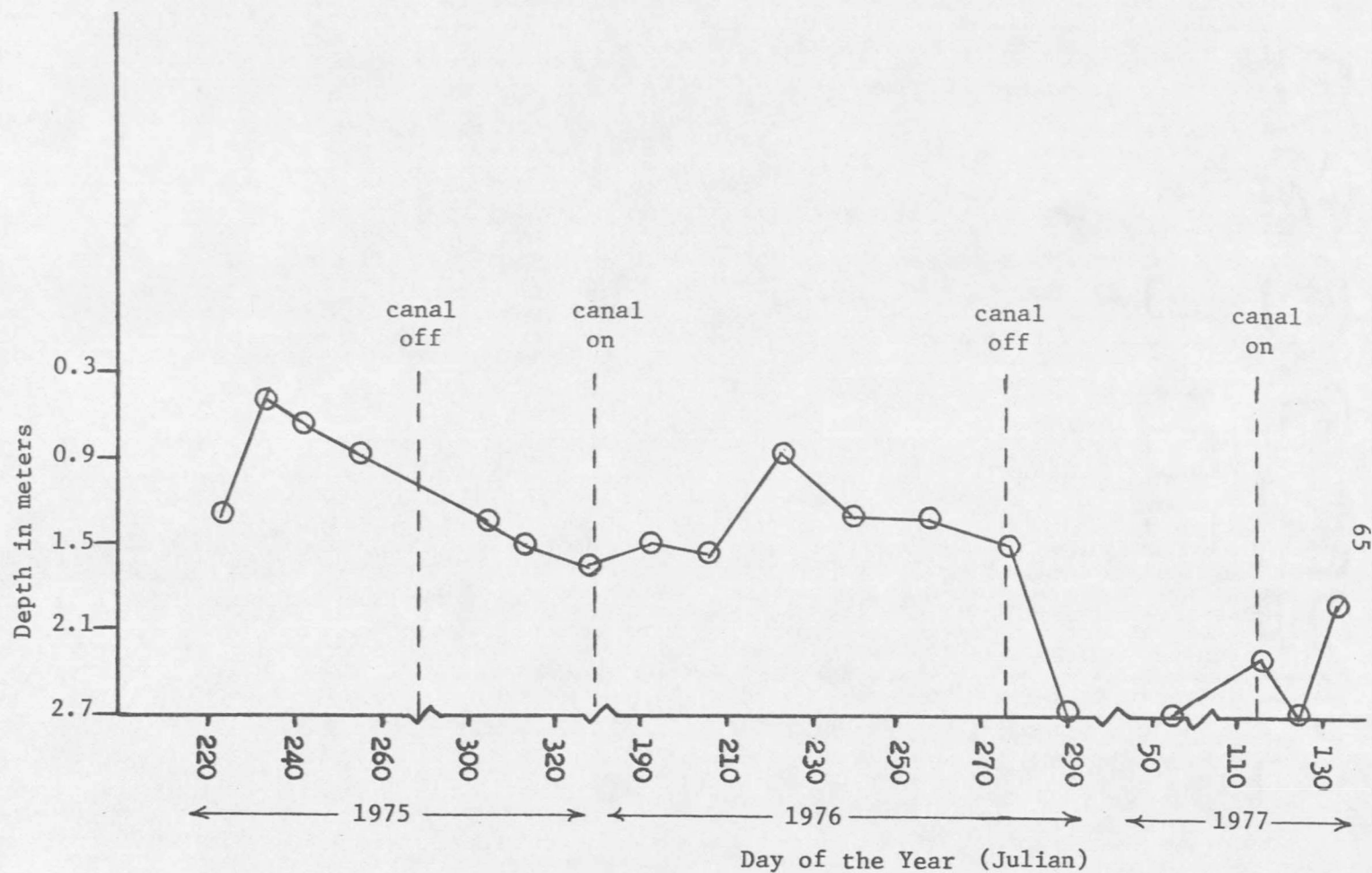


Figure III-B5. Piezometric head with time. Essentially all three piezometers at this site (1.5 m, 2.1 m, 2.7 m) and access tube are superimposed and are represented as one line.

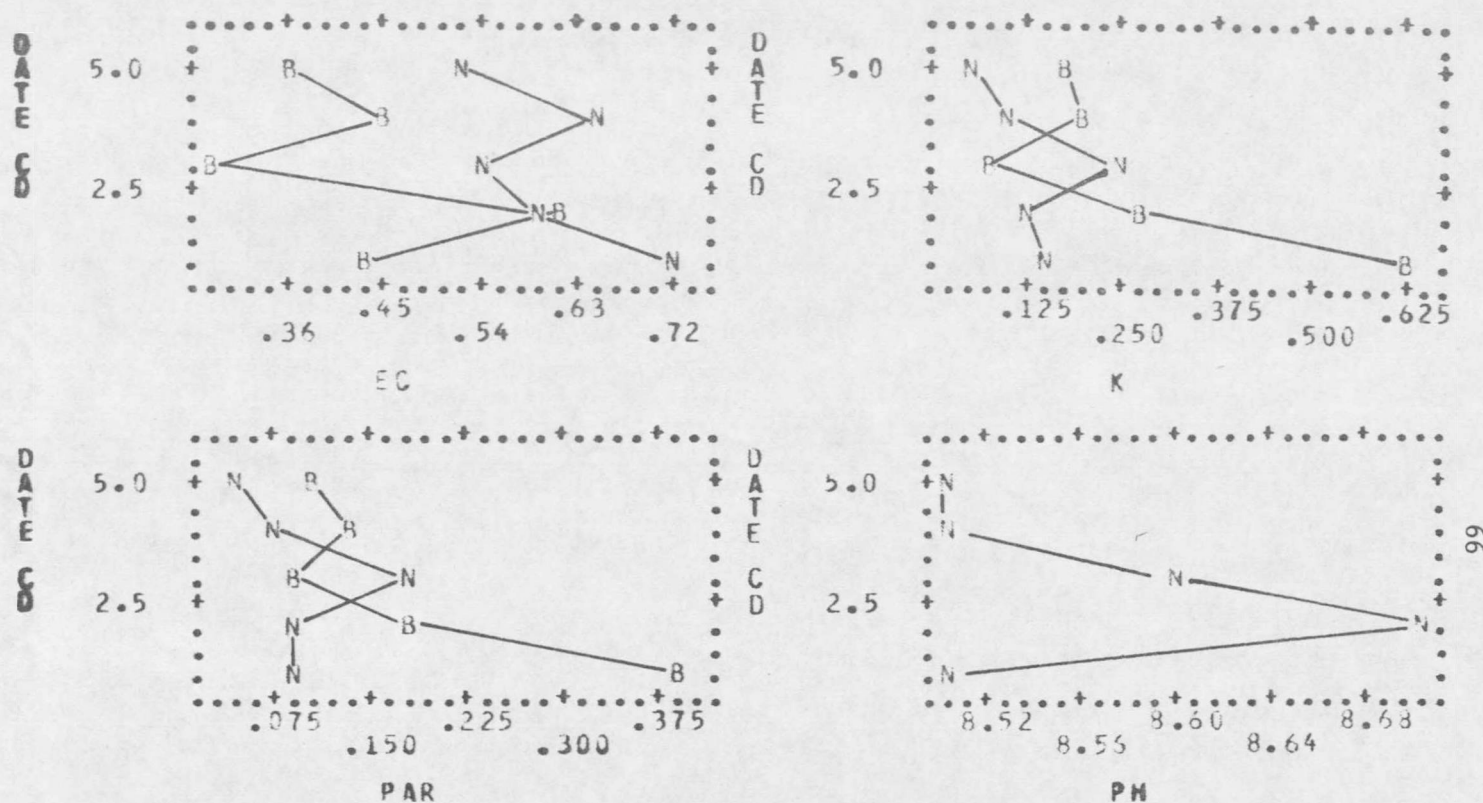


Fig. III-B6. Electrical conductivity (mmhos/cm), K (meq/l), potassium adsorption ratio (PAR), and pH of groundwater vs. time. The B and N data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-B5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

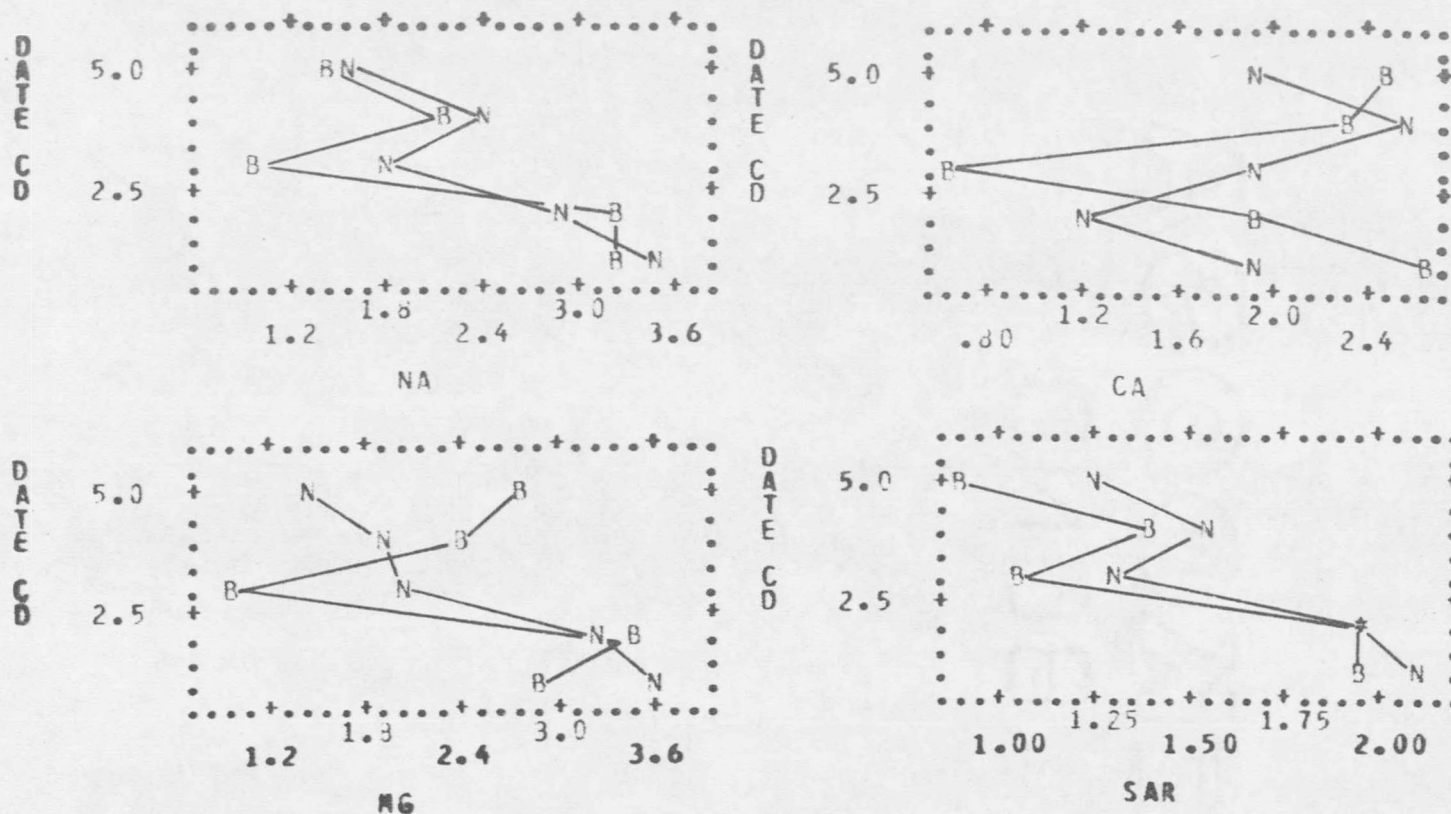


Fig. III-B7. Concentrations of major cations (meq/l) and sodium adsorption ratio of groundwater vs. time. The B and N data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-B5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

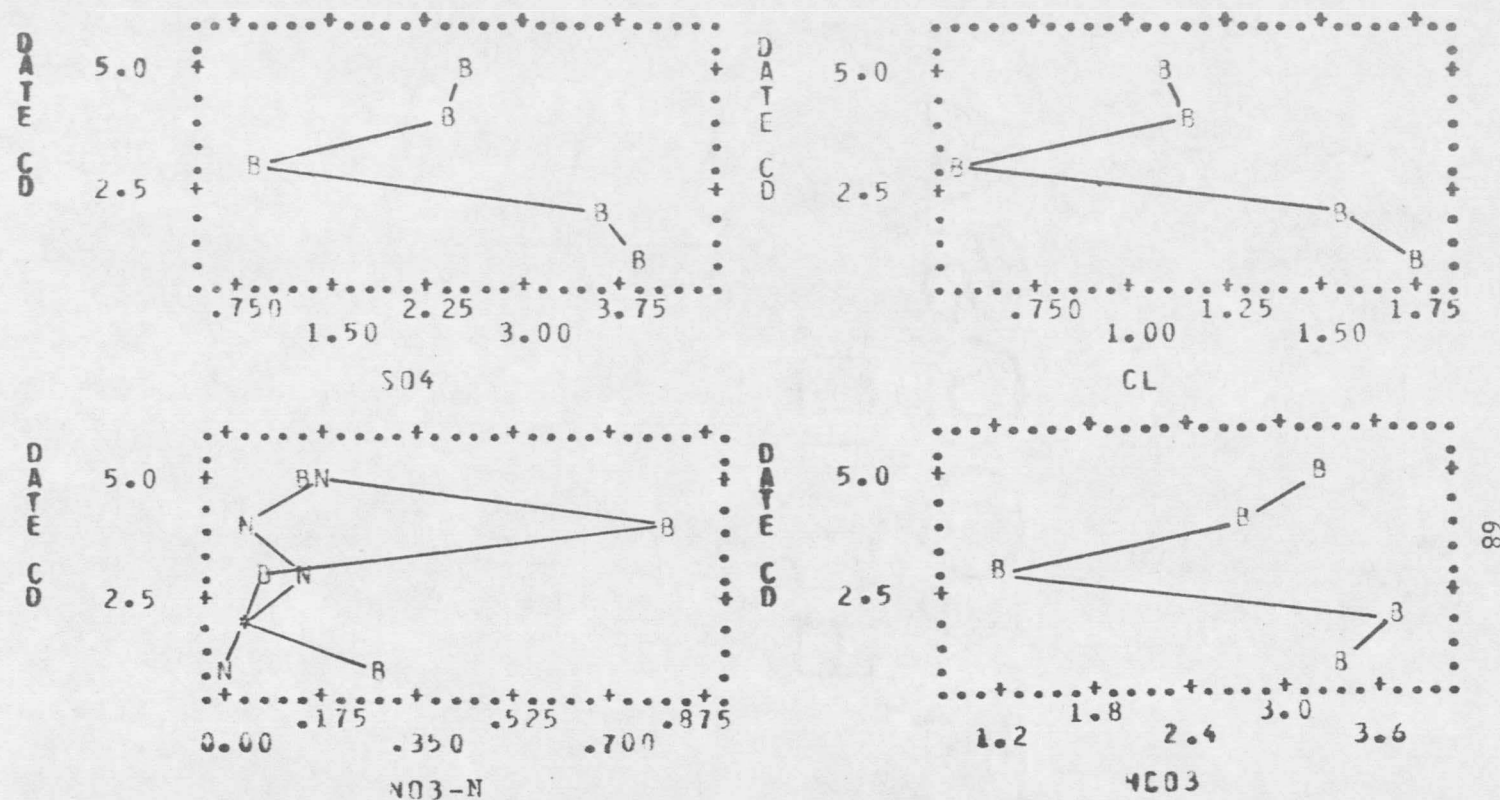


Fig. III-B8. Anion concentrations of groundwater (meq/l) vs. time. These data are for 1975 only. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-B5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

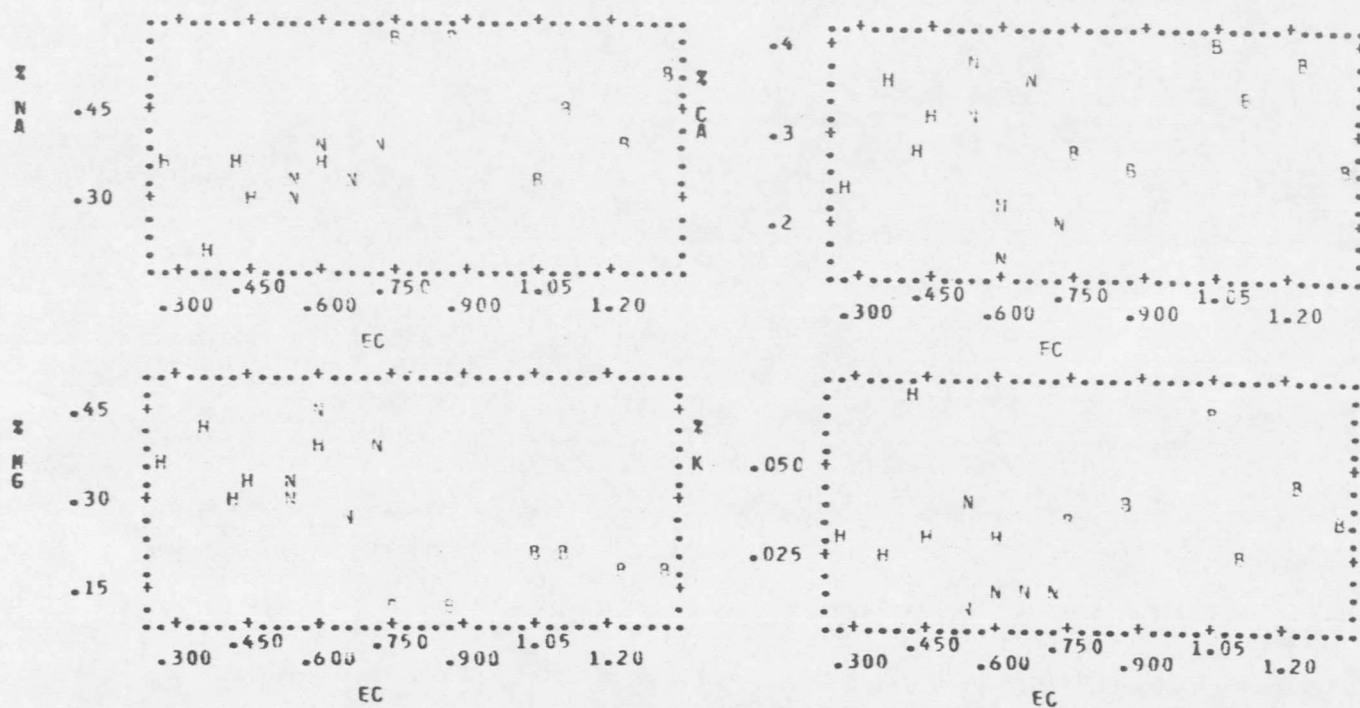


Fig. III-B9. Individual cation fractions (cation/total cations) as a function of EC for groundwater and soil. Data points B, H, and N represent soil, groundwater 1975 and groundwater 1976, respectively.

TABLE III-B1. SUMMARY STATISTICS OF SOIL VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.697*	2.33	.869	37.3
Mg	.520	2.49	.870	34.9
Ca	.192	1.95	.625	32.1
K	-.130	.206	.169	82.0
<u>Cation Fraction</u>				
Na	.485	.331	.052	15.7
Mg	-.008	.355	.053	14.9
Ca	-.241	.286	.077	26.9
K	-.376	.028	.017	60.7
SAR	.699*	1.55	.431	27.8
EC		.516	.135	26.1

1/ N = 10, $r_{.95} = .549$, and $r_{.99} = .715$.

TABLE III-B2. SUMMARY STATISTICS OF GROUNDWATER VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.628	5.71	1.05	18.4
Mg	.865*	2.22	.773	34.8
Ca	.682	4.07	1.43	35.1
K	.492	.500	.192	38.4
<u>Cation Fraction</u>				
Na	-.483	.467	.0957	20.5
Mg	.691	.174	.0354	31.0
Ca	.343	.319	.0623	19.5
K	.031	.0401	.0131	32.7
SAR	-.185	3.36	.738	21.9
EC		1.05	.212	20.2

1/ N = 6, $r_{.95} = .729$, and $r_{.99} = .882$.

TABLE III-B3. SUMMARY STATISTICS OF CATION RATIOS. 1/

GROUNDWATER					
<u>Correlation Coeff. w/EC</u>			<u>Means</u>		
	<u>Mg</u>	<u>Ca</u>		<u>Mg</u>	<u>Ca</u>
Na	.370	.386	Na	.951	1.29
Ca	-.079		Ca	.844	
N = 10			<u>Std. Dev.</u>		
	<u>r_{.95}</u>	<u>r_{.99}</u>		<u>Mg</u>	<u>Ca</u>
	.348	.715	Na	.190	.577
			Ca	.323	
SOIL					
<u>Correlation Coeff. w/EC</u>			<u>Means</u>		
	<u>Mg</u>	<u>Ca</u>		<u>Mg</u>	<u>Ca</u>
Na	-.705	-.437	Na	2.88	1.56
Ca	-.461		Ca	1.87	
N = 6			<u>Std. Dev.</u>		
	<u>r_{.95}</u>	<u>r_{.99}</u>		<u>Mg</u>	<u>Ca</u>
	.729	.882	Na	1.16	.577
			Ca	.312	

1/ The vertical numbers of the tables are numerators and the horizontal numbers are denominators. For example, the mean Na/Ca value is 1.29.

Site C

Site Description

This site is located near the west-center of the project and about three-fourths of the distance from the main canal to the Yellowstone River (Fig. I-3). The productivity is estimated as good. Corn was grown the first summer and sugar beets the second.

Soil-Groundwater Relationships

This site has a surface texture of silt loam with underlying lighter textures and gravel at about 2 m (Fig. III-C1). The distribution of analyzed chemical variables with depth are shown in Figures III-2, C3, and C4. The salt in the soil profile peaks at about .9 m. This is just above the water table (Fig. III-C5).

The sudden drop in EC at about 1.5 m seems to be correlated with a change in texture. This soil depth is below the water table for much of the summer. The pH follows changes in SAR with depth. The rather high level of $\text{NO}_3\text{-N}$ at the surface is probably due to chemical fertilizers, and the decrease below .9 m may be due to reducing conditions.

The depth of maximum EC corresponds with the Mg and Na peaks. Peaks of the major cations occur with increasing depth in the order: Ca, Mg, Na. The SAR curve follows that of Na since it is the dominant cation of the soil profile by a factor of 4 and 5 to Mg and Ca,

respectively. The K is distributed typically. The increase in NH_4OAc extractable K at 1.5 m is probably due to the clay textured horizon just above the gravel. The increase in water soluble K at the lower portion of the profile is atypical.

The piezometric head at various depths with time is presented in Figure III-C5. The access tube fluctuations are similar to those of the 2.1 m piezometer in late summer but higher in early summer. The 1.5 m and 2.1 m piezometers have about the same head throughout the summer indicating little vertical water movement in this zone. The 3.3 m piezometer had a slightly higher head indicating water moving up from deeper strata. Since the texture and hence the water-bearing properties of the lower depths greater than 1.8 m is not known it can only be speculated that the 3.3 m piezometer is not in a semiconfined aquifer and the higher head will result in water movement into the more shallow saturated zone.

The groundwater concentrations with time for both summers are shown in Figures III-C6, C7, and C8. The second data point during the first summer appears to be an outlier. Depending on the texture it takes from one to several irrigations to develop a good seal around the access pipe. It is reasoned that the second data point the first summer is an instance where leakage around the tube occurred because: (1) the elevated levels of ions agree with soil surface concentrations, i.e., Mg, Ca, K, NO_3 (compare Figs. III-C6-C8 and III-C2-C4); (2) Na

does not appear in the groundwater in excessive quantity for this sample and it is also low at the surface (compare Figs. III-C8 and C3). If it is assumed that leakage occurred during the first sampling period and the data point in question is given little weight, then there is little variation of Ca, Mg, and K at this site throughout both summer sampling periods. The Na increases in concentration throughout the summer and consequently the SAR increases. This is probably due to leaching of the profile for the following reasons: (1) the texture is coarse enough that the permeability would permit net leaching of irrigation water; (2) the maximum Na concentration is located just above the water table and the lighter textured zone of the profile. It is difficult to corroborate this net leaching by the piezometer data because piezometers can be read only under saturated conditions.

The cation fractions of soil and groundwater as a function of EC are shown in Figure III-C9. The value removed from the others is assumed an outlier. The EC of the soil is higher than the groundwater. The soil data points that are in close proximity to groundwater values are those of the lower profile. The cation fractions of Na and K are higher in the soil, Ca is about the same, and Mg is lower than in groundwater.

The summary statistics of cations, cation fractions, EC, and SAR are shown in Tables III-C1 and C2. The mean sodium value is much higher in the soil. Magnesium and calcium are only slightly higher in

the soil. The cations rank $\text{Na} > \text{Mg} > \text{Ca}$ in both groundwater and soil. Sodium is most variable in the soil and least variable in the groundwater. There is no one groundwater cation that is chiefly responsible for changes in EC. The SAR and EC are higher in the soil profile than in groundwater.

Cation ratios are shown in Table III-C3. The Na/Ca is similar in both groundwater and soil. The soil Na/Mg ratio is double that of the groundwater. The Ca/Mg ratio of the soil is considerably higher than the groundwater.

Summary

Site productivity is good. The textures at this site are generally light with gravel at about 2 m. The cation peaks occur with depth in the order $\text{Ca} > \text{Mg} > \text{Na}$. The groundwater Na and SAR probably increase over the summer because of leached soil Na. Cation concentrations are higher in the soil. They maintain the same rank in both soil and water ($\text{Na} > \text{Mg} > \text{Ca}$). The concentration of soil sodium is three times that of the groundwater. In addition to leached water entering the groundwater, piezometer data indicate movement of water from 3.3 m to more shallow depths.

SITE C

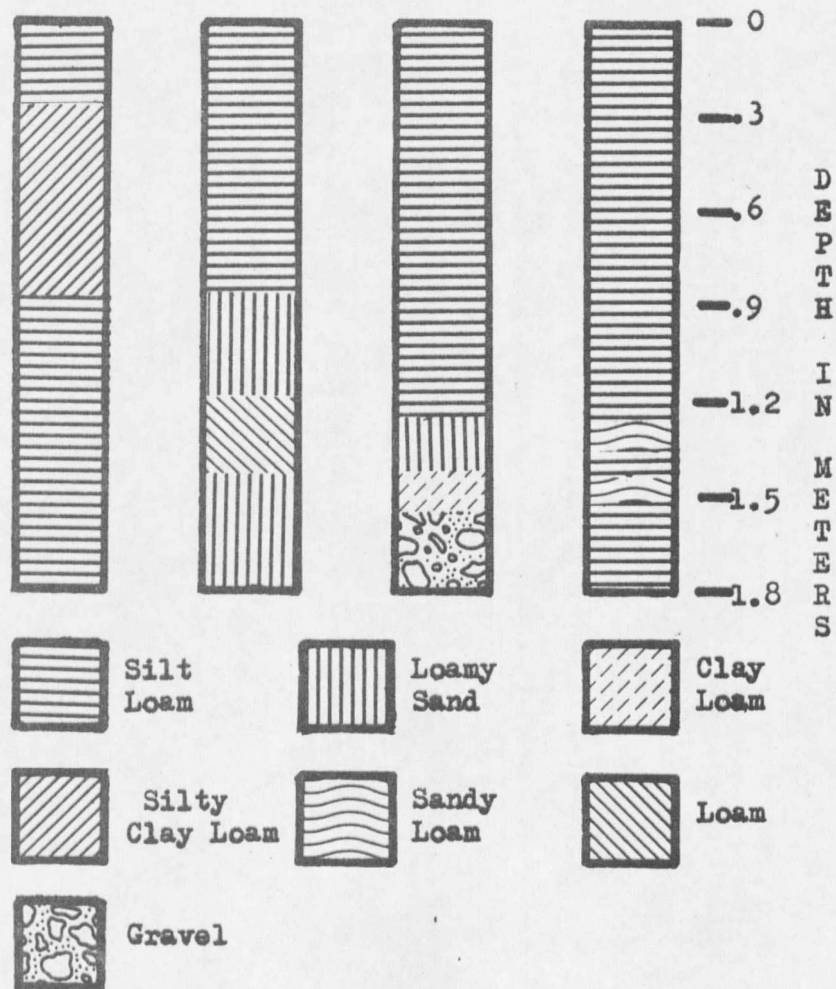


Fig. III-C1. Horization of soil profile at four sampling sites adjacent to groundwater access tube.

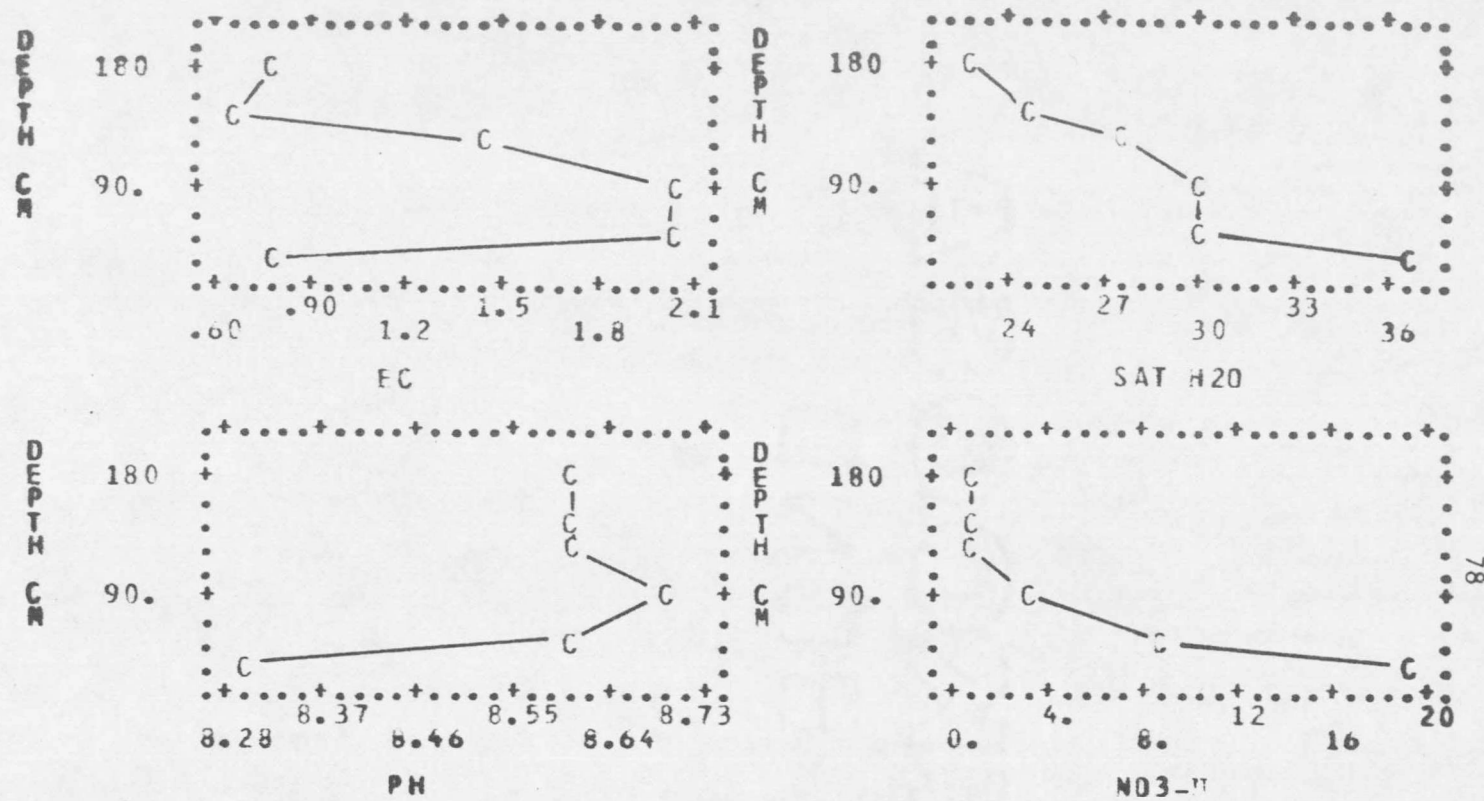


Fig. III-C2. Distribution of electrical conductivity (mmhos/cm), NO₃-N (ppm), pH, and saturated water percentage of the soil with depth. The pH and EC are of the saturated extract.

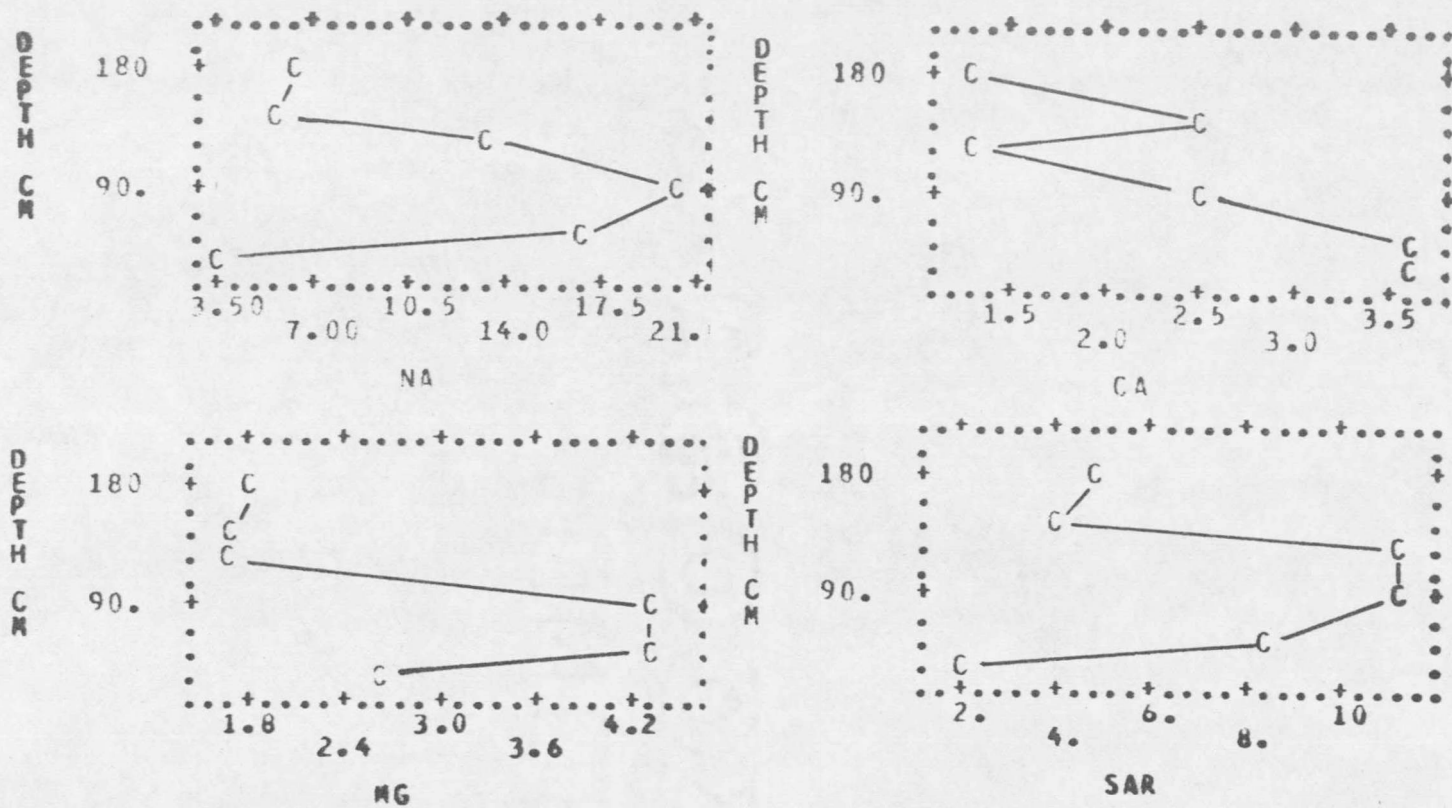


Fig. III-C3. Distribution of major cations (meq/l) of saturated extract and sodium adsorption ratio (SAR) with soil depth.

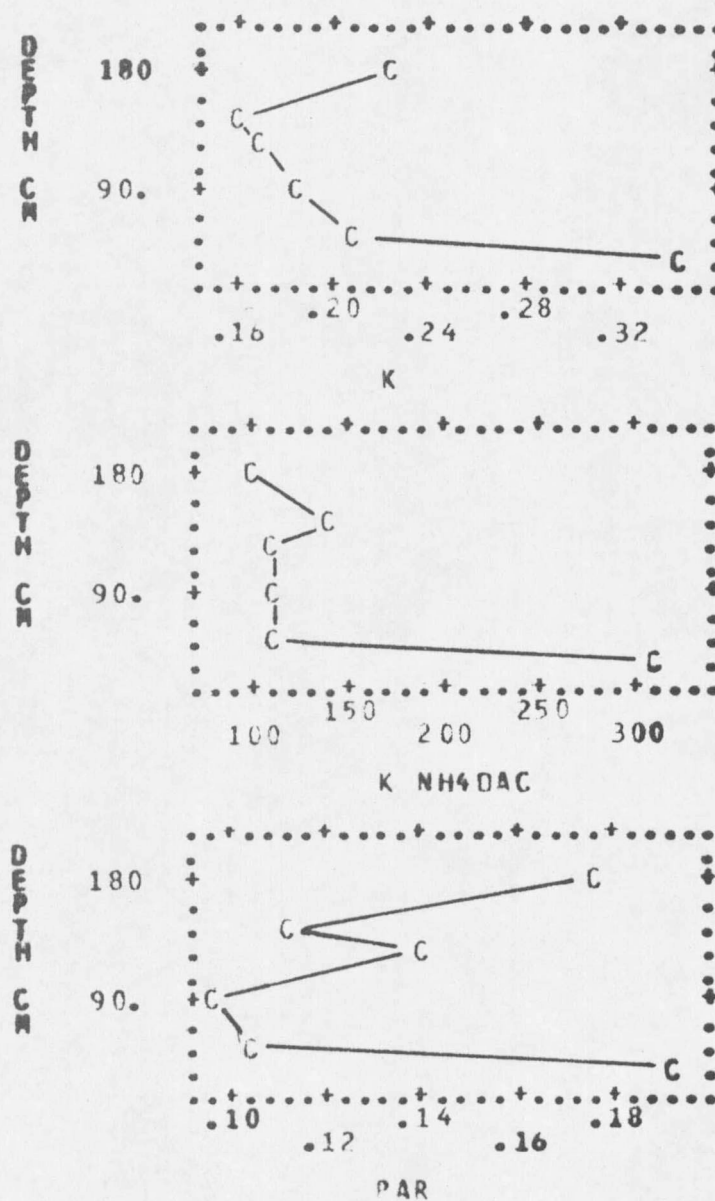


Fig. III-C4. Distribution of water soluble K (meq/l), ammonium acetate extractable K (ppm), and the potassium adsorption ratio with depth.

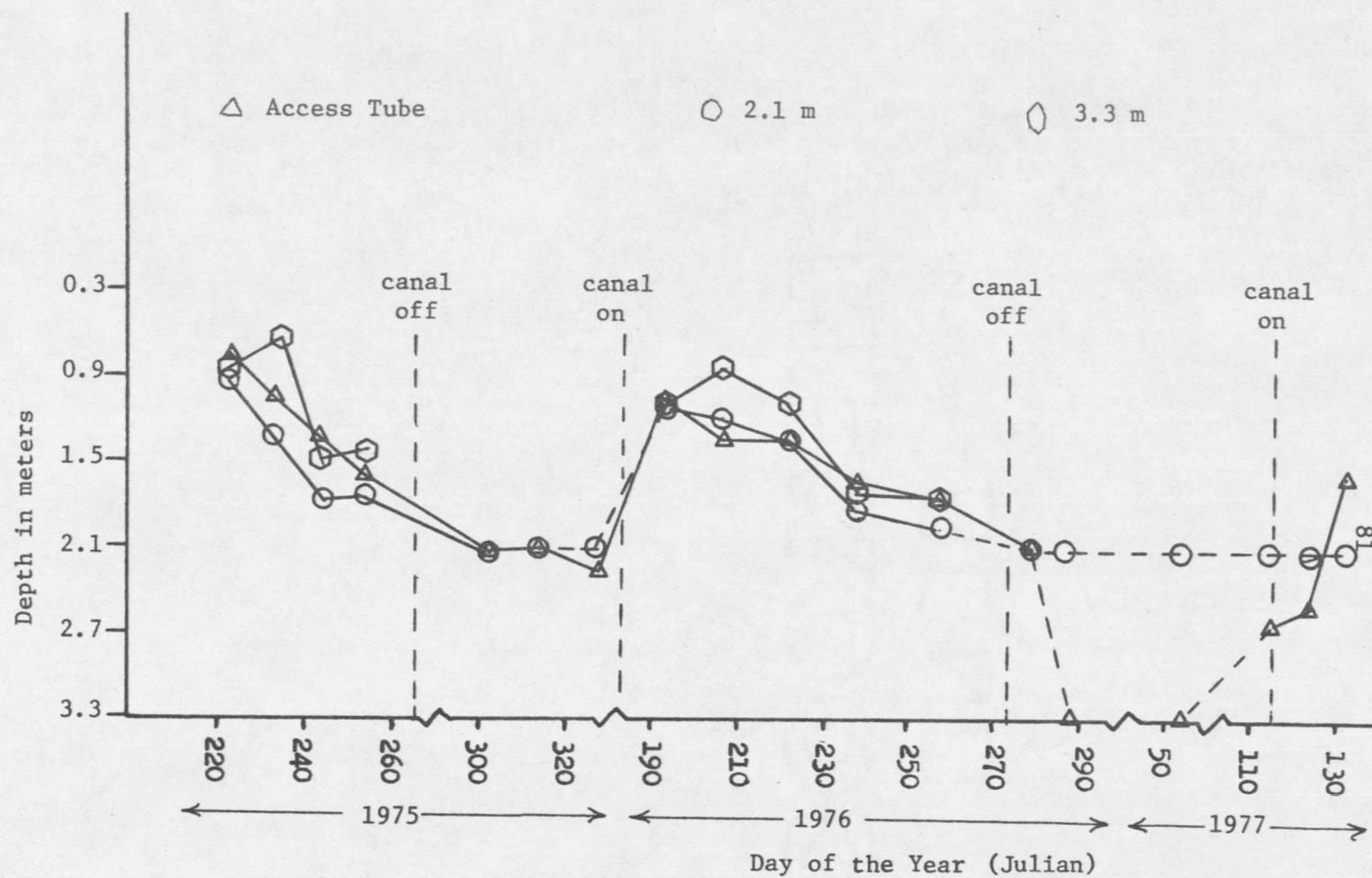


Figure III-C5. Piezometric head with time. The 1.5 meter piezometer is superimposed on the 2.1 meter piezometer. Data points connected by dashed lines represent unsaturated conditions at the depth sampled by the piezometer.

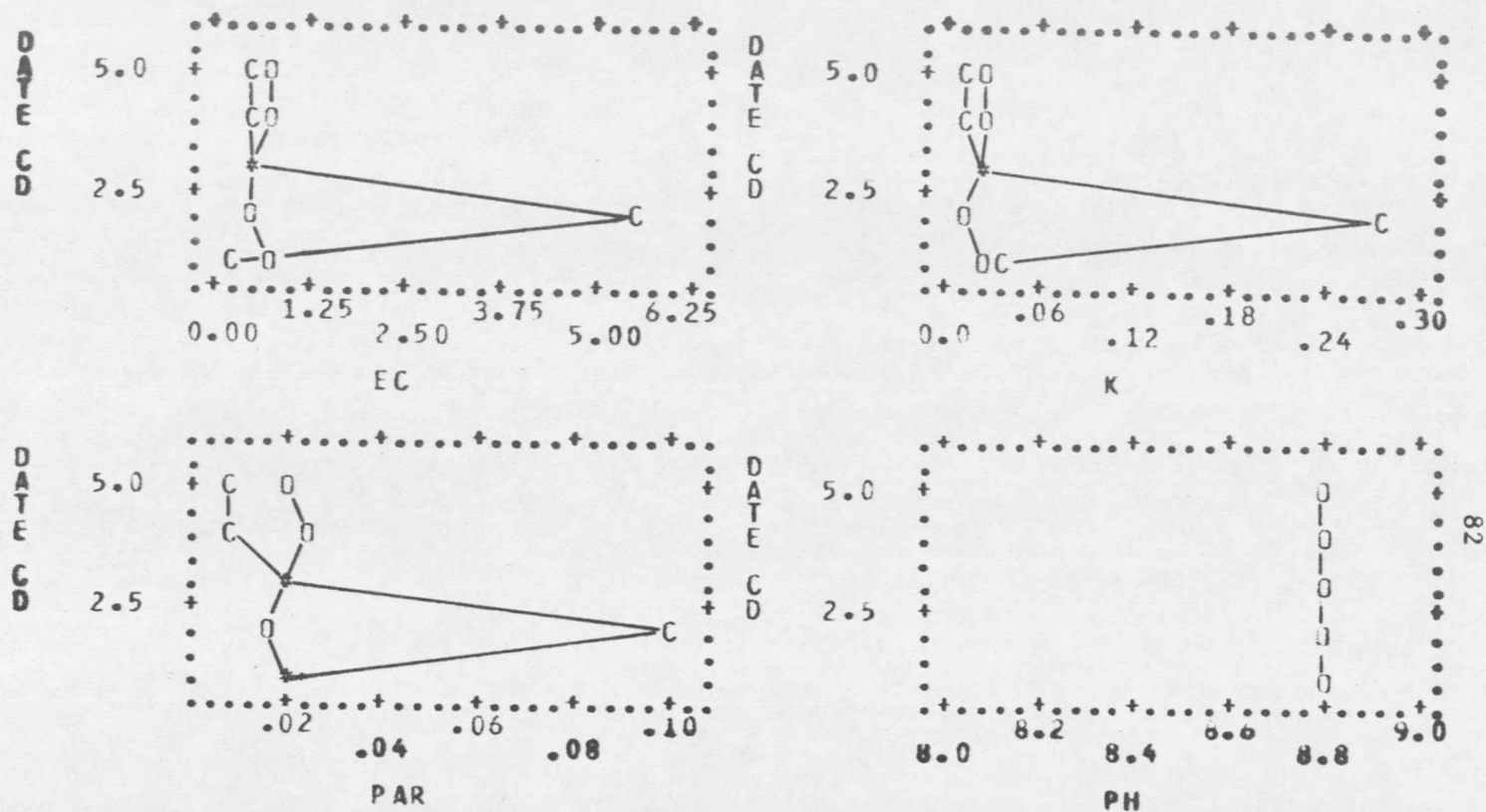


Fig. III-C6. Electrical conductivity (mmhos/cm), K (meq/l), potassium adsorption ratio (PAR), and pH of groundwater vs. time. The C and O data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-C5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian Day 207, etc.

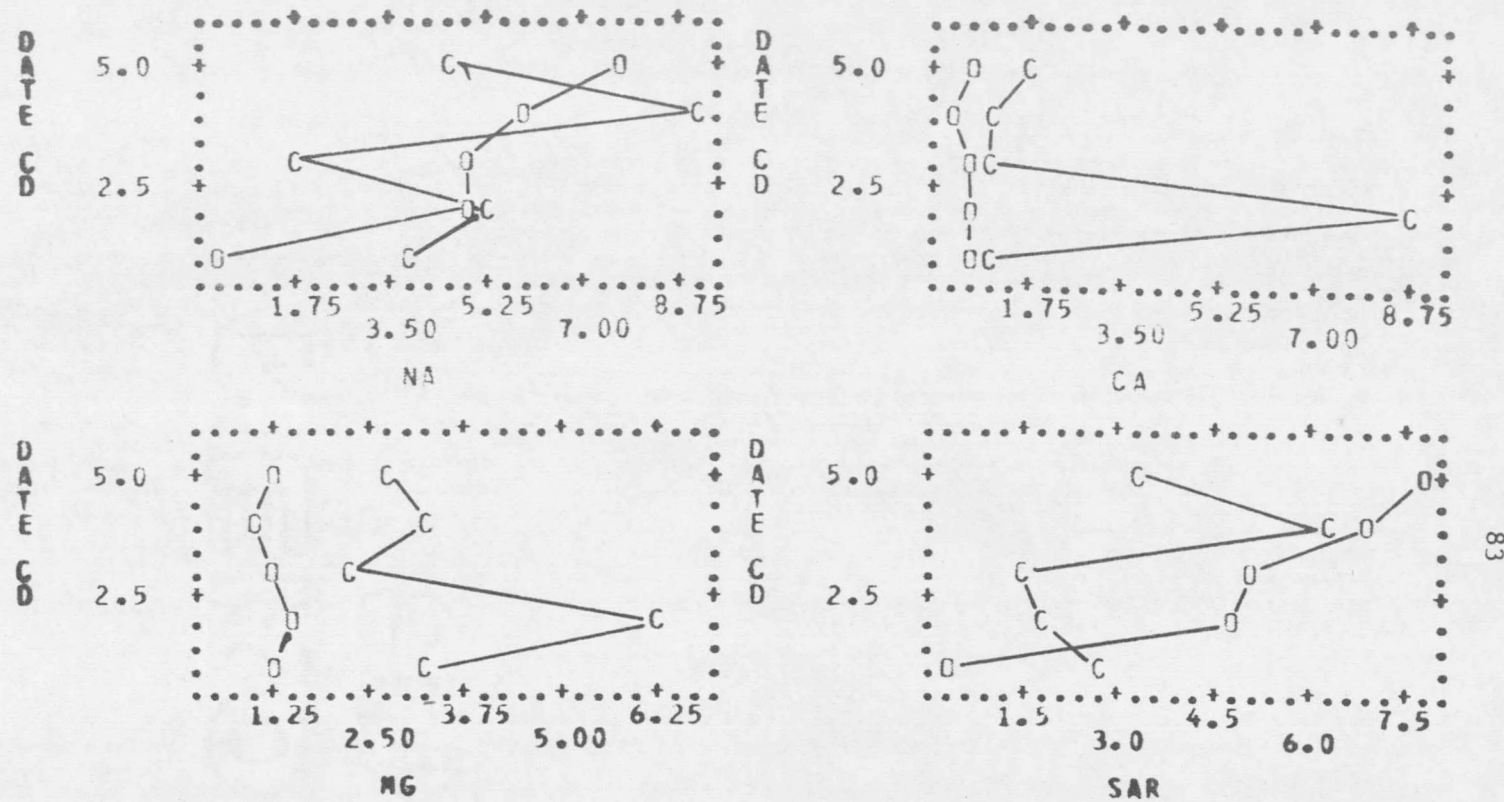


Fig. III-C7. Concentrations of major cations (meq/l) and sodium adsorption ratio of ground-water vs. time. The C and O data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-C5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

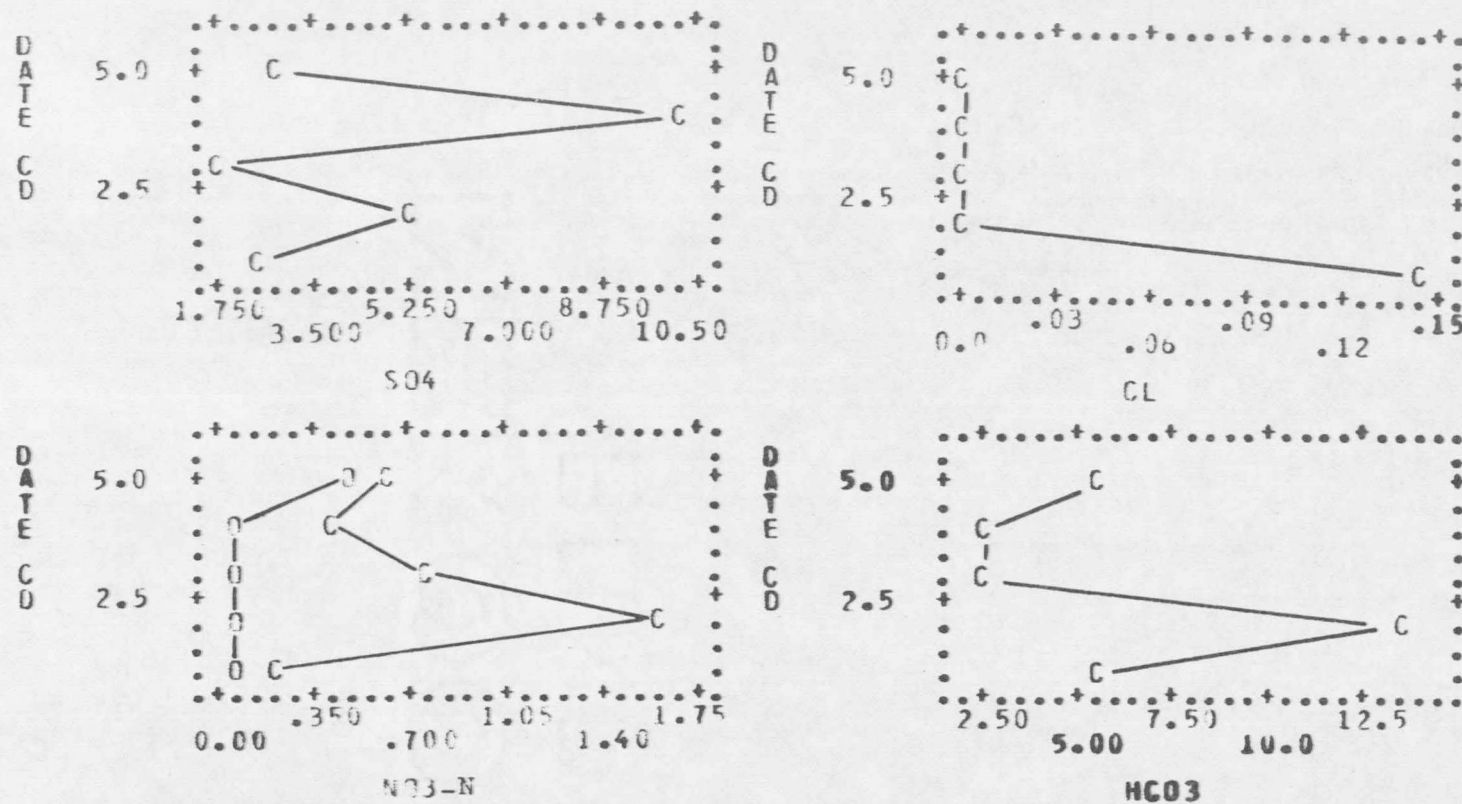


Fig. III-C8. Anion concentrations of groundwater (meq/l) vs. time. These data are for 1975 only. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-C5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.



Fig. III-C9. Individual cation fractions (cation/total cations) as a function of EC for groundwater and soil. Data points C, I, and O represent soil, groundwater 1975 and groundwater 1976, respectively.

TABLE III-C1. SUMMARY STATISTICS OF SOIL VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.977**	11.0	6.92	62.9
Mg	.821*	2.74	1.28	46.7
Ca	.205	2.46	1.06	43.1
K	-.345	.213	.0662	31.0
<u>Cation Fraction</u>				
Na	.618	.633	.165	26.1
Mg	-.454	.175	.0537	30.7
Ca	-.634	.175	.109	62.3
K	-.802*	.0164	.0104	63.4
SAR	.840	6.93	3.86	55.7
EC		1.28	.639	49.9

1/ N = 6, $r_{.95} = .729$, and $r_{.99} = .882$.

TABLE III-C2. SUMMARY STATISTICS OF GROUNDWATER VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev	CV
Na	.148	4.87	2.49	51.2
Mg	-.398	2.38	1.61	67.6
Ca	-.046	1.67	2.50	149.7
K	.034	.0449	.0793	176.6
<u>Cation Fraction</u>				
Na	.260	.548	.226	41.2
Mg	-.411	.284	.130	45.8
Ca	-.047	.164	.119	72.6
K	.105	.00428	.00379	88.6
SAR	.420	4.03	2.46	61.0
EC		.539	.140	25.9

1/ N = 10, $r_{.95} = .549$, and $r_{.99} = .715$.

TABLE III-C3. SUMMARY STATISTICS OF CATION RATIOS. 1/

GROUNDWATER

Correlation Coeff. w/EC

	Mg	Ca
Na	.571*	.516
Ca	.131	

N = 10

 $r_{.95} = .549$ $r_{.99} = .715$ Means

	Mg	Ca
Na	2.67	5.84
Ca	.566	

Std. Dev.

	Mg	Ca
Na	1.96	4.76
Ca	.309	

SOIL

Correlation Coeff. w/EC

	Mg	Ca
Na	.444	.589
Ca	-.648	

N = 6

 $r_{.95} = .729$ $r_{.99} = .882$ Means

	Mg	Ca
Na	4.15	5.28
Ca	.957	

Std. Dev.

	Mg	Ca
Na	2.25	3.61
Ca	.389	

1/ The vertical numbers of the tables are numerators and the horizontal numbers are denominators. For example, the mean Na/Ca value is 5.84.

Site D

Site Description

This site is about one-half mile from the river on the western end of the study area (Fig. I-3). The soil is developed in recent alluvium. The productivity is rated as poor. Small grain was grown the first summer and sugar beets the second.

Soil-Groundwater Relationships

The texture at this site is shallow loam over gravel (Fig. III-D1). The depth to gravel varies from .5 to 1.2 m. Figures III-D2, D3, and D4 show the distribution of the measured soil properties with depth. The peak salt concentration is just above the water table at about 1 m.

The saturated moisture content and pH vary very little with depth. The $\text{NO}_3\text{-N}$ decreases with depth. The depth of the EC peak corresponds with the Na and SAR peaks as well. The Mg and Ca reach a peak of .6 m and have similar shapes. The K is typically distributed except for a low surface level of water soluble K.

The changes in piezometric and access tube heads over time are shown in Figure III-D5. The piezometric head of the lower depths reaches a peak in early summer. The water is at 1.2 m through most of the summer.

The groundwater access tube was reinstalled at the beginning of the second summer at this site. The concentrations of groundwater

constituents vs. time are shown in Figures III-D6, D7, and D8. The ionic concentrations of the first sampling date the second year seem to be unusually high. It is possible that the soil hadn't sealed around the access tube. In this light textured soil one irrigation would adequately seal the access tube. Movement of irrigation water down along sides of the tube would result in contamination of the groundwater sample with concentrations more in line with those of the upper soil profile.

The EC of the groundwater is about one-fourth that of the profile directly above. The SARs are of similar magnitude. Sulfate is the major anion present. The sulfate and nitrate decrease throughout the summer. The major cations were less variable the first summer. The pH increased from 8.6 to 9.1 during the second summer.

Cation fractions are shown for groundwater and soil data vs. EC in Figure III-D9. This enables a comparison to be made between relative amounts of cations in the soil and groundwater while also being able to assess the absolute magnitude of salts present (EC). Relative to the soils, percent Na is higher in the groundwater, Ca lower, and Mg and K similar. The difference of total salts between soil and groundwater can be seen by the amount the soil values are displaced to the right of the groundwater values.

Summary statistics for this site are shown in Tables III-D1 and D2. There is a significant positive correlation between groundwater Na,

Mg, K, and SAR, compared to EC. The CVs reveal that Ca is the most variable groundwater cation and Mg the least. The CVs of the cation percentages show that the Na fraction is the most stable, Mg intermediate, and Ca and K the most variable.

The variability of the soil cations are about the same. As the total salt in the profile increases the percentage Mg also increases while the fraction of Ca and K decreases. The percent Na is the least variable but is not correlated with EC.

The cation ratios are shown in Table III-D3. The Na ratios are higher in the groundwater while the Ca/Mg ratio is higher in the soil. The Ca/Mg ratio decreases as the total salt decreases.

Summary

The soil at this site is shallow and light textured. The EC of the groundwater is one-fourth that of the soil profile just above the water table. The Ca, Mg, Na, SAR, and EC all have a similar distribution in the soil profile. The peak concentrations of soil cations and SAR occur in the order Ca = Mg at .6 m, SAR = EC = Na at .9 m. The water table is at about 1.2 m through the summer. In the soil and groundwater percent Na is the least variable chemical constituent. The cations have about the same variability in the soil.

SITE D

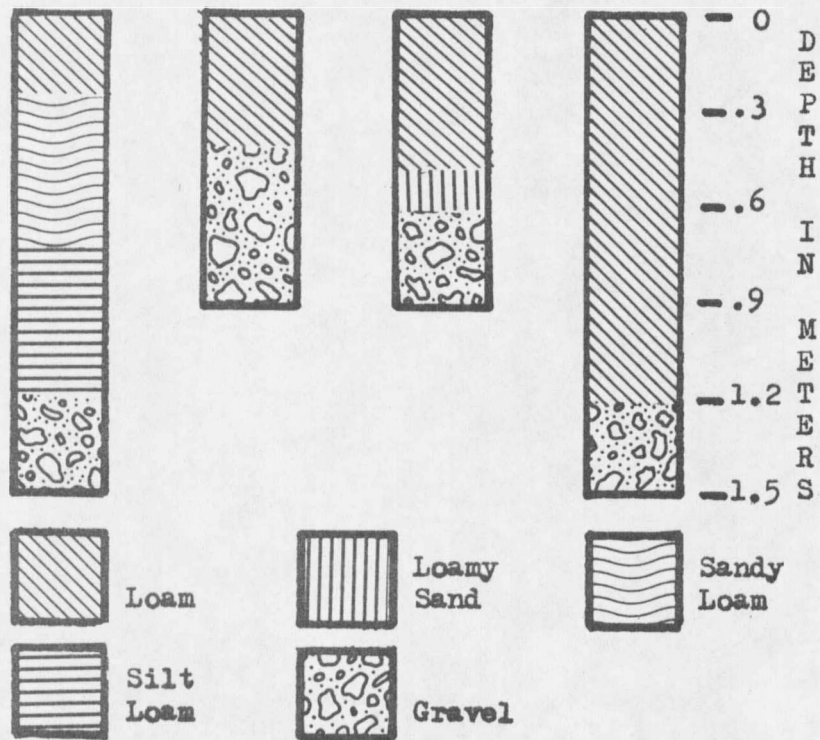


Fig. III-D1. Horizonation of soil profile at four sampling sites adjacent to groundwater access tube.

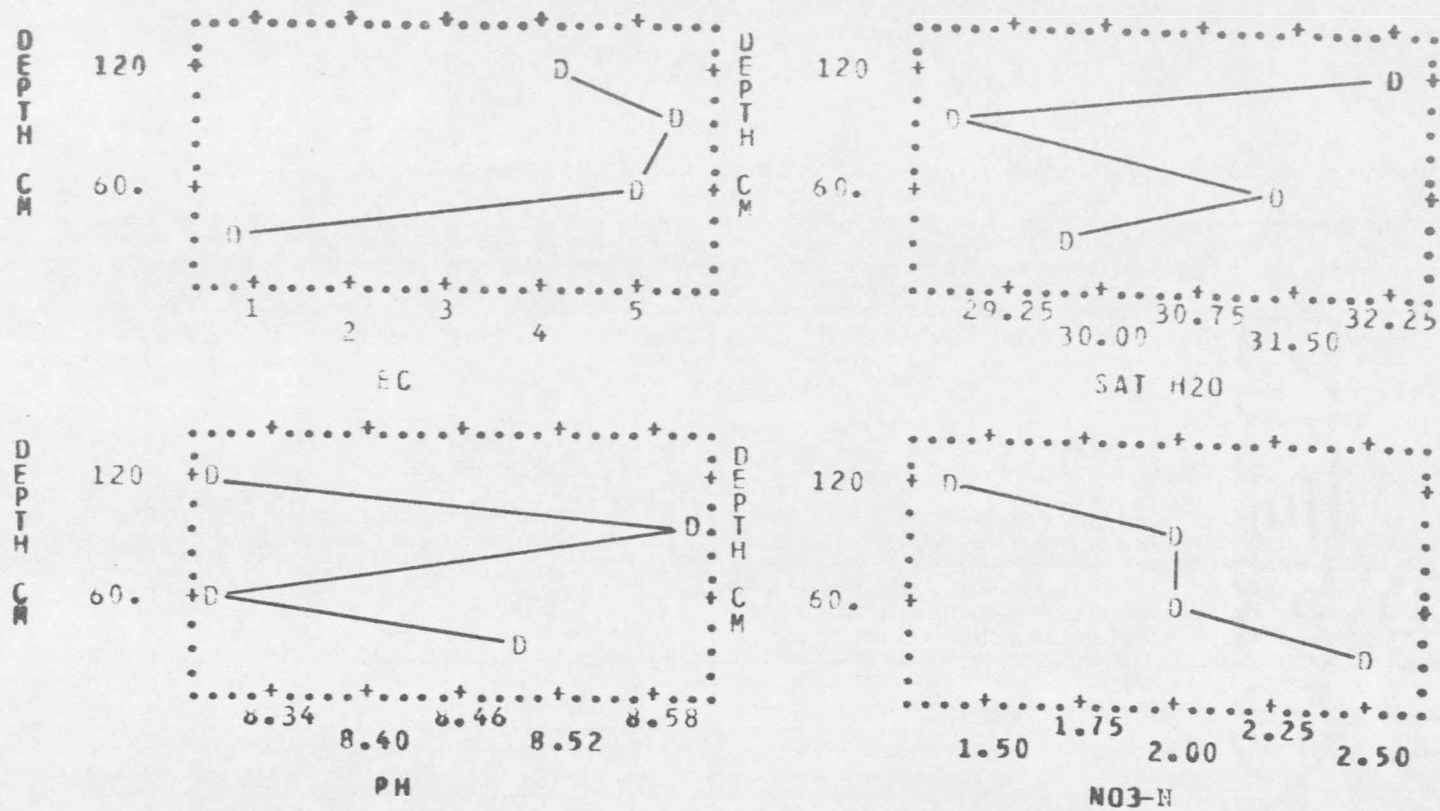


Fig. III-D2. Distribution of electrical conductivity (mmhos/cm), NO₃-N (ppm), pH, and saturated water percentage of the soil with depth. The pH and EC are of the saturated extract.

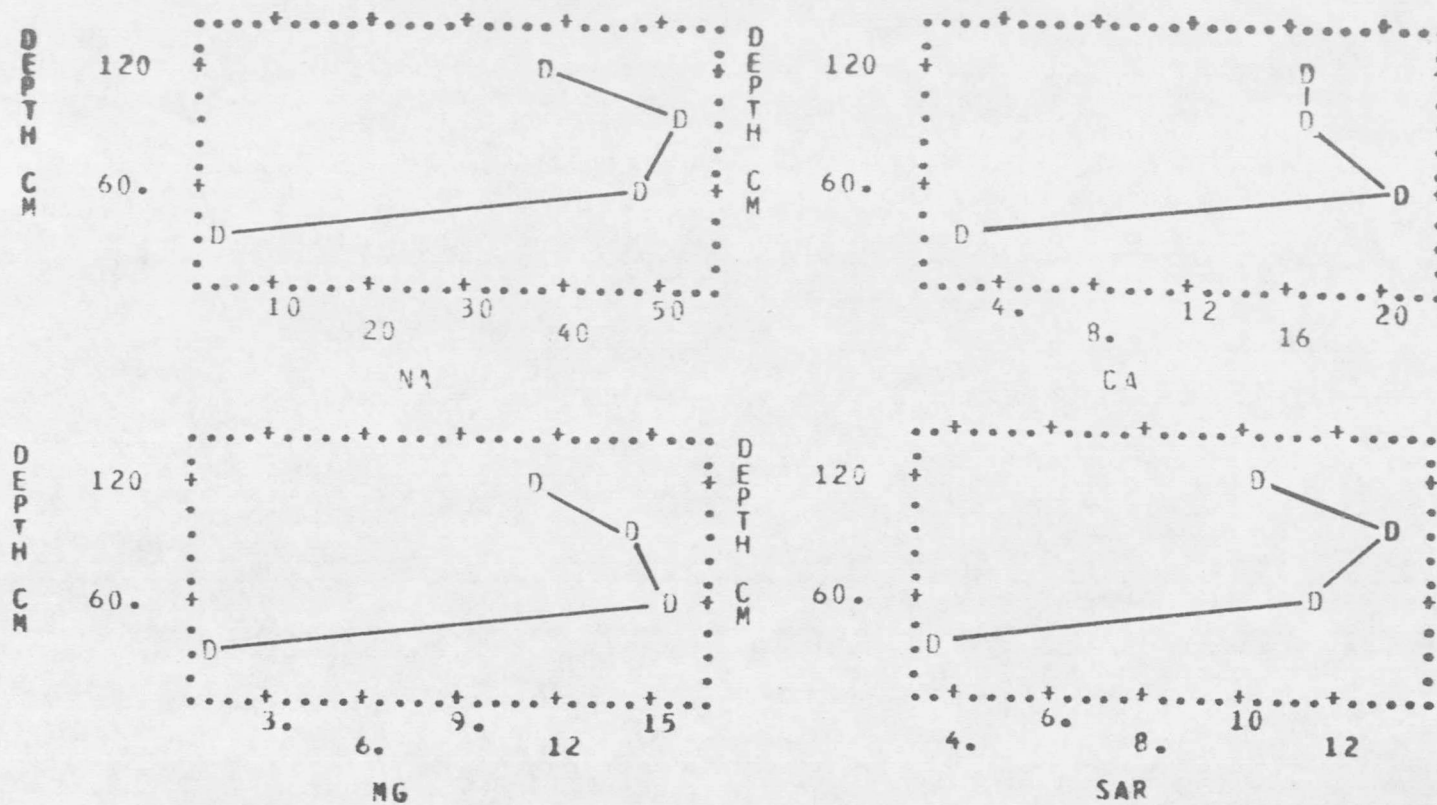


Fig. III-D3. Distribution of major cations (meq/l) of saturated extract and sodium adsorption ratio (SAR) with soil depth.

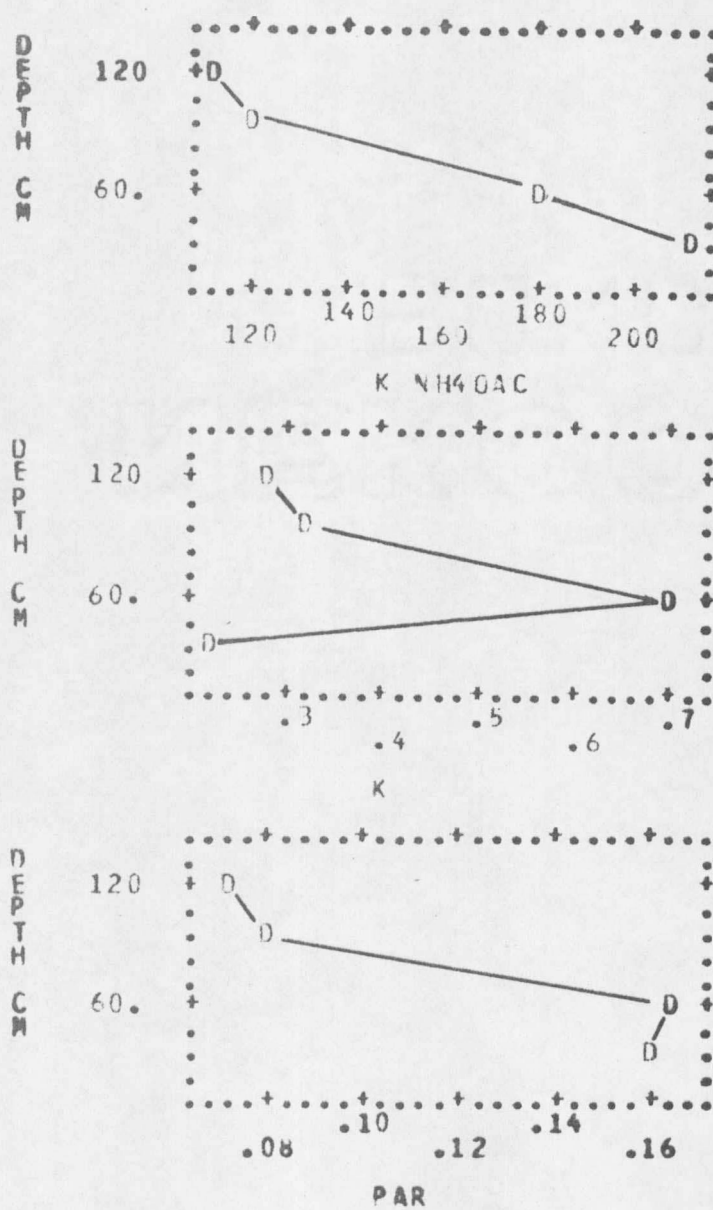


Fig. III-D4. Distribution of water soluble K (meq/l), ammonium acetate extractable K (ppm), and the potassium adsorption ratio with depth.

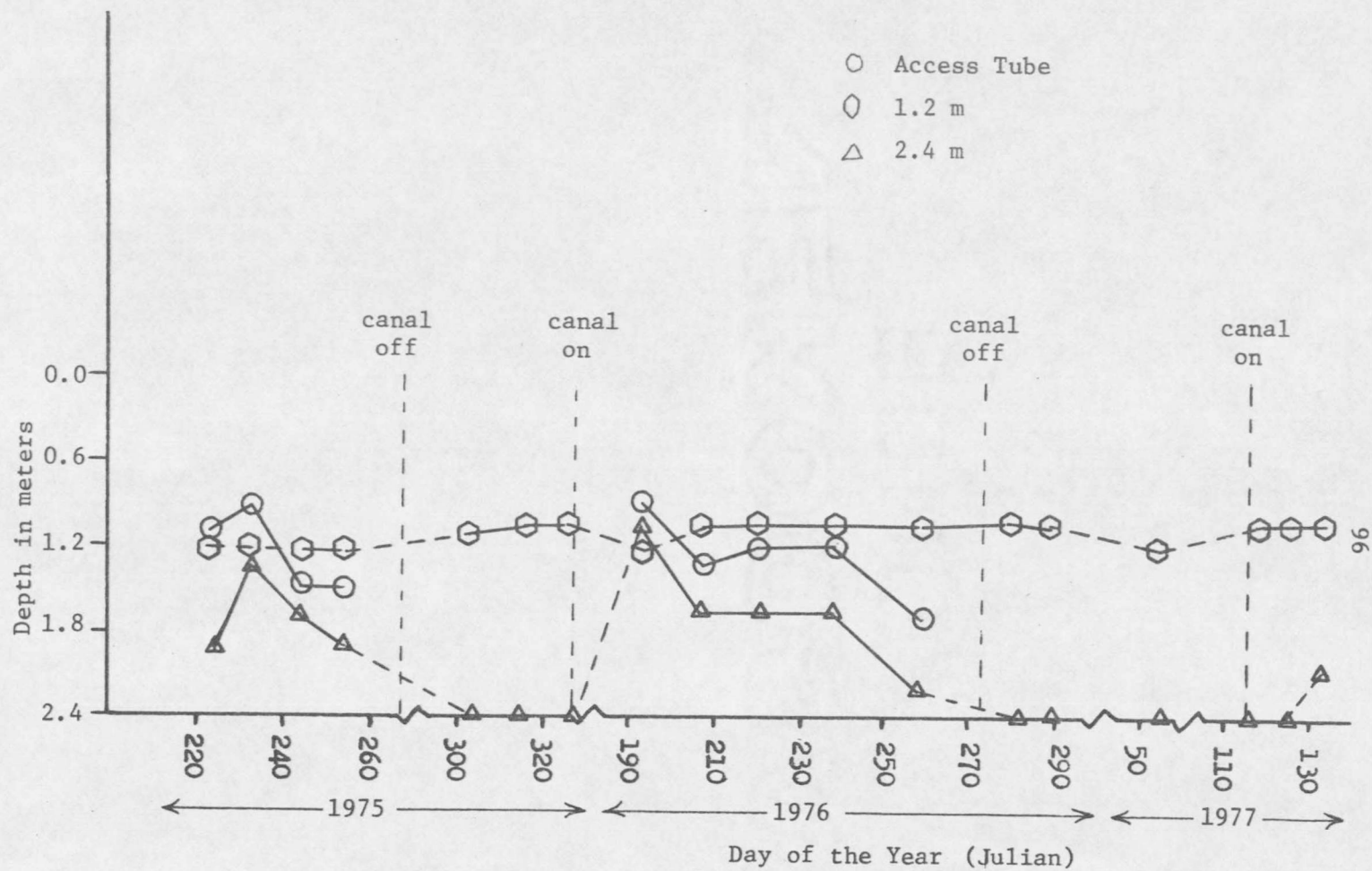


Figure III-D5. Piezometric head with time. Data points connected by dashed lines represent unsaturated conditions at the depth sampled by that piezometer. The 2.4 meter piezometer fluctuations closely follow 1.5 and 1.8 meter piezometers and is represented by one line.

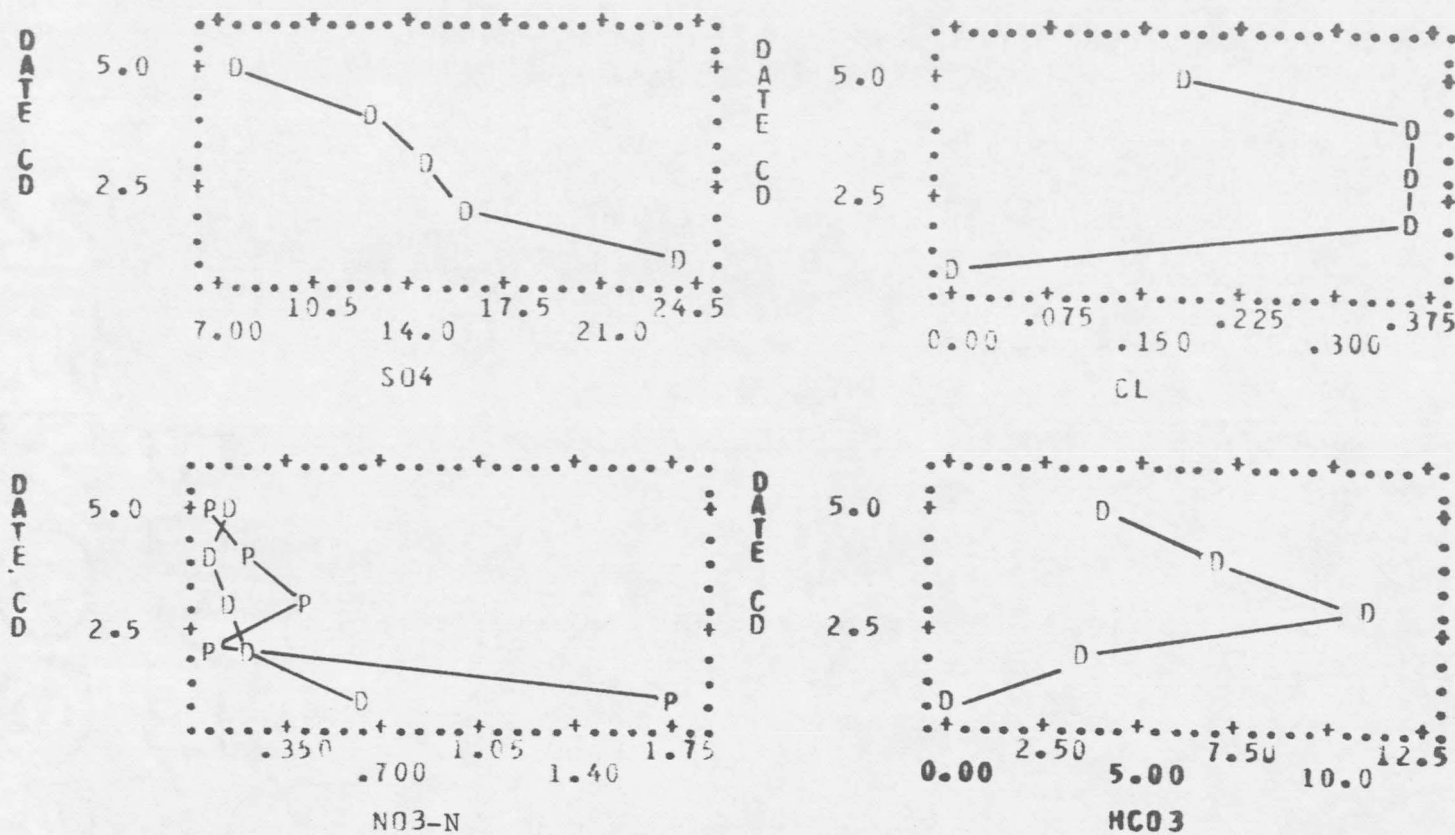


Fig. III-D6. Anion concentrations of groundwater (meq/l) vs. time. These data are for 1975 only. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-D5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

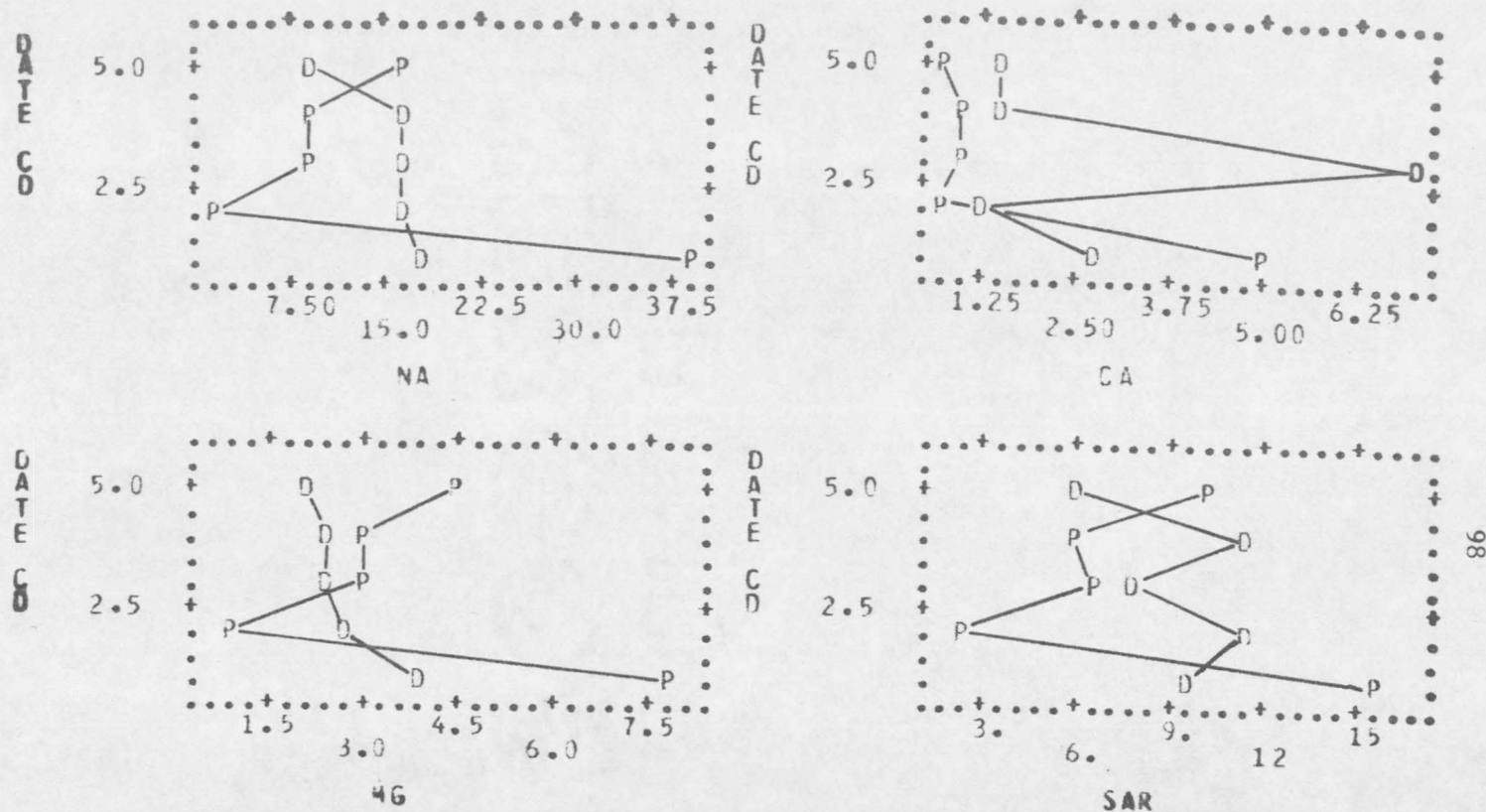


Fig. III-D7. Concentrations of major cations (meq/l) and sodium adsorption ratio of groundwater vs. time. The D and P data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-D5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

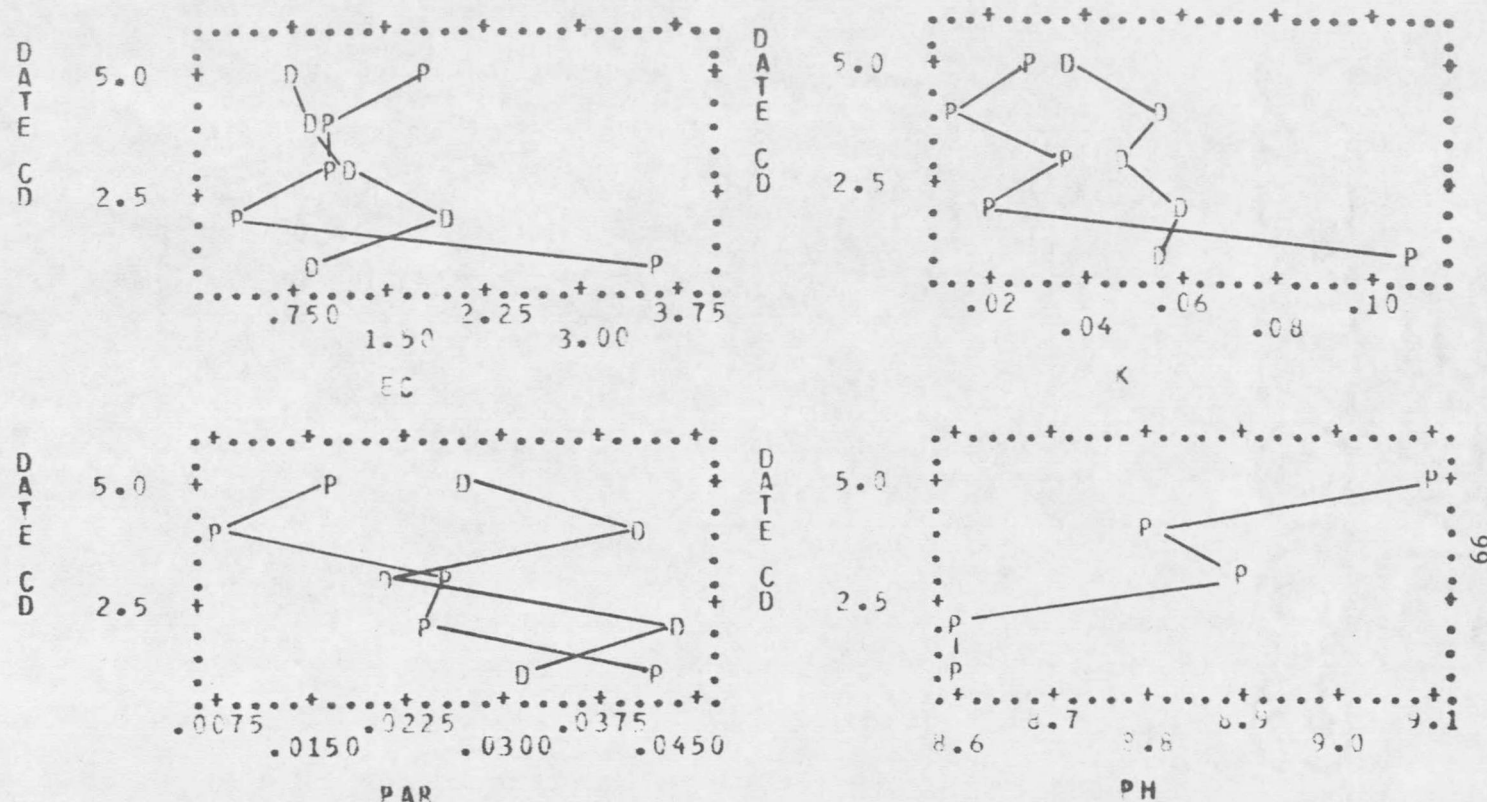


Fig. III-D8. Electrical conductivity (mmhos/cm), K (meq/l), potassium adsorption ratio (PAR), and pH of groundwater vs. time. The D and P data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-D5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

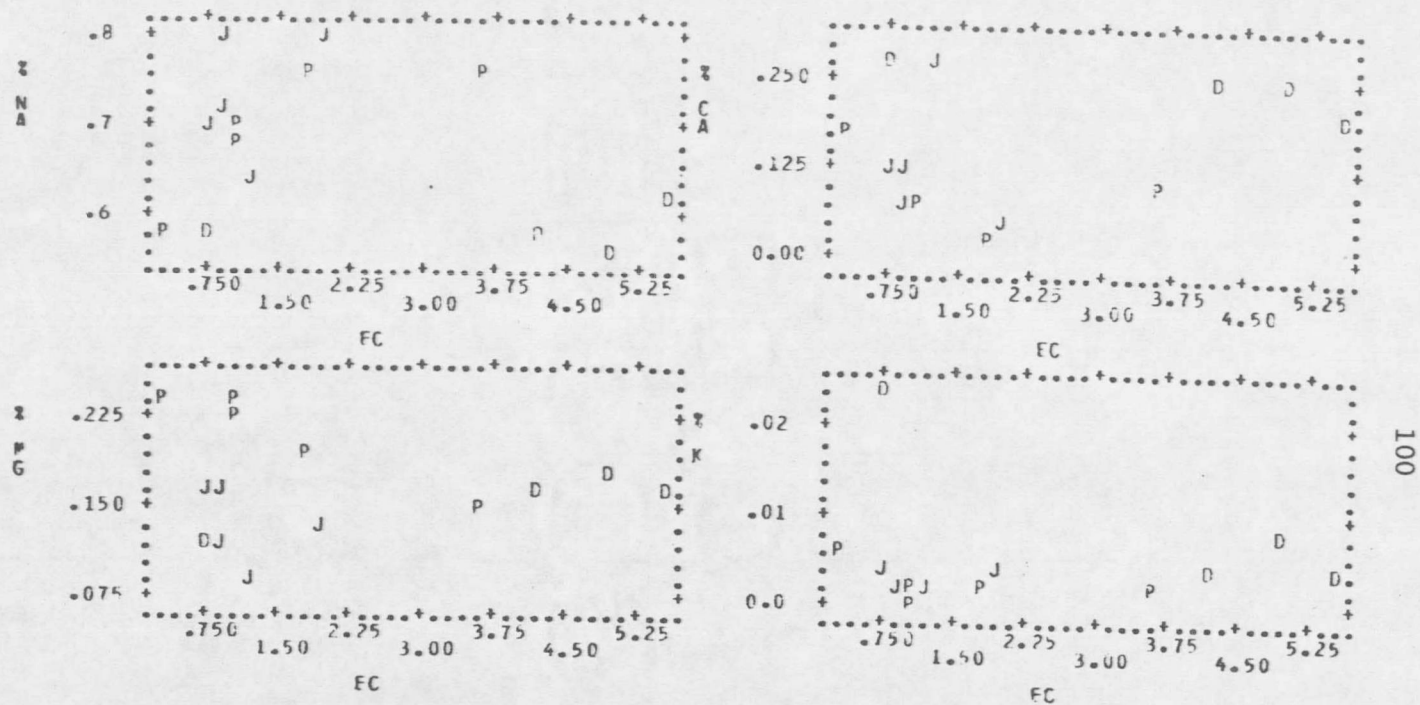


Fig. III-D9. Individual cation fractions (cation/total cations) as a function of EC for groundwater and soil. Data points D, J, and P represent soil, groundwater 1975 and groundwater 1976, respectively.

TABLE III-D1. SUMMARY STATISTICS OF GROUNDWATER VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.909**	15.1	9.88	65.4
Mg	.896**	3.22	1.85	57.4
Ca	.411	2.23	2.11	94.6
K	.768**	.0454	.0273	60.1
<u>Cation Fraction</u>				
Na	.509	71.6	6.86	9.6
Mg	-.288	17.1	4.97	29.0
Ca	-.296	11.0	6.77	61.5
K	-.383	.250	.126	50.4
SAR	.842**	8.80	3.66	41.6
EC		1.35	.903	66.9

1/ N = 10, $r_{.95} = .549$, and $r_{.99} = .715$.

TABLE III-D2. SUMMARY STATISTICS OF SOIL VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	Cv
Na	.999**	36.2	21.6	59.7
Mg	.981*	10.6	6.63	62.5
Ca	.956*	14.2	7.98	56.2
K	.533	.373	.216	57.9
<u>Cation Fraction</u>				
Na	.502	58.5	2.72	4.6
Mg	.946*	16.0	2.80	18.1
Ca	-.909*	24.5	3.52	14.4
K	-.948*	1.00	.961	96.1
SAR	.966**	9.69	4.16	42.9
EC		3.89	2.13	54.8

1/ N = 4, $r_{.95} = .886$, and $r_{.99} = .989$.

TABLE III-D3. SUMMARY STATISTICS FOR CATION RATIOS. 1/

GROUNDWATER					
<u>Correlation Coeff. w/EC</u>			<u>Means</u>		
	<u>Mg</u>	<u>Ca</u>		<u>Mg</u>	<u>Ca</u>
Na	.285	.332	Na	4.60	8.94
Ca	-.104		Ca	.781	
N = 10			<u>Std. Dev.</u>		
	<u>r_{.95}</u>	<u>= .549</u>		<u>Mg</u>	<u>Ca</u>
	<u>r_{.99}</u>	<u>= .715</u>	Na	1.60	5.39
			Ca	.822	
SOIL					
<u>Correlation Coeff. w/EC</u>			<u>Means</u>		
	<u>Mg</u>	<u>Ca</u>		<u>Mg</u>	<u>Ca</u>
Na	-.885	.775	Na	3.75	2.44
Ca	-.999**		Ca	1.60	
N = 4			<u>Std. Dev.</u>		
	<u>r_{.95}</u>	<u>= .886</u>		<u>Mg</u>	<u>Ca</u>
	<u>r_{.99}</u>	<u>= .989</u>	Na	.762	.472
			Ca	.565	

1/ The vertical numbers of the tables are numerators and the horizontal numbers are denominators. For example, the mean Na/Ca value is 8.94.

Site E

Site Description

This site is located close to the main canal (Fig. I-3). Sugar beets were raised the first year and corn the second. The productivity is rated as excellent.

Soil-Groundwater Relationships

Figure III-E1 shows that the textural distribution with depth is a sandy loam for about the upper .5 meter and a sandy clay throughout the rest of the profile.

The measured soil variables are shown in Figures III-E2, E3, and E4. The EC is relatively low throughout the profile but has a strong peak at about .9 m. This depth is slightly below the textural change and slightly above the groundwater maximum.

The profile $\text{NO}_3\text{-N}$ is generally high. The surface saturation percentage is possibly high because of organic matter accumulation.

As expected, the EC-depth curve corresponds closely with the Na and Mg-depth curves. The Ca, Mg, and Na curves have very similar shapes. Calcium is higher at the surface than Mg or Na but is less than either for the remainder of the profile. The K content is higher near the surface and drops off rapidly with depth.

Piezometer height over time is shown in Figure III-E5. All of the piezometers and the access tube responded the same so only the data for

the 4.5 m piezometer are presented. During the irrigation season the groundwater height remained relatively stable at 1.0 to 1.5 m. The groundwater level at this site is highly dependent upon irrigation or the canal.

The groundwater variables for the two seasons are shown in Figures III-E6, E7, and E8. The access tube installed in 1976 was destroyed by cultivation and had to be replaced; thus, only four groundwater samples were obtained. The ion concentration of the groundwater was generally low but higher in 1976 than 1975. The reason for the fluctuation both within and between years is not apparent but may be associated with irrigations. The EC data are particularly striking; during 1975 EC decreased with time but increased with time during 1976. Except for a high level in the first sample, NO_3 remained stable at about .5 meq/l both years.

For both years the Mg concentration was generally higher than the sodium.

The anions of the groundwater followed similar changes in concentration over time, being high in early summer but quickly approaching a smaller more stable concentration.

Relative levels of cations vs. EC are shown in Figure III-E9. At this site the relative amount of any of the cations is about the same for the soil and groundwater. This is different from other sites where the groundwater contained more sodium and the soil more calcium.

A statistical summary of groundwater and soil variables is given in Tables III-E1, E2, and E3. Only fluctuations in Mg had a statistically significant influence on the EC of the groundwater. As would be expected, fluctuations in the relatively soluble ions (Mg and Na) had a significant influence on the EC of the soil. Calcium is the least variable of the groundwater cations. Sodium was the least variable on a percentage basis. Percent Mg had a positive correlation with EC but Ca a negative. The quality index ratios of Na/Mg, Ca/Mg, and Na/Ca of both the groundwater and the soil are approximately 1; this is different from other sites.

Summary

The productivity is excellent. The EC is low throughout the profile. The Ca, Mg, and Na curves have similar distribution with depth. They have similar means although $Na > Mg > Ca$.

The piezometers and access tube had similar heads over time. The groundwater level is dependent upon canal flow or irrigation.

Mg is the dominant cation of the groundwater. Sulfate is by far the dominant anion. Magnesium had a significant influence on the EC of the groundwater. Cation ratios are approximately 1.

SITE E

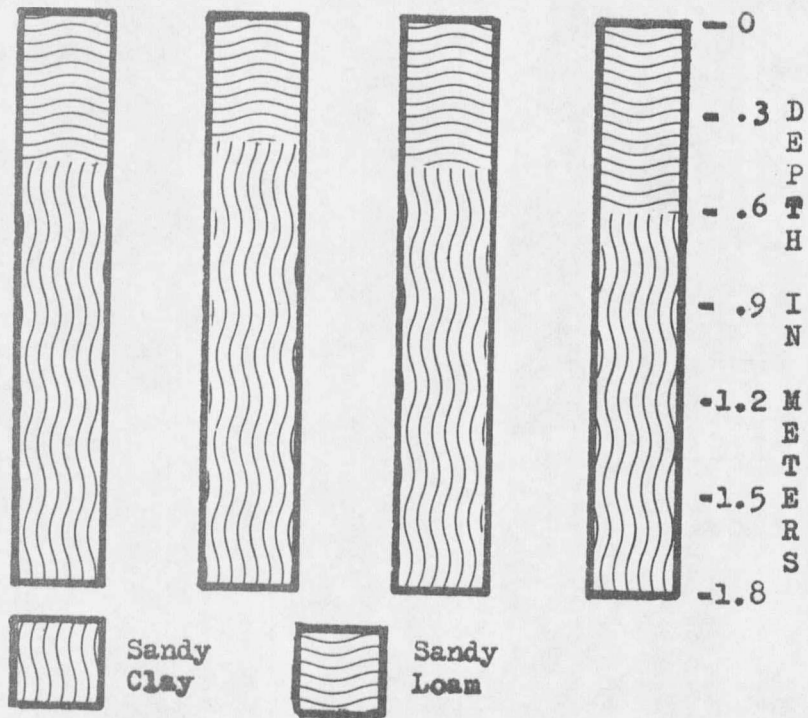


Fig. III-E1. Horizonation of soil profile at four sampling sites adjacent to groundwater access tube.

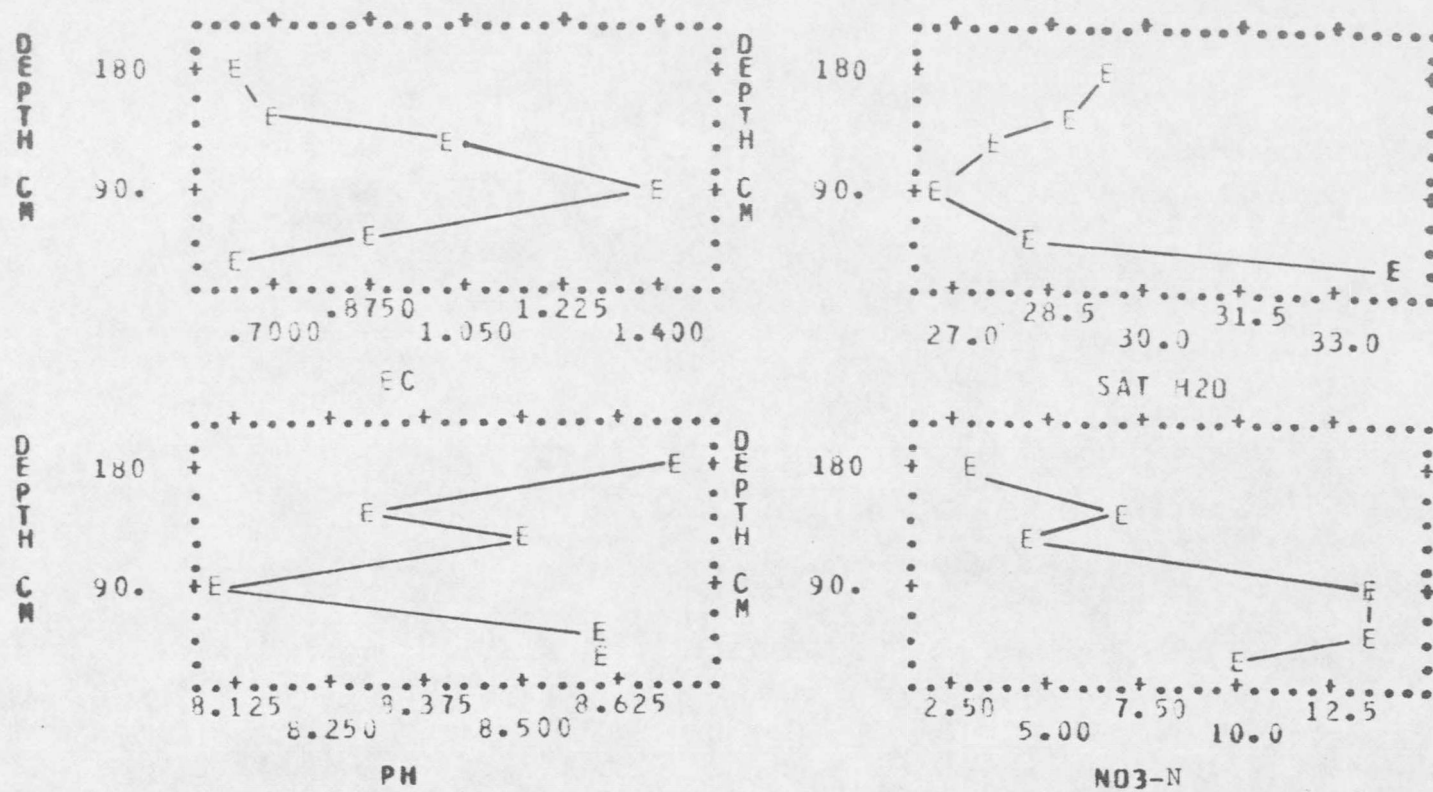


Fig. III-E2. Distribution of electrical conductivity (mmhos/cm), NO₃-N (ppm), pH, and saturated water percentage of the soil with depth. The pH and EC are of the saturated extract.

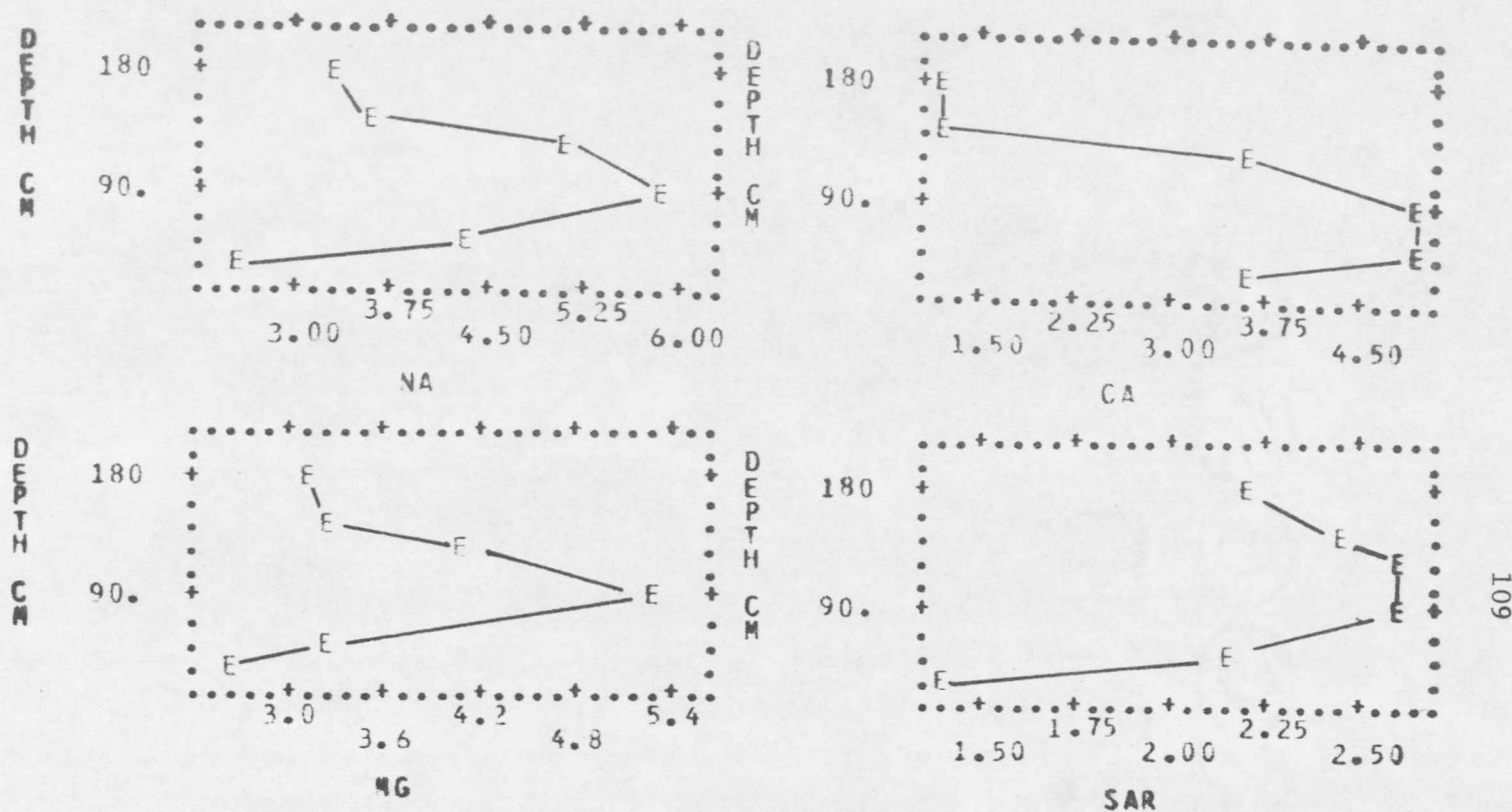


Fig. III-E3. Distribution of major cations (meq/l) of saturated extract and sodium adsorption ratio (SAR) with soil depth.

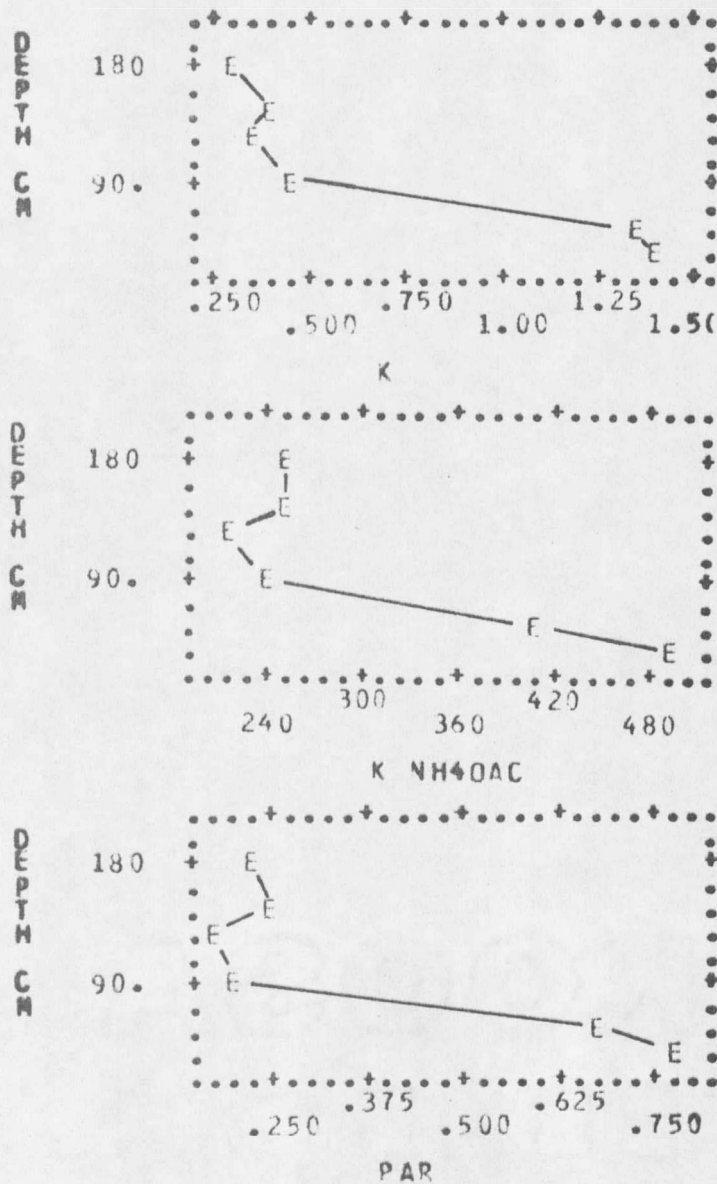
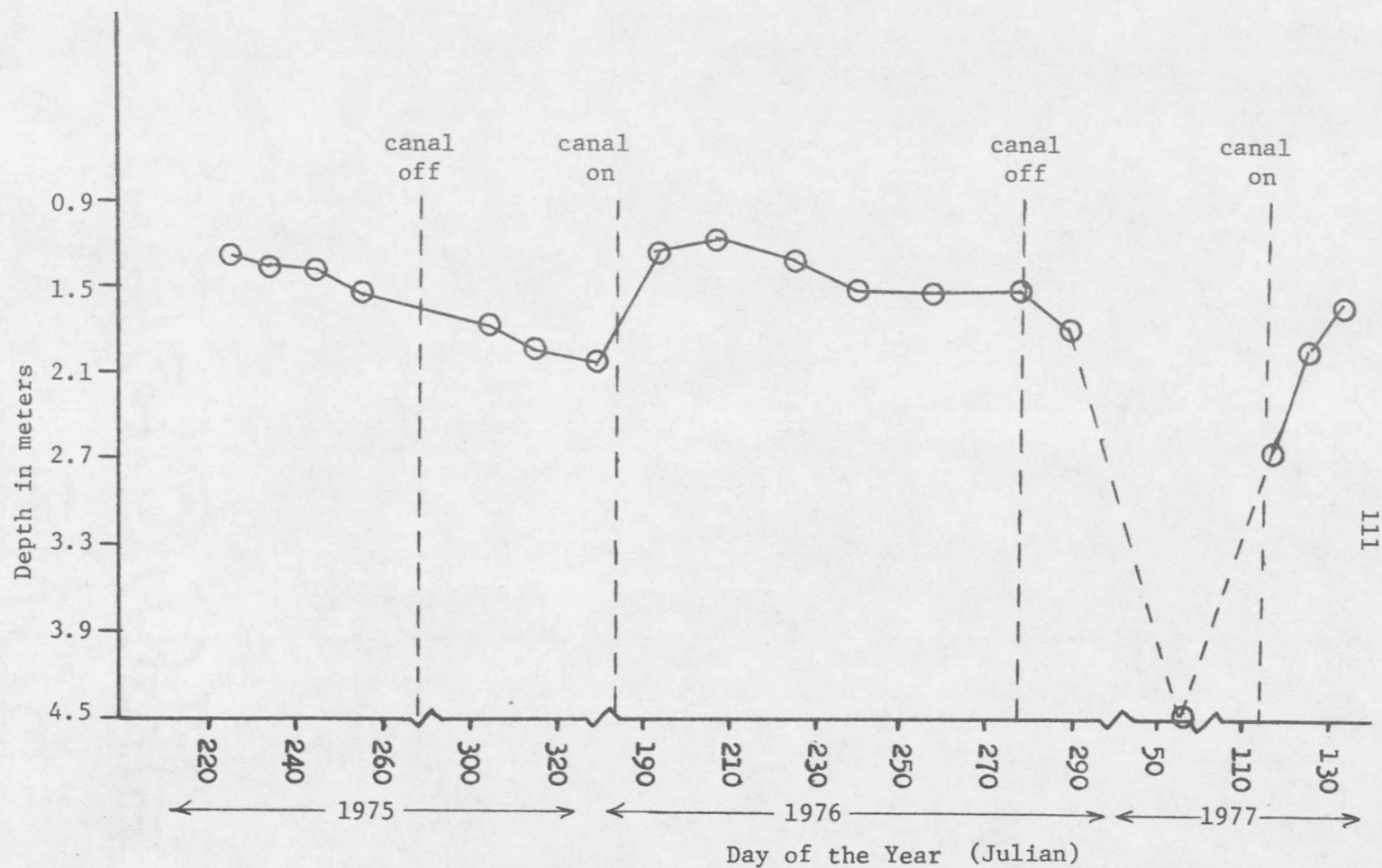


Fig. III-E4. Distribution of water soluble K (meq/l), ammonium acetate extractable K (ppm), and the potassium adsorption ratio with depth.



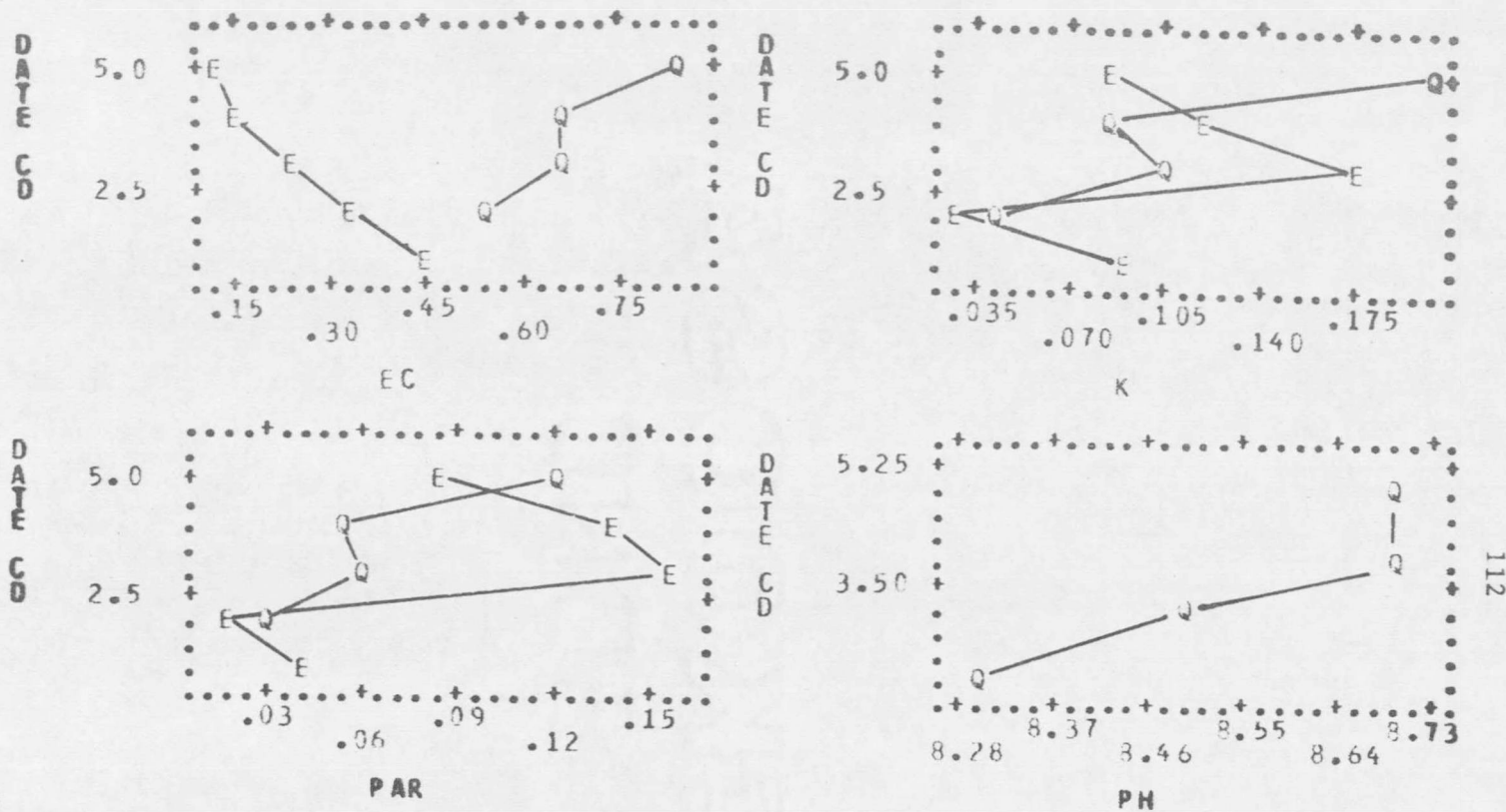


Fig. III-E6. Electrical conductivity (mmhos/cm), K (meq/l), potassium adsorption ratio (PAR), and pH of groundwater vs. time. The E and Q data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-E5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

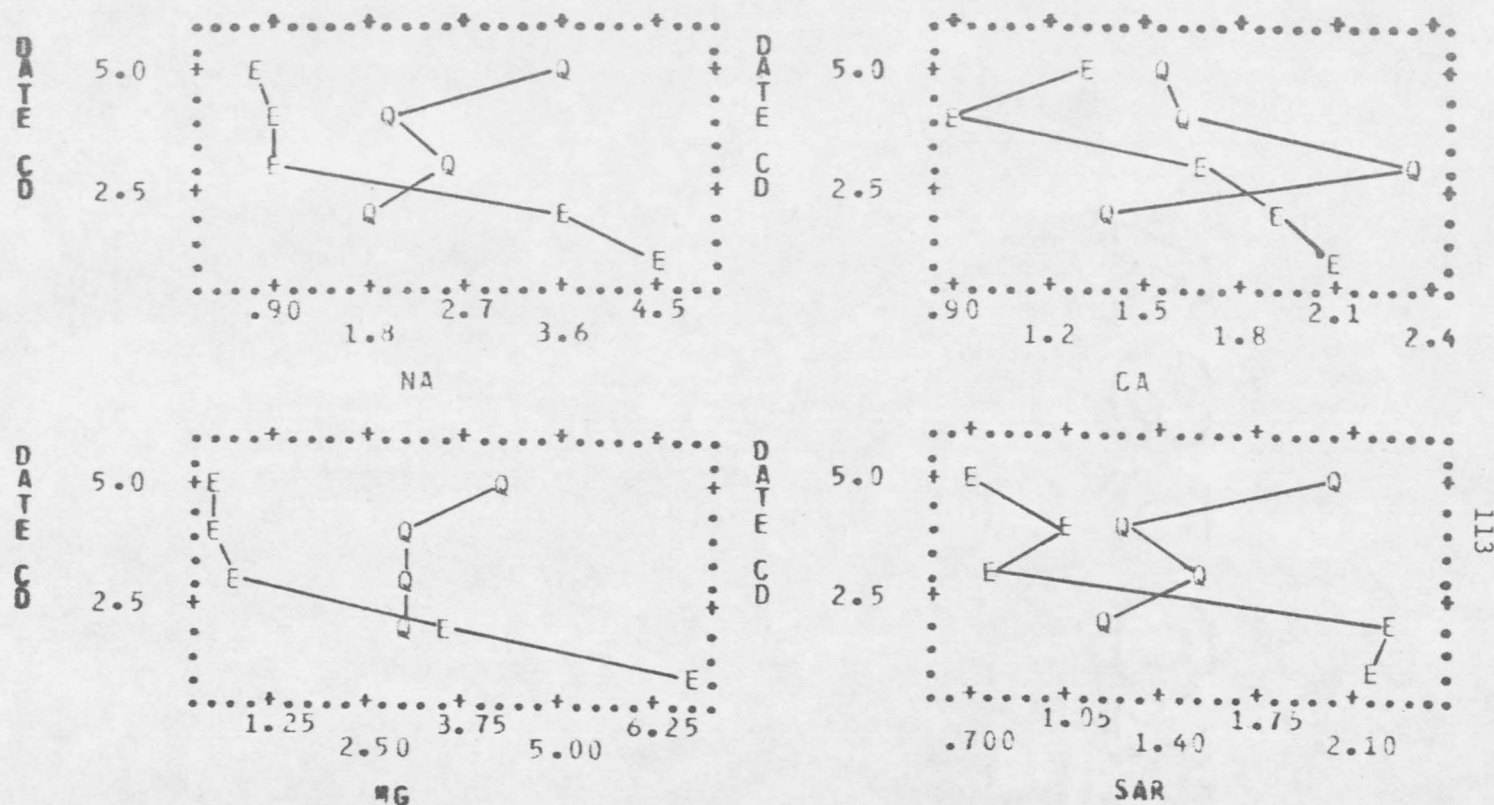


Fig. III-E7. Concentrations of major cations (meq/l) and sodium adsorption ratio of ground-water vs. time. The E and Q data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-E5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

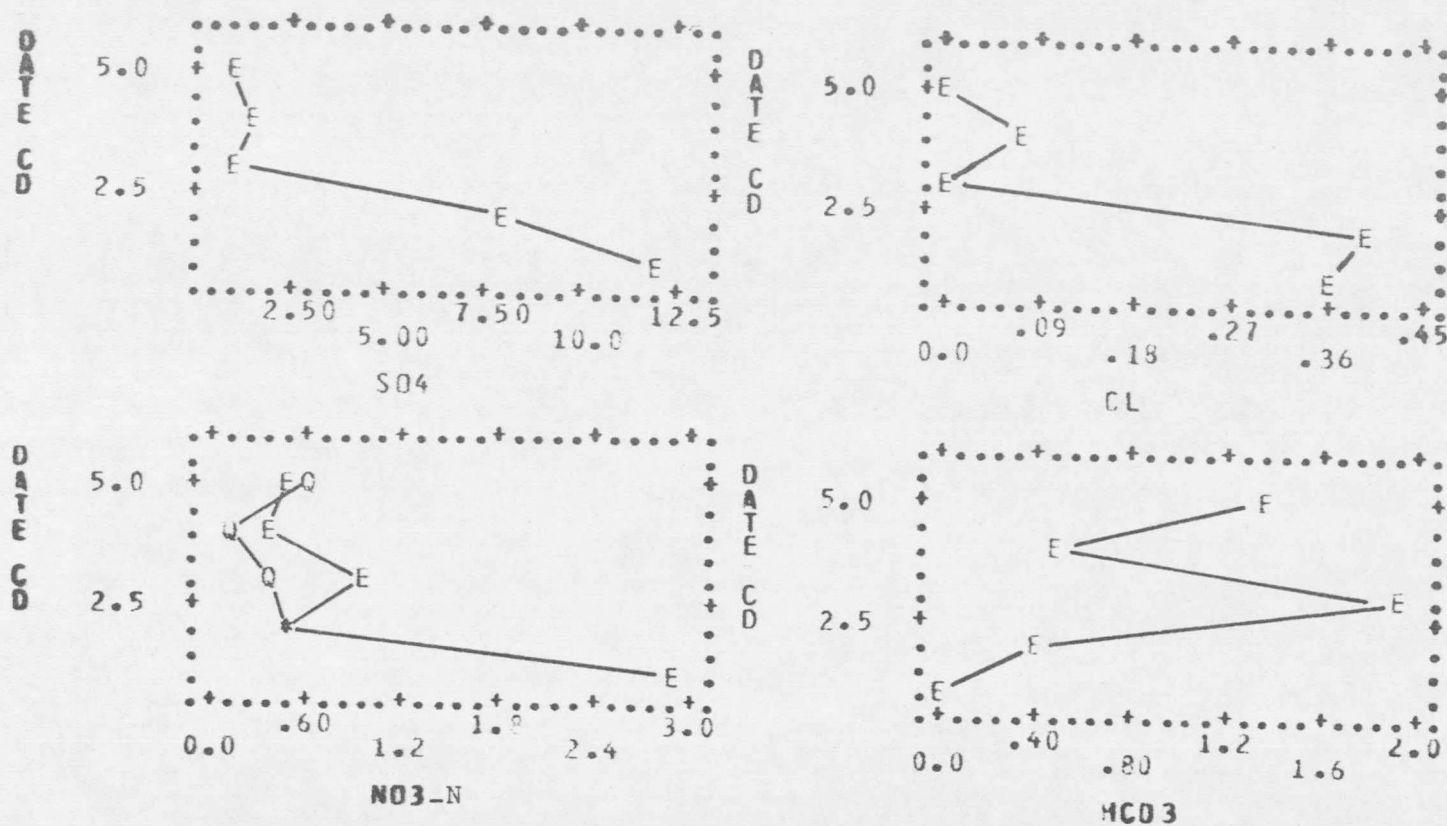


Fig. III-E8. Anion concentrations of groundwater (meq/l) vs. time. These data are for 1975 only. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-E5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

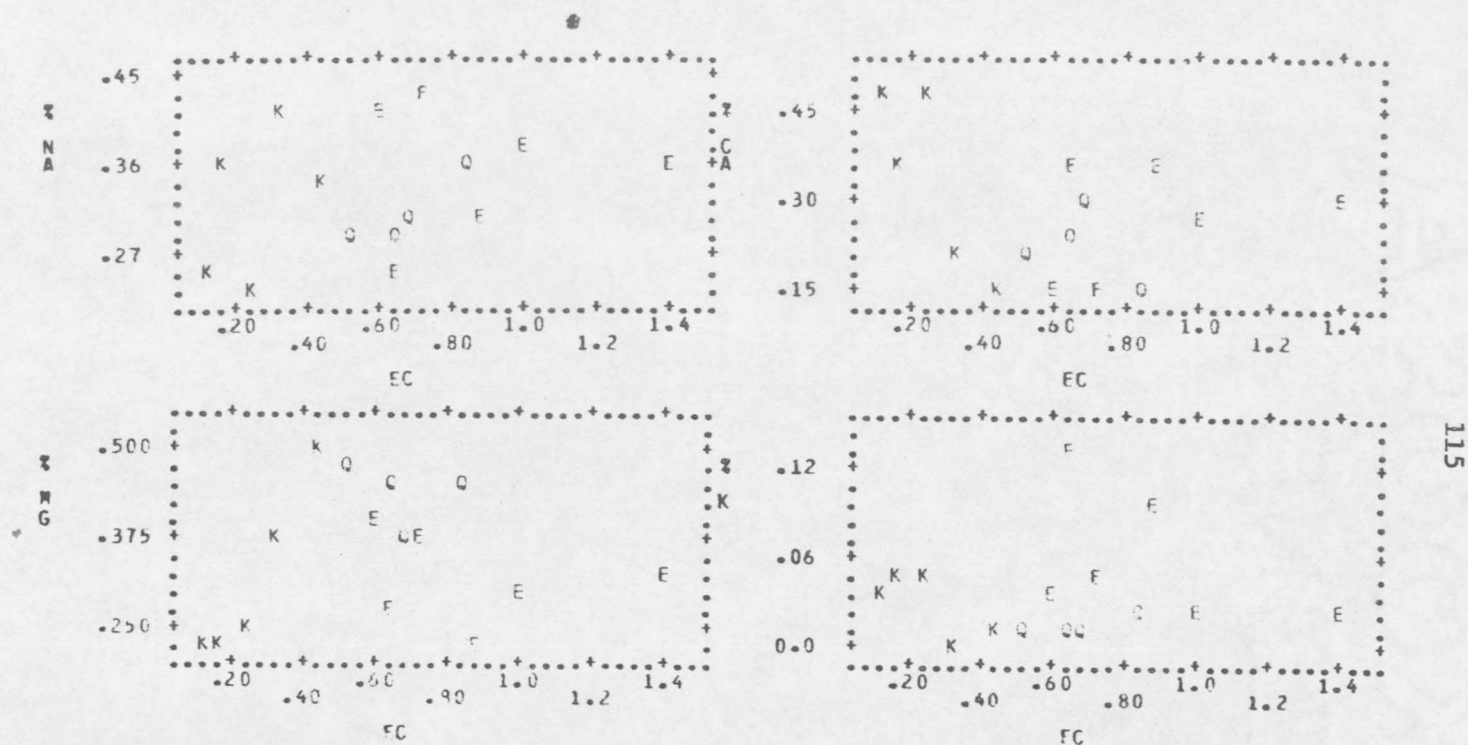


Fig. III-E9. Individual cation fractions (cation/total cations) as a function of EC for groundwater and soil. Data points E, K, and Q represent soil, groundwater 1975 and groundwater 1976, respectively.

TABLE III-E1. SUMMARY STATISTICS OF SOIL VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.941**	4.10	1.23	30.0
Mg	.968**	3.62	.953	26.3
Ca	.681	3.25	1.65	50.8
K	-.249	.705	.517	73.3
<u>Cation Fraction</u>				
Na	.037	.356	.0685	19.2
Mg	-.162	.318	.0616	19.4
Ca	.315	.264	.0927	35.1
K	-.486	.0621	.0448	72.1
SAR	.608	2.22	.444	20.0
EC		.879	.302	34.4

1/ N = 6, $r_{.95} = .729$, and $r_{.99} = .882$.

TABLE III-E2. SUMMARY STATISTICS OF GROUNDWATER VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.534	2.27	1.39	61.2
Mg	.617*	2.85	1.99	69.8
Ca	.437	1.64	.445	27.1
K	.233	.103	.0566	54.9
<u>Cation Fraction</u>				
Na	.202	.318	.0543	17.1
Mg	.788**	.372	.113	30.4
Ca	-.724*	.289	.125	43.3
K	-.555	.0211	.0175	82.9
SAR	.509	1.44	.592	41.1
EC		.439	.248	56.5

1/ N = 9, $r_{.95} = .582$, and $r_{.99} = .750$.

TABLE III-E3. SUMMARY STATISTICS OF CATION RATIOS. 1/

GROUNDWATER

Correlation Coeff. w/EC

	Mg	Ca
Na	-.743*	.568
Ca	-.785**	

N = 9

 $r_{.95} = .582$ $r_{.99} = .750$ Means

	Mg	Ca
Na	.927	1.33
Ca	.969	

Std. Dev.

	Mg	Ca
Na	.308	.657
Ca	.746	

SOIL

Correlation Coeff. w/EC

	Mg	Ca
Na	.338	-.360
Ca	.167	

N = 6

 $r_{.95} = .729$ $r_{.99} = .882$ Means

	Mg	Ca
Na	1.13	1.62
Ca	.906	

Std. Dev.

	Mg	Ca
Na	.138	.930
Ca	.463	

1/ The vertical numbers of the tables are numerators and the horizontal numbers are denominators. For example, the mean Na/Ca value is 1.33.

Site F

Site Description

Site F is located just south of the "shallow to gravel" area in the center of the study area (Fig. I-3). The productivity at this site is rated as good. There is a well-established stand of alfalfa at this site. Blocky structure was found to a depth of .45 to .60 m. This site and the pasture at Site B were the only two sites to have well-developed structure. This is probably a result of a low SAR.

Soil-Groundwater Relationships

The top 1.6 m is clay loam with sandy clay the remainder of the profile (Fig. III-F1). The concentrations of soil variables with depth are shown in Figures III-F2, F3, and F4. There is little salt the first .6 m. At the structural boundary there is a sudden increase in salt and again at the textural change. The saturation moisture percentage is constant for the top meter and then decreases with depth. The profile has a low level of $\text{NO}_3\text{-N}$ except for the surface depth increment. The range in pH is from 7.5 to 8.7 in upper profile but is less variable with depth.

The Na, Mg, and Ca have similar distributions with depth. The Mg and Ca decrease in the first .6 m and then increase to a maximum at 1.2 and .9 m, respectively. The Na peak is at 1.5 m. Typically the

three major cations peak with depth in the order $\text{Ca} > \text{Mg} > \text{Na}$. The SAR is lowest in the top .9 m and then increases with depth. The K of the saturated extract does not parallel a decrease with depth of ammonium acetate extractable K but peaks at mid profile.

The change in piezometric heads at various depths with time is shown in Figure III-F5. The piezometer data indicate that water is moving into the 2.7 m depth from above and below presumably due to irrigation and the gravel aquifer, respectively. The groundwater in the access tube averages about 1.8 m throughout the summer.

The concentration of groundwater variables with time is shown in Figures III-F6, F7, and F8. The EC of the groundwater is much less than that of the profile. The pH increased through the summer. The K concentration seems to control PAR.

The SAR of the groundwater reaches a peak of between 7 and 10 by the end of the summer which coincides with the Na maximum and Ca minimum. Magnesium had similar early and late summer concentrations. Groundwater pH increases with increasing SAR. Sulfate is by far the dominant anion of the groundwater. Cation fractions of soil and groundwater vs. EC are shown in Figure III-F9. The Na fraction is higher in the groundwater than in the soil, percent K and Ca are less, and Mg about the same.

Summary statistics of groundwater and soil cation concentrations, ratios, EC, and SAR are given in Tables III-F1, F2, and F3. Major

cation concentration means rank $\text{Na} > \text{Ca} > \text{Mg}$ in both soil and groundwater. Changes in groundwater concentrations of Na and Mg are chiefly responsible for changes in EC. There is a significant negative correlation between the cation fraction of Mg and K with EC of the soil profile. Magnesium (both absolute concentrations and the cation fraction) is the least variable soil and groundwater cation. The average groundwater EC is 1.14 mmhos/cm as opposed to an EC of 8 of the saturated extract of the profile just above the water table (compare Fig. III-F3 and Table III-F2). The SAR is higher in the groundwater than in the soil. The groundwater ratios of Na/Mg and Na/Ca are both greater than 4, whereas in the soil these ratios are 2.8 and 1.1, respectively. This illustrates the relative mobility of the three cations (more Na relative to Mg and Ca in groundwater than in soil).

Summary

The soil texture at this site is clay loam over sandy clay. There is an increase in salt at the structural boundary and textural change. The Na, Mg, and Ca have similar distributions in the soil profile. The peaks occur with depth in the order $\text{Ca} < \text{Mg} < \text{Na}$. The cation concentrations rank $\text{Na} > \text{Ca} > \text{Mg}$ in both the groundwater and soil profile.

The movement of groundwater is into the 2.7 m depth from above and below. Changes in Na and Mg concentrations in the groundwater are chiefly responsible for changes in EC. The EC is higher in the soil and SAR higher in the groundwater.

SITE F

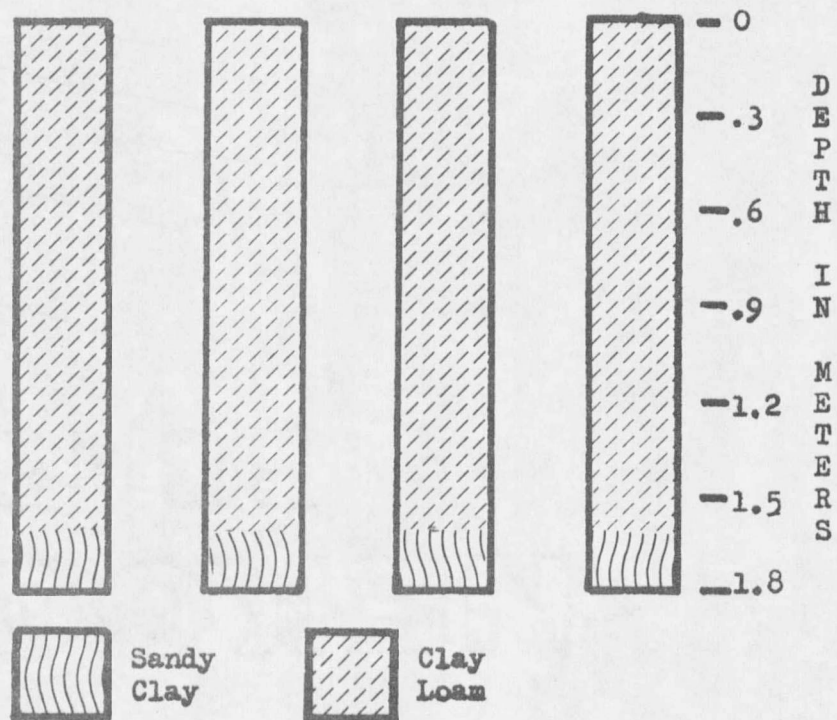


Fig. III-F1. Horizonation of soil profile at four sampling sites adjacent to groundwater access tube.

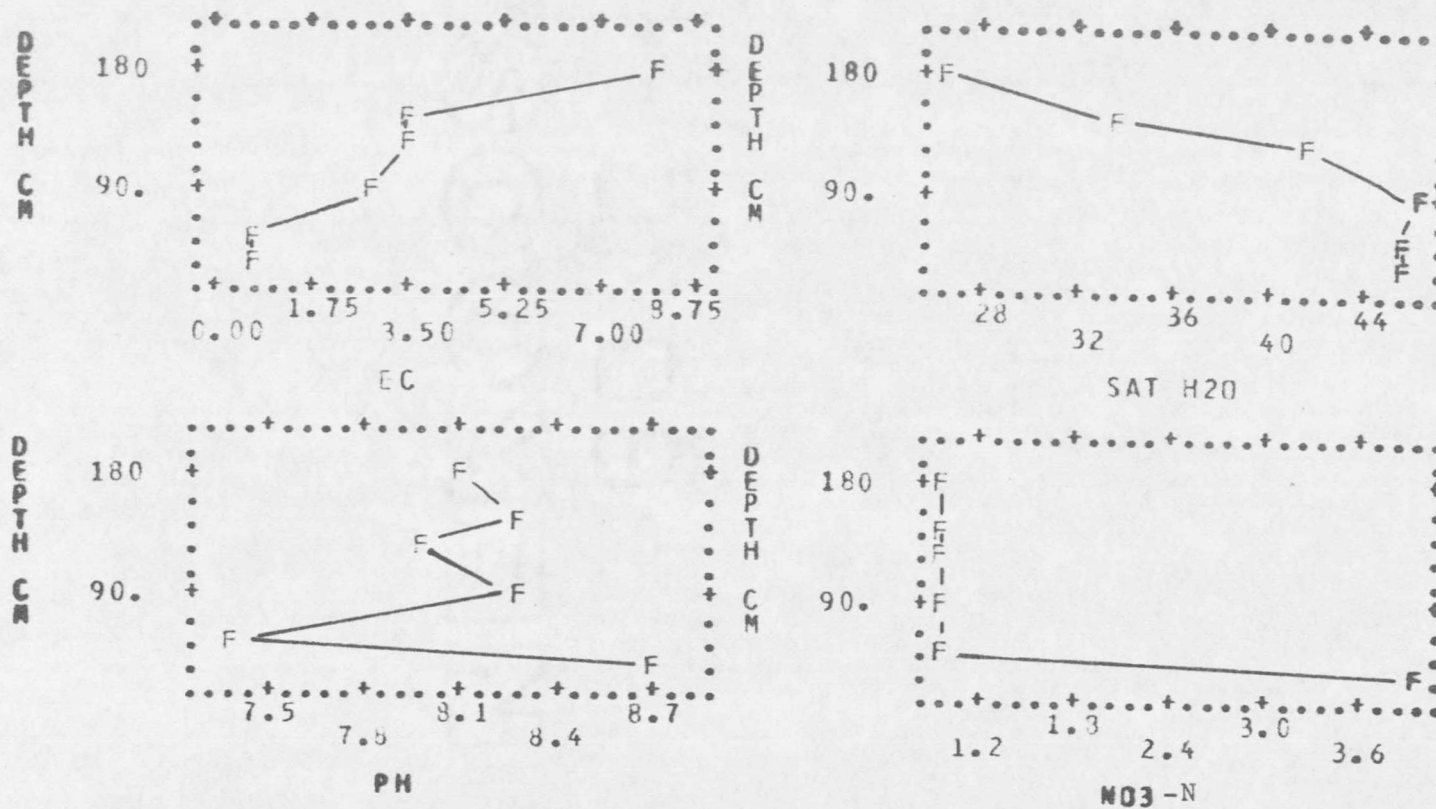


Fig. III-F2. Distribution of electrical conductivity (mmhos/cm), NO₃-N (ppm), pH, and saturated water percentage of the soil with depth. The pH and EC are of the saturated extract.

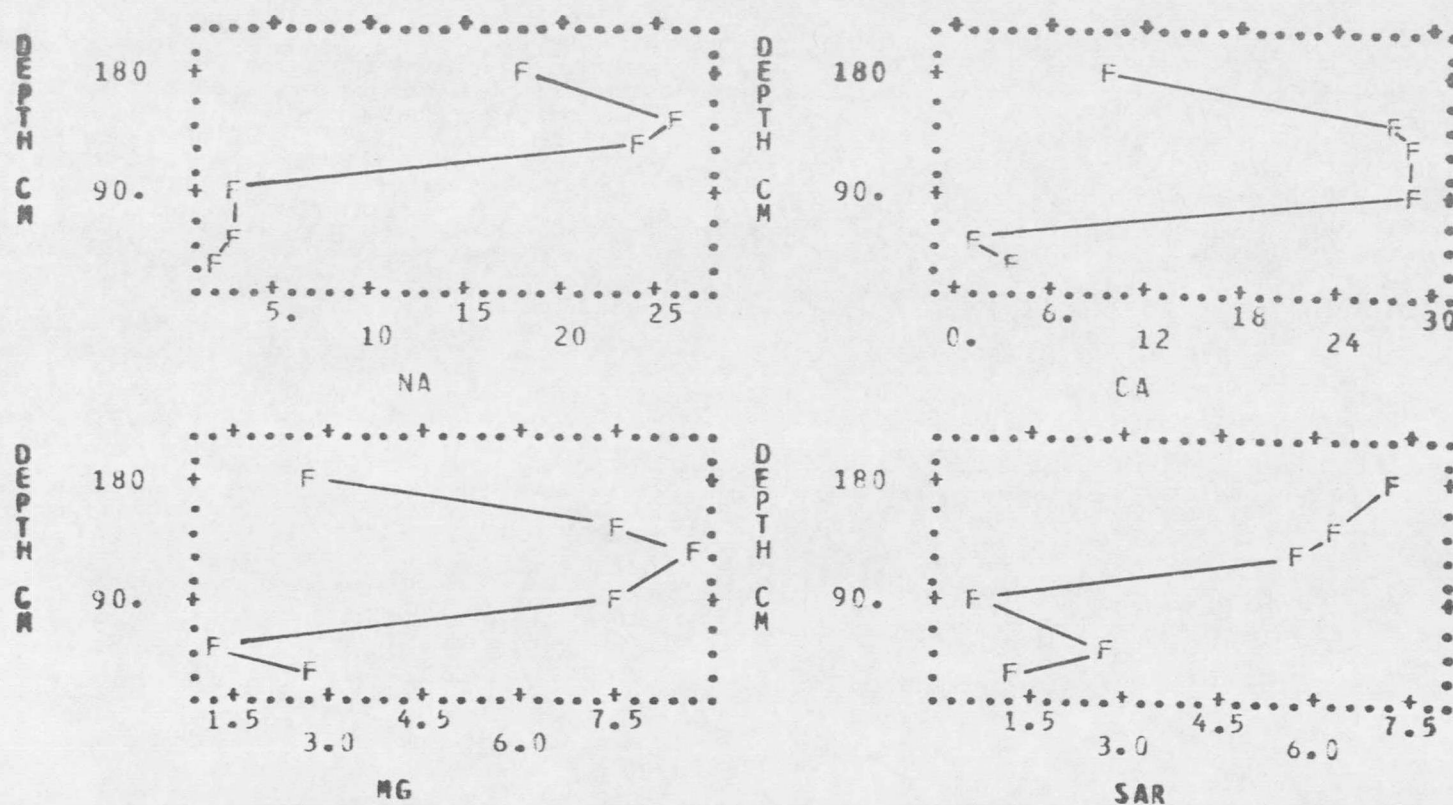


Fig. III-F3. Distribution of major cations (meq/l) of saturated extract and sodium adsorption ratio (SAR) with soil depth.

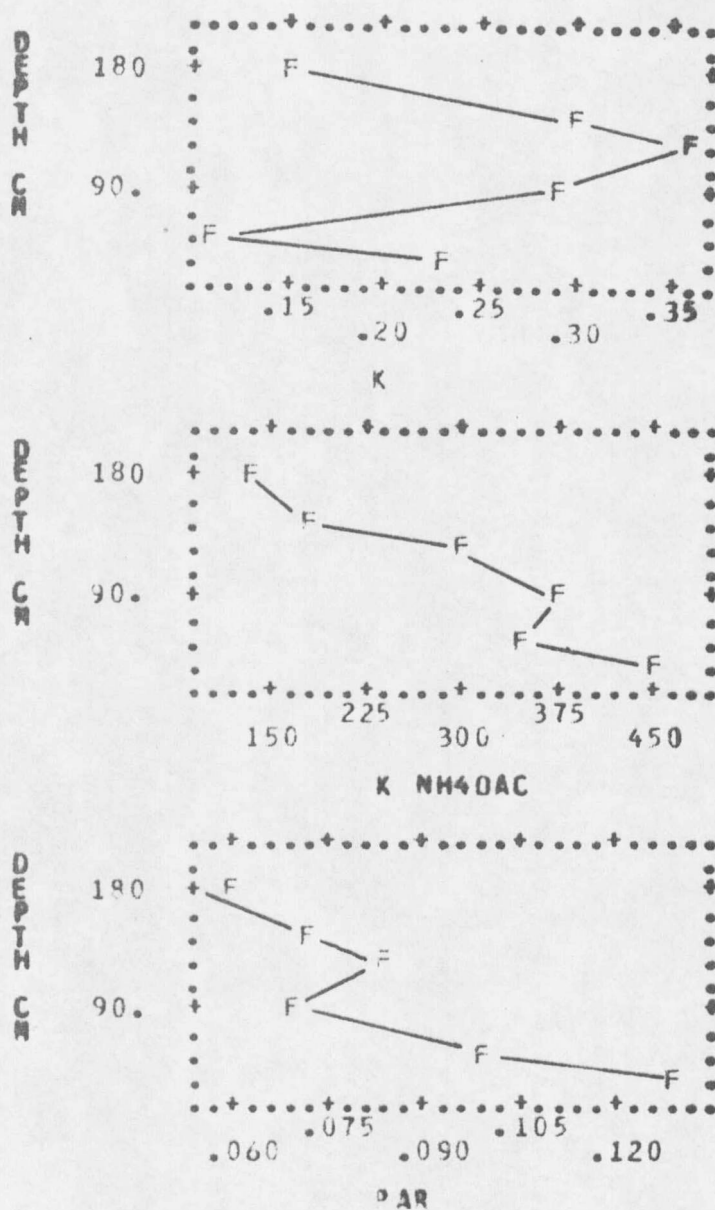


Fig. III-F4. Distribution of water soluble K (meq/l), ammonium acetate extractable K (ppm), and the potassium adsorption ratio with depth.

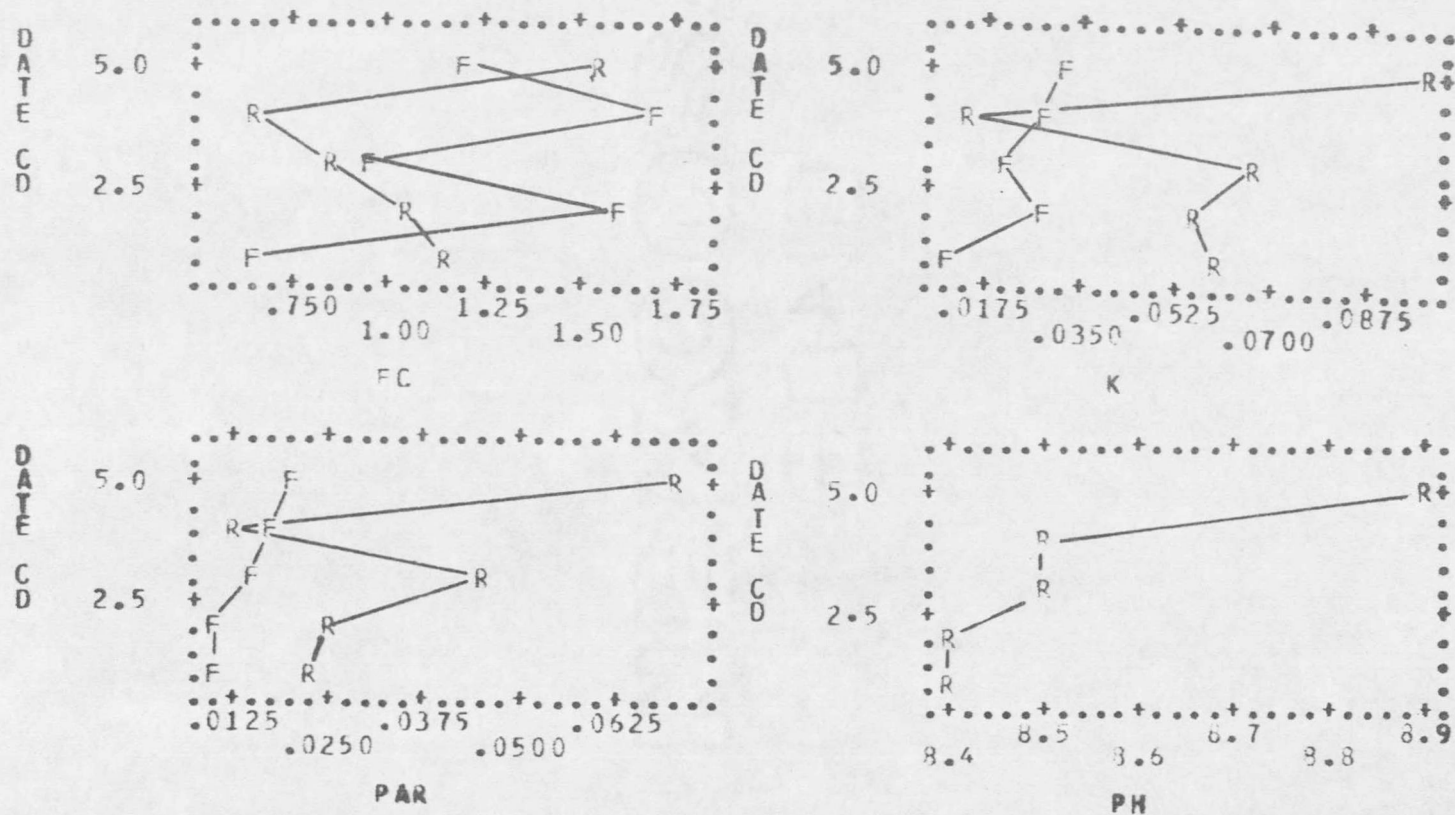


Fig. III-F6. Electrical conductivity (mmhos/cm), K (meq/l), potassium adsorption ratio (PAR), and pH of groundwater vs. time. The F and R data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-F5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

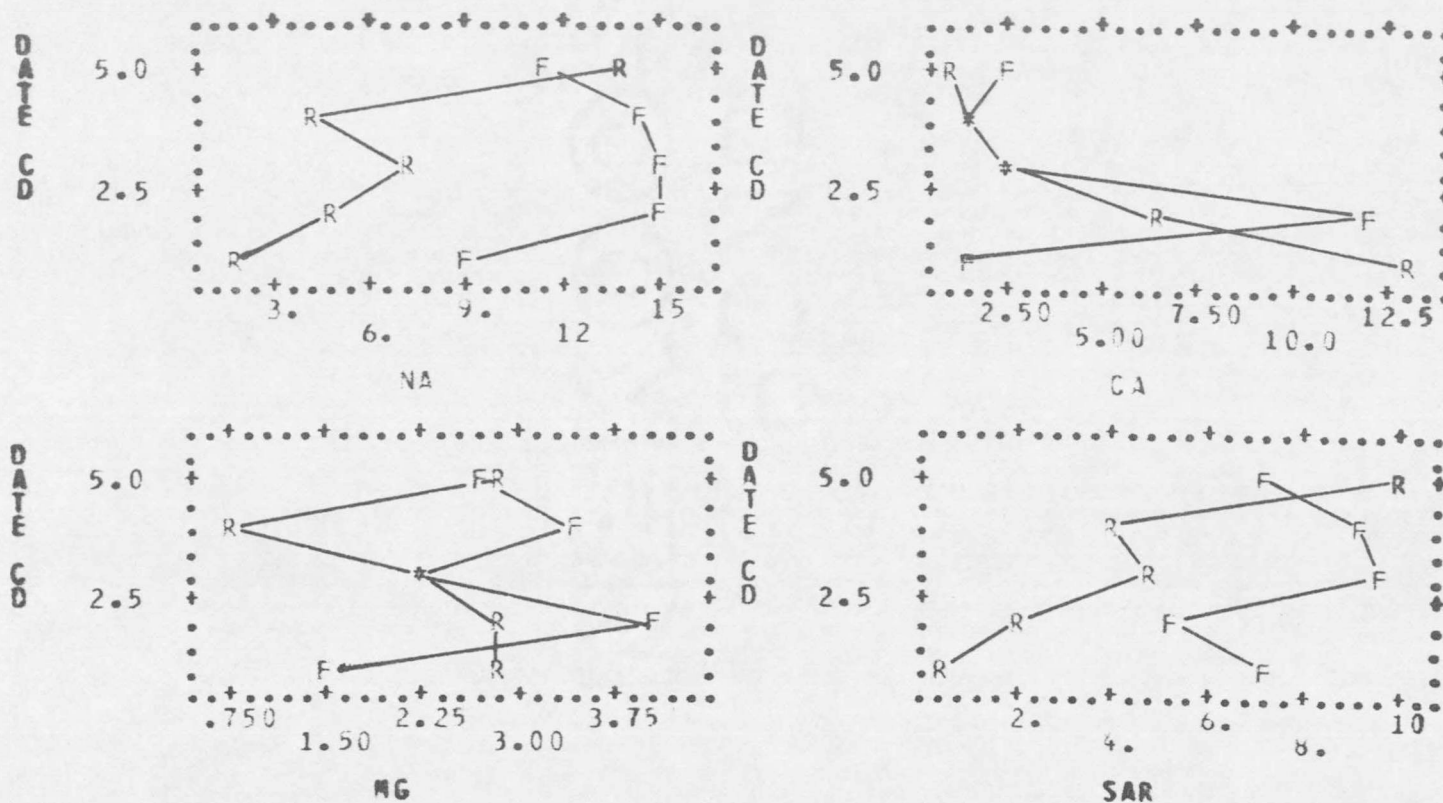


Fig. III-F7. Concentrations of major cations (meq/l) and sodium adsorption ratio of groundwater vs. time. The F and R data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-F5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

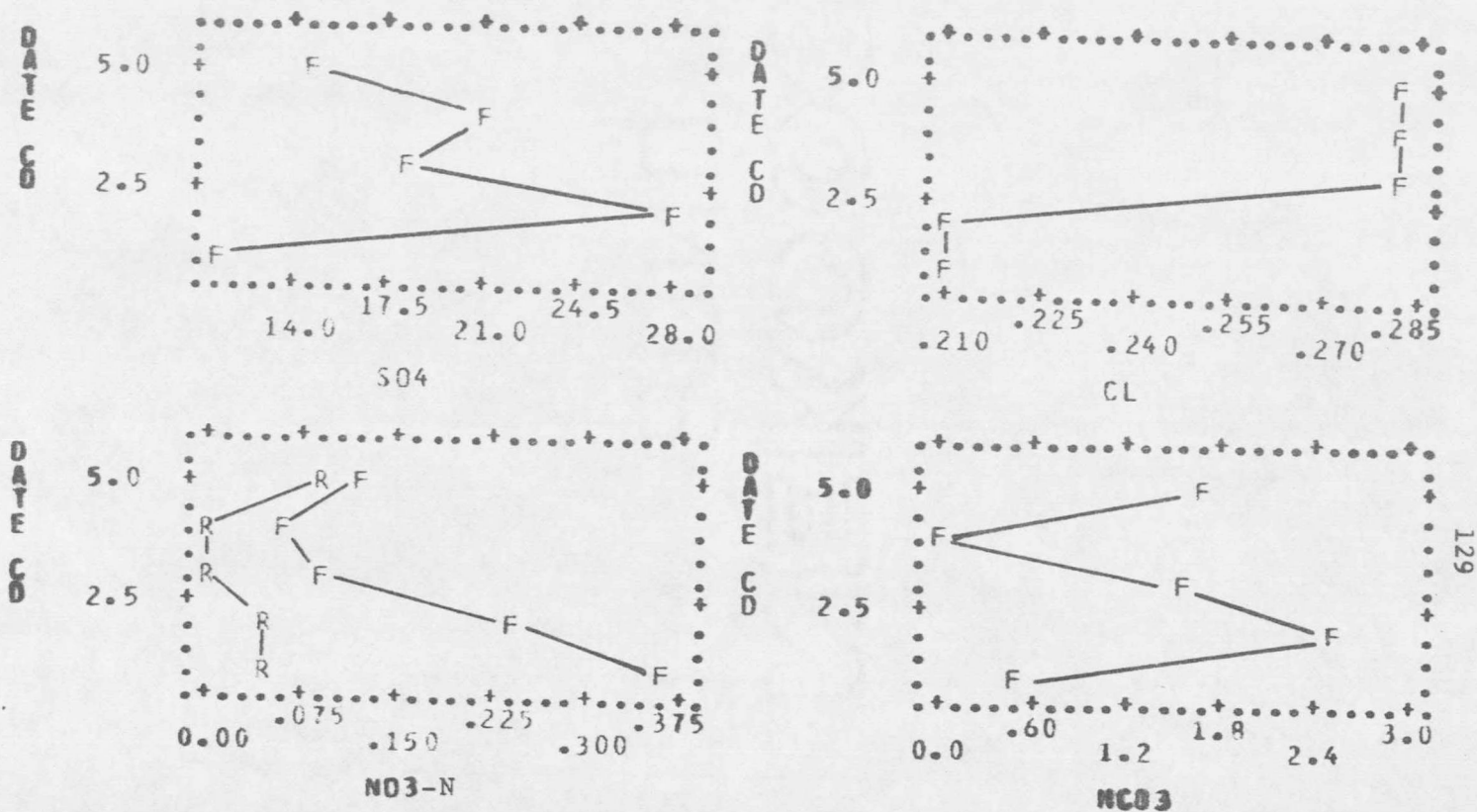


Fig. III-F8. Anion concentrations of groundwater (meq/l) vs. time. These data are for 1975 only. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-F5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.



Fig. III-F9. Individual cation fractions (cation/total cations) as a function of EC for groundwater and soil. Data points F, L, and R represent soil, groundwater 1975 and groundwater 1976, respectively.

TABLE III-F1. SUMMARY STATISTICS OF SOIL VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.571	12.7	11.3	88.9
Mg	.121	5.06	3.21	63.4
Ca	.229	16.7	13.3	79.6
K	-.029	.240	.0955	39.8
<u>Cation Fraction</u>				
Na	.416	.375	.193	51.5
Mg	-.826*	.178	.0814	45.7
Ca	-.035	.434	.170	39.2
K	-.732*	.0115	.00944	82.1
SAR	.753*	3.93	2.77	70.5
EC		3.22	2.79	86.6

1/ N = 6, $r_{.95} = .729$, and $r_{.99} = .882$.

TABLE III-F2. SUMMARY STATISTICS OF GROUNDWATER VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.576*	9.69	5.08	52.4
Mg	.892**	2.55	.910	35.7
Ca	.263	4.50	4.23	94.0
K	.314	.0415	.0275	66.3
<u>Cation Fraction</u>				
Na	.007	.583	.222	38.1
Mg	.254	.153	.030	19.6
Ca	-.043	.261	.213	81.6
K	-.019	.00271	.00187	69.0
SAR	.330	5.96	3.21	53.9
EC		1.14	.379	33.2

1/ N = 10, $r_{.95} = .549$, and $r_{.99} = .715$.

TABLE III-F3. SUMMARY STATISTICS OF CATION RATIOS. 1/

GROUNDWATER					
<u>Correlation Coeff. w/EC</u>			<u>Mean</u>		
	Mg	Ca		Mg	Ca
Na	-.194	.396	Na	4.03	4.64
Ca	-.068		Ca	1.70	
N = 10			<u>Std. Dev.</u>		
r _{.95} = .549				Mg	Ca
r _{.99} = .715			Na	1.85	4.42
			Ca	1.30	
SOIL					
<u>Correlation Coeff. w/EC</u>			<u>Mean</u>		
	Mg	Ca		Mg	Ca
Na	.841*	.151	Na	2.76	1.12
Ca	.712		Ca	2.80	
N = 6			<u>Std. Dev.</u>		
r _{.95} = .729				Mg	Ca
r _{.99} = .882			Na	2.27	.874
			Ca	1.27	

1/ The vertical numbers of the tables are numerators and the horizontal numbers are denominators. For example, the mean Na/Ca value is 4.64.

Site G

Site Description

Site G is located close to the Yellowstone River near the center of the project (Fig. I-3). The productivity is estimated as poor. Corn was grown both years. The soil at this site has developed on recent alluvium.

Soil-Groundwater Relationships

The profile is relatively shallow at this site. There is a clay loam horizon about .5 m thick overlying sand with some interstratified sandy clay lenses (Fig. III-G1). Gravel is encountered at about 1.2 m.

The distribution of soil variables with depth is shown in Figures III-G2, G3, and G4. The EC reaches a maximum of 3.5 mmhos/cm at .9 m and is about 0.6 to 1.2 above and below this depth. The pH is near 8.4 at the surface and at about 1 m. The $\text{NO}_3\text{-N}$ is a maximum near the surface and decreases with depth.

The major cations show a maximum concentration at about .9 m, in the same zone as the high EC and pH. Calcium and Mg have identical profile distribution although the Ca is about five times the concentration of Mg. Sodium concentrations are slightly less than Ca. The SAR reaches a first peak at .9 m and a maximum at 1.5 m. Below 1.2 m the Na increases but Mg and Ca decrease. This results in an SAR maximum of 10 at 1.5 m.

The ammonium acetate extractable K is not typically distributed through the profile and is not closely correlated with water soluble K.

Changes in piezometric head at various depths are shown in Figure III-G5. The piezometer data indicate the groundwater is moving from 3 m to 2.4 m. The 2.4 m to 5.1 m piezometers had little difference in piezometric head. The water within the access tube was about 1.2 m throughout the first summer and 1.5 m the second. The 3-meter piezometric tube appeared to be especially responsive to canal-irrigation water, especially during the second winter and spring.

Concentration of groundwater variables, with time, are shown in Figures III-G6, G7, and G8. The groundwater EC varied significantly between years; during the second summer it was almost double that of the first. The absolute value of the K varied between years but had the same general shape with time. The PAR was almost identical between years. The pH varied little with time.

The Na and Mg of the groundwater each varied significantly between years but, within a year, were strikingly similar in shape although the Na concentration was about twice that of Mg. Within a year, the EC curves were almost identical to these cations. The absolute concentration of Ca was about double in the second year that of the first, but the fluctuations with time were almost identical both summers. This may have been due to the almost identical treatment of the corn crop the two years.

Cation fractions as a function of EC of the groundwater and soil are shown in Figure III-G9. Magnesium is the only cation fraction that obviously differs from that of the profile and is higher in the groundwater. The relative percentages seem to be grouped by year. The cation fractions of K and Na decreased and Mg and Ca increased in the groundwater the second summer compared to the first, but the absolute value of all cations increased the second summer.

Summary statistics of cation concentrations, ratios, EC, and SAR are shown in Tables III-G1, G2, and G3. Major cations rank as follows: $\text{Na} > \text{Ca} > \text{Mg}$ in both soil and groundwater. Sodium and Ca means are about double in the soil profile compared to groundwater whereas Mg is almost equal. Correlations indicate that increased concentrations of all four cations are responsible for increased groundwater EC. The percentages varied less than absolute values of groundwater cations. This holds true for all but K in the soil. The cation ratios of Na/Mg , Na/Ca , and Ca/Mg are higher in the soil than groundwater by 3, 1.5, and 2.5 times, respectively.

Summary

Site G has a poor level of productivity, probably because of the shallow soil. The soil profile is comprised of clay loam over sand with interstratified sandy clay. All major cation concentrations peak at about .9 m. Mean concentrations ranked $\text{Na} > \text{Ca} > \text{Mg}$ in both groundwater and soil. Ammonium acetate extractable K is at a minimum

at about the .9 m depth. Water soluble K is poorly correlated to ammonium acetate K. The water table was higher the first summer. Cation concentrations of the groundwater were higher the second summer. Na and Mg have dissimilar curves while Ca has similar curves for the two summers. All cation concentration in the groundwater have a significant positive correlation with EC. Ratios of Na/Mg, Na/Ca, and Ca/Mg are higher in the soil than groundwater.

SITE G

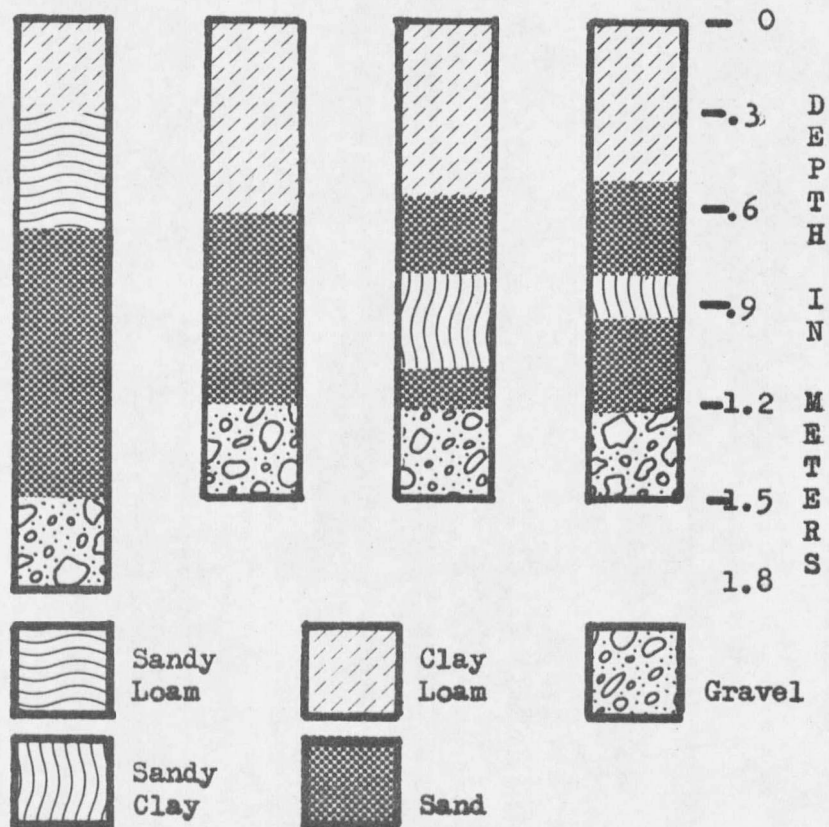


Fig. III-G1. Horizonation of soil profile at four sampling sites adjacent to groundwater access tube.

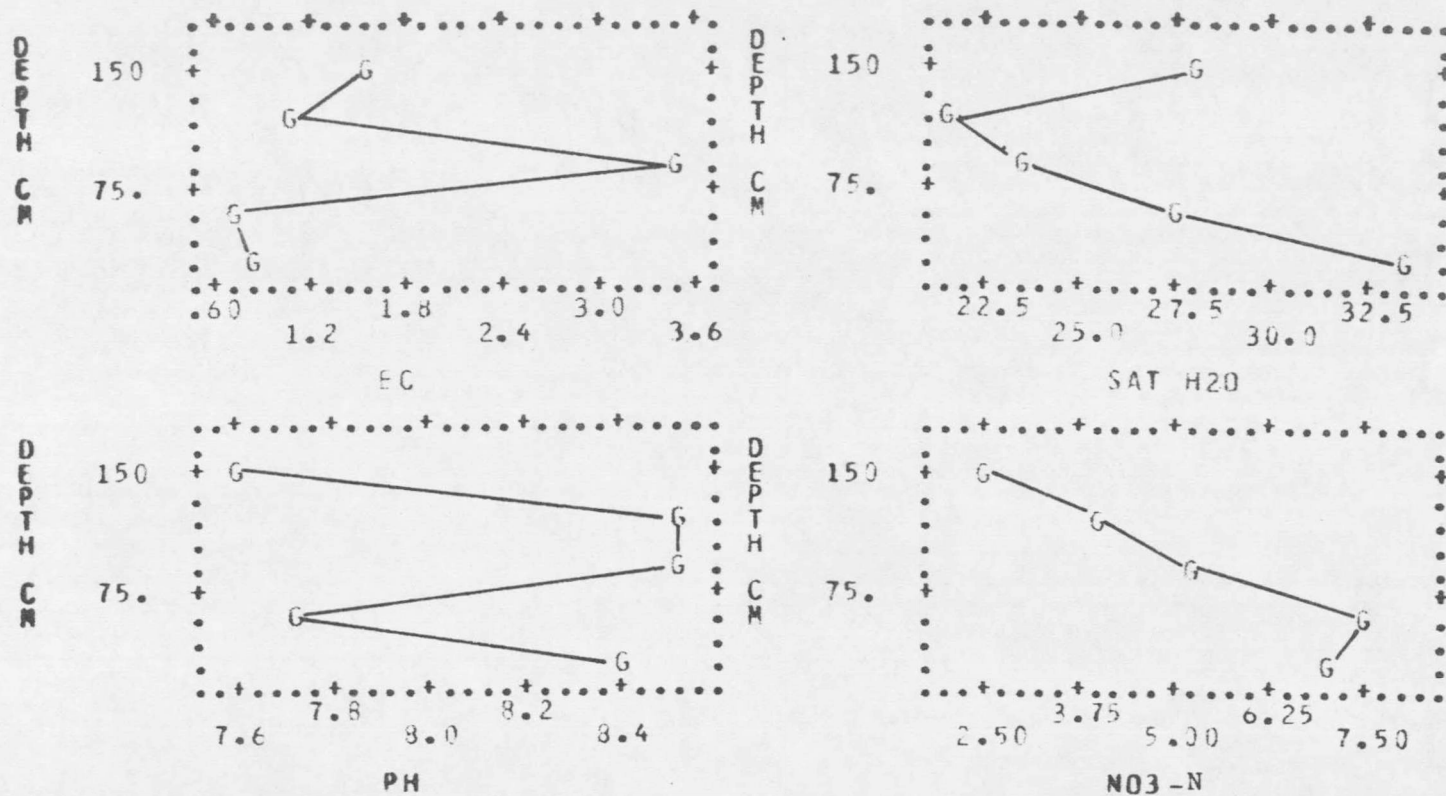


Fig. III-G2. Distribution of electrical conductivity (mmhos/cm), NO3-N (ppm), pH, and saturated water percentage of the soil with depth. The pH and EC are of the saturated extract.

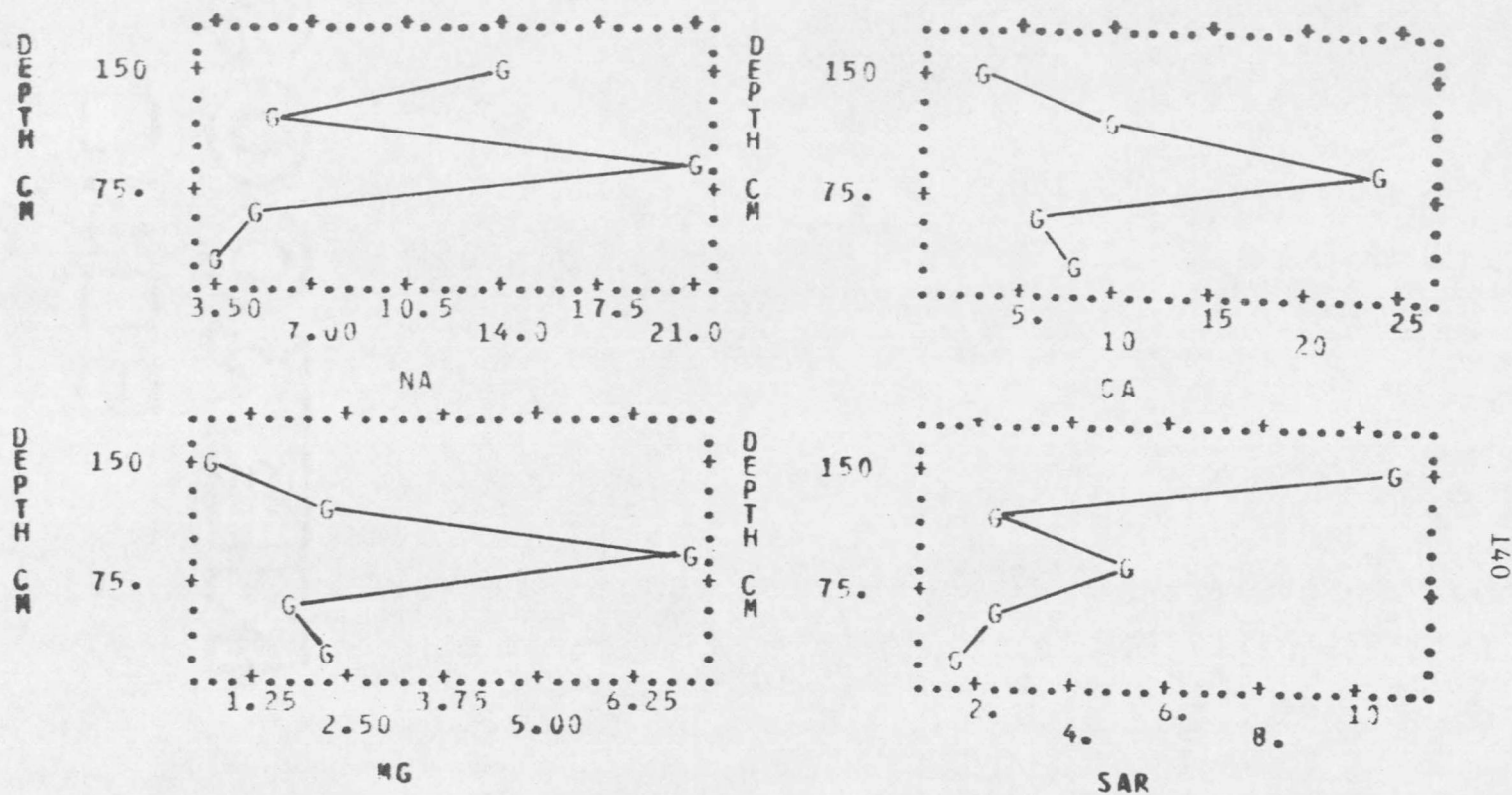


Fig. III-G3. Distribution of major cations (meq/l) of saturated extract and sodium adsorption ratio (SAR) with soil depth.

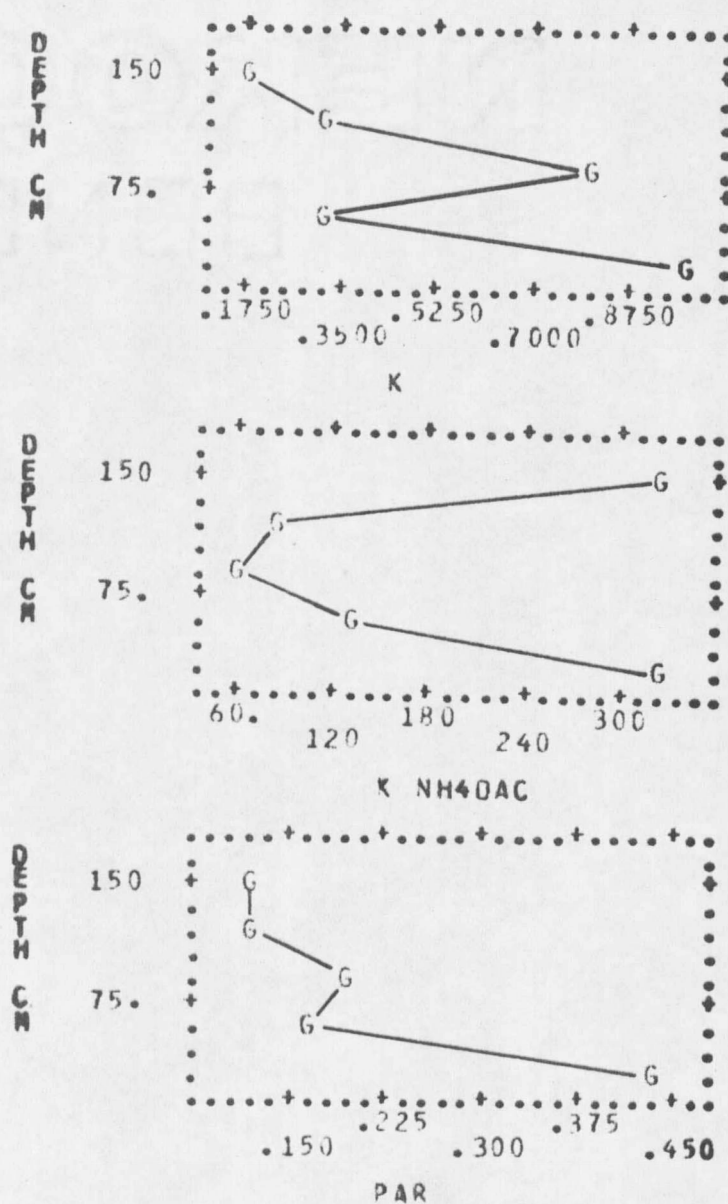


Fig. III-G4. Distribution of water soluble K (meq/l), ammonium acetate extractable K (ppm), and the potassium adsorption ratio with depth.

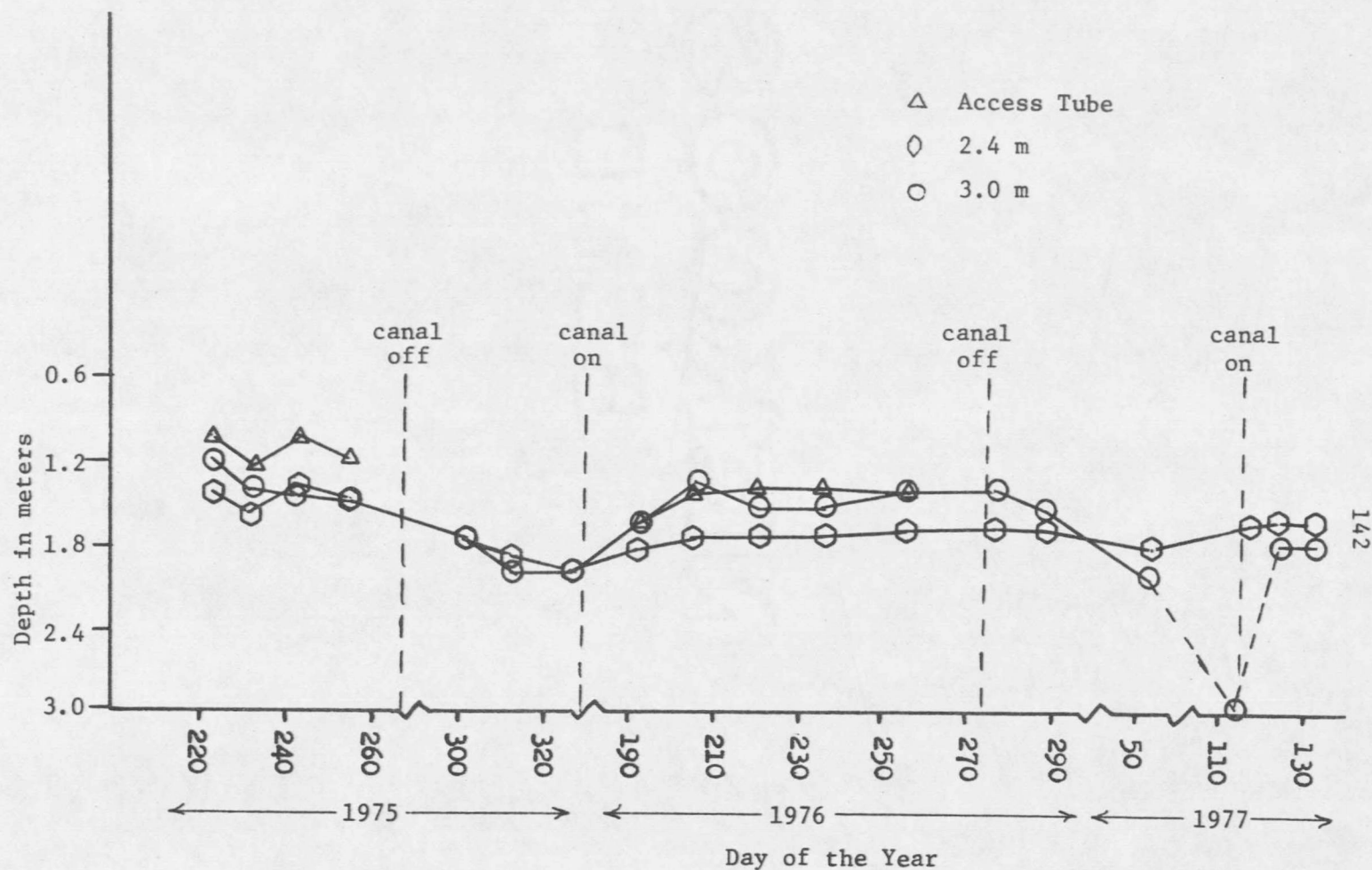


Figure III-G5. Piezometric head with time. Data points connected with dashed lines represent unsaturated conditions at the depth sampled by the piezometer. The 1.8 and 2.4 m piezometers are essentially the same and are plotted as one line.

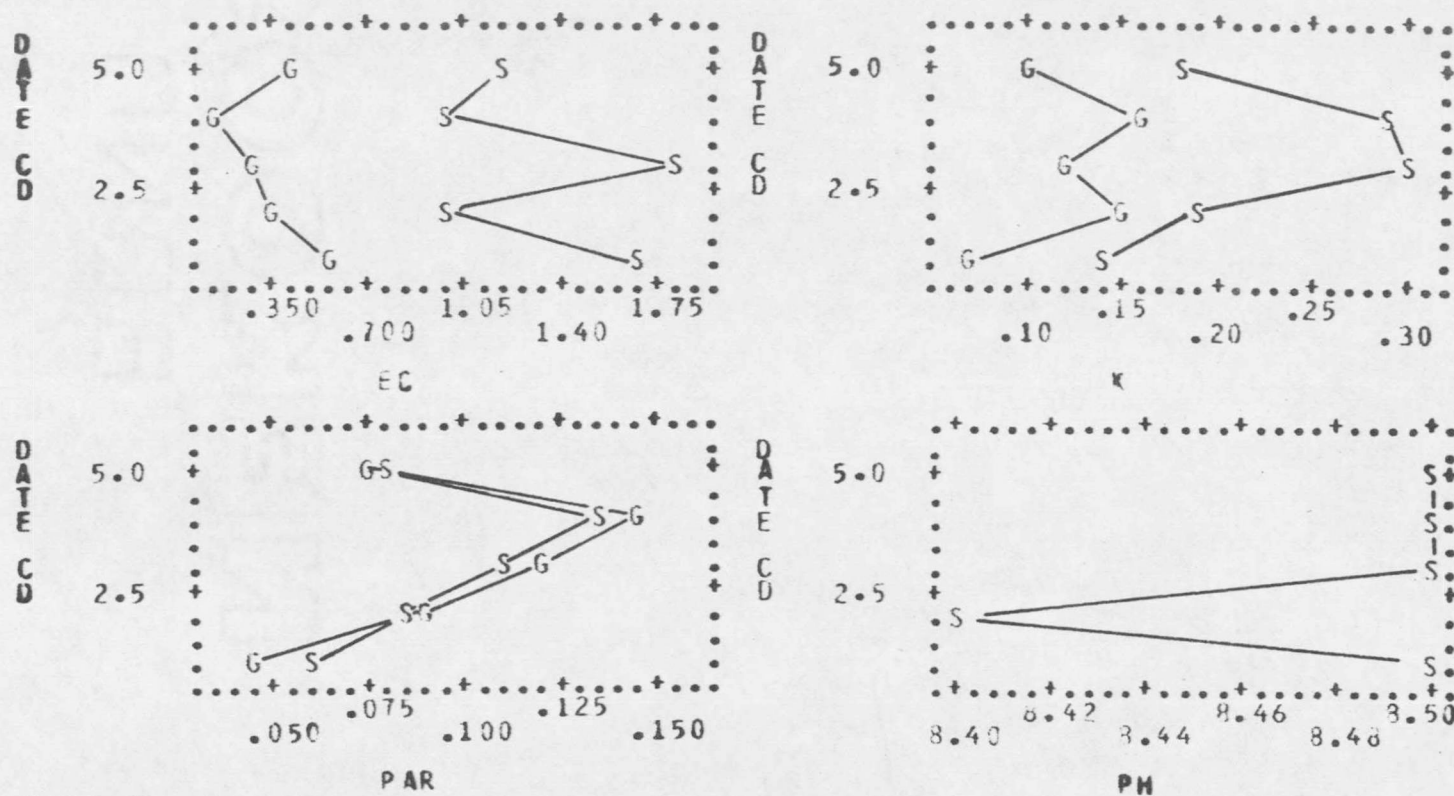


Fig. III-G6. Electrical conductivity (mmhos/cm), K (meq/l), potassium adsorption ratio (PAR), and pH of groundwater vs. time. The G and S data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-G5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

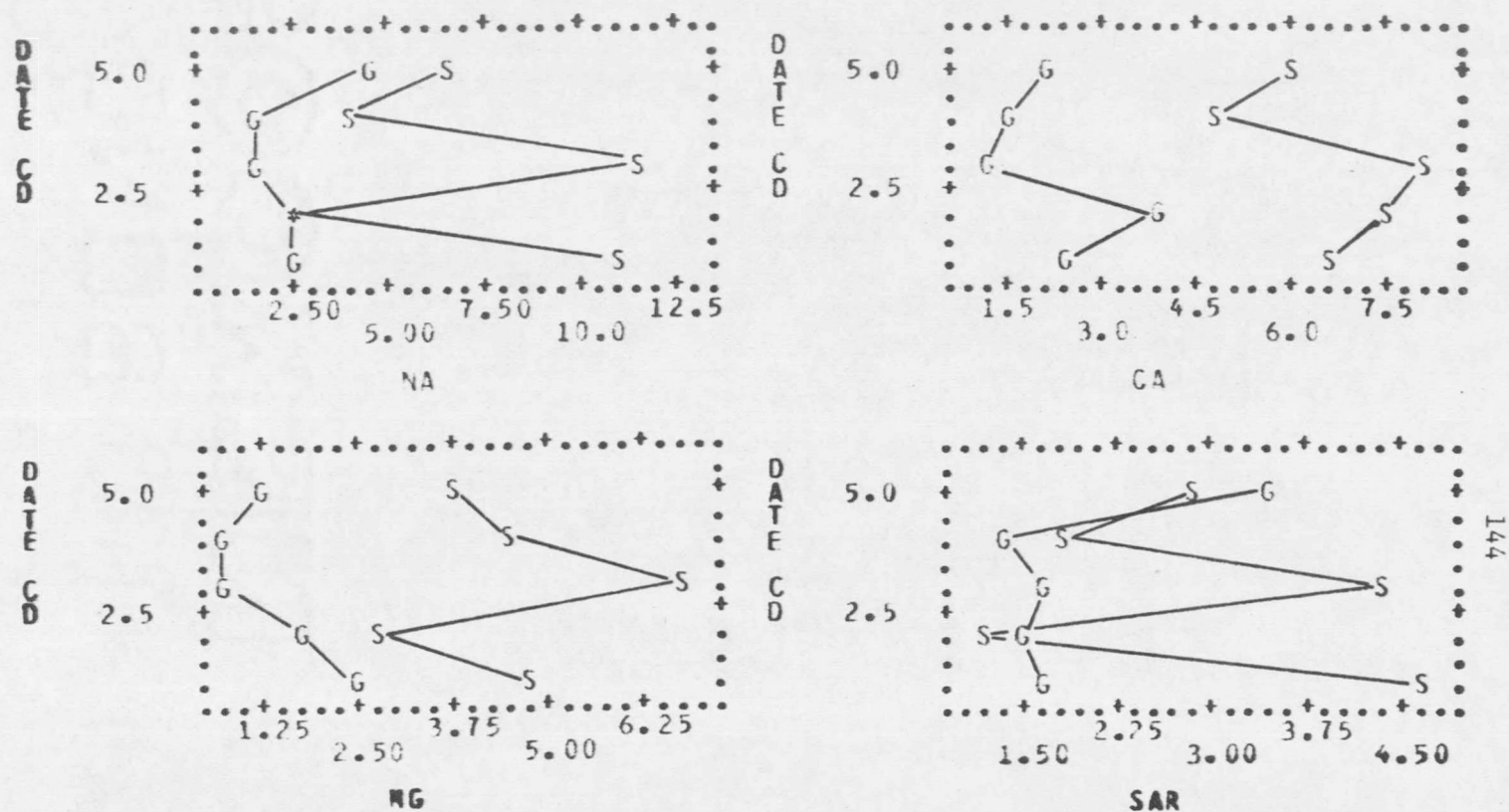


Fig. III-G7. Concentrations of major cations (meq/l) and sodium adsorption ratio of ground-water vs. time. The G and S data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-G5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

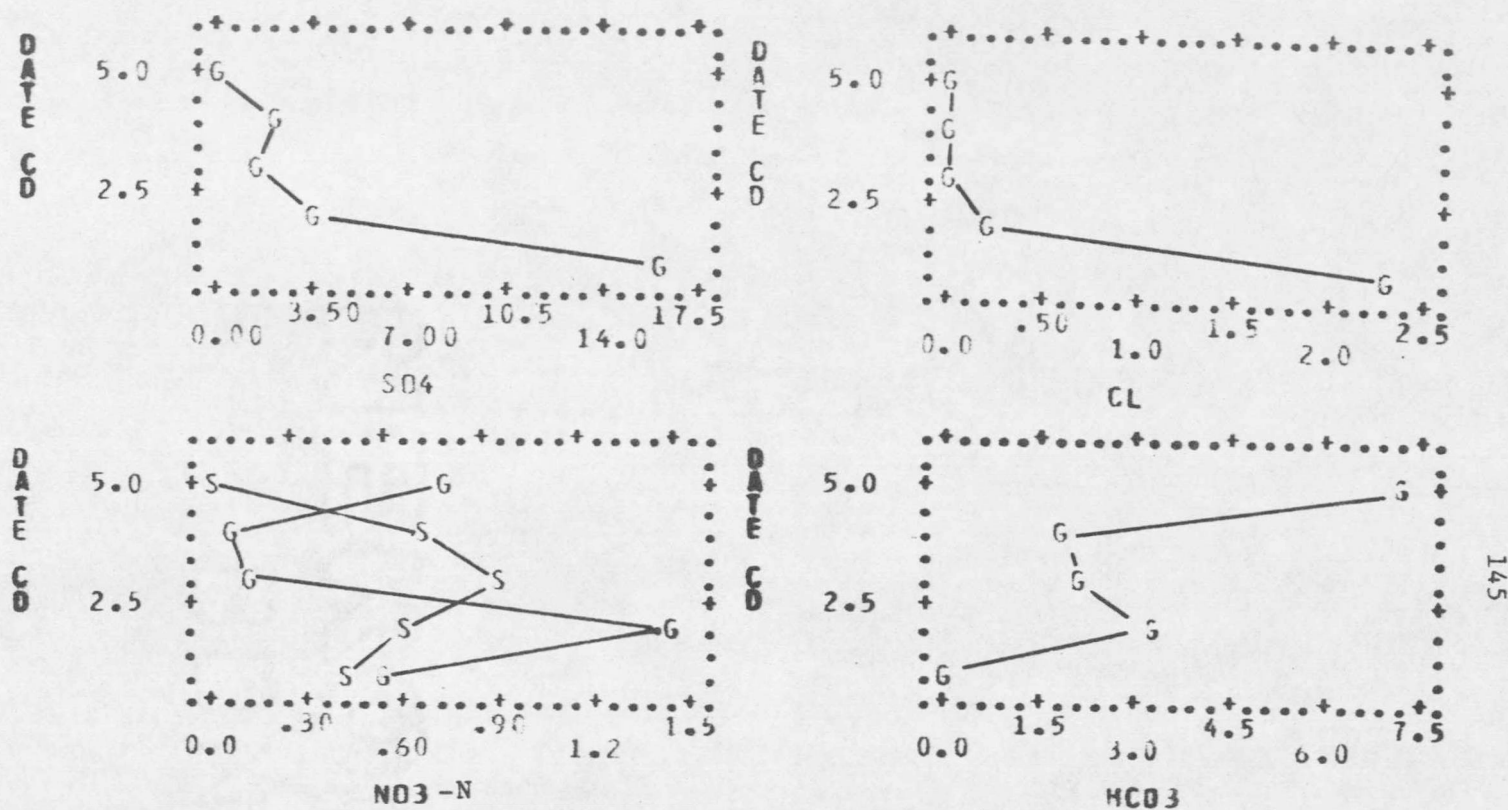


Fig. III-G8. Anion concentrations of groundwater (meq/l) vs. time. These data are for 1975 only. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-G5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

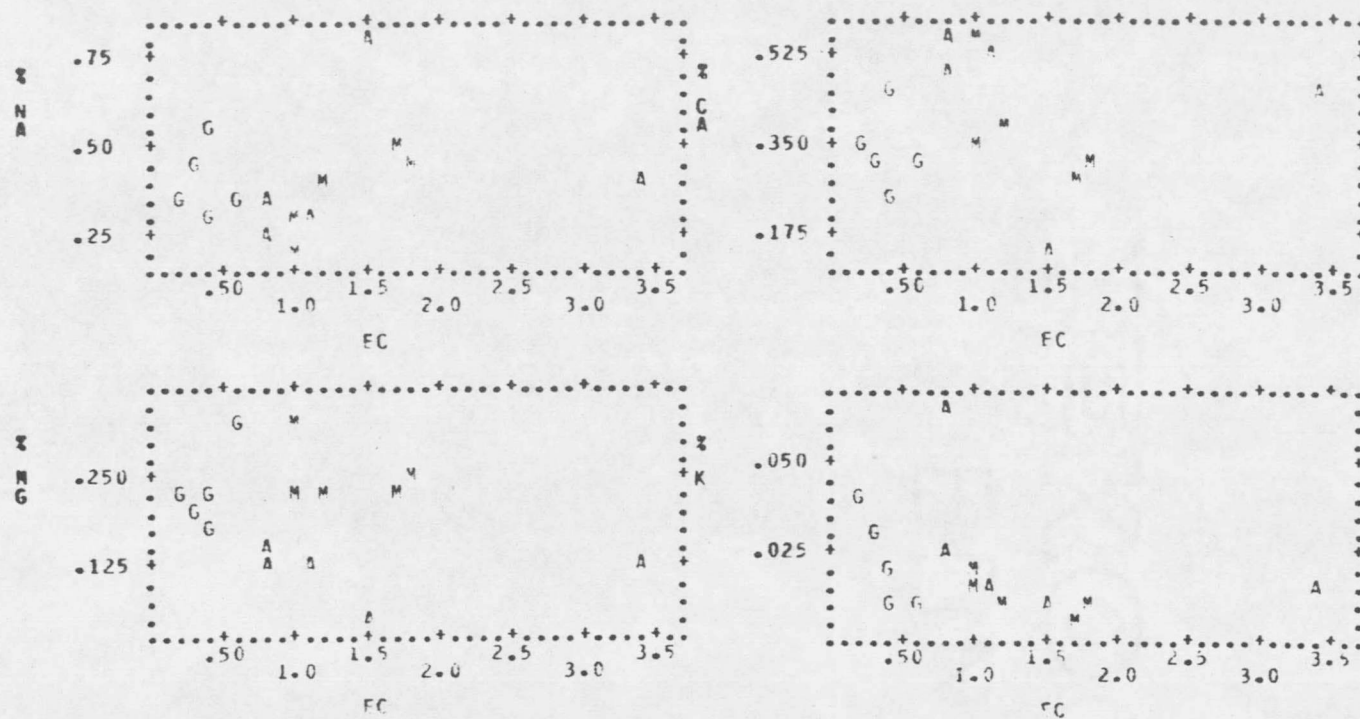


Fig. III-G9. Individual cation fractions (cation/total cations) as a function of EC for groundwater and soil. Data points A, G, and M represent soil, groundwater 1975 and groundwater 1976, respectively.

TABLE III-G1. SUMMARY STATISTICS OF SOIL VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.953**	9.80	7.51	76.6
Mg	.883*	2.80	2.41	86.1
Ca	.857*	10.1	8.29	82.1
K	.267	.510	.359	70.4
<u>Cation Fraction</u>				
Na	.179	.425	.217	51.1
Mg	-.051	.117	.0394	33.7
Ca	-.163	.432	.165	38.2
K	-.450	.0260	.0220	84.6
SAR	.378	4.48	3.78	84.4
EC		1.51	1.11	73.5

1/ N = 5, $r_{.95} = .805$, and $r_{.99} = .934$.

TABLE III-G2. SUMMARY STATISTICS OF GROUNDWATER VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.915**	4.85	3.72	76.7
Mg	.953**	2.99	1.95	65.2
Ca	.908**	4.40	2.60	59.1
K	.594*	.170	.0737	43.4
<u>Cation Fraction</u>				
Na	.081	.384	.105	27.3
Mg	.140	.238	.0532	22.4
Ca	-.098	.360	.0899	24.9
K	-.653*	.0176	.0108	61.4
SAR	.730**	2.45	1.27	51.8
EC		.853	.596	69.9

1/ N = 10, $r_{.95} = .549$, and $r_{.99} = .715$.

TABLE III-G3. SUMMARY STATISTICS OF CATION RATIOS. 1/

GROUNDWATER					
<u>Correlation Coeff. w/EC</u>			<u>Mean</u>		
	<u>Mg</u>	<u>Ca</u>		<u>Mg</u>	<u>Ca</u>
Na	-.076	.083	Na	1.72	1.17
Ca	-.183		Ca	1.57	
N = 10			<u>Std. Dev.</u>		
	<u>r_{.95}</u>	<u>= .549</u>		<u>Mg</u>	<u>Ca</u>
	<u>r_{.99}</u>	<u>= .715</u>	Na	.760	.536
			Ca	.493	
SOIL					
<u>Correlation Coeff. w/EC</u>			<u>Mean</u>		
	<u>Mg</u>	<u>Ca</u>		<u>Mg</u>	<u>Ca</u>
Na	.051	.056	Na	5.38	1.64
Ca	-.344		Ca	3.63	
N = 5			<u>Std. Dev.</u>		
	<u>r_{.95}</u>	<u>= .805</u>		<u>Mg</u>	<u>Ca</u>
	<u>r_{.99}</u>	<u>= .934</u>	Na	6.44	2.18
			Ca	.439	

1/ The vertical numbers of the tables are numerators and the horizontal numbers are denominators. For example, the mean Na/Ca value is 1.17.

Site H

Site Description

This site is located close to the canal on the eastern end of the study area (Fig. I-3). The site productivity is fair. It was in pasture both years. There is a feedlot about one-half mile south of this site next to the canal.

Soil-Groundwater Relationships

The upper 1.5 meters at this site have a clay texture with sandy clay the remainder of the profile (Fig. III-H1). The distribution of soil variables with depth are shown in Figures III-H2, H3, and H4.

Except for an unusually high EC at the surface the EC increases with depth to a maximum of 5 mmhos/cm. The saturation moisture percentage decreases slowly from 47 to 45% at .9 m and then drops sharply to 35%. It then increases to 43% at 1.8 m. The pH is fairly stable with depth at 8.3. Nitrate-nitrogen is stable at .9 ppm except for the surface depth increment.

The range of Na concentration is the greatest of the three major cations. It is 9 meq/l at the surface and 45 meq/l at 1.8 m. It is also the most abundant cation. Calcium has about one-half the range and is the next most abundant cation. Magnesium has a relatively narrow range and is less abundant than Ca or Na. Magnesium and calcium both

increase with depth to about .9 m. After decreasing for the next .3 m, Mg again increases to a maximum at 1.8 m. Calcium decreases for .6 m and is stable the remainder of the profile. Sodium increases with depth rather rapidly until 1.2 m where its concentration is stable for the next .6 m. It then increases at about the previous rate. The SAR increases with depth throughout the entire profile. Water soluble K does not seem to be correlated with ammonium acetate extractable K and varies little throughout the profile.

Changes in piezometric head at various depths with time are shown in Figure III-H5. The piezometer data are of limited value at this site because of the lack of responsiveness in the heavy textured soils. The 4.6 m piezometer rose for the entire study period. The 3.0 and 2.1 m piezometers show a very slight increase in head during the irrigation season. The water level in the access tube was about 1 meter below the ground surface indicating that it was influenced by a horizon not sampled by the piezometers which had a higher head.

Groundwater variable concentrations with time are shown in Figures III-H6, H7, and H8. The groundwater access tube had to be relocated the second summer. It was moved to the edge of the field, about 35 meters from its original position. The EC of the groundwater was much higher at the relocated site. The EC, potassium, and pH curves are similar in shape.

Na is by far the dominant groundwater cation followed by Mg and Ca. The Ca curve is similar in shape and magnitude both years while Na and Mg differ both in magnitude and shape between summers. All four cations have the same shape curves the summer of 1976 and Ca was the only one different the summer of 1975.

By far the dominant anion at this site is SO_4 . The SO_4 decreased by more than one-half its initial concentration the first summer as was true of the major cations and EC.

Relative proportions of the major cations vs. EC of the groundwater and soil are shown in Figure III-H9. The EC of the groundwater at the first access tube location is lower than that of the soil. The EC of the groundwater at the relocated site is higher than the soil profile at the original location. The percent Na is higher in the groundwater. Percentages of Ca and K are higher in the soil. Mg percentages are similar in the soil and water. Summary statistics for soil and water cations are shown in Tables III-H1 and H2.

The groundwater Na, SAR, and K are correlated with EC. Percent Na also has a positive correlation with EC while %Ca and %Mg have a negative correlation with EC. Ca has the lowest CV and Na the highest. Percent Na has the smallest CV. There were not significant correlations of soil cations and EC but Mg and K were the least variable.

Summary statistics for cation ratios are given in Table III-H3. The Ca/Mg ratio is half as large in the groundwater as in the soil.

The Na/Mg ratio is twice as large in the groundwater and the Na/Ca ratio increases by a factor of 5.

Summary

The texture at this site is clay over sandy clay. The productivity is fair. Cation peaks occur with depth in the order $\text{Ca} = \text{Mg} < \text{Na}$. Magnesium peaks again at 1.8 m. Cation concentration means rank $\text{Na} > \text{Ca} > \text{Mg}$ for soil and $\text{Na} > \text{Mg} > \text{Ca}$ for groundwater. All cations had positive correlations with EC of the groundwater.

SITE H

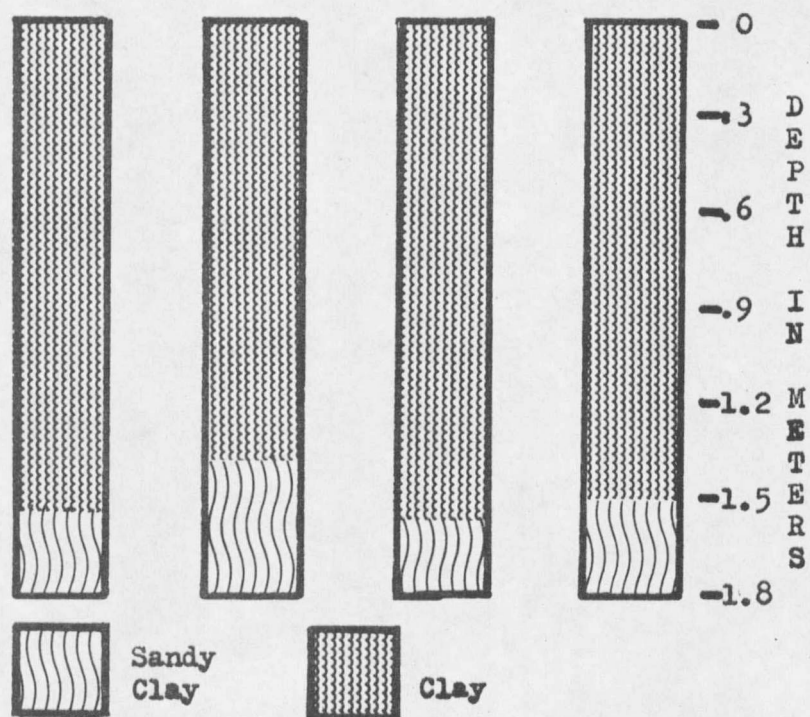


Fig. III-H1. Horization of soil profile at four sampling sites adjacent to groundwater access tube.

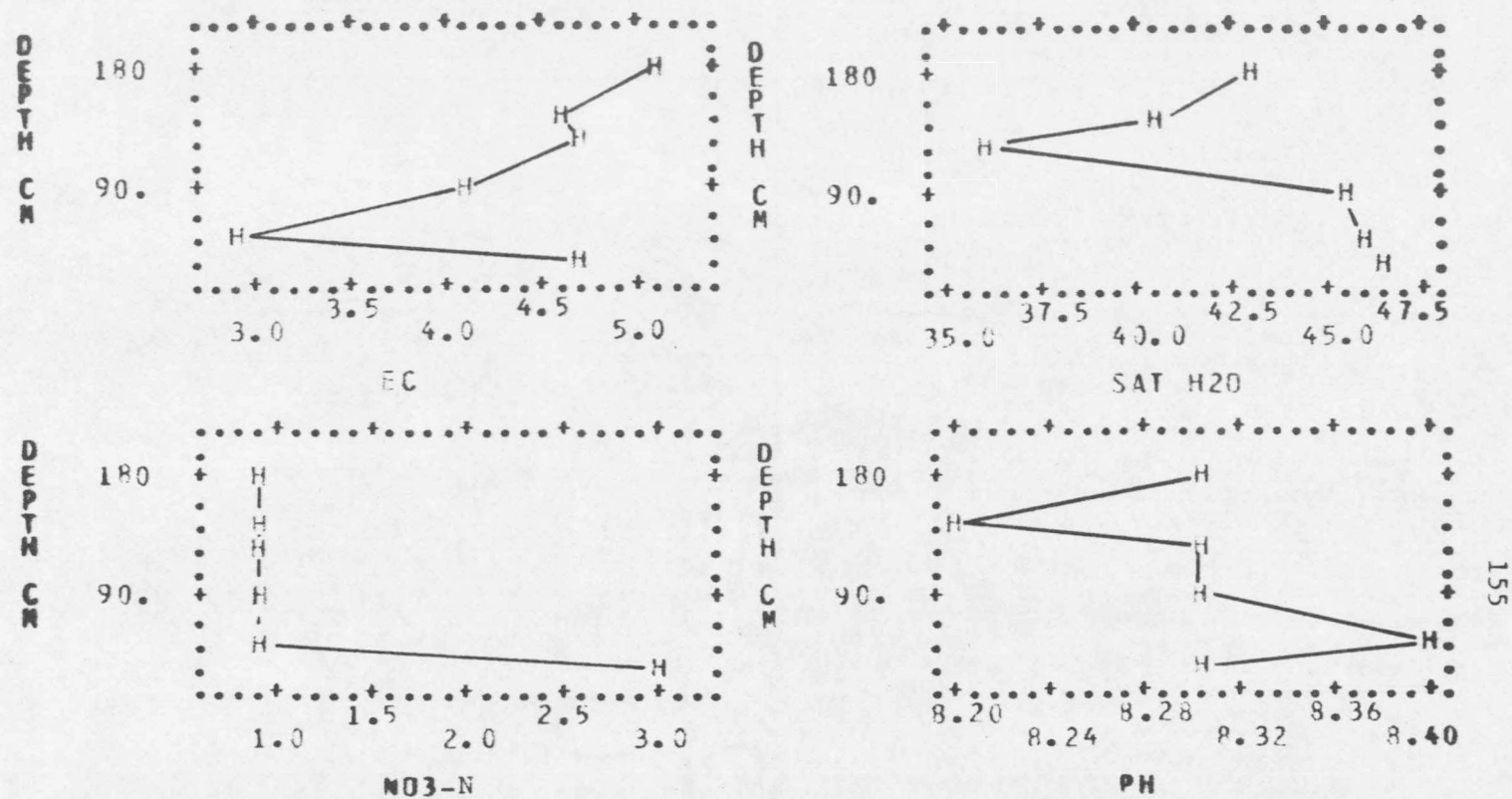


Fig. III-H2. Distribution of electrical conductivity (mmhos/cm), NO3-N (ppm), pH, and saturated water percentage of the soil with depth. The pH and EC are of the saturated extract.

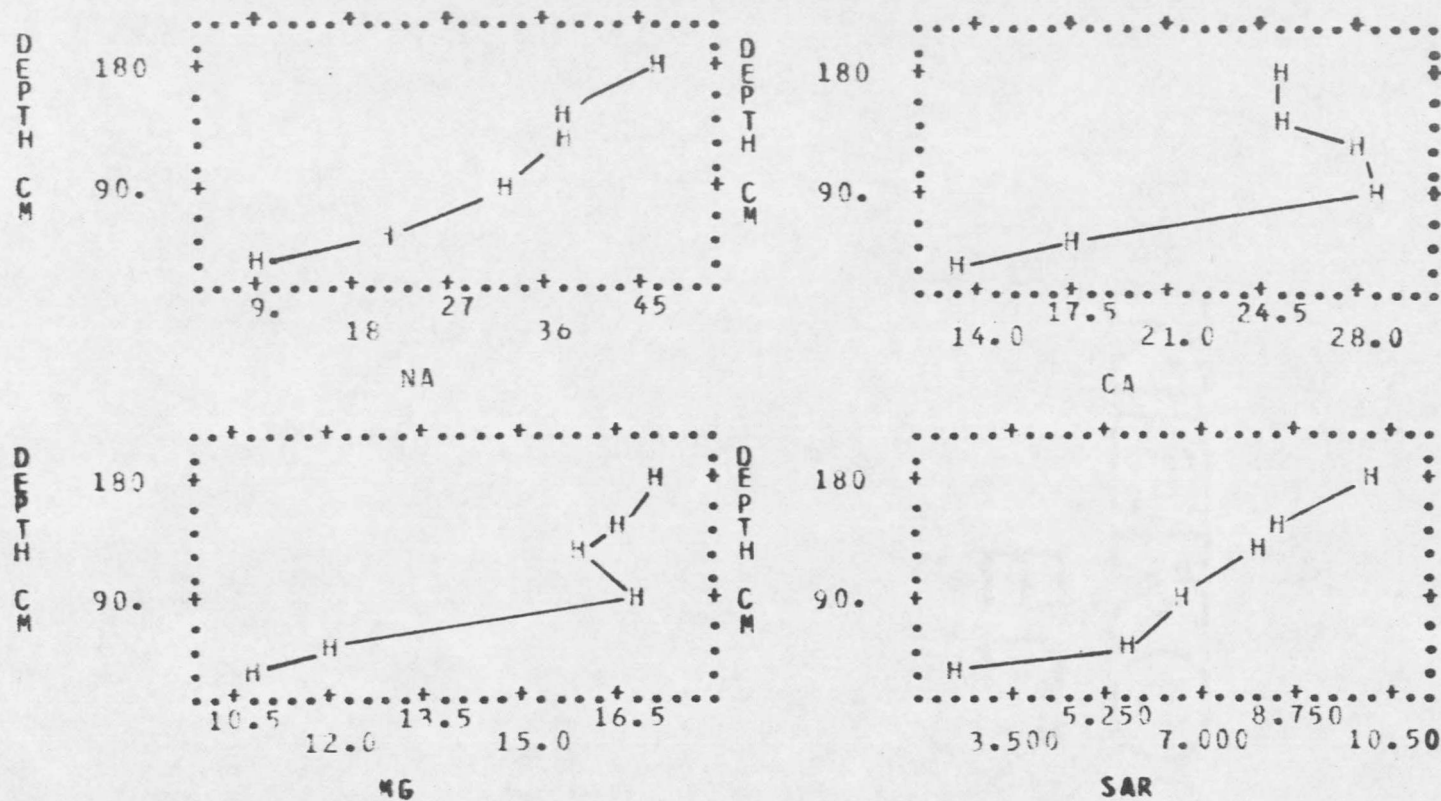


Fig. III-H3. Distribution of major cations (meq/l) of saturated extract and sodium adsorption ratio (SAR) with soil depth.

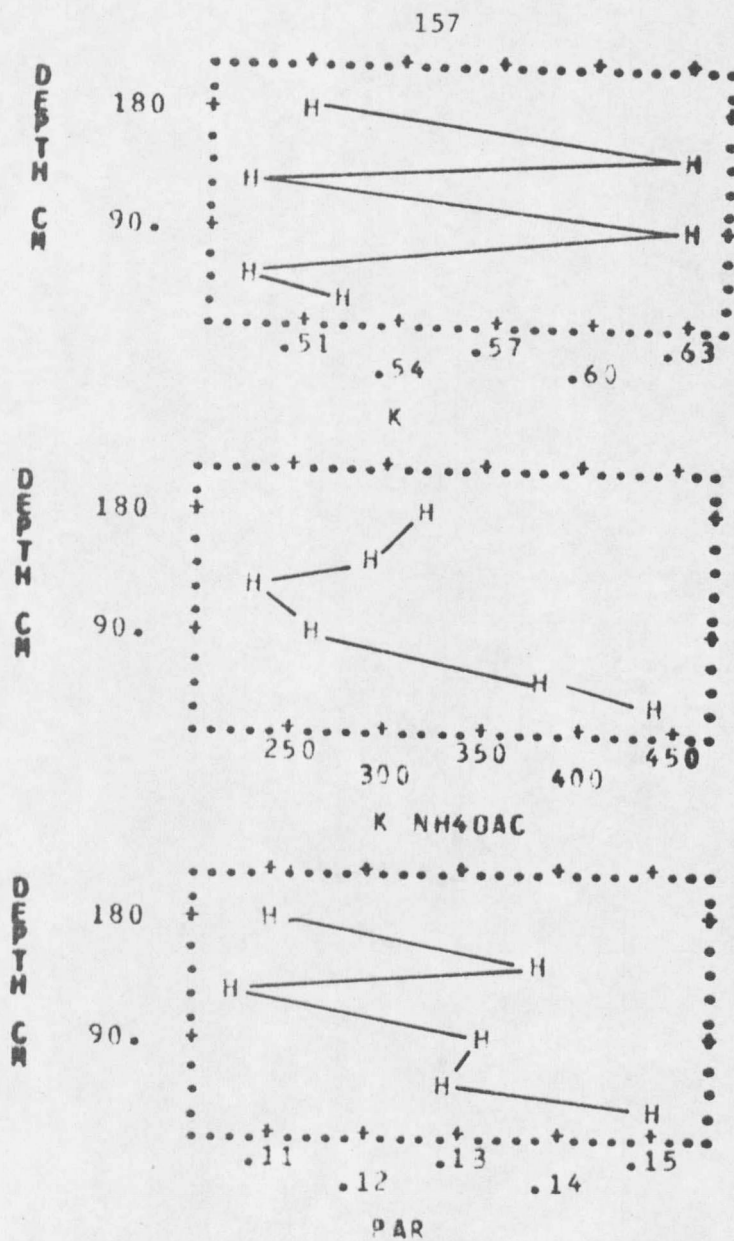
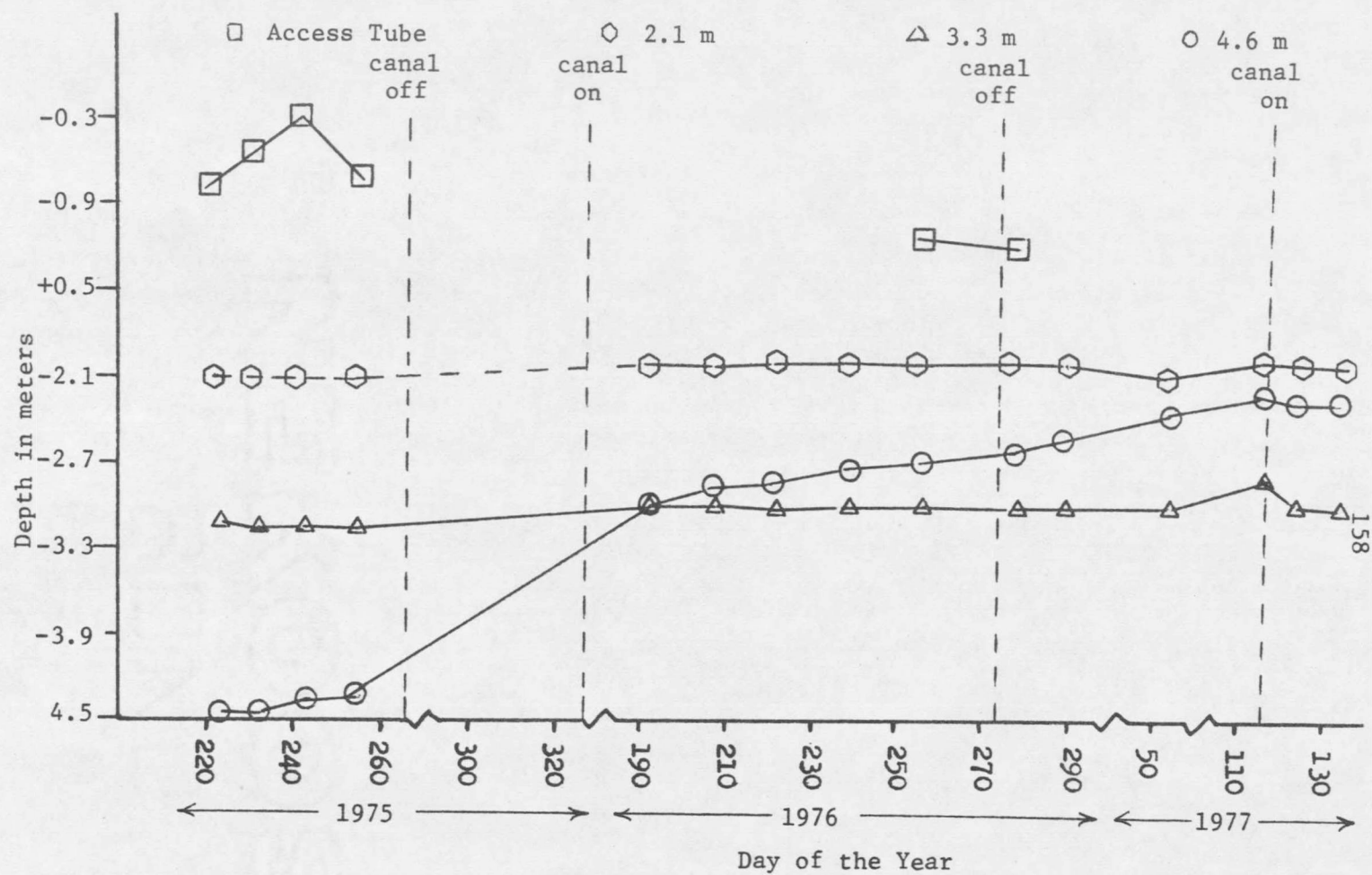


Fig. III-H4. Distribution of water soluble K (meq/l), ammonium acetate extractable K (ppm), and the potassium adsorption ratio with depth.



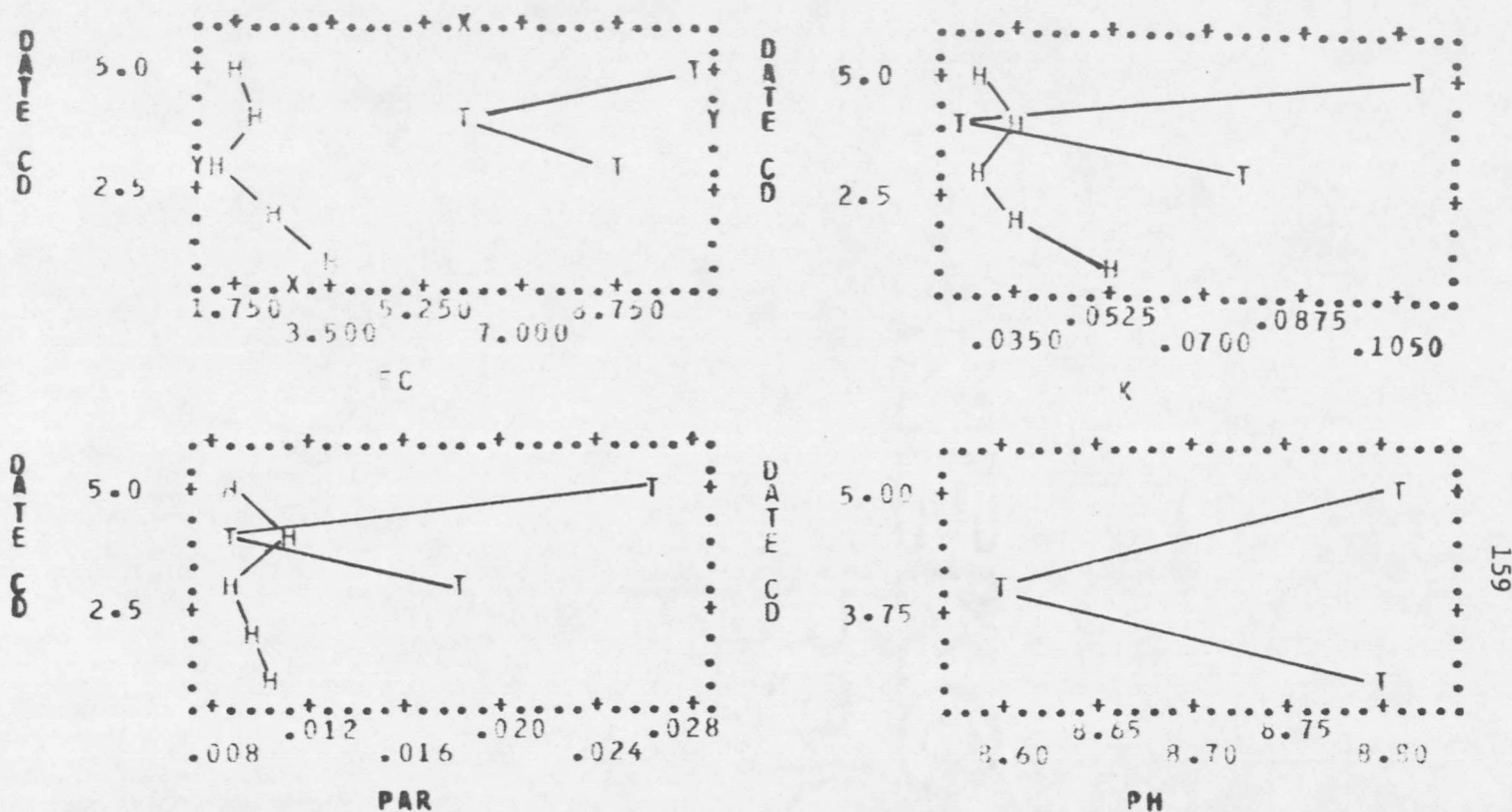


Fig. III-H6. Electrical conductivity (mmhos/cm), K (meq/l), potassium adsorption ratio (PAR), and pH of groundwater vs. time. The H and T data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-H5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

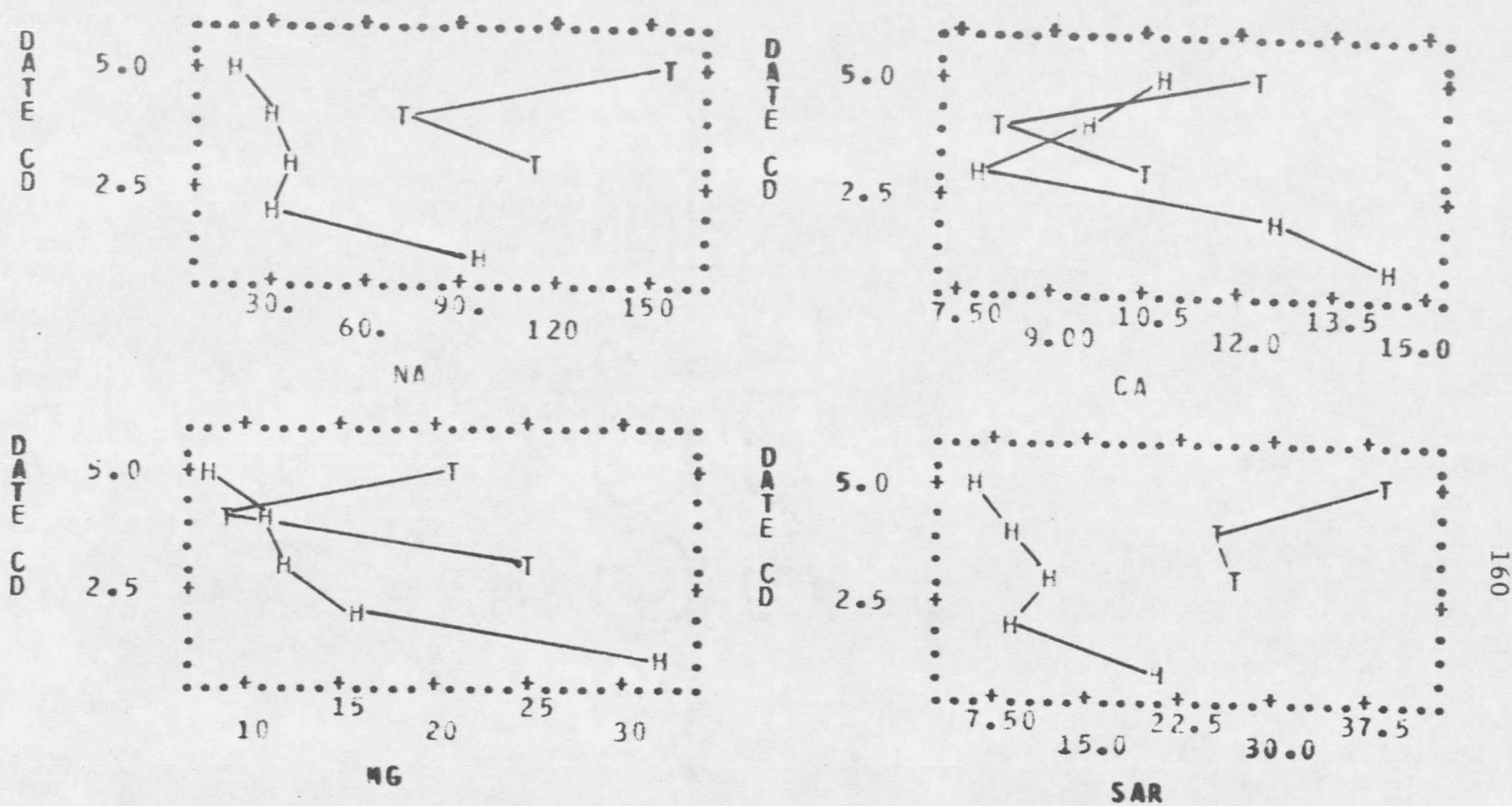


Fig. III-H7. Concentrations of major cations (meq/l) and sodium adsorption ratio of groundwater vs. time. The H and T data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-H5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

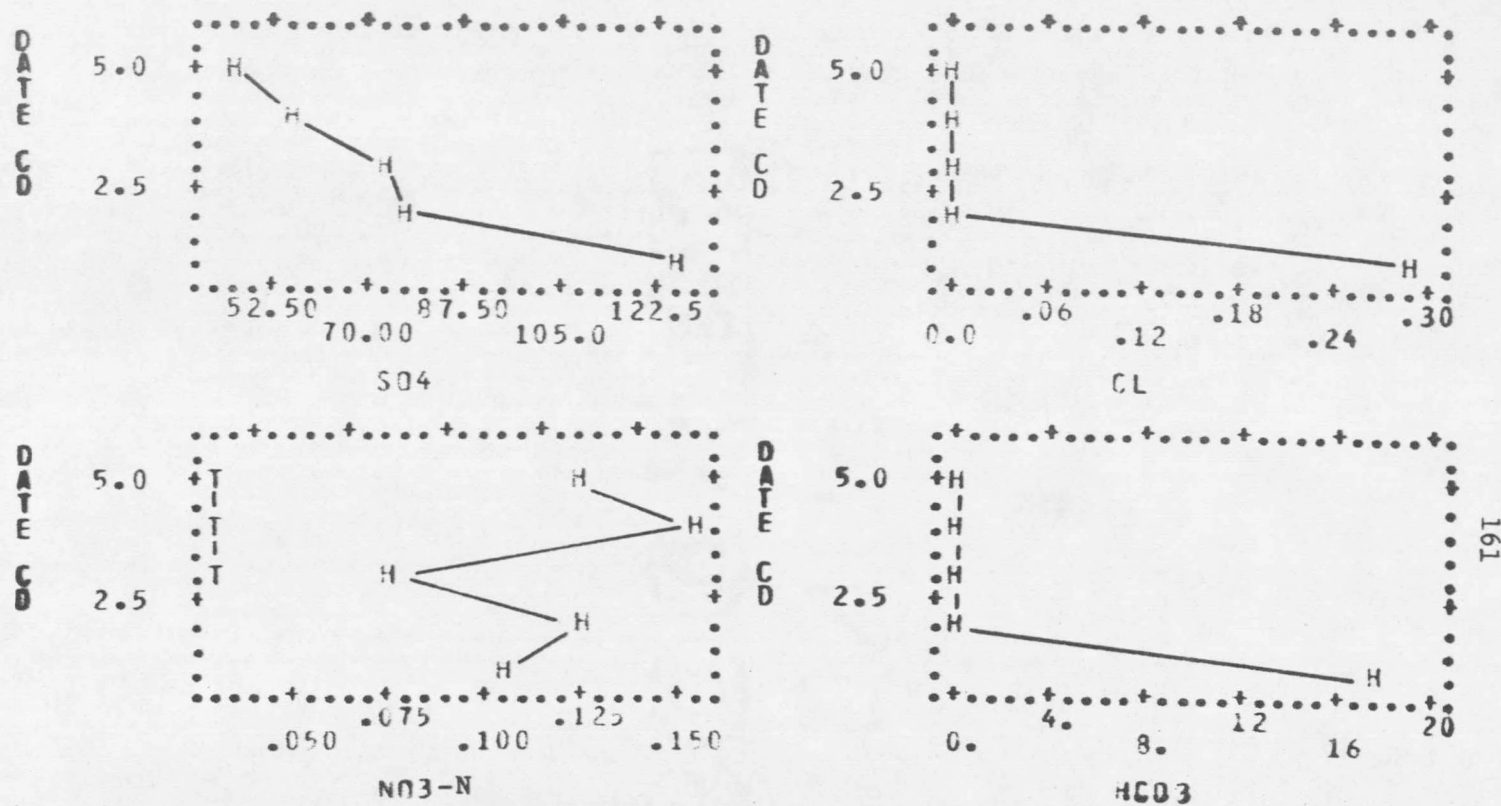


Fig. III-H8. Anion concentrations of groundwater (meq/l) vs. time. These data are for 1975 only. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-H5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

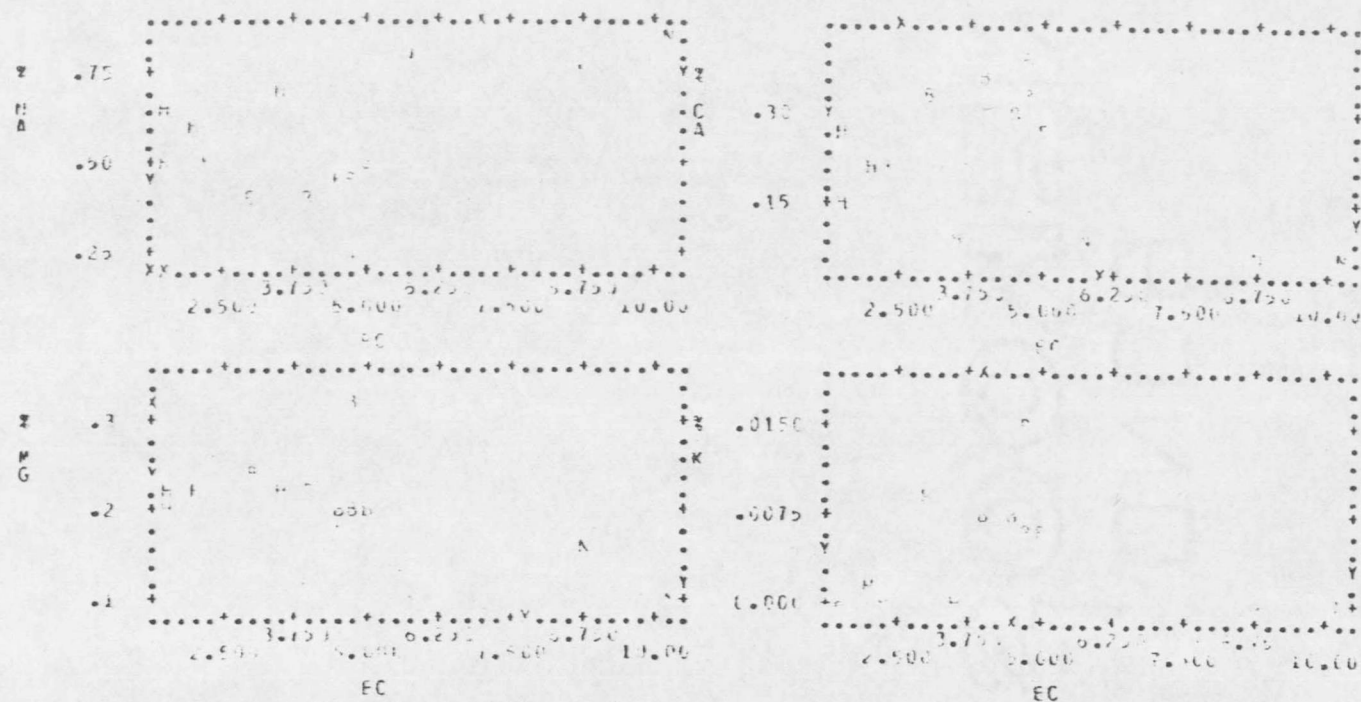


Fig. III-H9. Individual cation fractions (cation/total cations) as a function of EC for groundwater and soil. Data points B, H, and N represent soil, groundwater 1975 and groundwater 1976, respectively.

TABLE III-H1. SUMMARY STATISTICS OF SOIL VARIABLES. 1/

	Correlation Corr. w/EC	Mean	Std. Dev.	CV
Na	.426	30.9	13.8	44.7
Mg	.430	14.8	2.75	18.6
Ca	.307	22.9	16.3	71.2
K	.097	.545	.0668	12.3
<u>Cation Fraction</u>				
Na	.184	.425	.0884	20.8
Mg	-.129	.226	.0489	21.6
Ca	-.229	.339	.0411	12.1
K	-.159	.00878	.00365	41.6
SAR	.372	6.93	2.66	38.4
EC		4.35	.782	17.9

1/ N = 6, $r_{.95} = .729$, and $r_{.99} = .882$.

TABLE III-H2. SUMMARY STATISTICS OF GROUNDWATER VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.924**	70.2	50.0	71.2
Mg	.424	16.7	8.73	52.3
Ca	.418	10.8	2.28	21.1
K	.870**	.0483	.0292	60.5
<u>Cation Fraction</u>				
Na	.853**	.669	.124	18.5
Mg	-.758*	.187	.0596	30.4
Ca	-.789**	.144	.0768	53.3
K	-.283	.000528	.000157	29.7
SAR	.951**	18.4	11.6	63.0
EC		4.46	3.43	76.9

1/ N = 8, $r_{.95} = .621$, and $r_{.99} = .789$.

TABLE III-H3. SUMMARY STATISTICS OF CATION RATIOS. 1/

GROUNDWATER					
<u>Correlation Coeff. w/EC</u>			<u>Mean</u>		
	<u>Mg</u>	<u>Ca</u>		<u>Mg</u>	<u>Ca</u>
Na	.749*	.956**	Na	4.26	6.44
Ca	-.498		Ca	.764	
N = 8			<u>Std. Dev.</u>		
r _{.95} = .621				<u>Mg</u>	<u>Ca</u>
r _{.99} = .789			Na	2.64	4.14
			Ca	.301	
SOIL					
<u>Correlation Coeff. w/EC</u>			<u>Mean</u>		
	<u>Mg</u>	<u>Ca</u>		<u>Mg</u>	<u>Ca</u>
Na	.292	.281	Na	1.99	1.29
Ca	.053		Ca	1.53	
N = 6			<u>Std. Dev.</u>		
r _{.95} = .729				<u>Mg</u>	<u>Ca</u>
r _{.99} = .882			Na	.671	.402
			Ca	.193	

1/ The vertical numbers of the tables are numerators and the horizontal numbers are denominators. For example, the mean Na/Ca value is 6.44.

Site I

Site Description

This site is located on the eastern end of the project (Fig. I-3). The soils are made up of heavy clays (Fig. III-11). The productivity level is rated as fair. Sugar beets were grown the first summer and small grain the second. The growth of the beet crop in the area of the access tube was quite heterogeneous. Areas of above-average growth seemed to be distributed throughout a matrix of a suppressed stand of beets.

Soil-Groundwater Relationships

The texture of this site is clay (Fig. III-11). Distribution of soil variables with depth are shown in Figures III-12, 13, and 14. The level of salt throughout the profile is generally high with a peak at 1.2 m. The soil at this site is saline-sodic with an average profile SAR of 29 and EC of 12.6 mmhos/cm. The pH seems to be a mirror image of the profile EC. Its minimum is at the same depth as the EC maximum. The pH ranges more than one pH unit from a surface high of 8.8 to 7.5 at 1.2 m.

The saturation percentage is generally high and varies between 48 and 54% after the surface .3 m. Except for the surface .6 m there is little $\text{NO}_3\text{-N}$ present.

The major cations have similar profile distributions. The Ca and Mg peaks occur at the same depth of 1.2 m. The Ca has a sharp peak and is stable for the next .6 m below; Mg has a similar shape curve. The Ca and Mg levels of the profile are similar in magnitude. The profile Na is by far the dominant cation with a peak at .9 m of more than 200 meq/l of the saturated extract. The Na peak occurs above the Ca and Mg peaks. This suggests net water movement toward the surface. Potassium distribution is atypical in that it has the same shape curve as the major cations.

The change of piezometric head at various depths with time is shown in Figure III-15.

The groundwater at this site was relatively deep. The water level in the access tube was about 1.8 m the first summer and 2.2 m the second. The piezometers did not seem to be responsive to irrigation or canal leakage. The piezometer data at this site suggest that the aquifer supplying groundwater at this site is about 3 m deep.

The access tube at this site was reinstalled at the beginning of the second summer and again between the second and third sampling. This was due to tube damage from tillage. The last installation was at the edge of the field (about 50 m from the original site).

Concentrations of groundwater constituents with time are shown in Figures III-16, 17, and 18. The EC of the groundwater is about one-

fourth of that of the profile just above the water table (compare Fig. III-I3 and Fig. III-I6).

There is very little groundwater NO_3 at this site which is consistent with that in the soil profile. The pH of the groundwater is higher than that of the profile. This is probably due to the lower amount of salts present. Potassium concentrations seem to follow changes in EC.

Groundwater averages of Na, Mg, and Ca are about one-third, one-fourth, and one-sixth, respectively, of the soil profile immediately above (Figs. III-I2 and I7). This results in a slightly lower average groundwater SAR (19.6 vs. 25.8). The shapes of the major cation curves for the three groundwater samples taken during the latter part of the summer seem to be similar. The variation of the early summer values between years could be due to leakage around the access tube after installation. The dominant anion, by far, is SO_4 .

The relative values of the major cations can be seen in Figure III-I9. The percent Na is higher in the groundwater. Calcium and K percentages are higher in the soil. Magnesium isn't as obvious but seems to be lower in the soil.

The relative variation in percentages between soil and groundwater cations can be compared by the vertical spread of data points for a given year of the soil profile. The Ca and Na fractions are

more variable in the groundwater than in the soil while Mg and K have a similar range in both. The difference in EC is apparent by the distance between soil and groundwater values.

Summary statistics of groundwater and soil cations, cation fractions, cation ratios, EC, and SAR are shown in Tables III-II, I2, and I3. An increase in groundwater EC is associated with an increase in Na. The major mean cation concentrations rank $\text{Na} \gg \text{Mg} > \text{Ca}$ in both soil and groundwater. The EC of the groundwater is much less than that of the soil profile. The Na fraction is extremely stable throughout the profile and groundwater. The Ca/Mg ratio is twice as high in the soil as groundwater. The ratio of Na/Mg is about the same in both.

Summary

This site has a heavy clay texture and is saline-sodic. The profile EC peaks at 1.2 m. The major cation peaks occur with depth in the order $\text{Na} < \text{Mg} = \text{Ca}$. Their mean concentrations of the profile and groundwater rank $\text{Na} \gg \text{Mg} > \text{Ca}$. The groundwater is relatively deep. The percent Na is very stable in the soil and groundwater.

SITE I

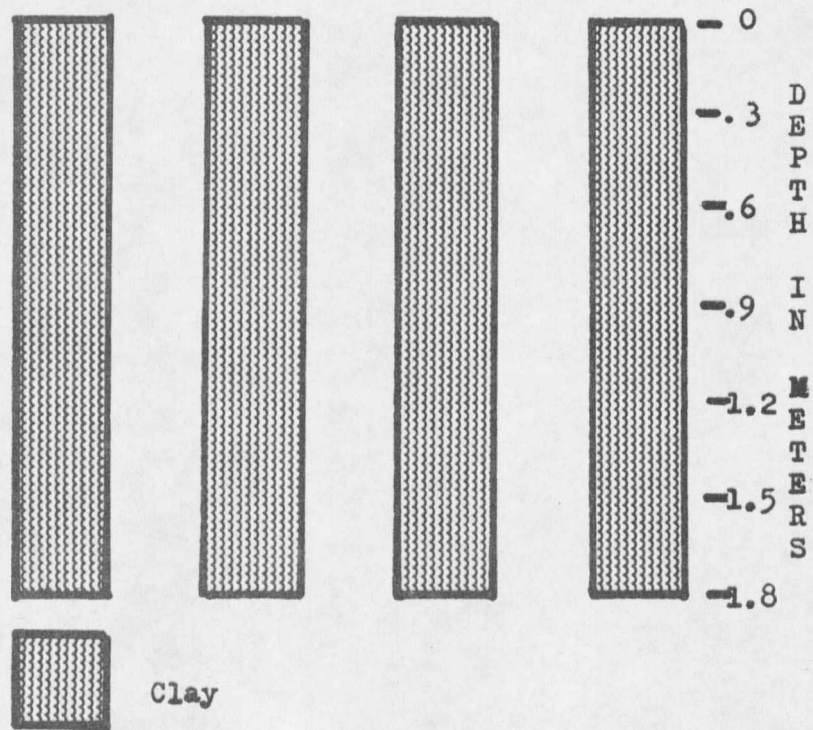


Fig. III-II. Horizonation of soil profile at four sampling sites adjacent to groundwater access tube.

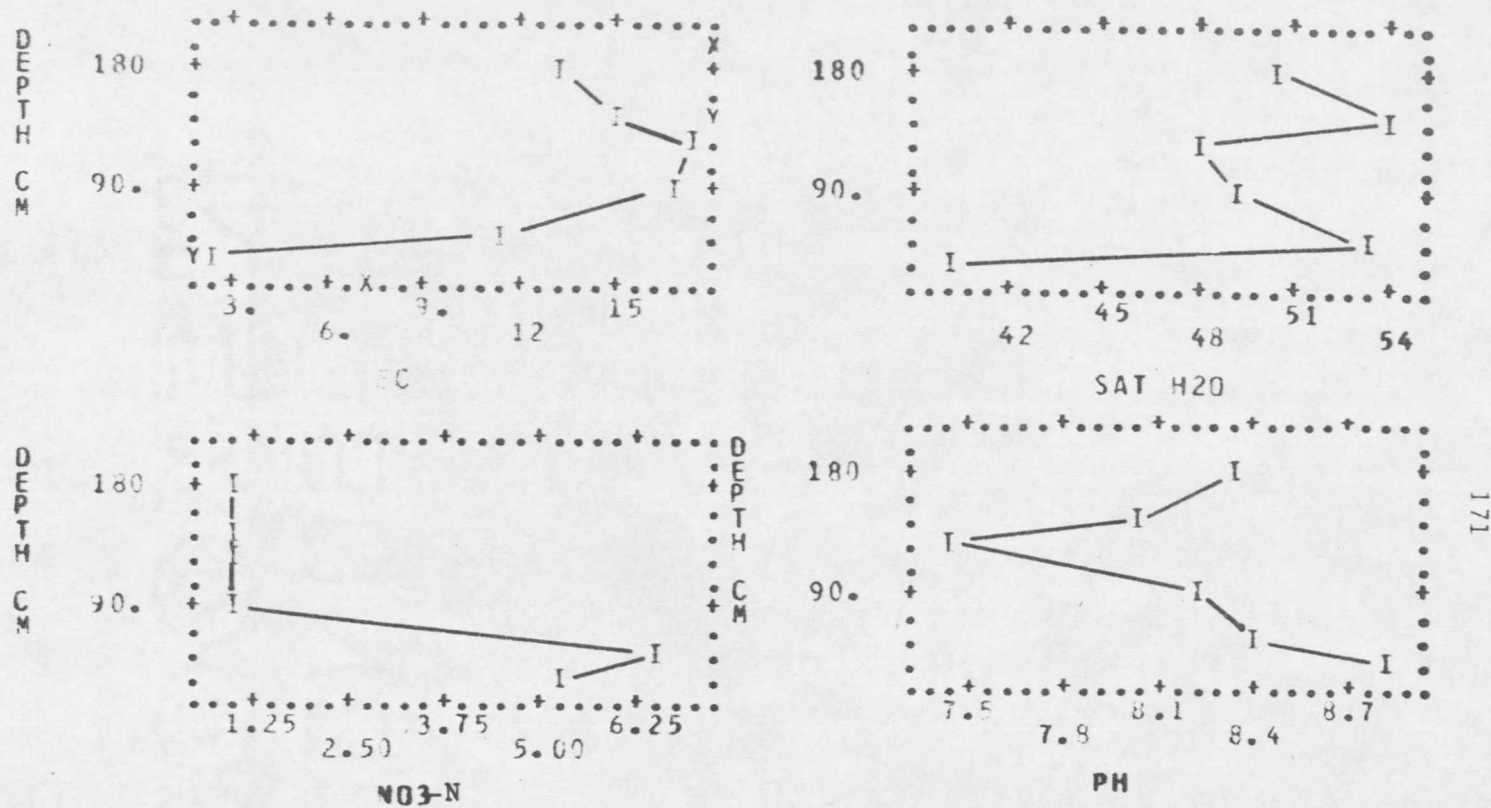


Fig. III-I2. Distribution of electrical conductivity (mmhos/cm), NO₃-N (ppm), pH, and saturated water percentage of the soil with depth. The pH and EC are of the saturated extract.

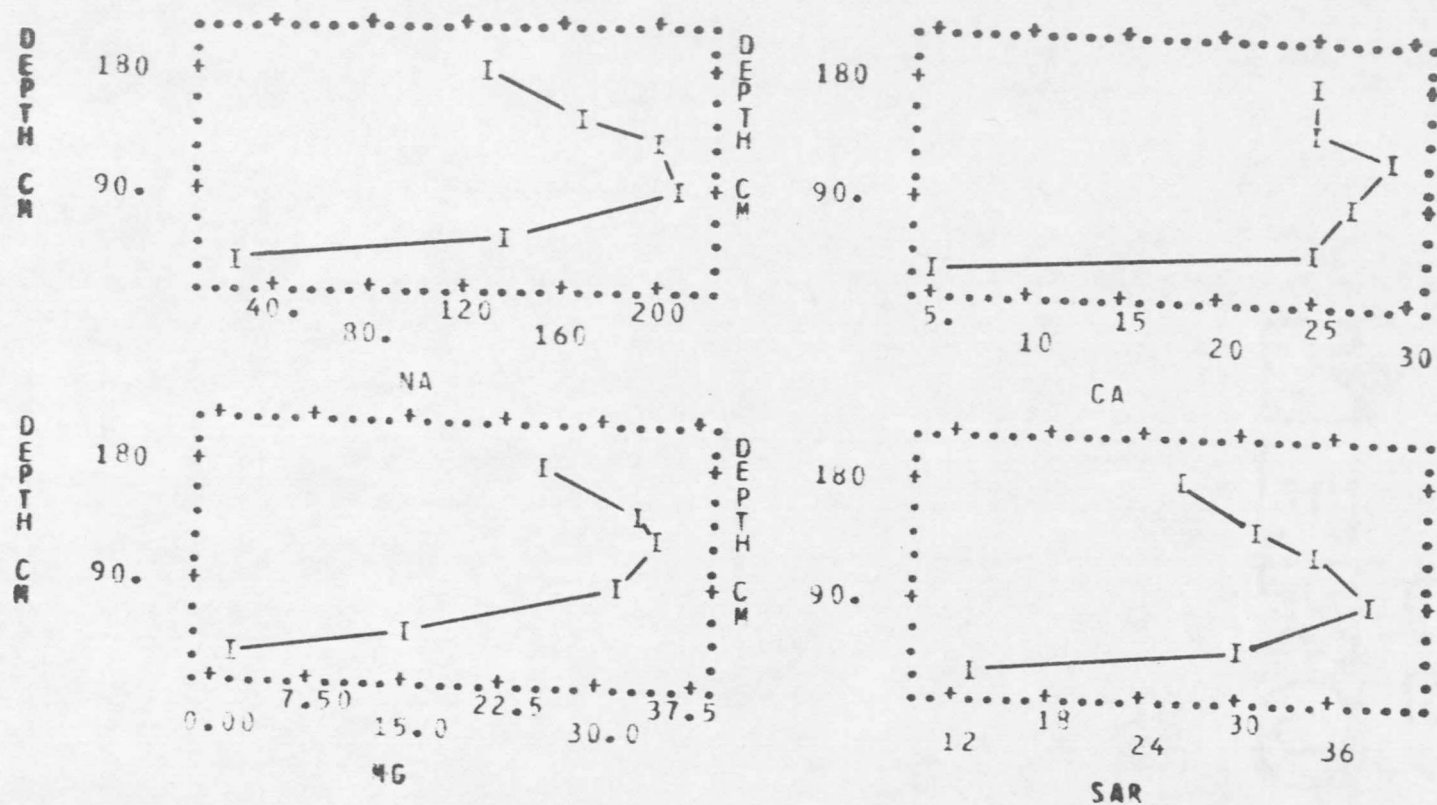


Fig. III-I3. Distribution of major cations (meq/l) of saturated extract and sodium adsorption ratio (SAR) with soil depth.

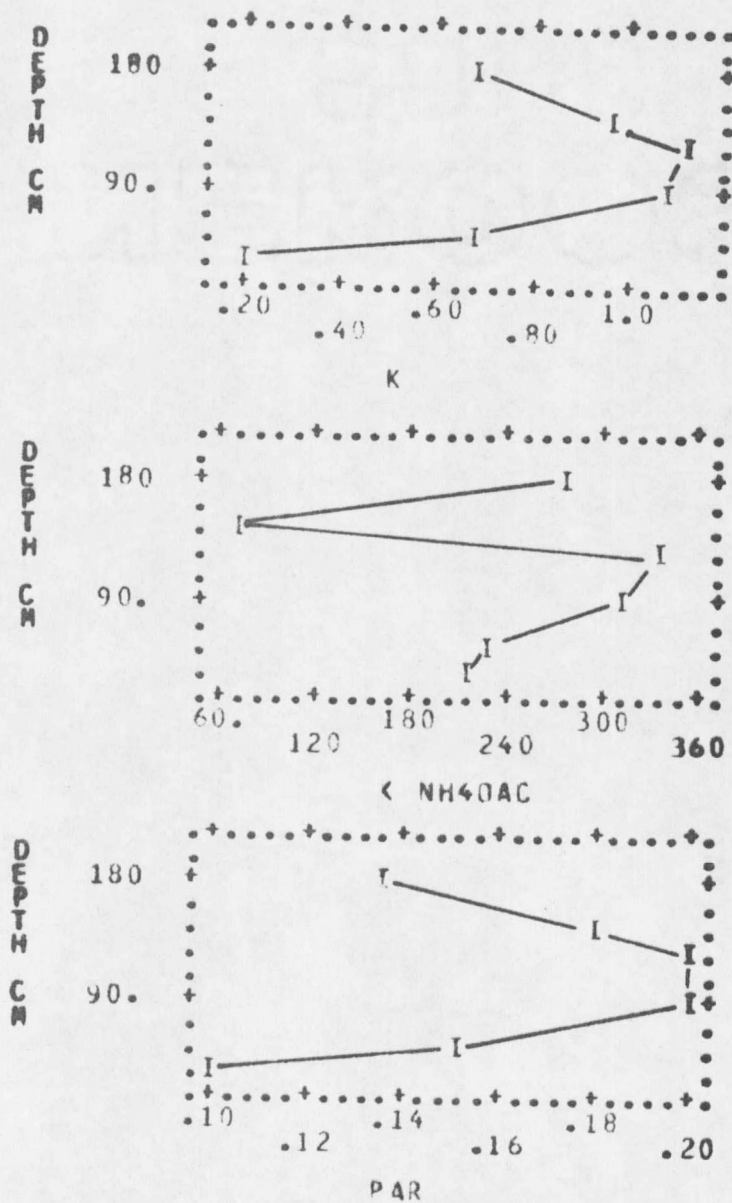


Fig. III-I4. Distribution of water soluble K (meq/l), ammonium acetate extractable K (ppm), and the potassium adsorption ratio with depth.

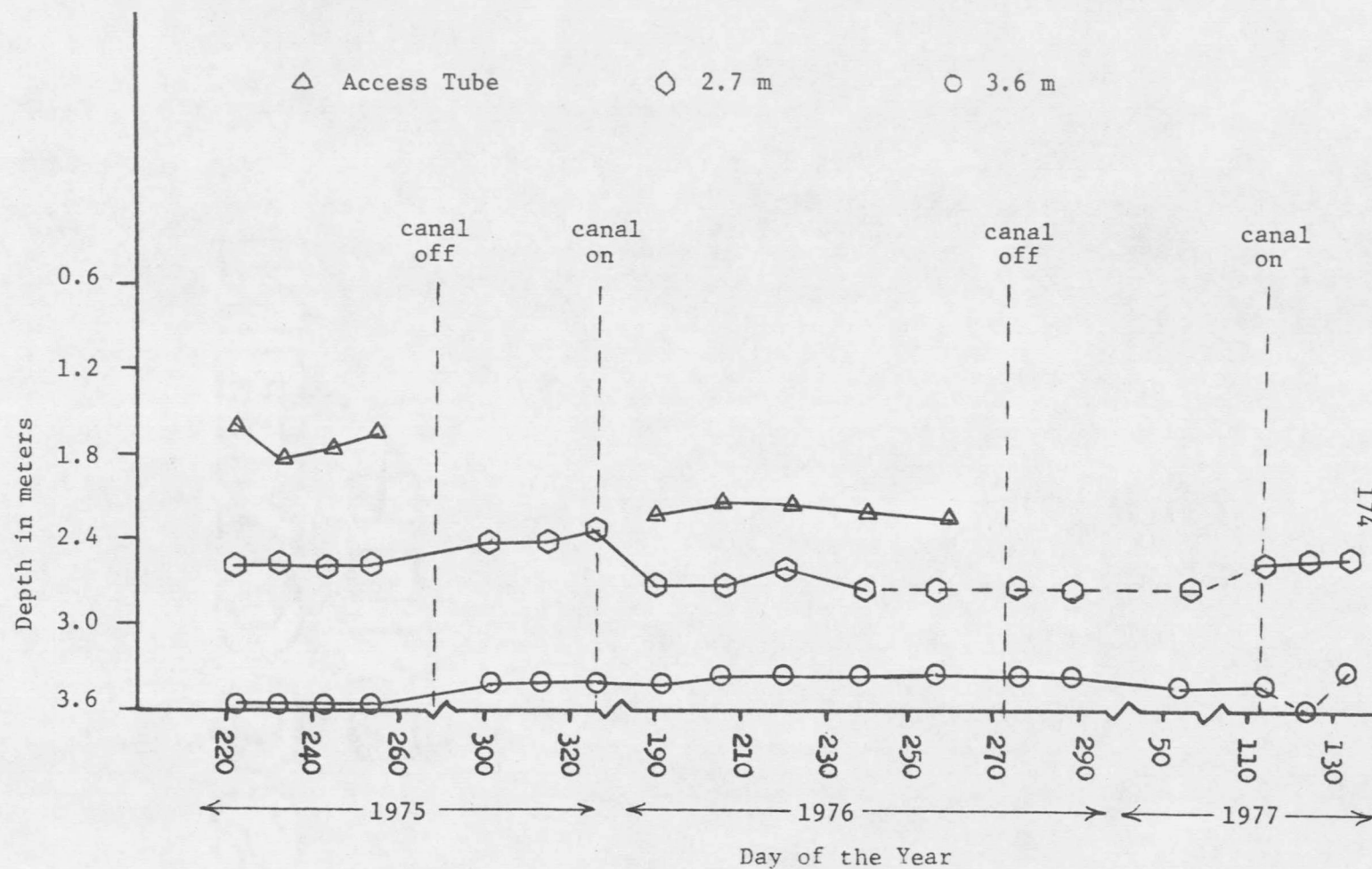


Fig. III-I5. Piezometric head with time. Data points connected with dashed lines represent unsaturated conditions at the depth sampled by that piezometer. The 1.8 m piezometer was above the saturated zone throughout study period.

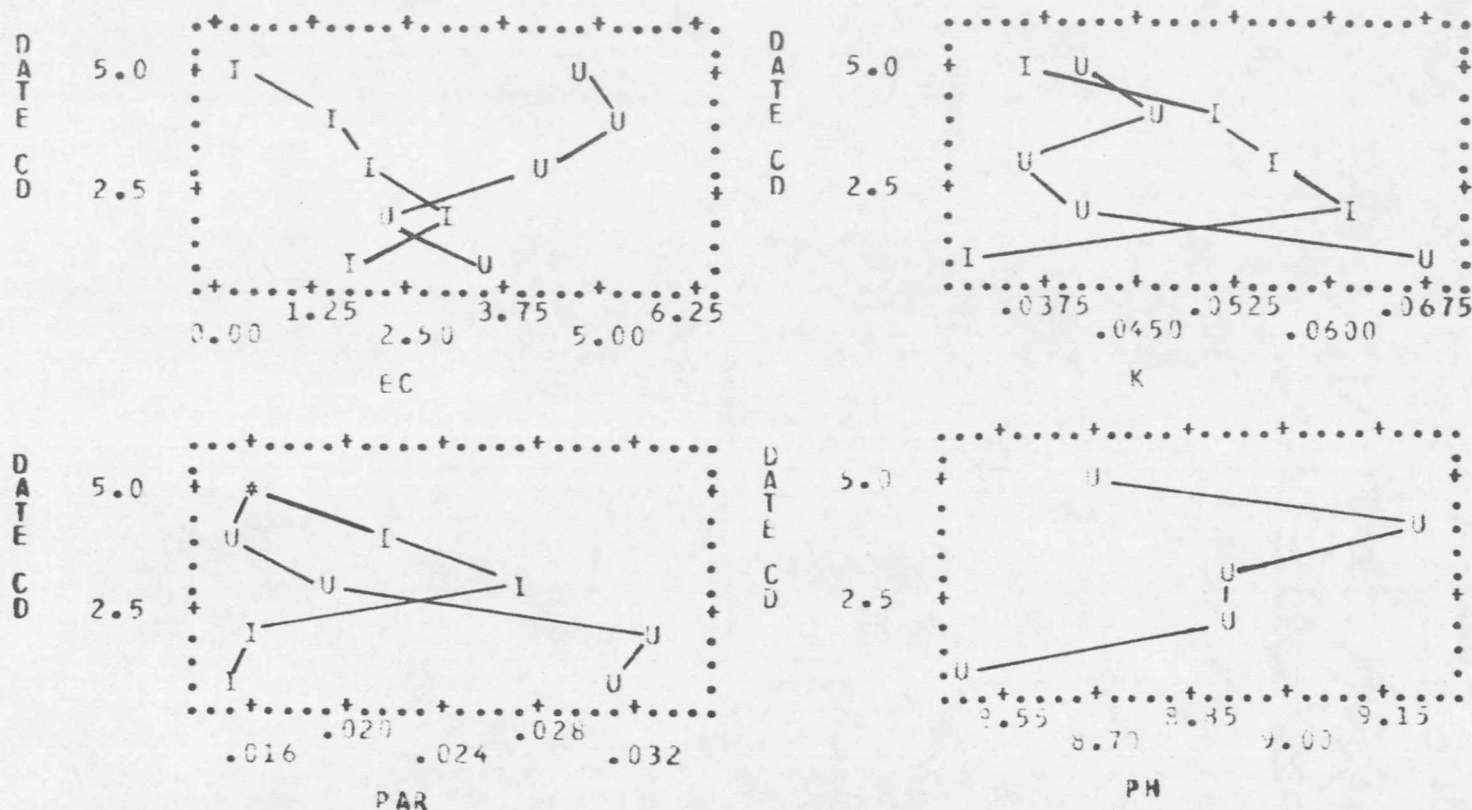


Fig. III-I6. Electrical conductivity (mmhos/cm), K (meq/l), potassium adsorption ratio (PAR), and pH of groundwater vs. time. The I and U data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-I5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

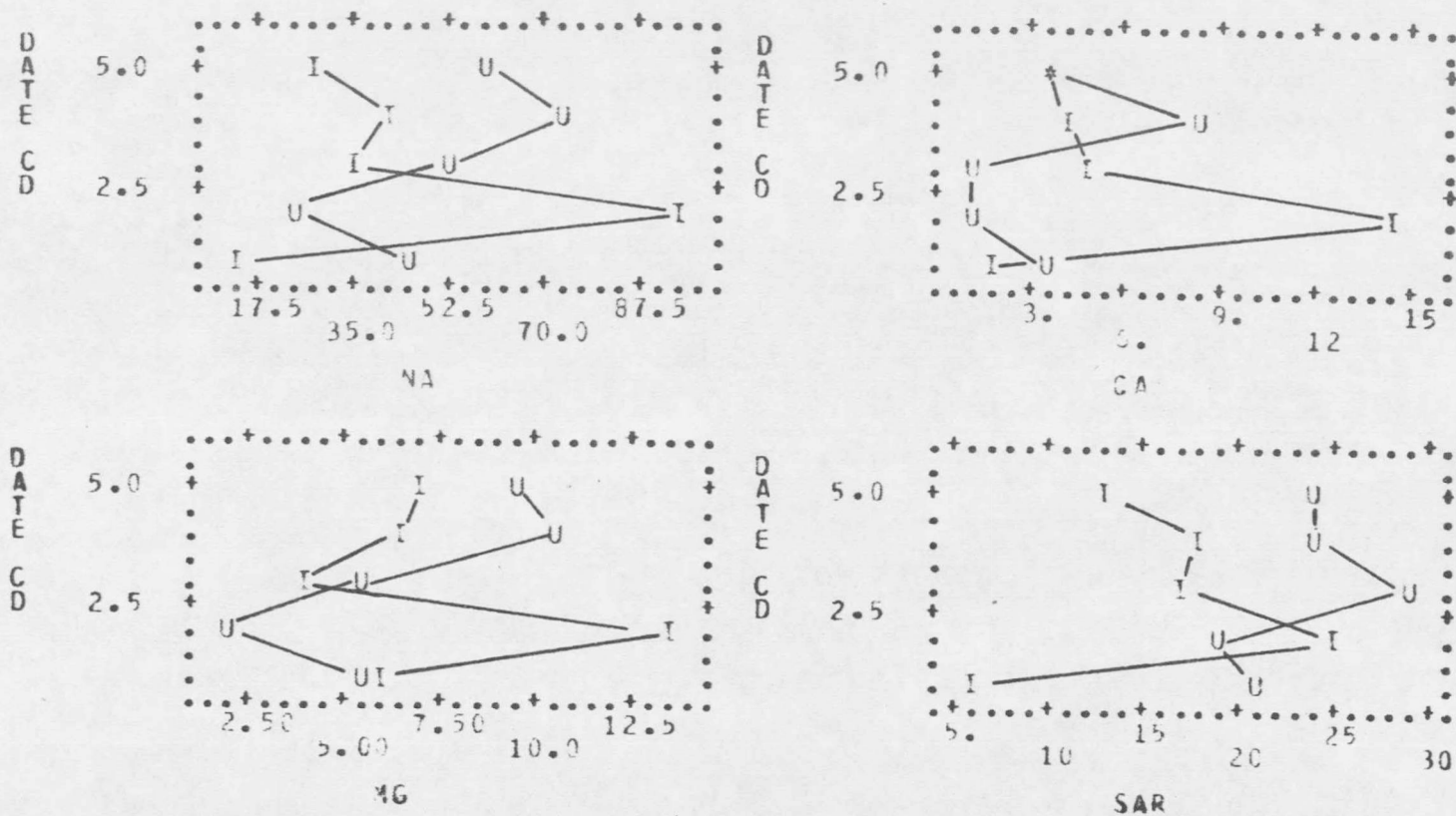


Fig. III-17. Concentrations of major cations (meq/l) and sodium adsorption ratio of groundwater vs. time. The I and U data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-15; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

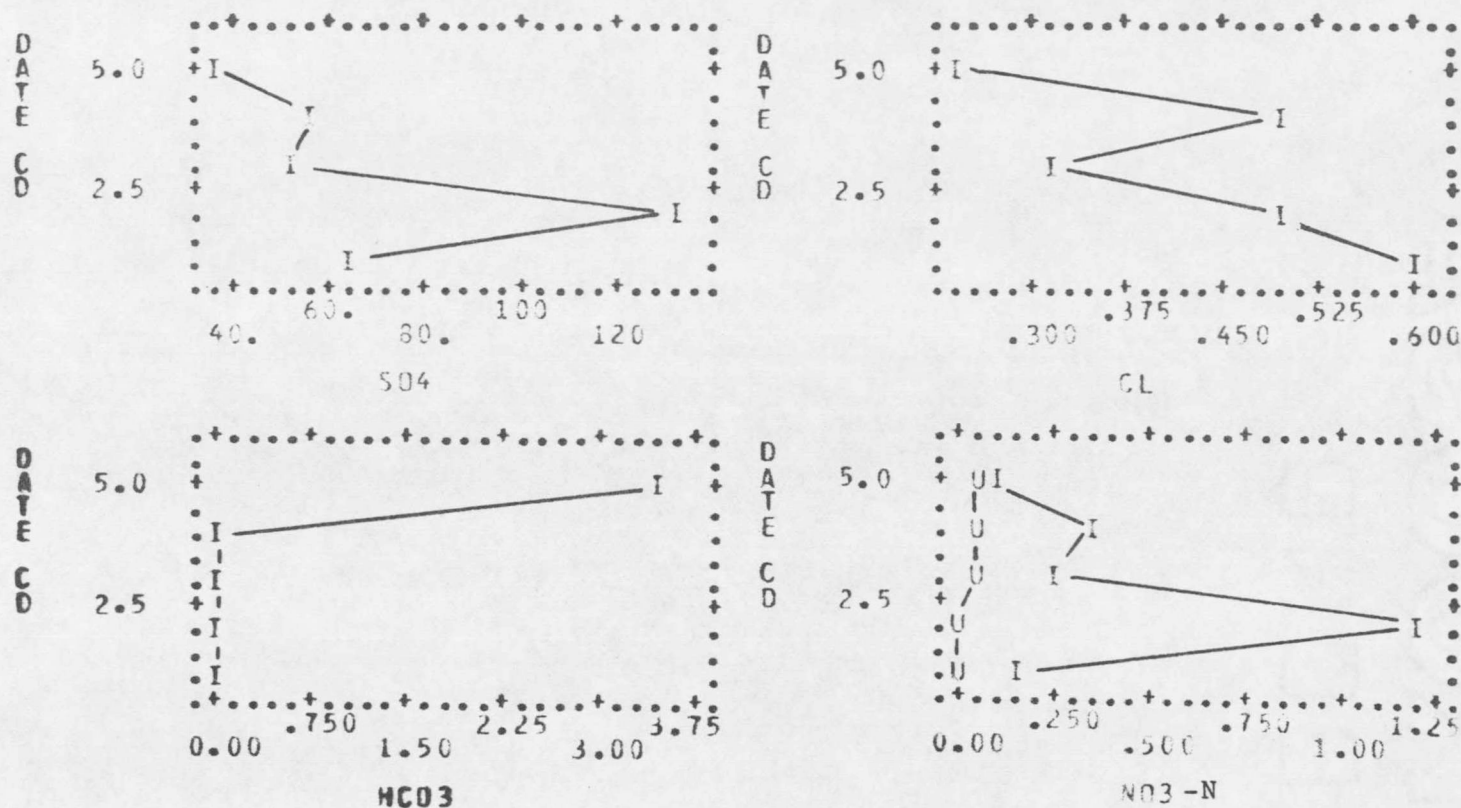


Fig. III-18. Anion concentrations of groundwater (meq/l) vs. time. These data are for 1975 only. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-15; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

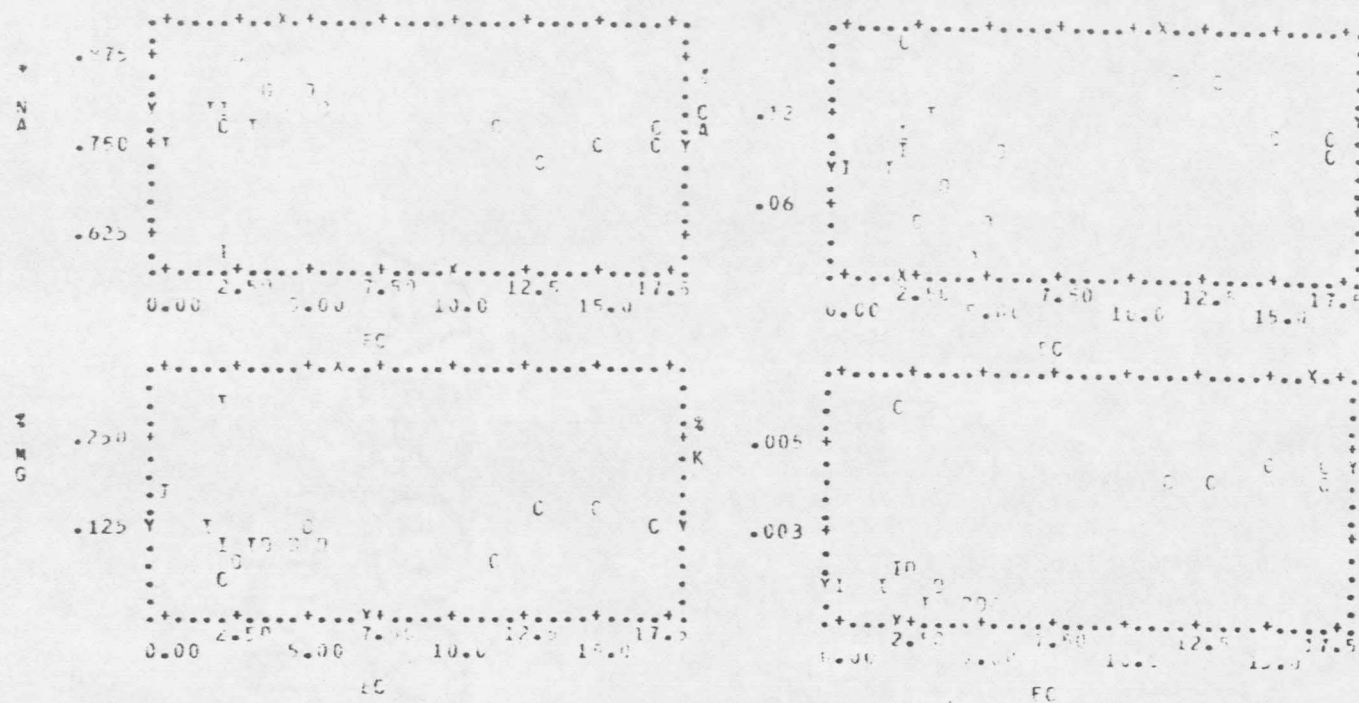


Fig. III-19. Individual cation fractions (cation/total cations) as a function of EC for groundwater and soil. Data points C, I, and O represent soil, groundwater 1975 and groundwater 1976, respectively.

TABLE III-II. SUMMARY STATISTICS OF SOIL VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.986**	143.7	67.3	46.8
Mg	.965**	23.3	12.8	54.9
Ca	.956**	22.7	8.85	38.9
K	.981**	.787	.350	44.5
<u>Cation Fraction</u>				
Na	-.331	.757	.0249	3.3
Mg	.859*	.111	.0369	33.2
Ca	-.912**	.128	.0250	19.5
K	-.847*	.00439	.000836	19.0
SAR	.955**	29.0	9.04	31.2
EC		12.6	5.59	44.4

1/ N = 6, $r_{.95} = .729$, and $r_{.99} = .882$.

TABLE III-I2. SUMMARY STATISTICS OF GROUNDWATER VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.619*	47.0	24.5	58.3
Mg	.390	6.99	3.40	48.6
Ca	.204	4.71	4.00	84.9
K	.125	.0466	.0118	25.3
<u>Cation Fraction</u>				
Na	.415	.793	.0803	10.1
Mg	-.336	.130	.0656	50.5
Ca	-.371	.0765	.0298	38.9
K	-.564*	.000958	.000416	43.4
SAR	.731**	19.6	6.51	33.2
EC		2.87	1.62	56.4

1/ N = 10, $r_{.95} = .549$, and $r_{.99} = .715$.

TABLE III-13. SUMMARY STATISTICS OF CATION RATIOS. 1/

GROUNDWATER

Correlation Coeff. w/EC

	Mg	Ca
Na	.243	.406
Ca	-.101	

N = 10

 $r_{.95} = .549$ $r_{.99} = .715$ Mean

	Mg	Ca
Na	2.80	13.4
Ca	.655	

Std. Dev.

	Mg	Ca
Na	3.03	9.64
Ca	.311	

SOIL

Correlation Coeff. w/EC

	Mg	Ca
Na	-.930**	.792*
Ca	-.975**	

N = 6

 $r_{.95} = .729$ $r_{.99} = .882$ Mean

	Mg	Ca
Na	7.96	6.10
Ca	1.42	

Std. Dev.

	Mg	Ca
Na	4.23	1.21
Ca	1.02	

1/ The vertical numbers of the tables are numerators and the horizontal numbers are denominators. For example, the mean Na/Ca value is 13.4.

Site J

Site Description

Site J is located close to the main canal on the eastern end of the study area (Fig. I-3). The productivity is rated as poor. It was in pasture for the duration of the study. There are visible surface salt deposits at this site. This soil is saline-sodic.

Soil-Groundwater Relationships

The soil has a heavy clay texture to 1.8 m (Fig. III-J1). Because of this and the plasticity associated with this site, we were unable to sample below 1.2 m with the equipment available.

The distribution of soil variables with depth are shown in Figures III-J2, J3, and J4. The EC of the soil profile reaches a peak at .6 m. The pH of this site is low relative to the rest of the study area (Fig. III-J2). The saturation percentage is high. The soil $\text{NO}_3\text{-N}$ is low and constant with depth.

The major cation and SAR peaks are consistent with that of the profile EC. The soil Mg is three times the concentration of Ca at this site. The surface ammonium acetate extractable K is high. It drops to half of this and is constant the rest of the profile.

The changes in piezometric head at various depths are shown in Figure III-J5. The 3.3 and 4.6 m piezometer data do not closely

follow canal activity. The 2.1 meter data does seem to be hydraulically associated with main canal activation in the spring and termination in the fall. The soil peak for EC and SAR indicate there is no net movement of irrigation water beyond .6 m. The texture alone (with a favorable SAR) would severely restrict water movement.

Concentrations of groundwater constituents with time are shown in Figures III-J6, J7, and J8. The groundwater EC at this site is well below that of the soil. The first three samples of 1975 are so enormously high that it suggests leakage of irrigation water down the side of the access tube. The other possibilities are a lateral source of groundwater with extremely variable salt content or contamination of the sample by irrigation water somehow entering the tube from the surface. The groundwater ion concentrations are much less than that of the profile if the initial three samples are not considered. The great difference in soil and groundwater salts suggest that the water movement at this site is upward. The surface .3 m seem to be relatively depleted of salt from downward movement of irrigation water.

Cation fractions as a function of EC are shown in Figure III-J9. The percentages of individual cations are very stable throughout the profile. Groundwater percentages are quite variable. This is especially true during lower salt concentrations.

Summary statistics for groundwater and soil variables are shown in Tables III-J1, J2, and J3. The percentage of Na is extremely

stable throughout the profile. The Na percentage in the groundwater is stable also. The absolute values of the major cations within the groundwater were variable and all were correlated with EC. The Na/Mg ratio was almost constant while all others changed with changing EC (Table III-J3).

Summary

This site has a heavy clay texture and is saline-sodic. The productivity is poor. The major cations peak at .6 m. Their concentrations rank as $\text{Na} \gg \text{Mg} > \text{Ca}$ in both soil and groundwater. The groundwater concentrations are well below those of the profile.

SITE J

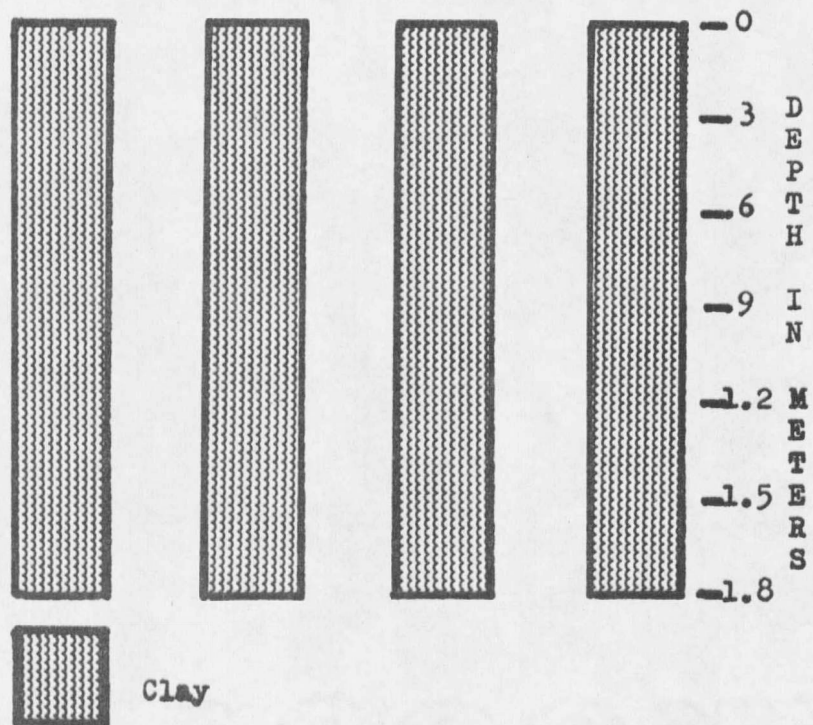


Fig. III-J1. Horizonation of soil profile at four sampling sites adjacent to groundwater access tube.

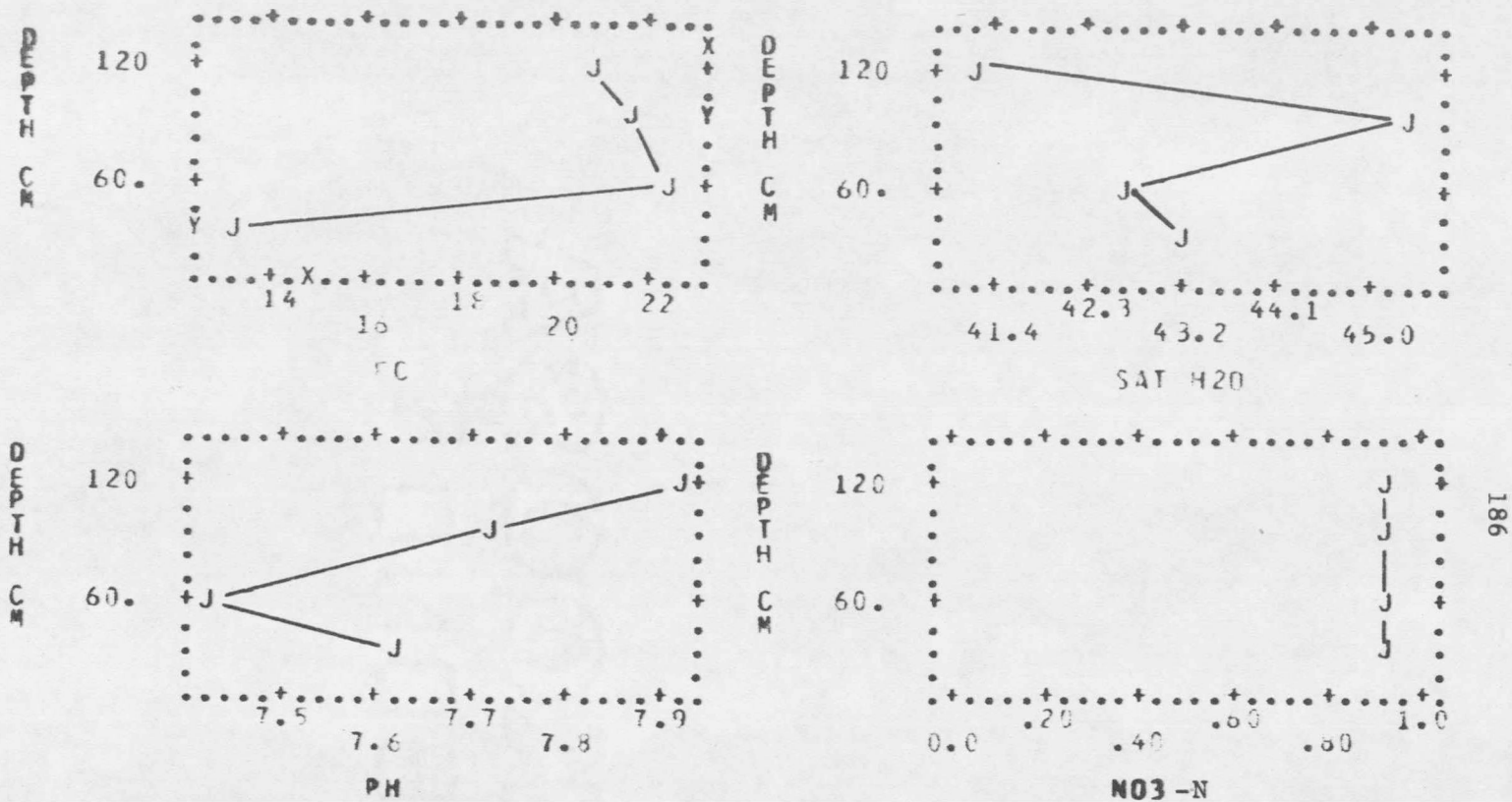


Fig. III-J2. Distribution of electrical conductivity (mmhos/cm), NO₃-N (ppm), pH, and saturated water percentage of the soil with depth. The pH and EC are of the saturated extract.

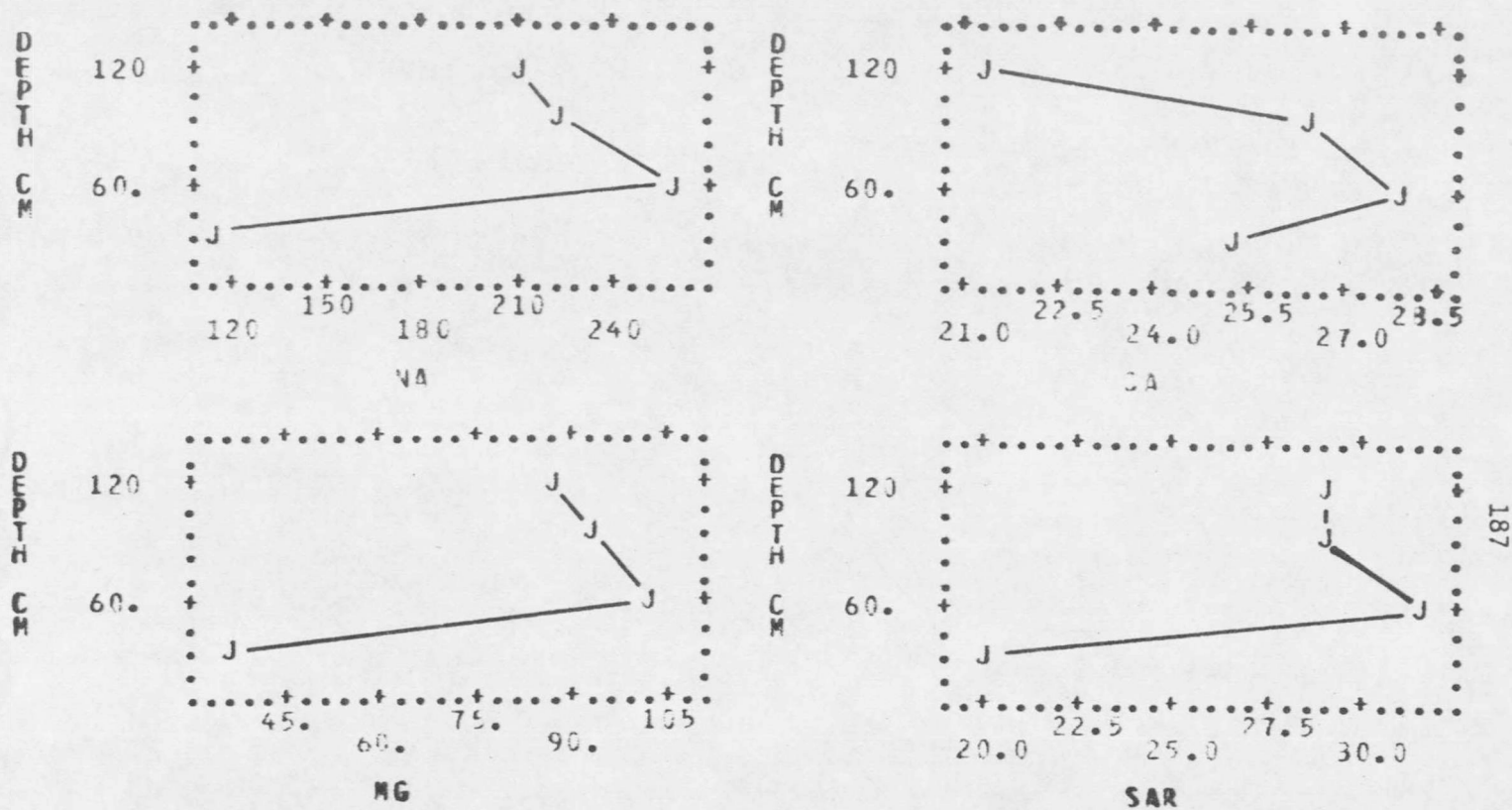


Fig. III-J3. Distribution of major cations (meq/l) of saturated extract and sodium adsorption ratio (SAR) with soil depth.

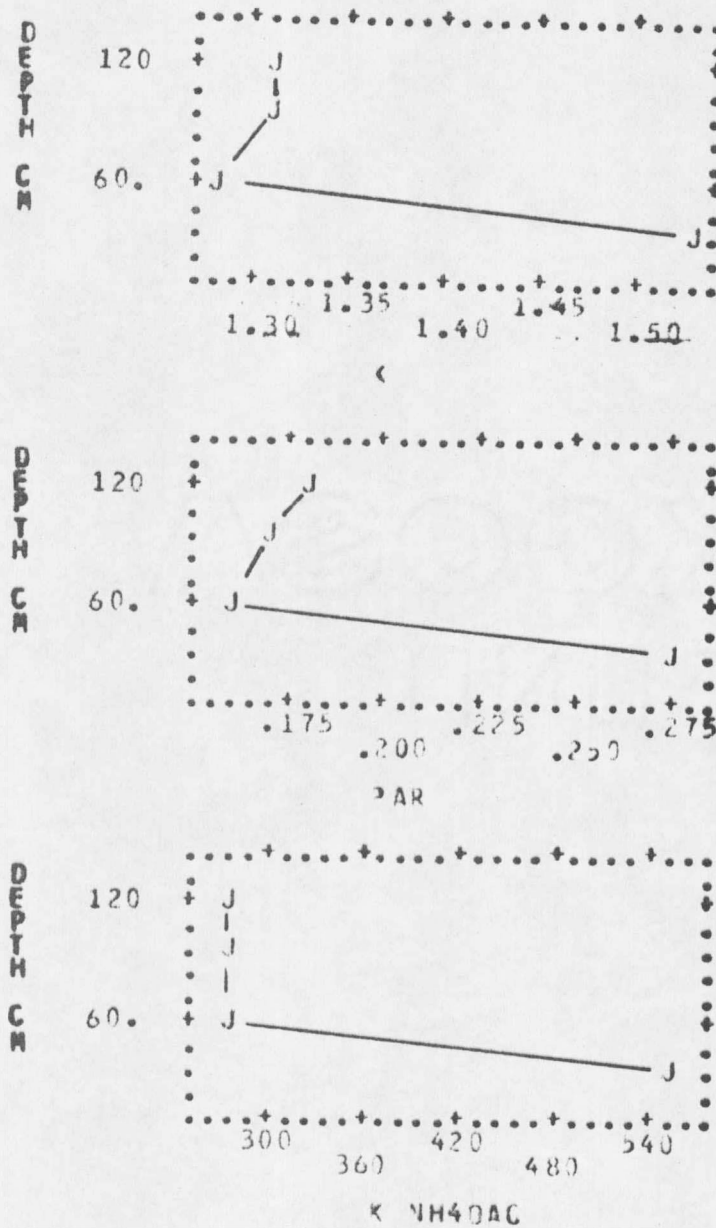


Fig. III-J4. Distribution of water soluble K (meq/l), ammonium acetate extractable K (ppm), and the potassium adsorption ratio with depth.

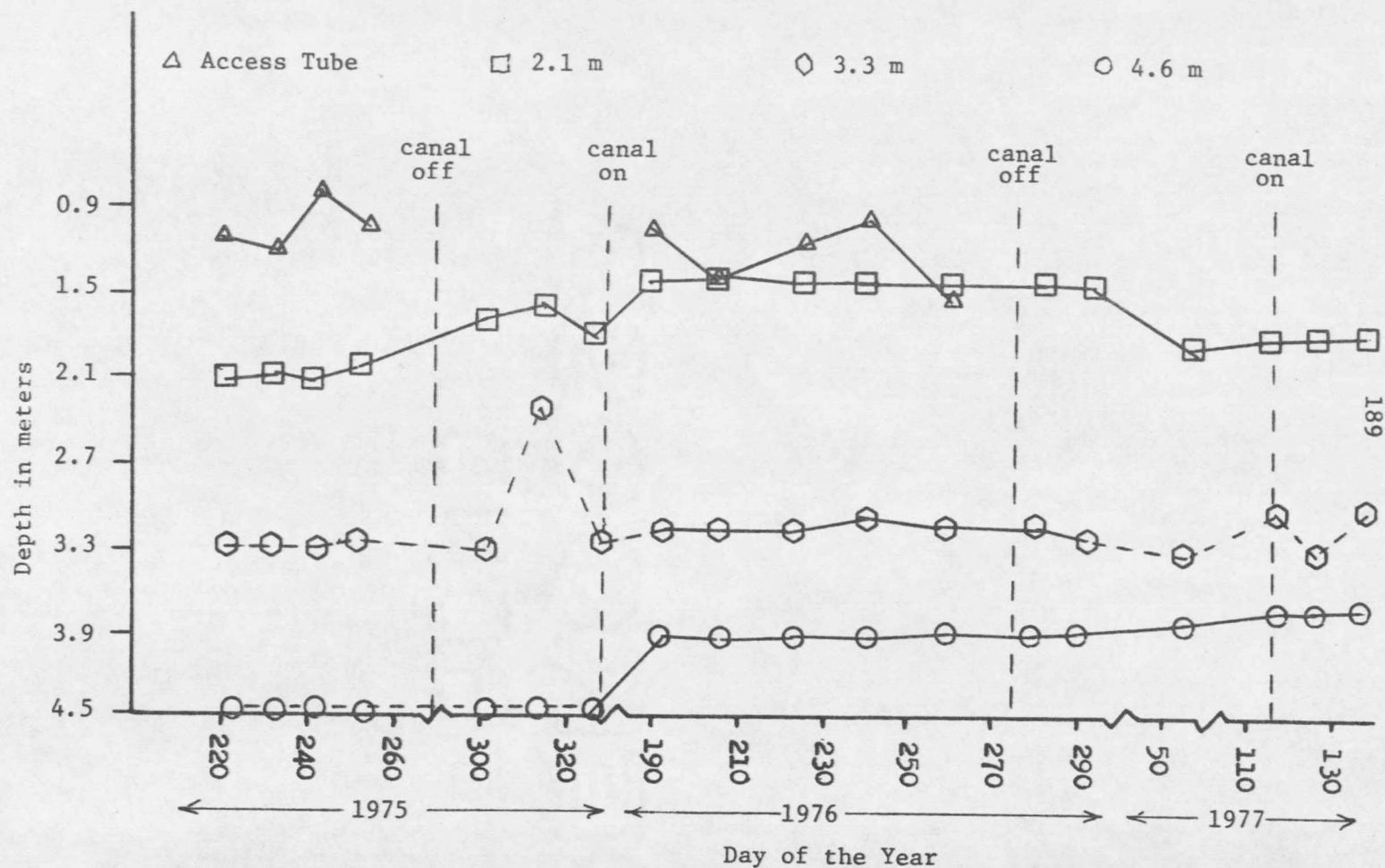


Figure III-J5. Piezometric head with time. Data points connected with dashed lines represent unsaturated conditions at the depth sampled by that piezometer.

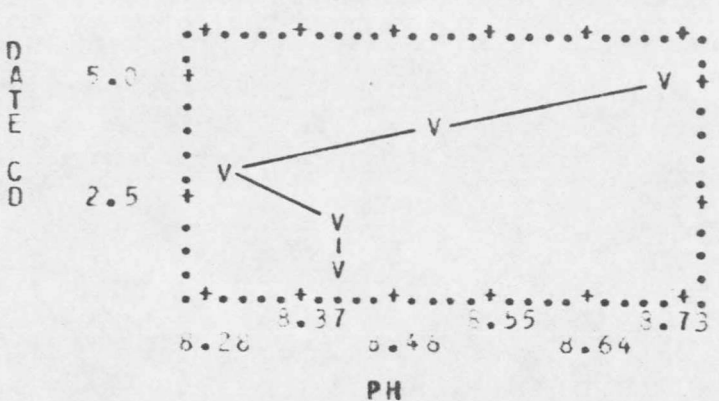
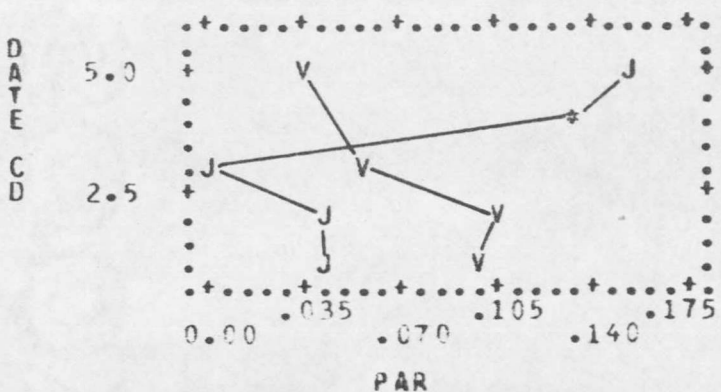
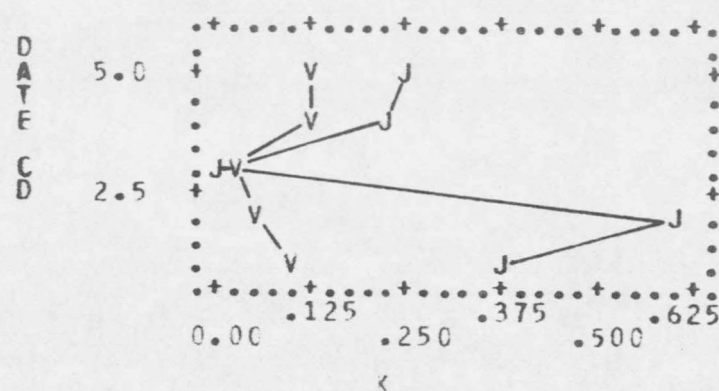
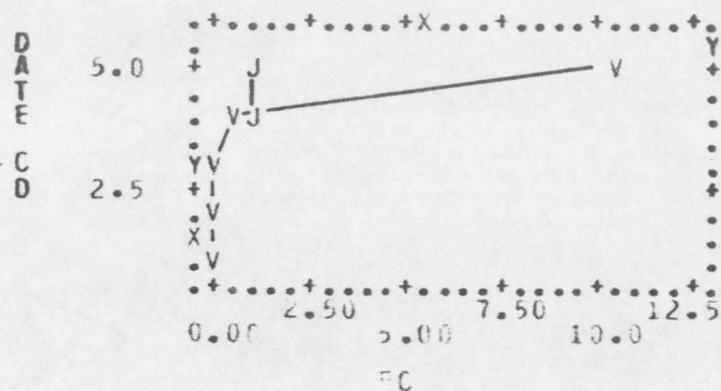


Fig. III-J6. Electrical conductivity (mmhos/cm), K (meq/l), potassium adsorption ratio (PAR), and pH of groundwater vs. time. The J and V data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-J5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

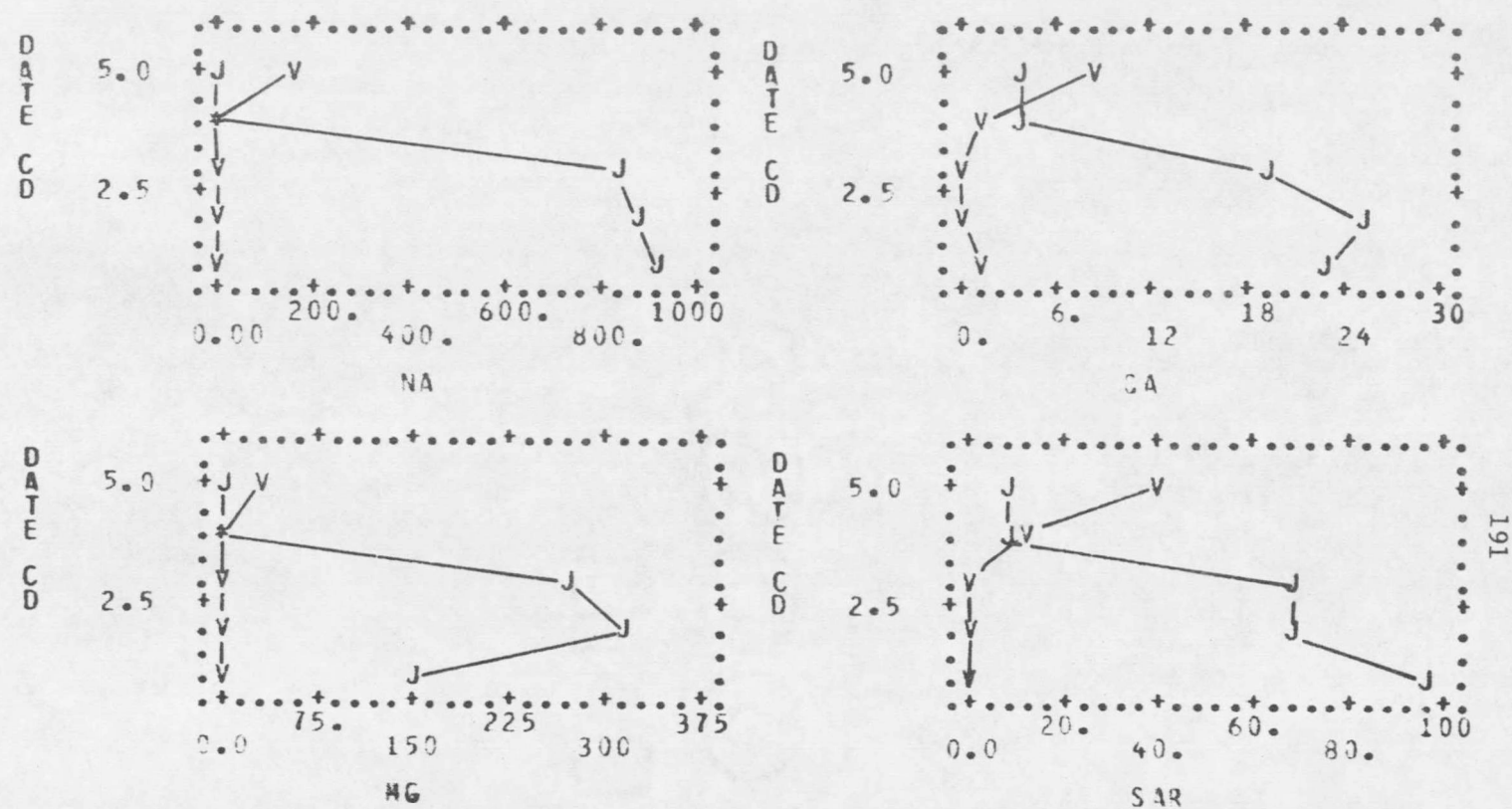


Fig. III-J7. Concentrations of major cations (meq/l) and sodium adsorption ratio of groundwater vs. time. The J and V data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-J5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

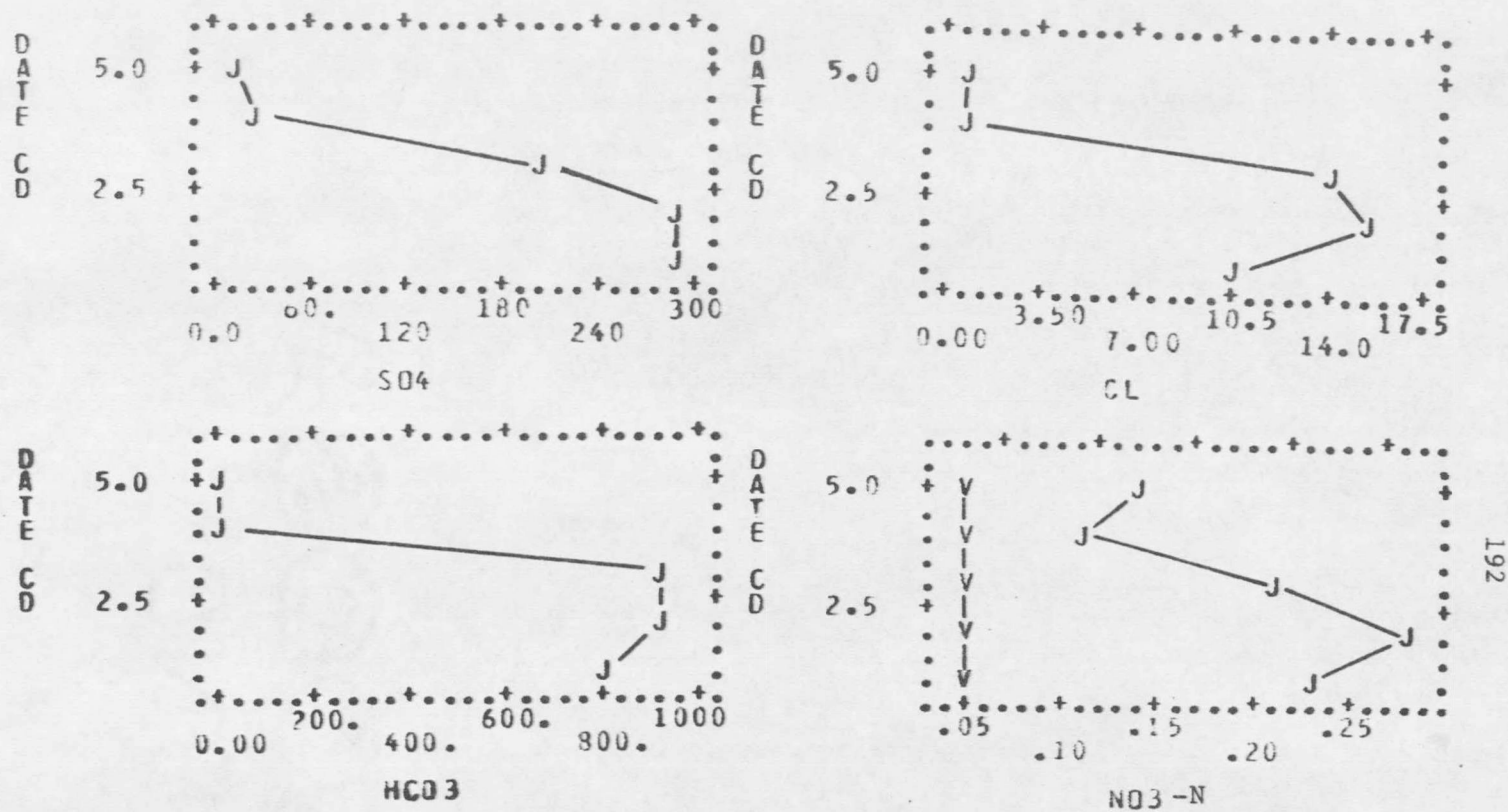


Fig. III-J8. Anion concentrations of groundwater (meq/l) vs. time. These data are for 1975 only. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-J5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.



Fig. III-J9. Individual cation fractions (cation/total cations) as a function of EC for groundwater and soil. Data points D, J, and P represent soil, groundwater 1975 and groundwater 1976, respectively.

TABLE III-J1. SUMMARY STATISTICS OF SOIL VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.984*	20.1	61.9	30.8
Mg	.994**	79.7	29.6	37.1
Ca	.098	25.2	2.82	11.2
K	-.999**	1.36	.116	8.5
<u>Cation Fraction</u>				
Na	.823	.652	.0102	1.6
Mg	.981*	.253	.0302	11.9
Ca	-.980	.0897	.0363	40.5
K	-1.00**	.00498	.00251	50.4
SAR	.988**	27.4	4.97	18.1
EC		19.4	4.23	21.8

1/ N = 4, $r_{.95} = .886$, and $r_{.99} = .989$.

TABLE III-J2. SUMMARY STATISTICS OF GROUNDWATER VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.998**	29.4	59.3	201.7
Mg	1.00**	4.25	8.58	201.9
Ca	.930**	2.40	2.69	112.1
K	.118	.128	.0815	63.7
<u>Cation Fraction</u>				
Na	.491	.616	.223	36.2
Mg	-.249	.153	.0734	47.9
Ca	-.585	.209	.138	66.0
K	-.576	.0217	.0180	82.9
SAR	.955**	10.6	14.3	134.9
EC		1.90	3.85	202.6

1/ N = 7, $r_{.95} = .669$, and $r_{.99} = .833$.

TABLE III-J3. SUMMARY STATISTICS OF CATION RATIOS. 1/

GROUNDWATER					
<u>Correlation Coeff. w/EC</u>			<u>Mean</u>		
	<u>Mg</u>	<u>Ca</u>		<u>Mg</u>	<u>Ca</u>
Na	.093	.867**	Na	6.04	6.48
Ca	.948**		Ca	1.31	
N = 7			<u>Std. Dev.</u>		
r _{.95} = .669				<u>Mg</u>	<u>Ca</u>
r _{.99} = .833			Na	5.44	7.37
			Ca	.458	
SOIL					
<u>Correlation Coeff. w/EC</u>			<u>Mean</u>		
	<u>Mg</u>	<u>Ca</u>		<u>Mg</u>	<u>Ca</u>
Na	-.975*	.951*	Na	2.60	8.01
Ca	-.985*		Ca	.373	
N = 4			<u>Std. Dev.</u>		
r _{.95} = .886				<u>Mg</u>	<u>Ca</u>
r _{.99} = .989			Na	.317	2.45
			Ca	.213	

1/ The vertical numbers of the tables are numerators and the horizontal numbers are denominators. For example, the mean Na/Ca value is 6.48.

Site K

Site Description

This site is located on the eastern end of the study area close to the River (Fig. I-3). The access tube is located in an alfalfa field. The productivity is rated as good.

Soil-Groundwater Relationships

The textural horization at this site consists of 1 m of loam over sandy clay or sand. Gravel is encountered at about 1.5 m (Fig. III-K1). Concentrations of selected soil chemical constituents are shown in Figures III-K2, K3, and K4. The EC of the soil profile peaks sharply at 1.2 m. The pH varies more than one unit and is minimum at the EC maximum. There is a small quantity of $\text{NO}_3\text{-N}$ at the surface. The saturation percentage is low and the mirror image of the profile SAR.

Ca is the dominant cation of the soil profile. Magnesium and Ca have sharp peaks at 12 m. Na generally increases with depth. The SAR also increases with depth except for the location of the Mg and Ca peaks where it is somewhat depressed. The ammonium acetate extractable K is relatively uniform below .3 m and not correlated with water soluble K.

Changes in piezometric head at various depths with time are shown in Figure III-K5. The piezometer data indicate that the 1.8 m depth

responds to canal activity and during the irrigation season has the highest piezometric head.

Concentrations of groundwater chemical variables with time are shown in Figures III-K6, K7, and K8. The groundwater EC followed the same pattern both summers although it was lower the second year. Potassium concentration with time graphed as mirror images between years.

The curves of the major cations are similar in shape to that of the EC. The groundwater Na is greater than that of the profile where as Mg and Ca are less. This results in an average groundwater SAR that is double that of the profile immediately above.

The major anion, as with all sites, is SO_4 . There is very little groundwater $\text{NO}_3\text{-N}$ at this site.

Cation fractions of soil and groundwater as a function of EC are shown in Figure III-K9.

Percentages of individual cations vary less within the soil profile. The groundwater samples with an EC less than .4 mmhos/cm have quite variable cation percentages while those above this are stable.

Summary statistics of groundwater and soil variables are shown in Tables III-K1, K2, and K3. All major cations are associated with increased EC of the groundwater. As the percent Na increases the EC increases while other cation percentages decrease. Cation mean concentrations rank $\text{Na} > \text{Ca} > \text{Mg}$ in the groundwater and $\text{Ca} > \text{Na} > \text{Mg}$ in

the soil. This site is unique in having Ca as the most abundant soil cation. The EC of the profile is about twice that of the groundwater. The Ca/Mg ratios of the soil and groundwater are high at this site. Sodium ratios are much lower in the soil.

Summary

Textures at this site are sandy and the soil is shallow. The productivity is good. The major cations peak with depth in the order $\text{Ca} = \text{Mg} < \text{Na}$. Their mean concentrations rank $\text{Na} > \text{Ca} > \text{Mg}$ in the groundwater and $\text{Ca} > \text{Na} > \text{Mg}$ in the soil.

SITE K

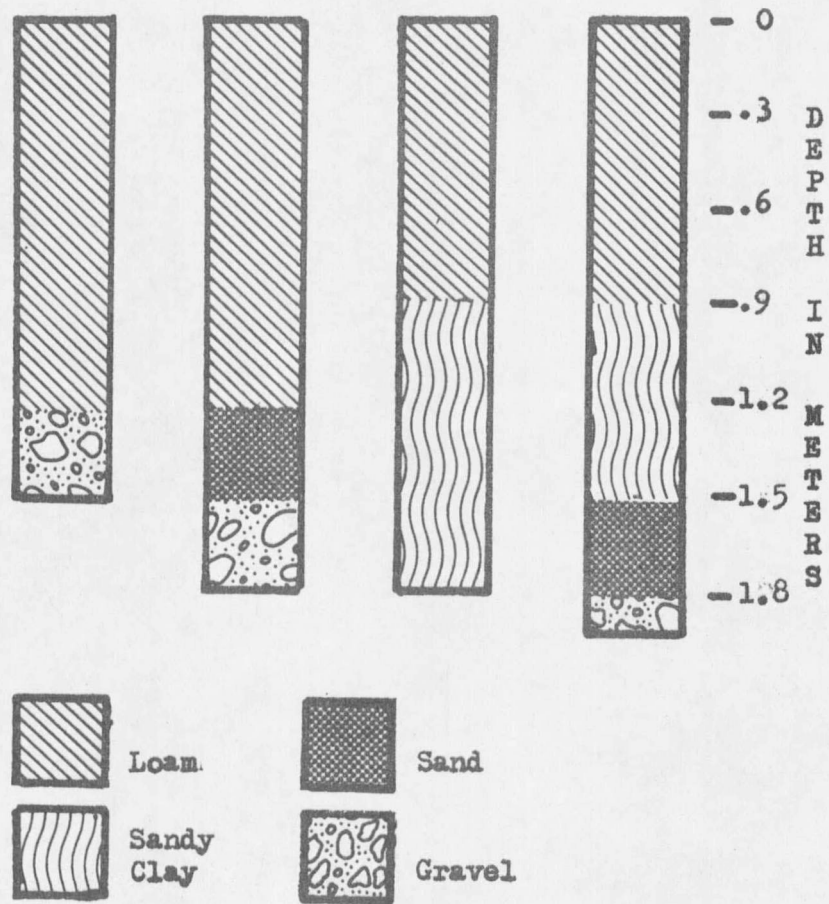


Fig. III-K1. Horization of soil profile at four sampling sites adjacent to groundwater access tube.

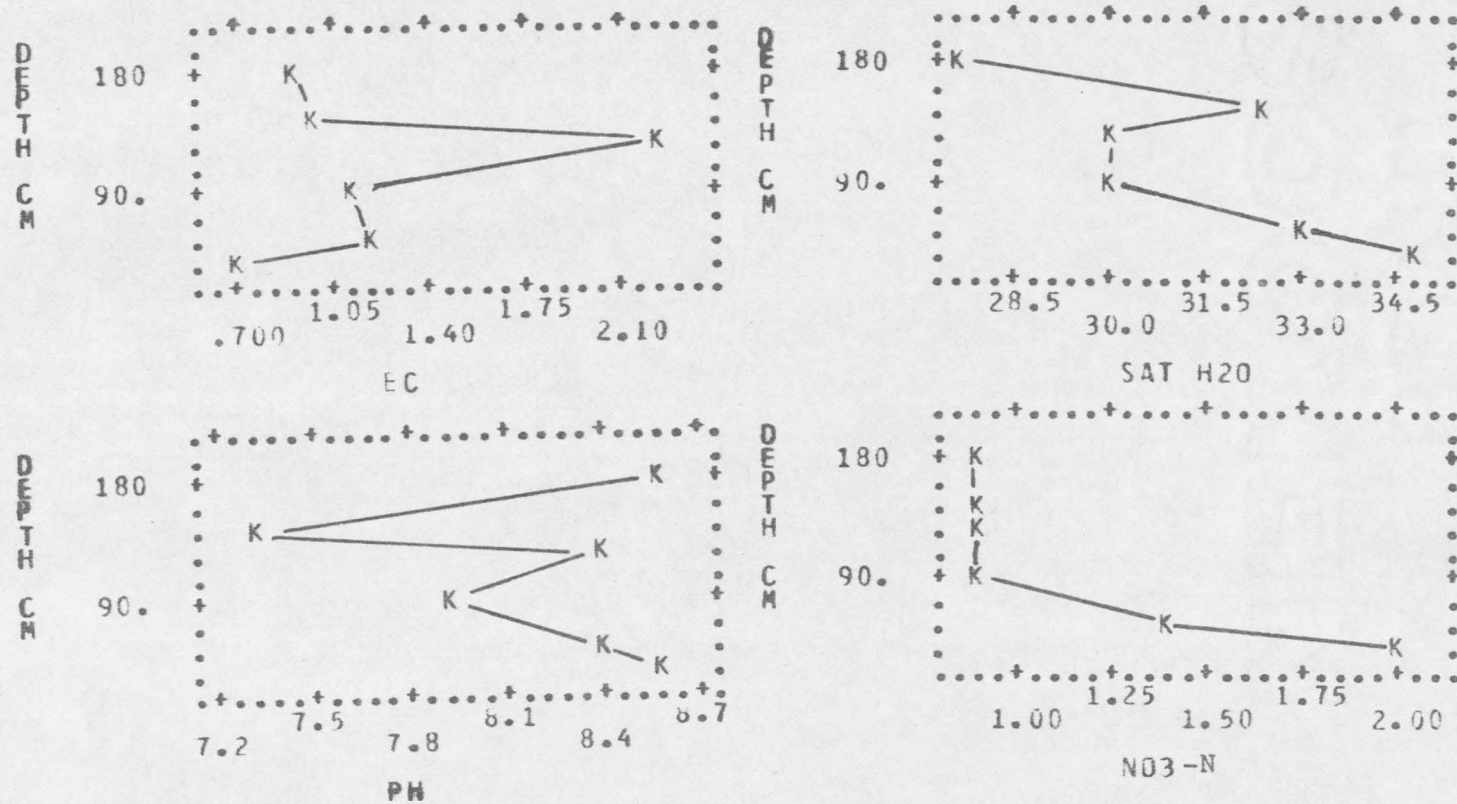


Fig. III-K2. Distribution of electrical conductivity (mmhos/cm), NO₃-N (ppm), pH, and saturated water percentage of the soil with depth. The pH and EC are of the saturated extract.

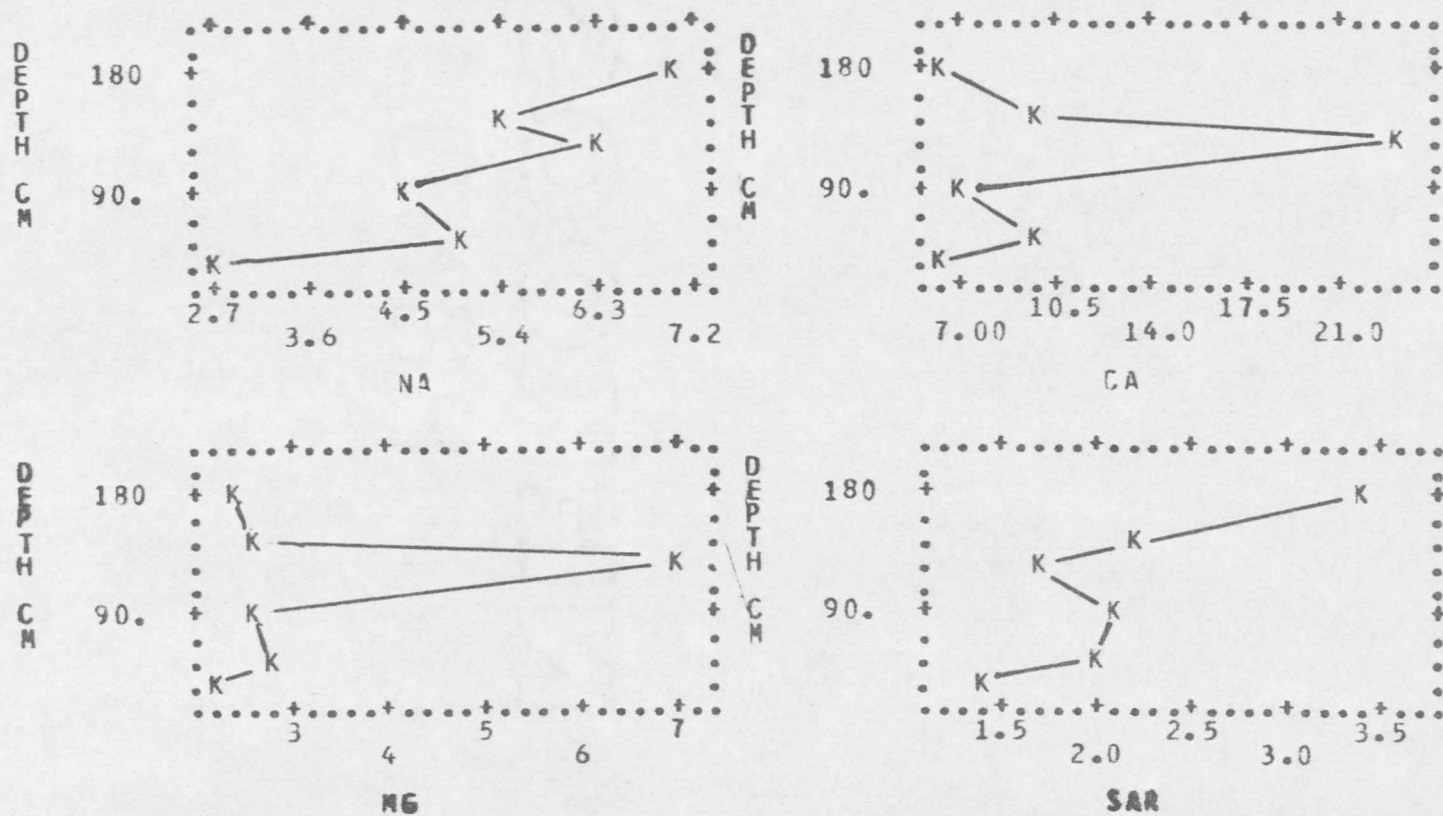


Fig. III-K3. Distribution of major cations (meq/l) of saturated extract and sodium adsorption ratio (SAR) with soil depth.

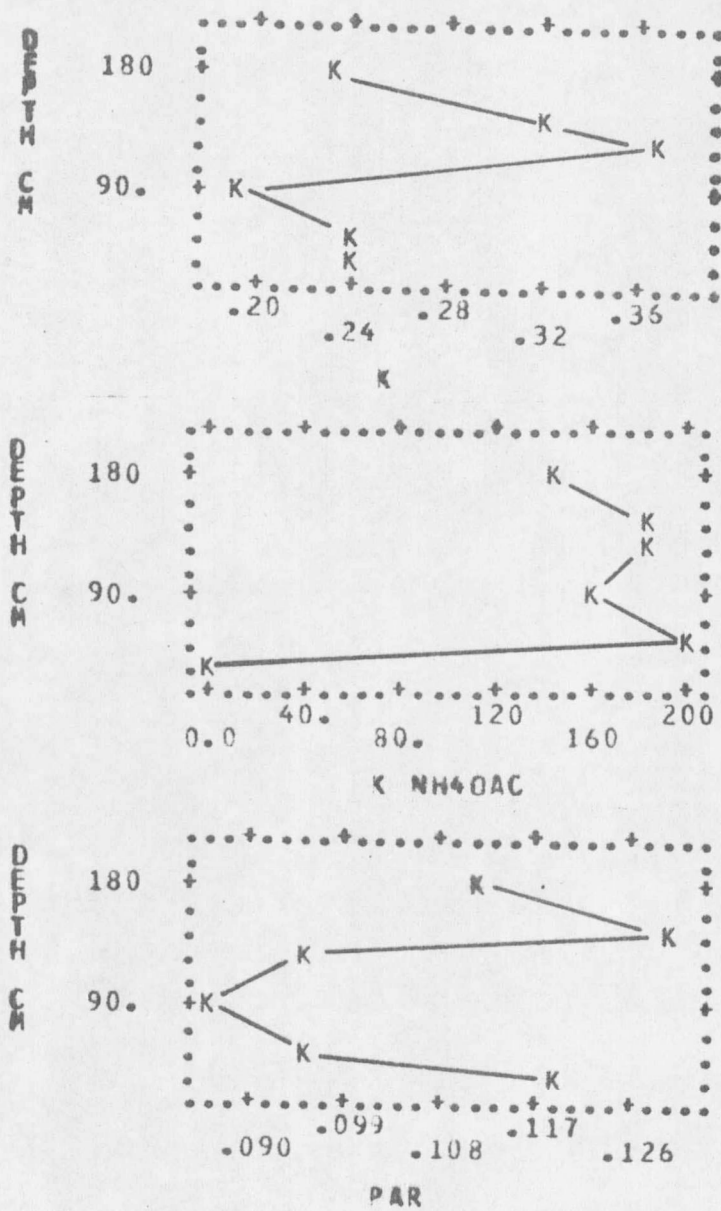


Fig. III-K4. Distribution of water soluble K (meq/l), ammonium acetate extractable K (ppm), and the potassium adsorption ratio with depth.

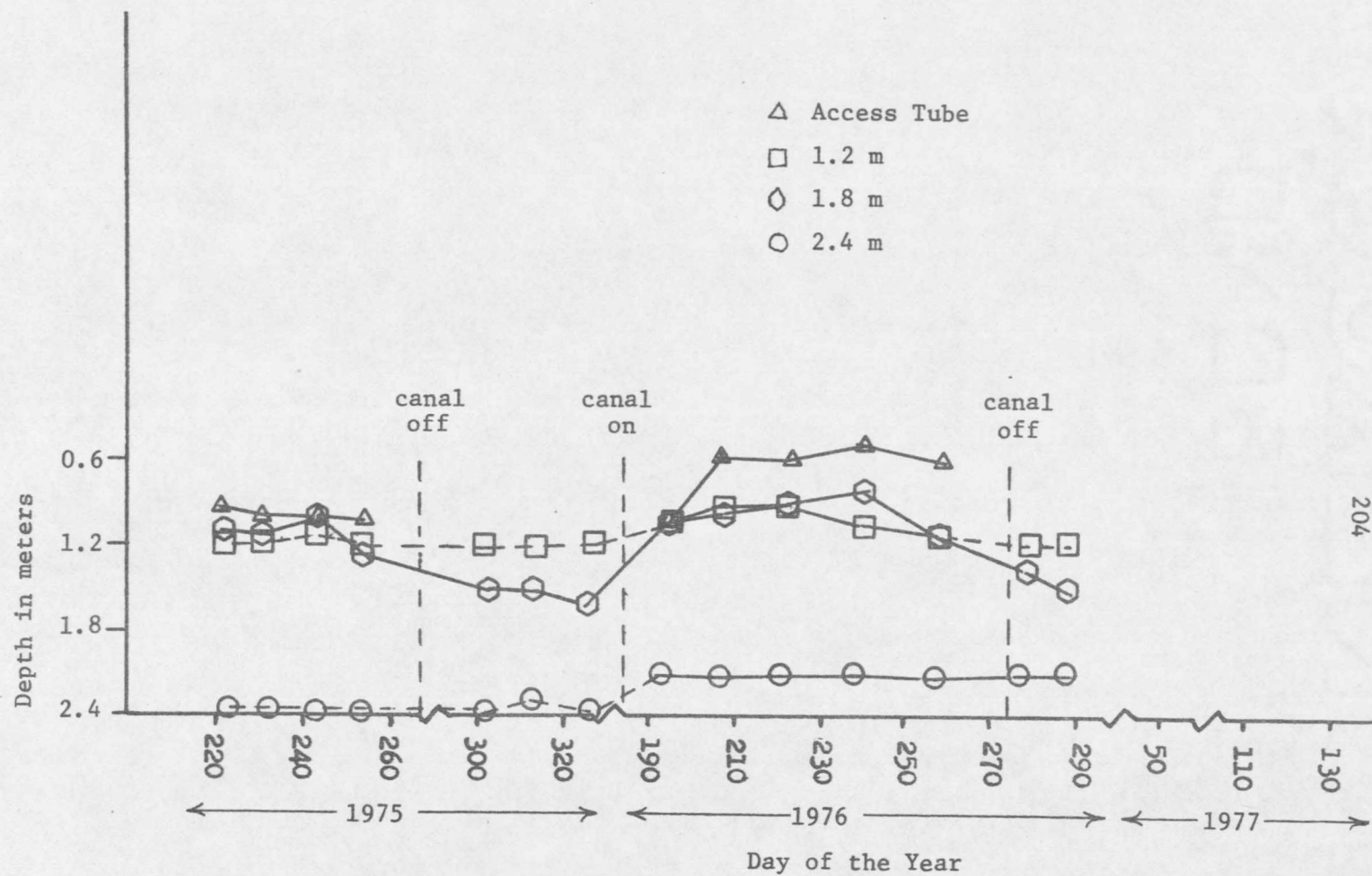


Figure III-K5. Piezometric head with time. Data points connected with dashed lines represent unsaturated conditions at the depth sampled by that piezometer.

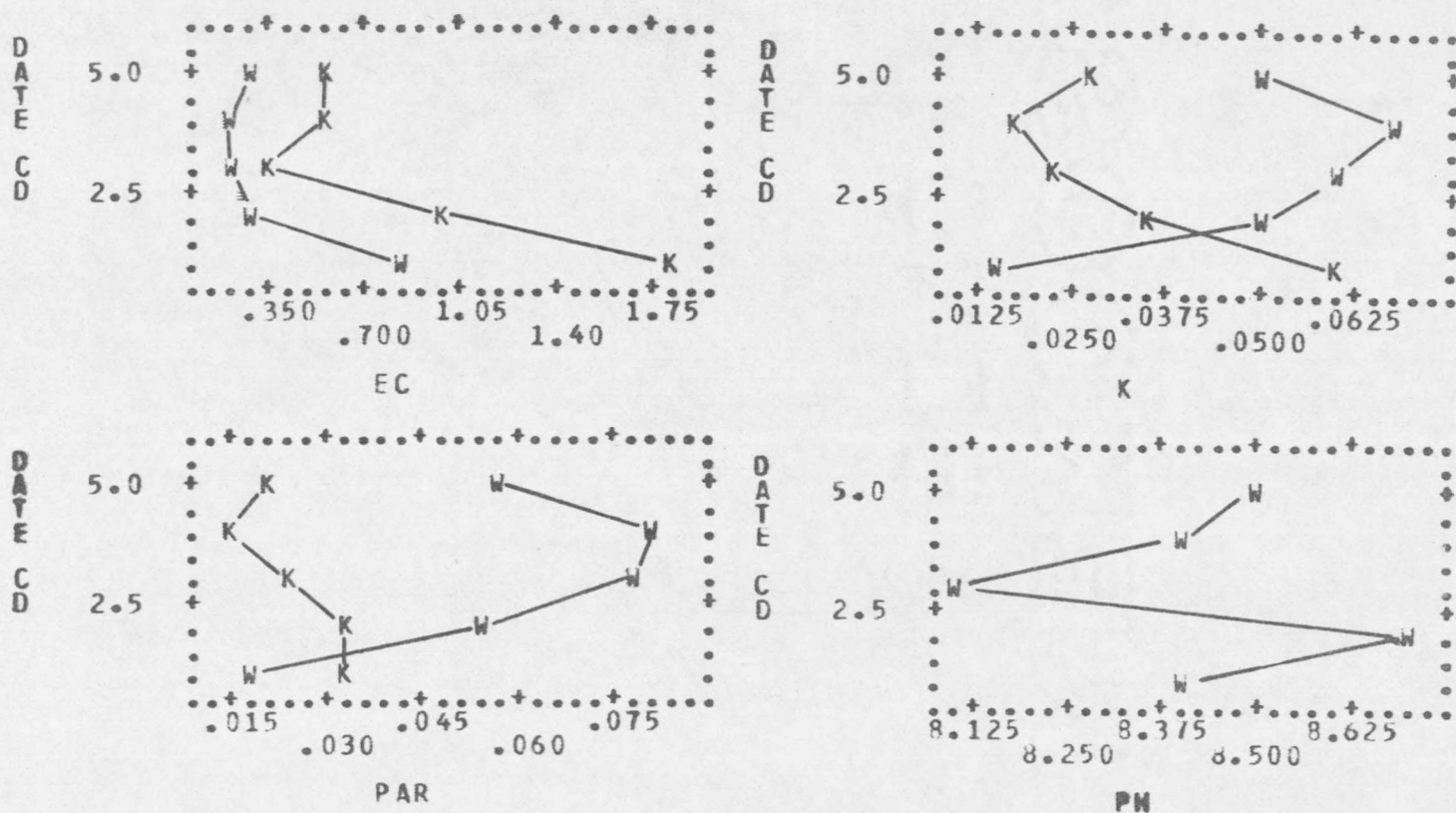


Fig. III-K6. Electrical conductivity (mmhos/cm), K (meq/l), potassium adsorption ratio (PAR), and pH of groundwater vs. time. The K and W data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-K5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

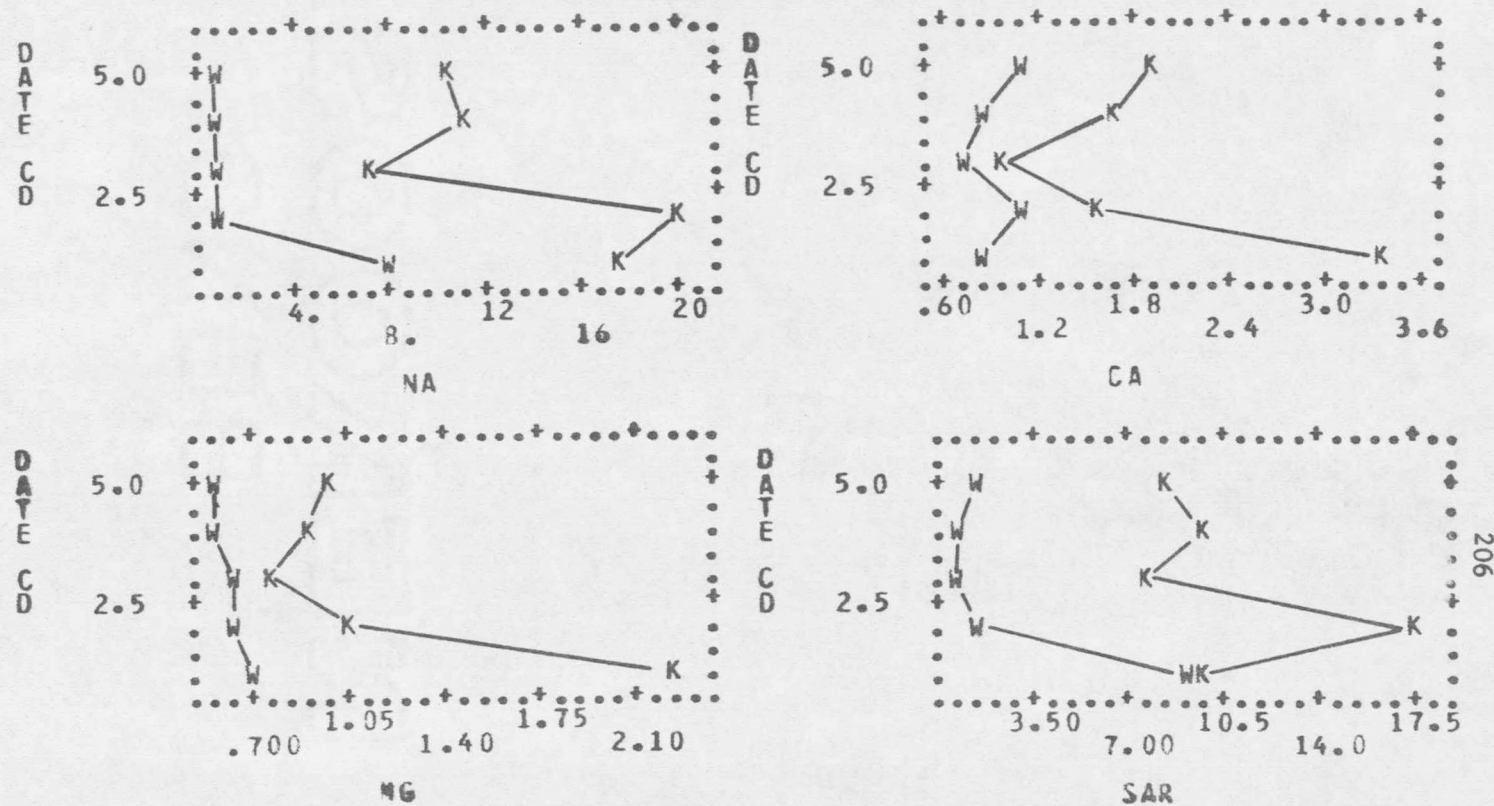


Fig. III-K7. Concentrations of major cations (meq/l) and sodium adsorption ratio of ground-water vs. time. The K and W data points are for 1975 and 1976, respectively. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-K5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

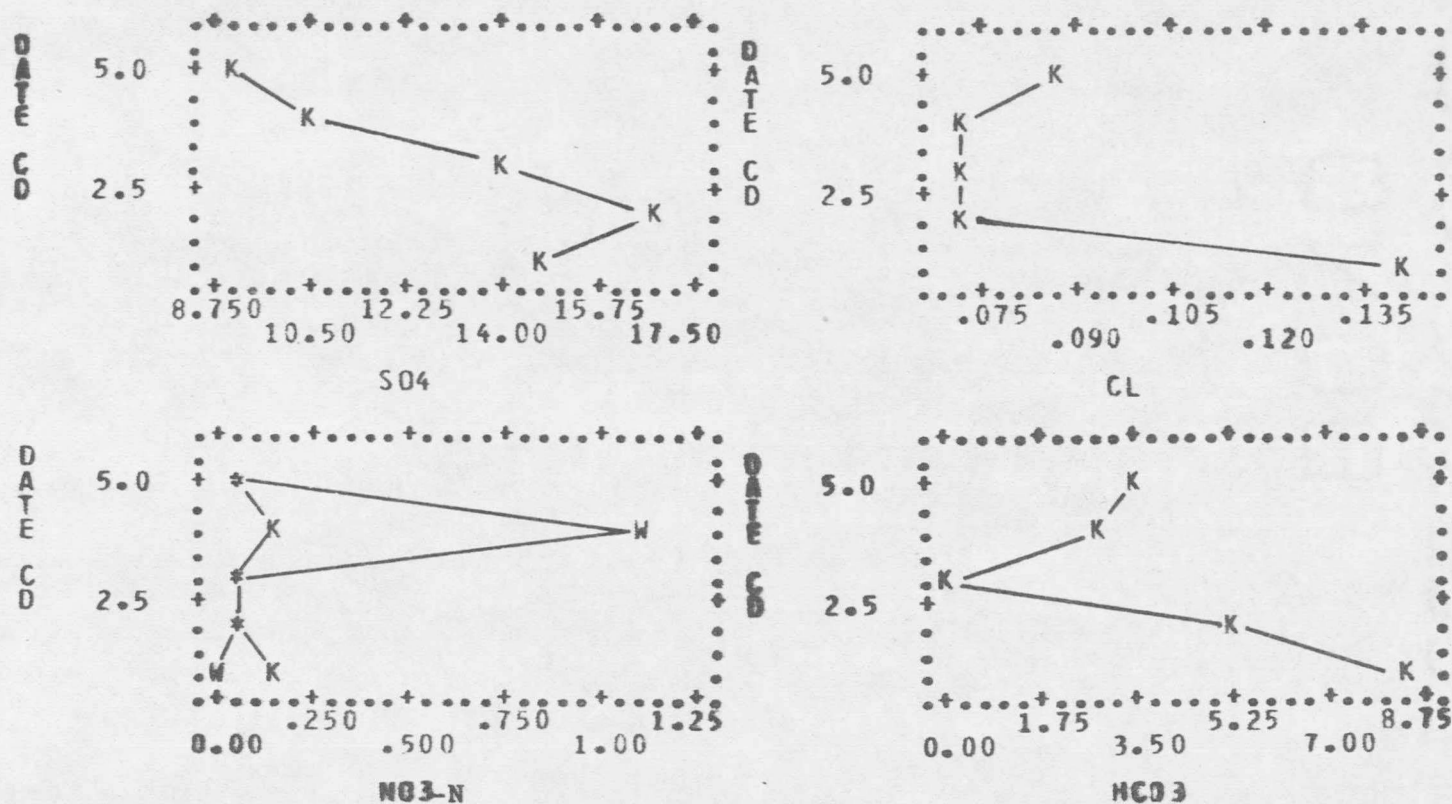


Fig. III-K8. Anion concentrations of groundwater (meq/l) vs. time. These data are for 1975 only. The date code (DATE CD) represents the five sampling dates approximately two weeks apart. The actual dates are those of Fig. III-K5; the second date of 1975 is Julian day 224, the first date of 1976 is Julian day 207, etc.

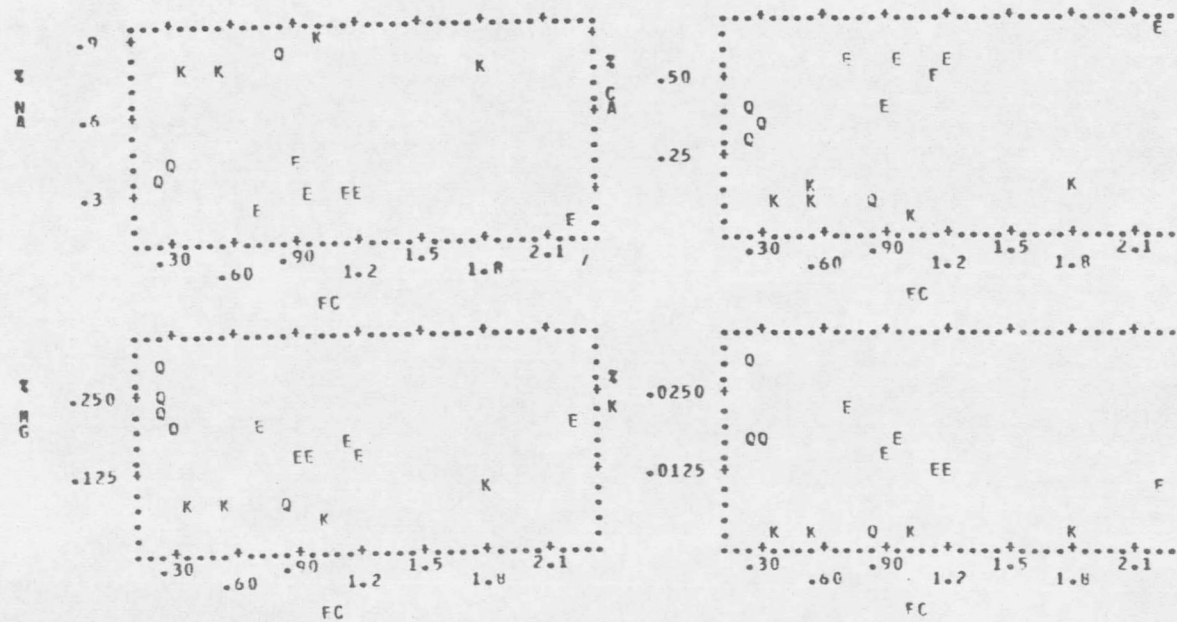


Fig. III-K9. Individual cation fractions (cation/total cations) as a function of EC for groundwater and soil. Data points E, K, and Q represent soil, groundwater 1975 and groundwater 1976, respectively.

TABLE III-K1. SUMMARY STATISTICS OF SOIL VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.478	5.17	1.49	28.8
Mg	.974**	3.32	1.80	54.2
Ca	.962**	10.2	6.42	62.9
K	.675	.265	.0665	25.1
<u>Cation Fraction</u>				
Na	-.592	.293	.0899	30.7
Mg	.255	.173	.0209	12.1
Ca	.641	.518	.0795	15.3
K	-.818*	.0150	.00393	26.2
SAR	-.247	2.11	.701	33.2
EC		1.19	.545	45.8

1/ N = 6, $r_{.95} = .729$, and $r_{.99} = .882$.

TABLE III-K2. SUMMARY STATISTICS OF GROUNDWATER VARIABLES. 1/

	Correlation Coeff. w/EC	Mean	Std. Dev.	CV
Na	.834**	7.79	7.08	90.9
Mg	.920**	.892	.496	55.6
Ca	.852**	1.40	.805	57.5
K	-.007	.0408	.0197	48.3
<u>Cation Fraction</u>				
Na	.586*	.635	.231	36.4
Mg	-.564*	.141	.0925	65.6
Ca	-.581*	.213	.131	61.5
K	-.579	.0107	.0121	113.1
SAR	.649	6.67	5.51	82.6
EC		.613	.494	80.6

1/ N = 10, $r_{.95} = .549$, and $r_{.99} = .715$.

TABLE III-K3. SUMMARY STATISTICS OF CATION RATIOS. 1/

GROUNDWATER

Correlation Coeff. w/EC

	<u>Mg</u>	<u>Ca</u>
Na	.503	.506
Ca	-.032	

N = 10

 $r_{.95} = .549$ $r_{.99} = .715$ Mean

	<u>Mg</u>	<u>Ca</u>
Na	7.79	5.08
Ca	1.56	

Std. Dev.

	<u>Mg</u>	<u>Ca</u>
Na	6.09	4.12
Ca	.299	

SOIL

Correlation Coeff. w/EC

	<u>Mg</u>	<u>Ca</u>
Na	-.533	-.504
Ca	.379	

N = 6

 $r_{.95} = .729$ $r_{.99} = .882$ Mean

	<u>Mg</u>	<u>Ca</u>
Na	1.74	.603
Ca	3.00	

Std. Dev.

	<u>Mg</u>	<u>Ca</u>
Na	.672	.301
Ca	.473	

1/ The vertical numbers of the tables are numerators and the horizontal numbers are denominators. For example, the mean Na/Ca value is 5.08.

Streamline Discussion

In order to consider the groundwater flow of the area certain assumptions must be made. It is assumed that the gravel layer is continuous. In respect to water transmitting properties, the soils of the area are very heterogeneous and anisotropic. The hydraulic conductivity of the gravel aquifer is so much greater than overlying soil that it is assumed most of the lateral water movement toward the river is through this aquifer. The gravel layer acts as a semi-confined aquifer. Since the thickness of the gravel aquifer is not known, no attempt will be made to quantify groundwater flow.

The groundwater flow parallels topography. The piezometric surface of the study area for the gravel aquifer is shown in Figure III-5. The deepest piezometer at most sites is in contact with the gravel aquifer. The sites where contact was not made are A, E, H, I, and J. In most of these sites the coarser textures above the gravel were penetrated so changes in the piezometric head of the gravel aquifer are reflected by these piezometers. Site H is the only site that had an unresponsive lower piezometer which rose during the entire study period as it came into equilibrium with the head at this depth. The assumption of penetration of coarse-textured strata above the gravel is based on (1) unpublished Bureau of Reclamation depth-to-gravel map (this also supports the gravel continuity assumption since the drill logs used to construct this map were much more numerous than those of

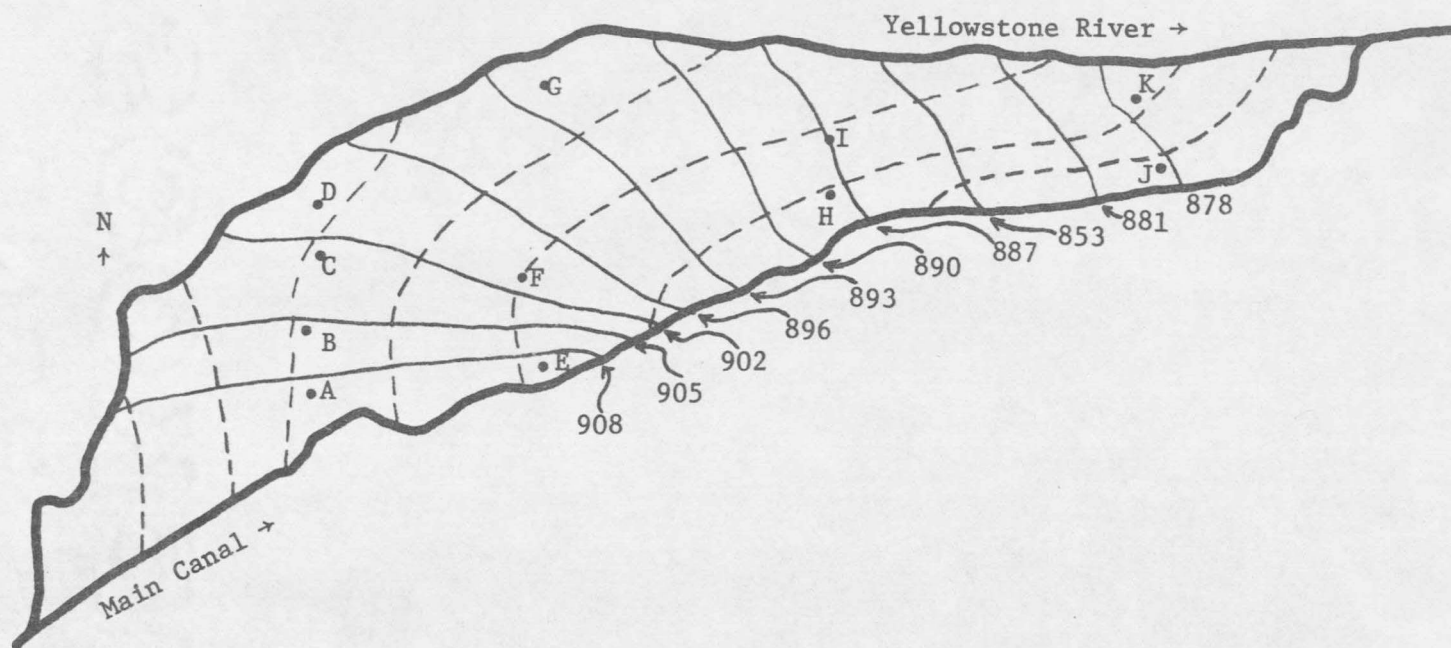


Fig. III-5. Piezometric surface of the study area on 10/15/76. Solid lines are lines of equipotential (in meters above sea level) and dashed lines are streamlines.

this study and gravel was encountered between 1 to 7 meters in all cases), (2) the rapid change in piezometric head with time suggests coarse textures, and (3) the resistance to piezometer insertion through coarse textures could be felt. In most sites there was little difference in piezometric head with depth at a given site. This suggests little vertical movement of groundwater.

The groundwater flow parallels topography. Figure III-5 was constructed by plotting the piezometric head of the deepest piezometer at each site. The piezometric heads are expressed in meters above sea level. Equipotential lines were then drawn and streamlines were constructed perpendicular to equipotential lines. The groundwater flow is almost due north on the western end of the study but becomes almost due east on the eastern end. The potential gradient decreases from west to east (.28% in streamline ABCD to .15% in streamline HK). Streamline EFI has the highest potential gradient between sites E and F and a much lower gradient the remainder, .36% and .16%, respectively.

Most sites fall on common streamlines. These are labeled streamlines ABCD, EFI, and HK where the letters are previously established site labels. Sites G and J did not fall on streamlines common to any other site and are considered only as individual sites. The chemical properties of the soil and groundwater of these streamlines are considered in the following section.

Streamline ABCD

Groundwater monitoring sites A, B, C, and D are in the same approximate streamline. According to piezometric surface maps groundwater flow is from site A-B-C-D, from the main canal to the Yellowstone River. Groundwater flow is almost due north. Figures III-6, 7, 8, 9, and 10 show the distribution of cations and SAR with depth in the soil at sites A, B, C, and D. The small figures in the lower right corner represent groundwater means for the two summers of the respective cation in the soil graph. All concentrations are in meq/liter.

Soil

There are three obvious possibilities for the present distribution of salts in the soil profiles: (1) It is possible that the distributions are an expression of salt concentrations of the original alluvium in which these soils have developed and the project has not changed the original situation. Although this is a possibility, it is unlikely; (2) Soil salts could have been leached along this streamline and carried toward the river where they entered "down streamline" soils during periods of upward soil water movement; or (3) The distribution could be a sole function of leaching with no effect from upward movement from the aquifer. It is probable that the salt distributions are

the result of a combination of all three mechanisms and predominately the latter two.

Most soils of the study are developed on marine shale. Only the sites close to the river have developed in different parent material. In this streamline Site D is developed in Quaternary alluvium.

Since local soil conditions that determine water movement within the soil profile are a likely cause of salt distribution, they will be discussed in more detail.

The depth to the water table is one factor that influences the movement of salts and water in the soil profile. The water table is closer to the surface in the direction of the river (Table III-4). Depending on local properties that determine pore sizes within the soil profile (texture, structure, SAR, etc.), a critical depth to groundwater for a given site is reached where there is a net upward movement of water which tends to accumulate salts in the soil. Thus, an upward movement of water will result in increased soil salts above the water table. During periods of irrigation or other conditions conducive to downward movement of soil water the increased salts of the soil would be leached into the groundwater. This could also occur by diffusion of salt if the concentration gradient moves salt downward faster than it is being moved upward by water. Other factors being equal, the higher water table in the sites toward the river would tend to increase soil salts.

TABLE III-4. MEAN DEPTH TO THE WATER TABLE (ACCESS TUBE) FOR STREAM-LINES ABCD, EFI, AND HK. 1/

Site	Depth to Water	Site	Depth to Water	Site	Depth to Water
A	1.4	E	1.2	H	.9
B	1.2	F	1.6	K	.6
C	.9	I	2.2		
D	.9				

1/ Values are those of 1976 to minimize effect of erratic readings associated with initial installation (equilibration time and leakage around tube). All values are in meters.

The dynamics of the soil-water system tend to, in many cases, determine the depth in the soil profile where the maximum salt concentration is found. The depth of maximum concentration of a given salt will depend in part on its mobility which is determined by its solubility and tendency for adsorption in a soil system. The major anion of the groundwater is sulfate with an appreciable amount of bicarbonate at the less saline sites. The solubility of the major cations in such a system would be $\text{Na} > \text{Mg} > \text{Ca}$. It would seem that the position of the Na peak concentration in the profile relative to the Mg and Ca peaks could be used to determine the direction of net water movement in many cases; that is, the Na will be transported further by water movement.

At Site A the Na concentration increases with depth throughout the entire soil profile. Magnesium peaks near mid-profile and Ca peaks near the surface. It would seem that net leaching is occurring at Site A. At Site B the Na and Mg peaks are at about 1.2 m. The Ca again peaks near the surface. It appears that leaching has occurred to a more shallow depth than Site A. At Site C the Na peak is similar to the Mg peak and is more shallow than Site B. The Na peak at Site D is just below the Mg and Ca reaches a peak at about the same depth as Site C. It appears that the depth of maximum concentration of Na and Mg is related to the depth to the water table in this streamline.

Let us now consider the soil variables individually. The Na concentrations of soil and groundwater are shown in Figure III-6. All sites have similar surface concentrations of Na. Profile Na increases in the direction of the river. The Na concentration of Sites A, B, and C converge at 1.5 m but diverge again below the water table. If the small graph of the Na groundwater means is compared to the level of Na at the deepest point in the soil profile, it can be seen that the four sites rank in the same order for soil and groundwater Na levels ($B > C > A > D$). Upper soil profile concentrations of Na seem to be independent of groundwater concentrations.

Streamline Mg values are shown in Figure III-7. The profile Mg behaves similar to Na. As with Na, the surface concentrations are similar for all sites. The Mg concentrations of the upper profile increase in the direction of the river. The Mg peaks in the profile are nearer the surface than those of Na in the profile. The peaks are larger, sharper and closer to the surface in the direction of the river. The sharp peak at Site A at 1.2 m is associated with a sand layer. Although upper profile concentrations of Mg are different, they seem to approach a common lesser concentration with depth in Sites A, B, and C.

Calcium concentrations are shown in Figure III-8. The profile Ca decreases in the direction of the river with the exception of Site D. The first three sites are highest at the surface and decrease with depth. Site D has developed in different parent material (Quaternary

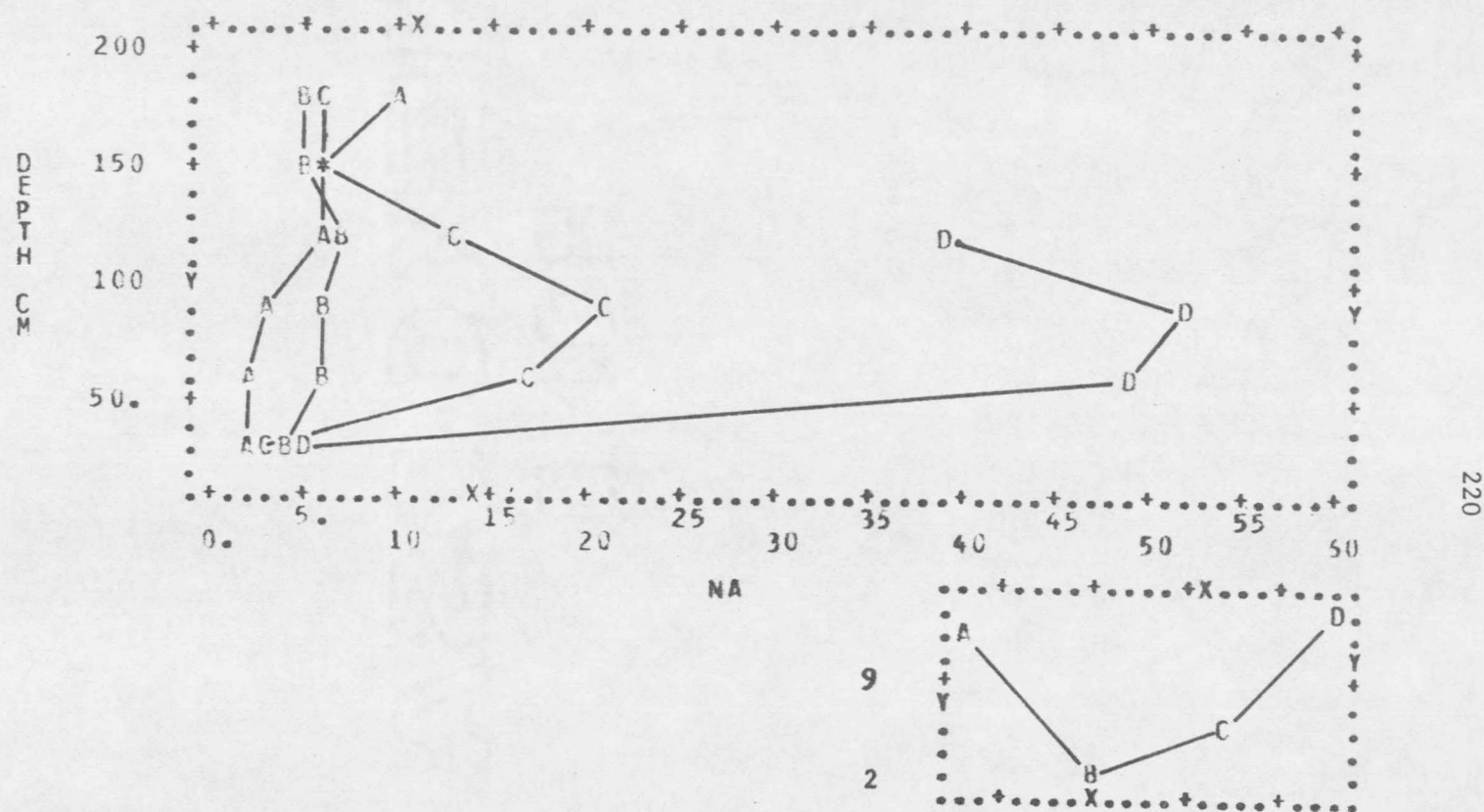


Fig. III-6. The large graph shows the distribution of Na with depth the soil profiles along streamline ABCD. The concentrations are in meq/l of the saturated extract. The small graph shows the 2-year groundwater means for the streamline sites. The concentrations are in meq/l. The horizontal axis shows the relative positions of sites along the streamline from the irrigation canal to the Yellowstone River.

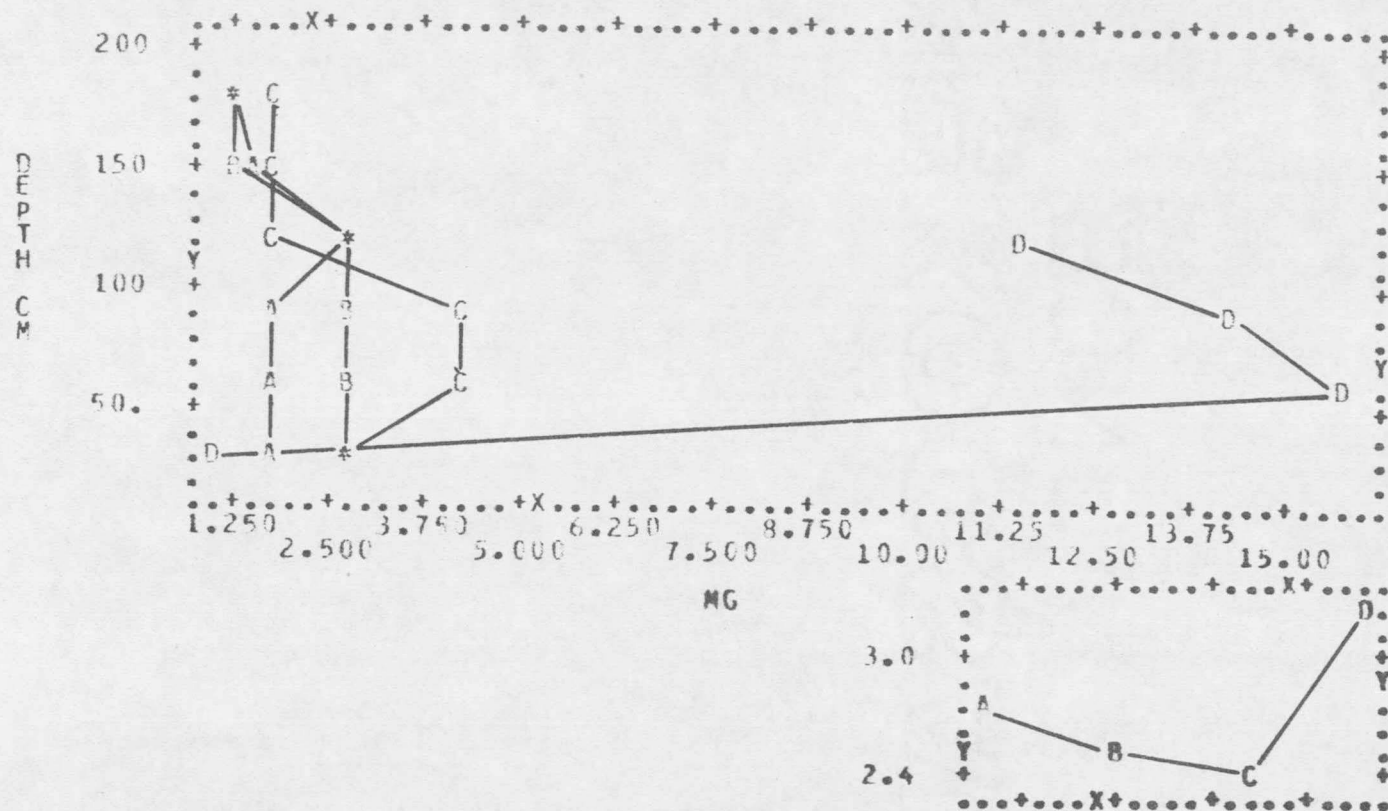


Fig. III-7. The large graph shows the distribution of Mg with depth of the soil profiles of streamline ABCD. The concentrations are in meq/l of the saturated extract. The small graph shows the 2-year groundwater means for the streamline sites. The concentrations are in meq/l. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

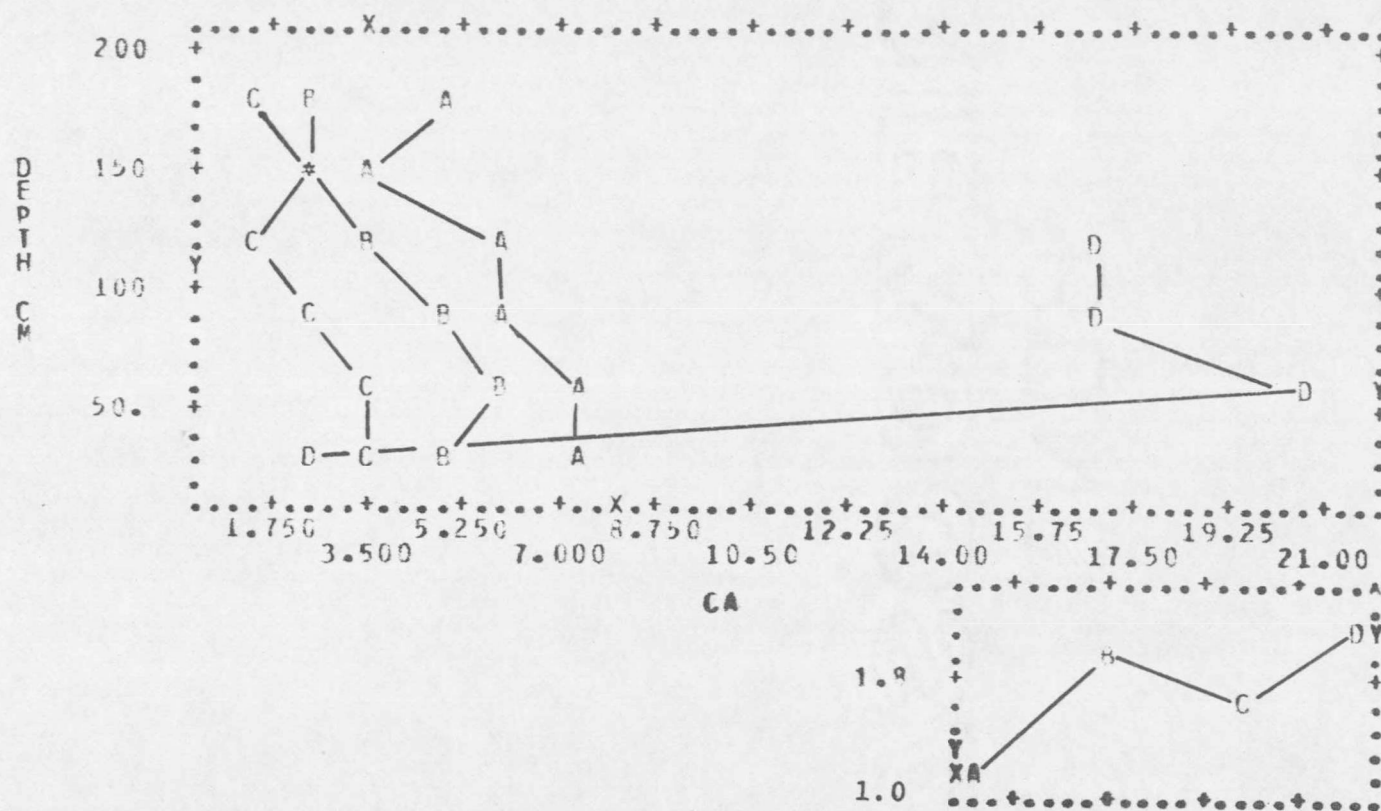


Fig. III-8. The large graph shows the distribution of Ca with depth of the soil profiles of streamline ABCD. The concentrations are in meq/l of the saturated extract. The small graph shows the 2-year groundwater means for the streamline sites. The concentrations are in meq/l. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

alluvium) which might be the reason for differences in profile concentrations.

The K concentrations are shown in Figure III-9. Surface concentrations of K decrease in the direction of the river but the lower profile concentrations are similar in magnitude. Site D does not have a typical distribution of K for this part of the study area. Typically K concentrations are high at the surface and decrease with depth. The lower profile concentration of K at Site B is clearly higher than the other three sites. This is also true of the groundwater means suggesting that groundwater concentrations of K are dependent on profile levels.

The SAR of streamline ABCD soil and groundwater are shown in Fig. III-10. The soil SAR curves are similar to those of Na. Both soil and groundwater SAR increase in the direction of the river. This suggests that Na is becoming higher in relative concentration in both the soil and groundwater "down streamline." The soils of the area are predominately heavy textured with expanding type clays. Problems of permeability due to dispersion of clays at Sites C and D would be expected at the 1 m depth.

Groundwater

The groundwater concentrations of Ca generally increase in the direction of the river. The groundwater concentrations have a reverse gradient to that of the soil profile. This suggests that the ground-

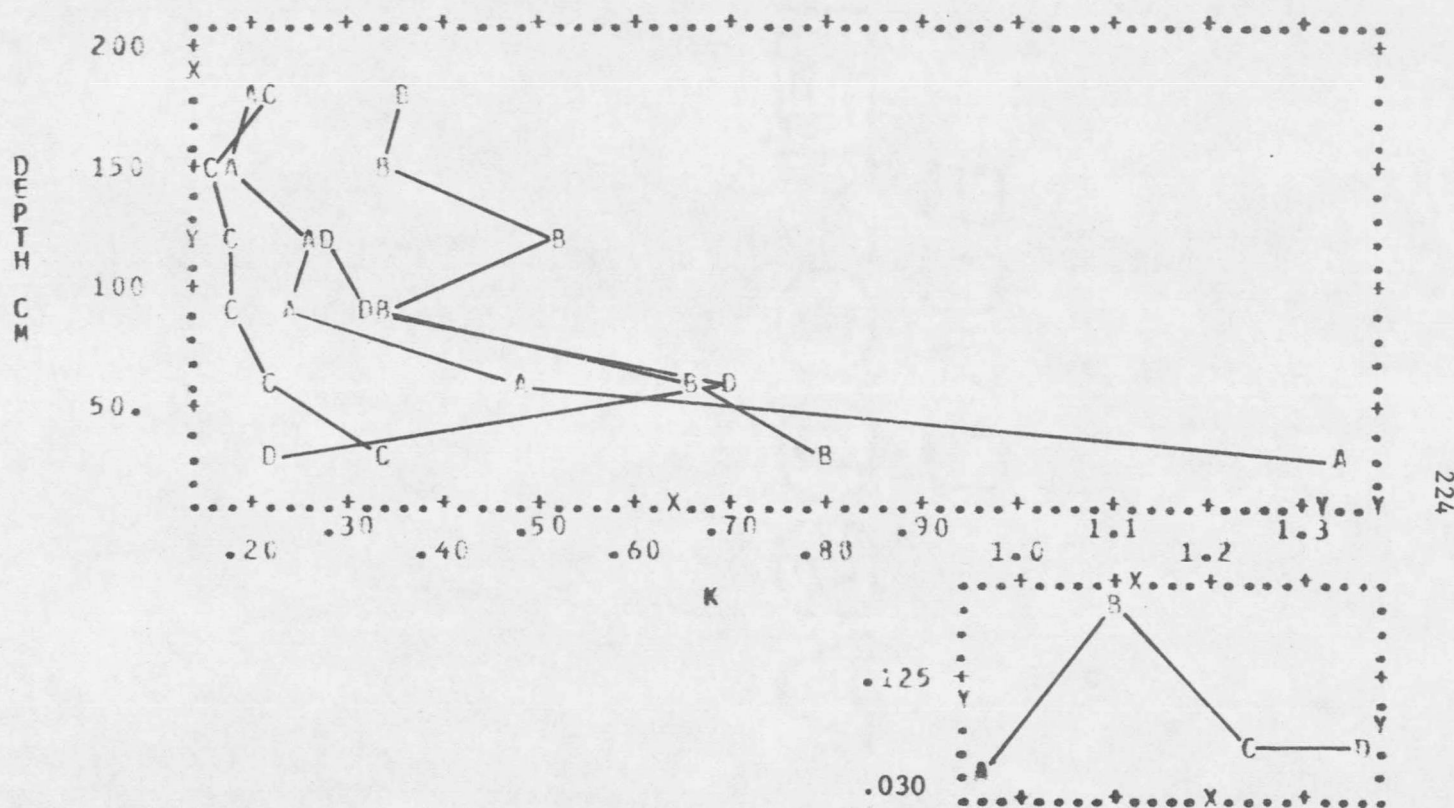


Fig. III-9. The large graph shows the distribution of K with depth of the soil profiles of streamline ABCD. The concentrations are in meq/l of the saturated extract. The small graph shows the 2-year groundwater means for the streamline sites. The concentrations are in meq/l. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

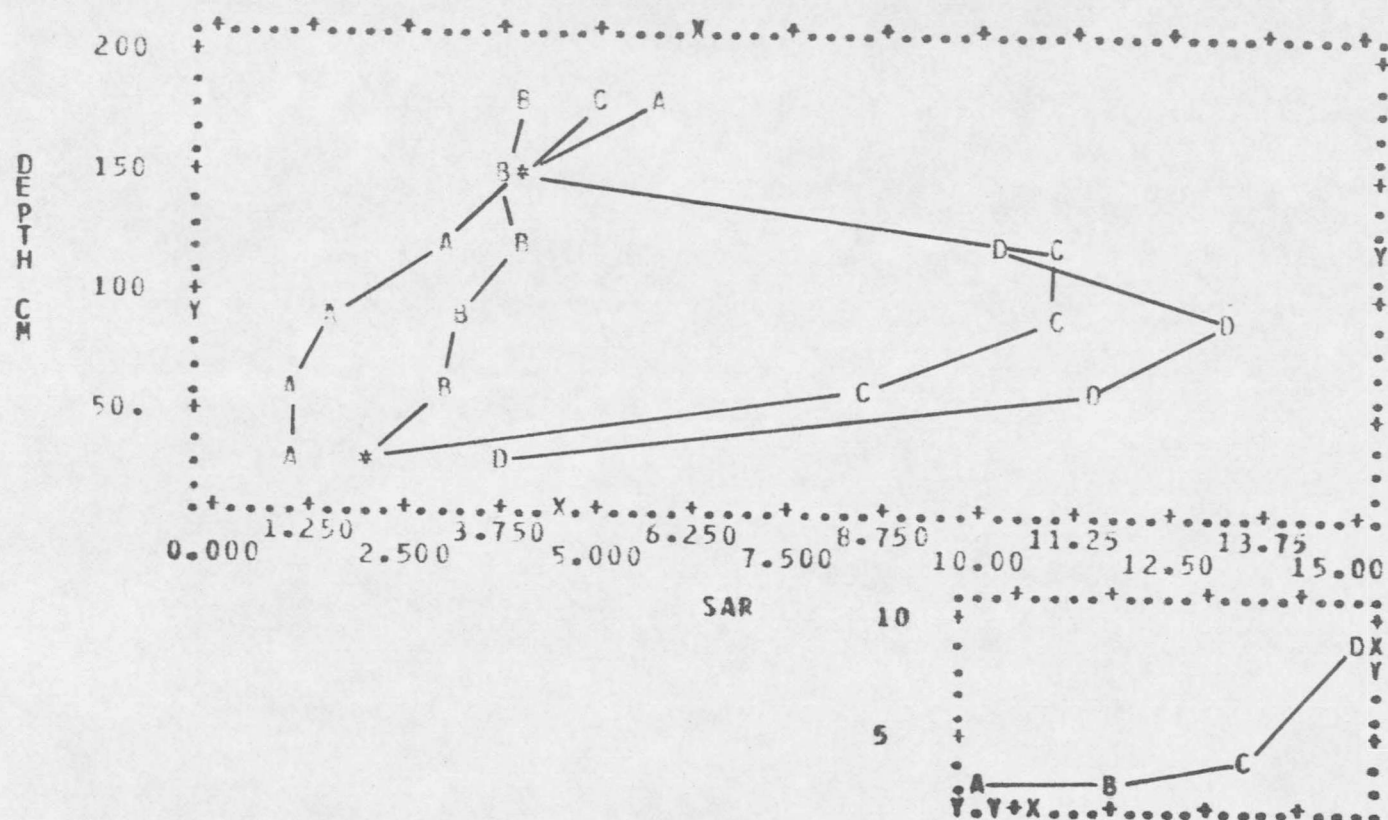


Fig. III-10. The large graph shows the distribution of SAR with depth of the soil profiles of streamline ABCD. The small graph shows the 2-year groundwater means for the streamline sites. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

water Ca becomes more concentrated as a function of horizontal accumulation in the direction of the river.

The concentrations of Na, Mg, and Ca of the groundwater are similar in magnitude to that of the soil profile close to the water table for Sites A, B, and C. Groundwater concentrations at Site D are much less than that of the profile. This suggests that the critical depth to the water table has been reached which allows net movement of water toward the surface increasing the level of profile salt.

Summary

The soil Na, SAR, and Mg increase in the direction of the river. Also, the peaks are closer to the surface as is the water table. Soil concentrations of calcium decrease in the direction of the river. Site D is anomalous in its Ca and K distribution. The surface K also decreases in the direction of the river.

The groundwater concentrations of Ca increased in the direction of the river which is the reverse of soil concentrations. This suggests that the groundwater concentrations are dependent on the location within the streamline and not profile concentrations. The Na, Mg, and K concentrations are similar in the lower soil profile and groundwater. The Na and Mg of the groundwater follow similar trends within the streamline. This is consistent with their relative mobility within a soil-water system.

The increased SAR "down streamline" is reaching levels which would adversely affect the structure of clay soils.

Streamline EFI

Streamline EFI is located in the middle of the study area (Fig. III-5). This is the transition zone where the groundwater flow changes from north to east. The salt of both the soil and groundwater increases in the direction of the river.

Soil

The distribution of cations and SAR with depth of the three sites contained in this streamline and the groundwater means for those sites are shown in Figures III-11, 12, 13, 14, and 15. The surface concentrations of each of the major cations are similar at all sites. The Na, Mg, and Ca increase in both the soil and groundwater in the direction of the river. The water table at all sites is deep and increases in depth in the direction of the river (Table III-5).

Soil profile sodium distribution and groundwater concentrations are shown in Figure III-11. The position within the profile of the Na peaks of Sites E and F are consistent with water table levels. As the water becomes deeper so does the Na peak. Site I is a saline-sodic soil. The water table is deeper than the other two sites but the Na peak is about the same depth or higher in the profile. This would suggest that the depth of the water table is not a major influence on soil water and salt movement at Site I.

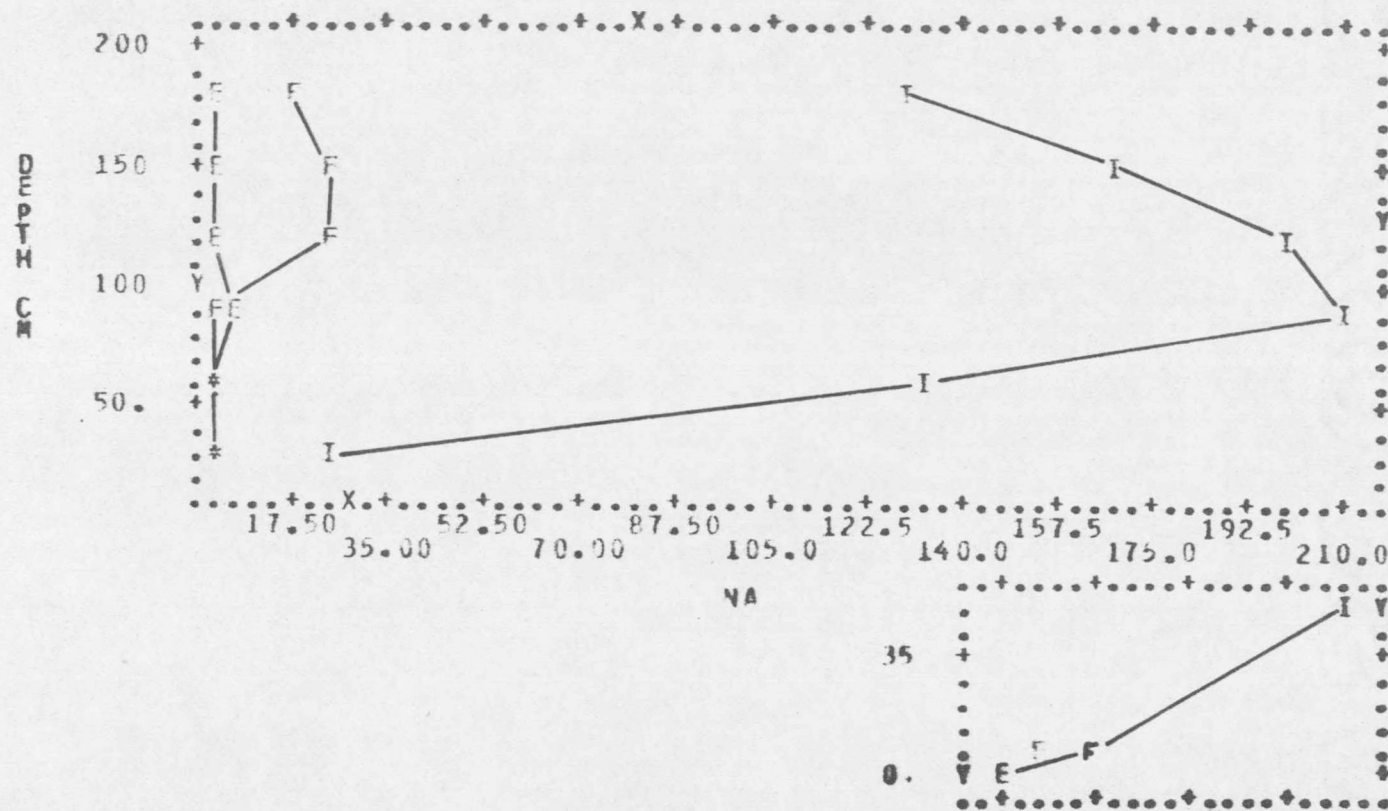


Fig. III-11. The large graph shows the distribution of Na with depth of the soil profiles of streamline EFI. The concentrations are in meq/l of the saturated extract. The small graph shows the 2-year groundwater means for the streamline sites. The concentrations are in meq/l. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

The Mg concentrations of this streamline are shown in Figure III-12. The Mg peak of Site I is below that of Na whereas those of E and F are equal or above the Na peak suggesting that net water movement of Site I is upward. This seems to be responsible for the excessive level of salts, especially Na and Mg, in this profile.

The Ca concentrations of soil and groundwater are shown in Figure III-13. The Ca peaks of F and I are equal in both concentration and profile location. Their peaks are both deeper than Site F. The similarity of the Ca distribution at Sites F and I is striking. The relative concentrations of Na and Mg are very different. There seems to be several possibilities to explain this. It would seem that the Ca concentrations are a result of some pre-existing mechanism of deposition whereas the more mobile cations are a function of soil water movement within the profile. The contrast between Sites F and I could be the result of a cultural change. A stand of well-established alfalfa is being grown at Site F. This has resulted in well-developed soil structure which would greatly enhance permeability. It is possible that at some previous time Sites F and I had similar salt concentrations but the improved permeability at Site F has resulted in leached salts.

The K concentrations of soil and groundwater are shown in Figure III-14. Potassium distribution in the soil profile is different at each site. The potassium concentration at Site E is highest at

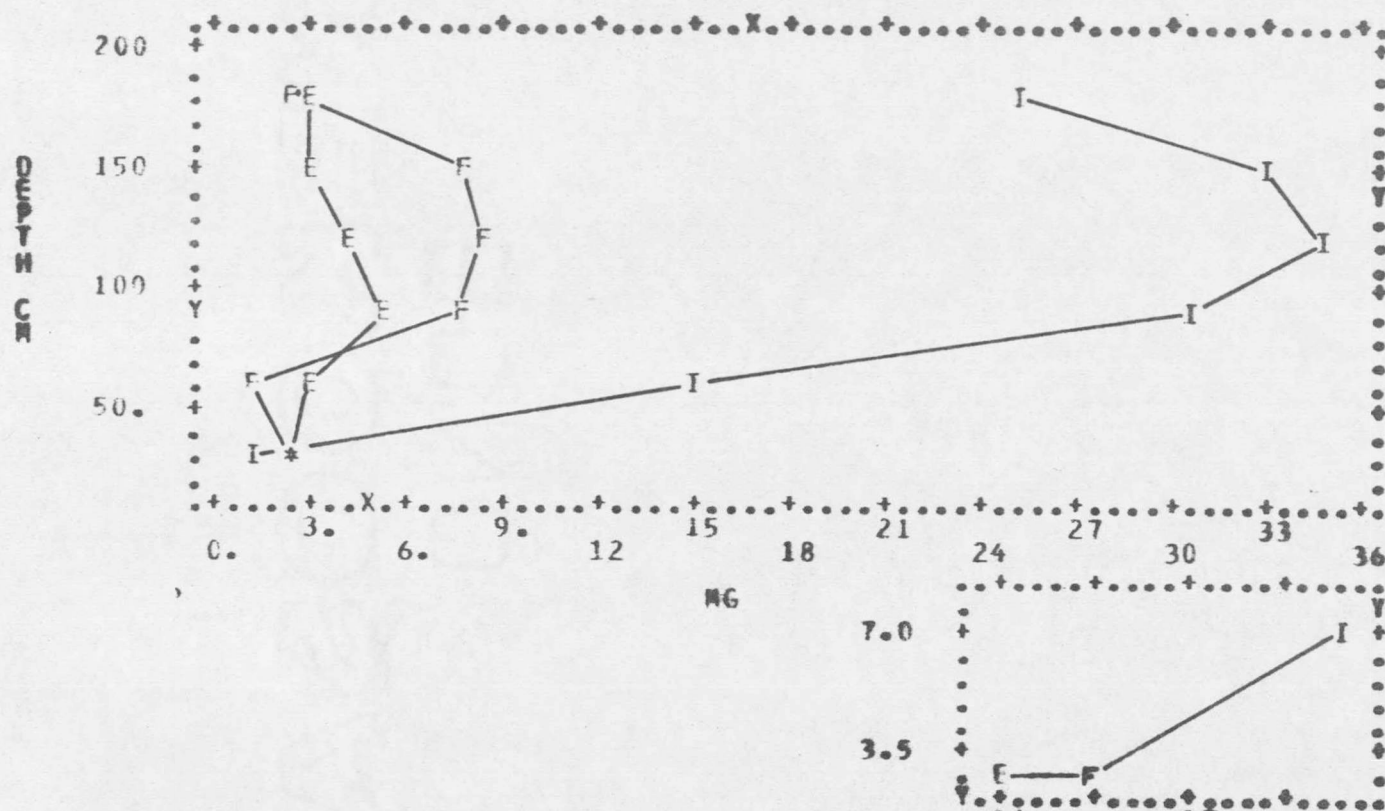


Fig. III-12. The large graph shows the distribution of Mg with depth of the soil profiles of streamline EFI. The concentrations are in meq/l of the saturated extract. The small graph shows the 2-year groundwater means for the streamline sites. The concentrations are in meq/l. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

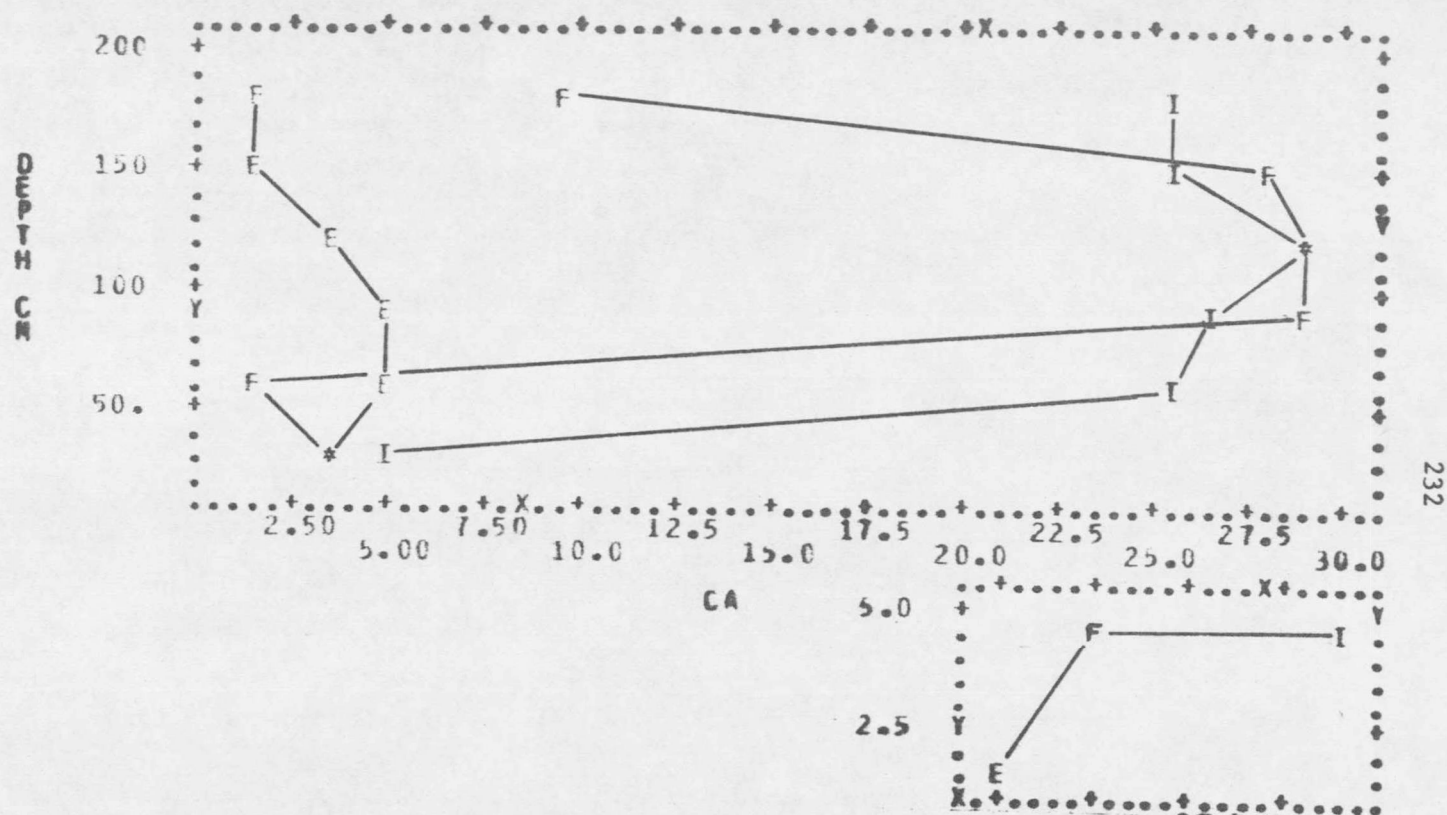


Fig. III-13. The large graph shows the distribution of Ca with depth of the soil profiles of streamline EFI. The concentrations are in meq/l of the saturated extract. The small graph shows the 2-year groundwater means for the streamline sites. The concentrations are in meq/l. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

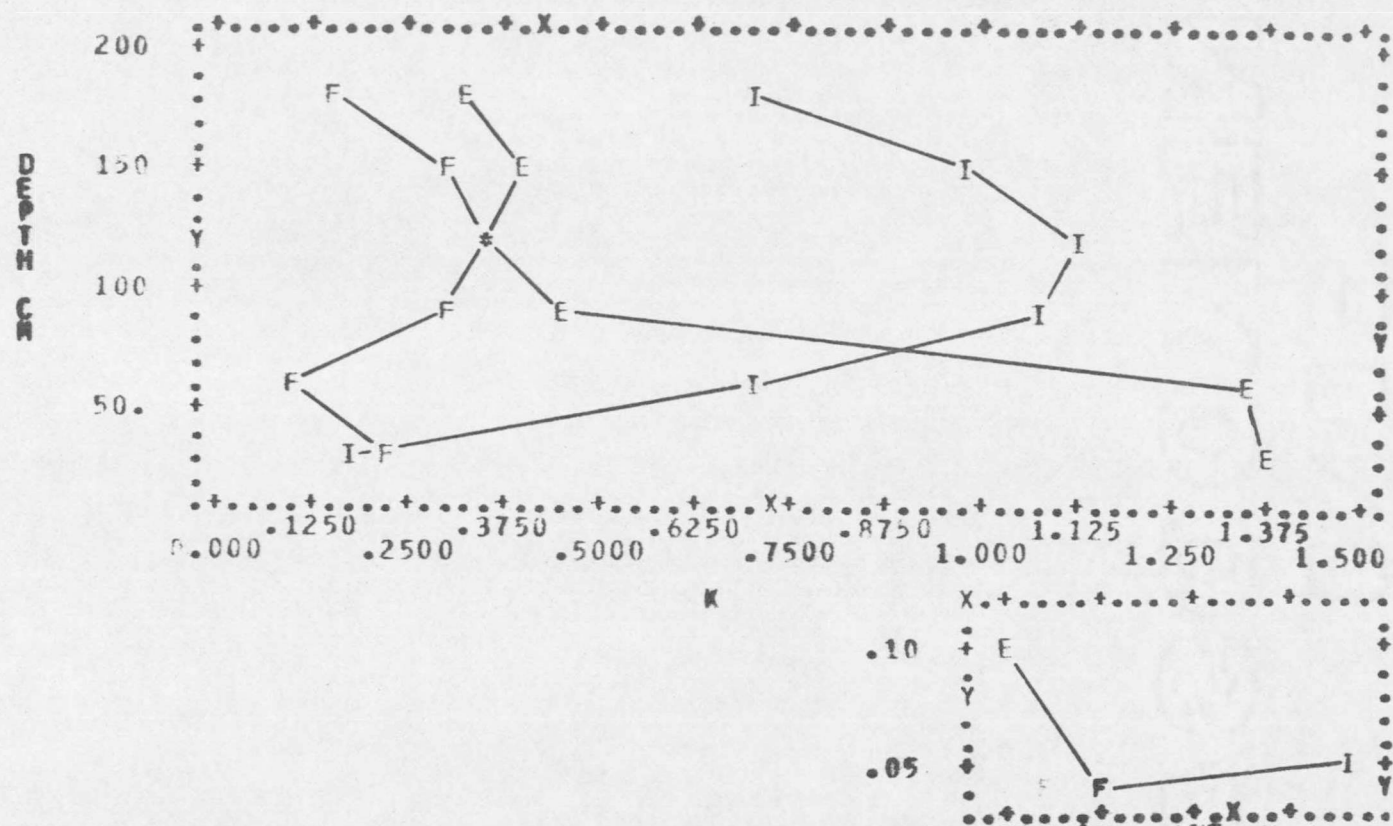


Fig. III-14. The large graph shows the distribution of K with depth of the soil profiles of streamline EFI. The concentrations are in meq/l of the saturated extract. The small graph shows the 2-year groundwater means for the streamline sites. The concentrations are in meq/l. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

the surface. This is true in the groundwater also. The distribution at Site I follows that of the other cations.

The SAR of both the soil and water increase in the direction of the river (Fig. III-15). The SAR of the lower profile and groundwater are similar in magnitude. The large bulge at about 1 m at Site I suggests that this is the point of equilibrium between upward and downward water movement. The SAR at Site I with its heavy clay texture would severely restrict water movement. Because of this, it seems that diffusion of salts would be a viable possibility to explain elevated groundwater salt concentrations at Site I. The SAR at Sites E and F would not be detrimental.

Groundwater

The relative concentrations of the major cations of the lower soil profile and groundwater are similar. The salt increases in concentration in the direction of the river in both groundwater and soil. Potassium levels of the groundwater seem to be associated with upper profile concentrations.

Summary

The salt and SAR of both the groundwater and soil increase in the direction of the river. The water table is relatively deep at all sites within the streamline and increases in depth toward the river.

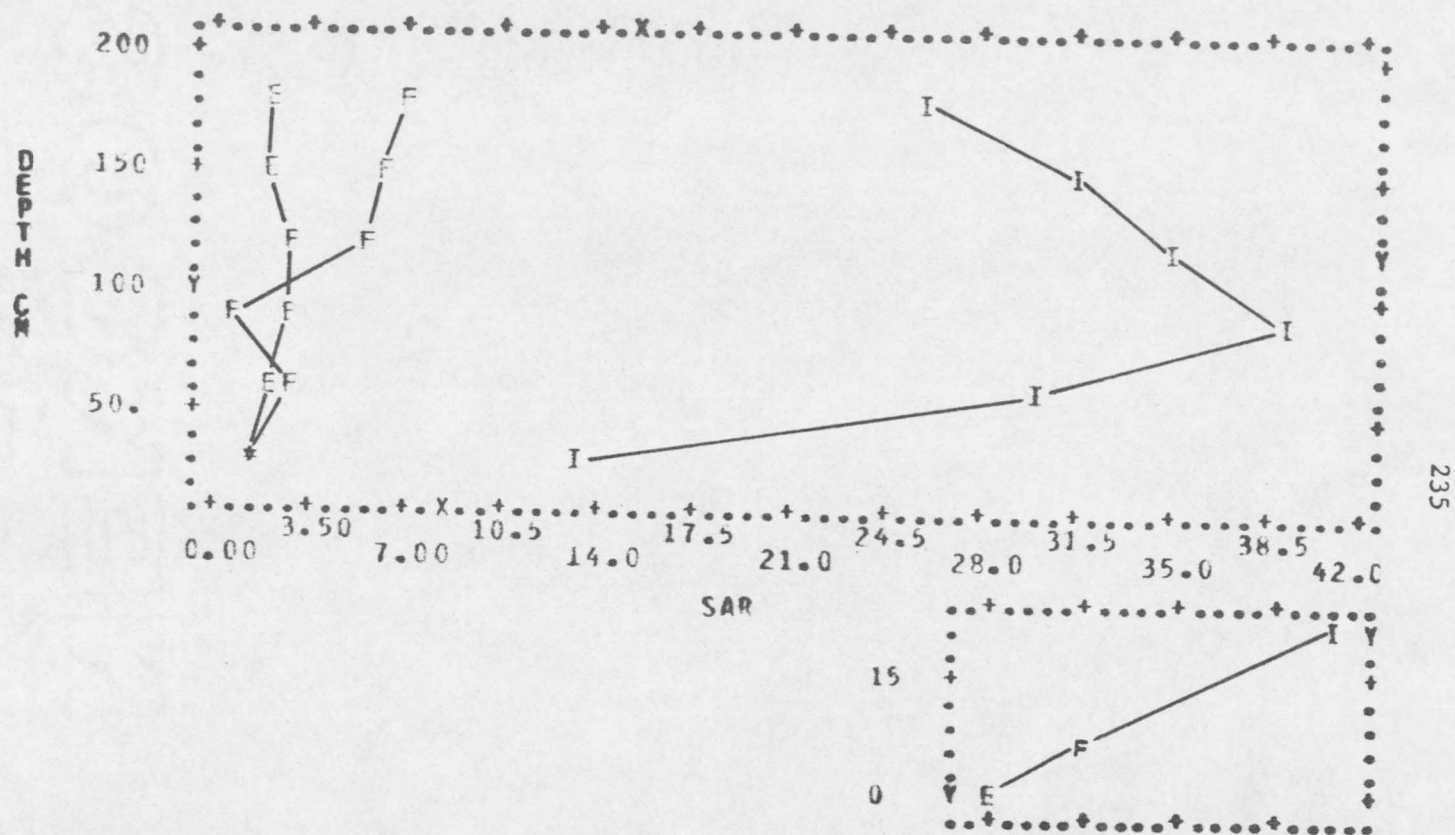


Fig. III-15. The large graph shows the distribution of SAR with depth of the soil profiles of streamline EFI. The small graph shows the 2-year groundwater means for the streamline sites. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

The profile concentrations of the more mobile cations seem to be dependent on permeability due to soil structure, textural horizonation, and SAR. The relative positions of profile peaks seem to be dependent on the dominant direction of soil water movement.

Streamline HK

Streamline HK is located on the eastern end of the study area (Fig. III-5). The groundwater flow is east, almost parallel to the canal and river.

The concentration of cations and SAR of the soil and groundwater is shown in Figures III-16, 17, 18, 19, and 20. All soil and groundwater constituents considered are higher at Site H.

Soil and groundwater Na concentrations are shown in Figure III-16. The sodium of the groundwater at each site is higher than anywhere in the soil profile. This and the increase with depth of Na suggest net leaching at both sites.

Soil and groundwater Mg and Ca are shown in Figures III-17 & 18, respectively. The soil Mg and Ca peaks are at the same depth but the Ca peaks are larger than Mg at each site. The peaks are slightly deeper at Site K. Consistent with the lower mobility of Mg and Ca in a soil system the groundwater concentrations are less than the soil profiles. The relative positions of cation peaks support net leaching.

The potassium distribution of the soil profiles are atypical (Fig. III-19). Typically K is high at the surface and decreases with depth. At Site K the potassium peak corresponds with Mg and Ca peaks. At Site H the potassium varies little with depth. Groundwater concentrations are consistent with soil levels.

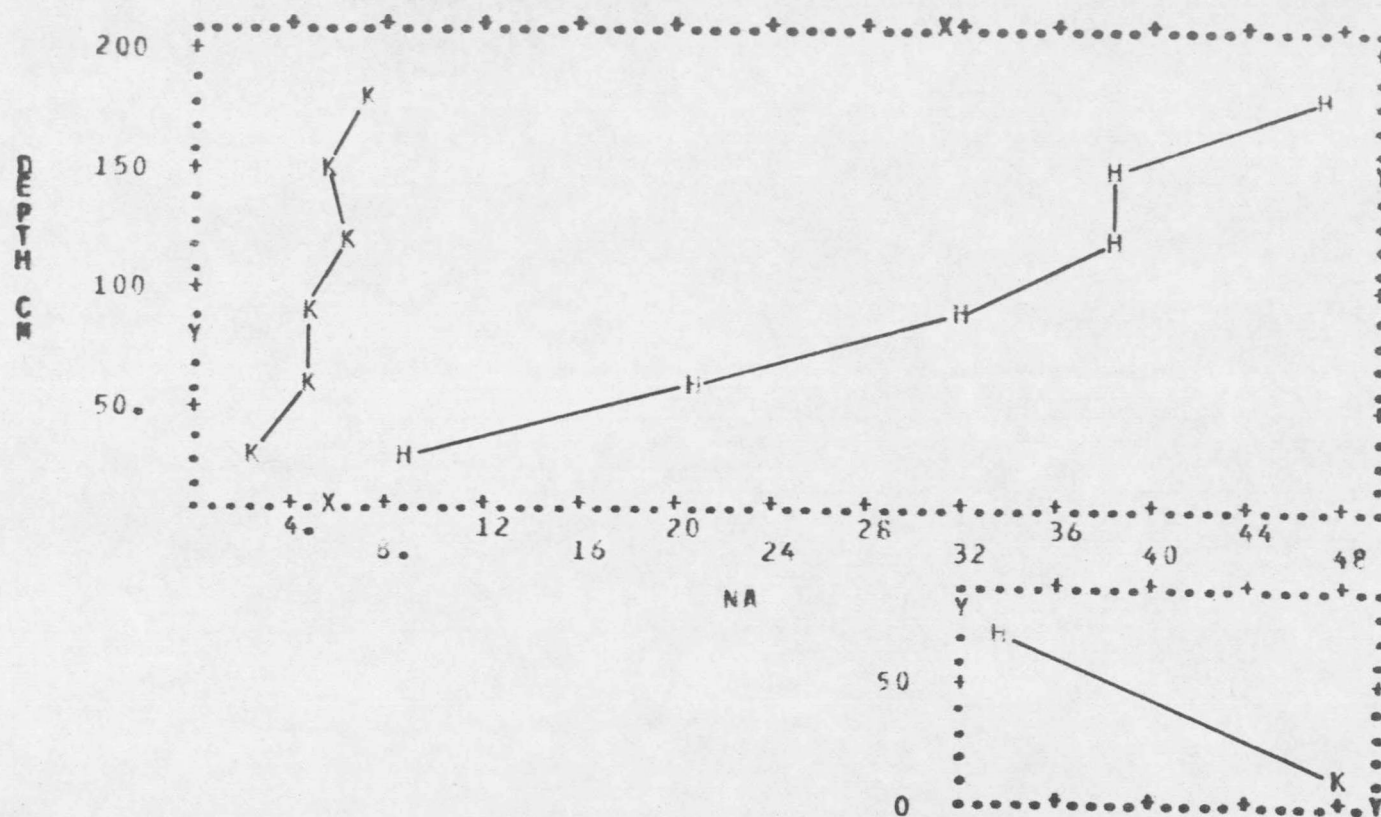


Fig. III-16. The large graph shows the distribution of Na with depth of the soil profiles of streamline HK. The concentrations are in meq/l of the saturated extract. The small graph shows the 2-year groundwater means for the streamline sites. The concentrations are in meq/l. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

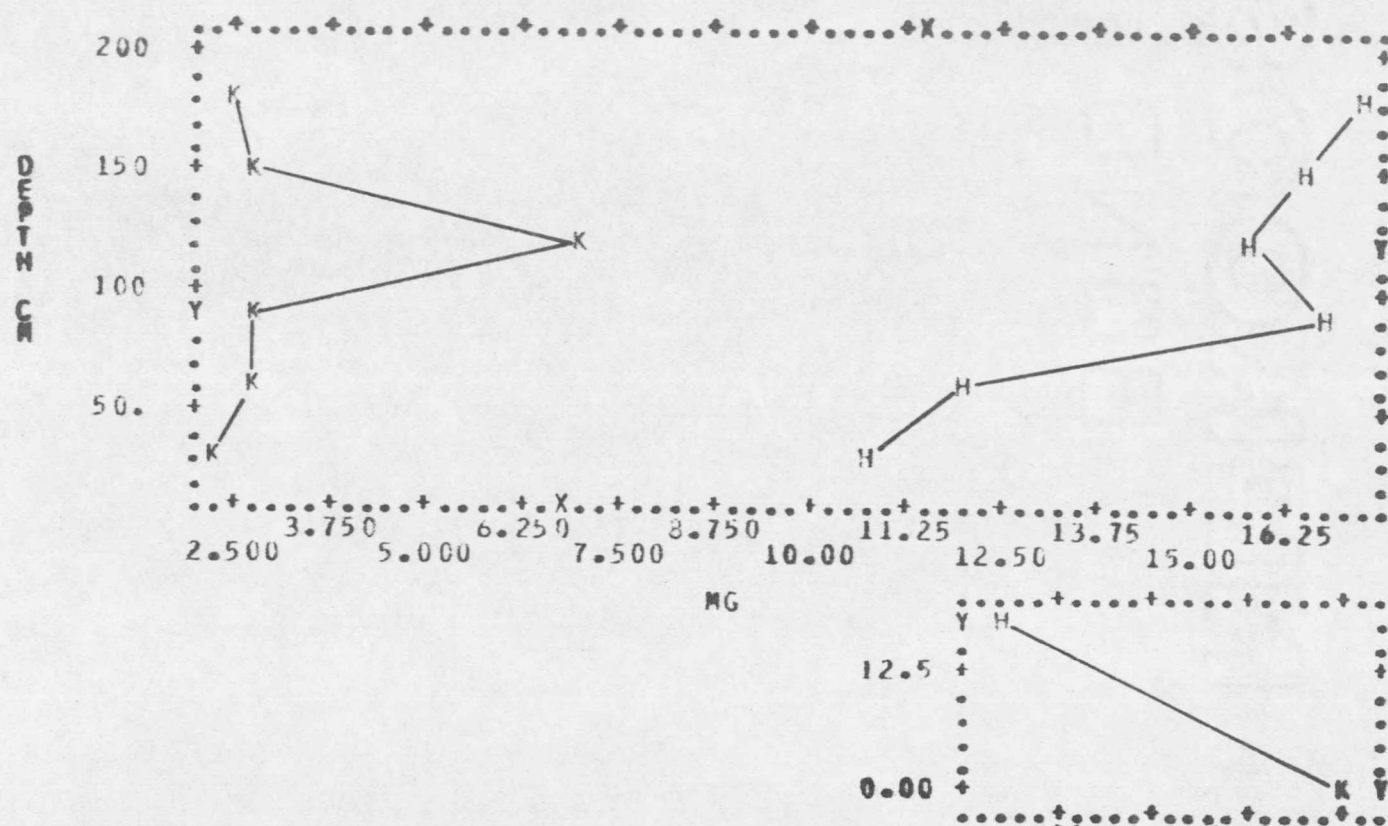


Fig. III-17. The large graph shows the distribution of Mg with depth of the soil profiles of streamline HK. The concentrations are in meq/l of the saturated extract. The small graph shows the 2-year groundwater means for the streamline sites. The concentrations are in meq/l. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

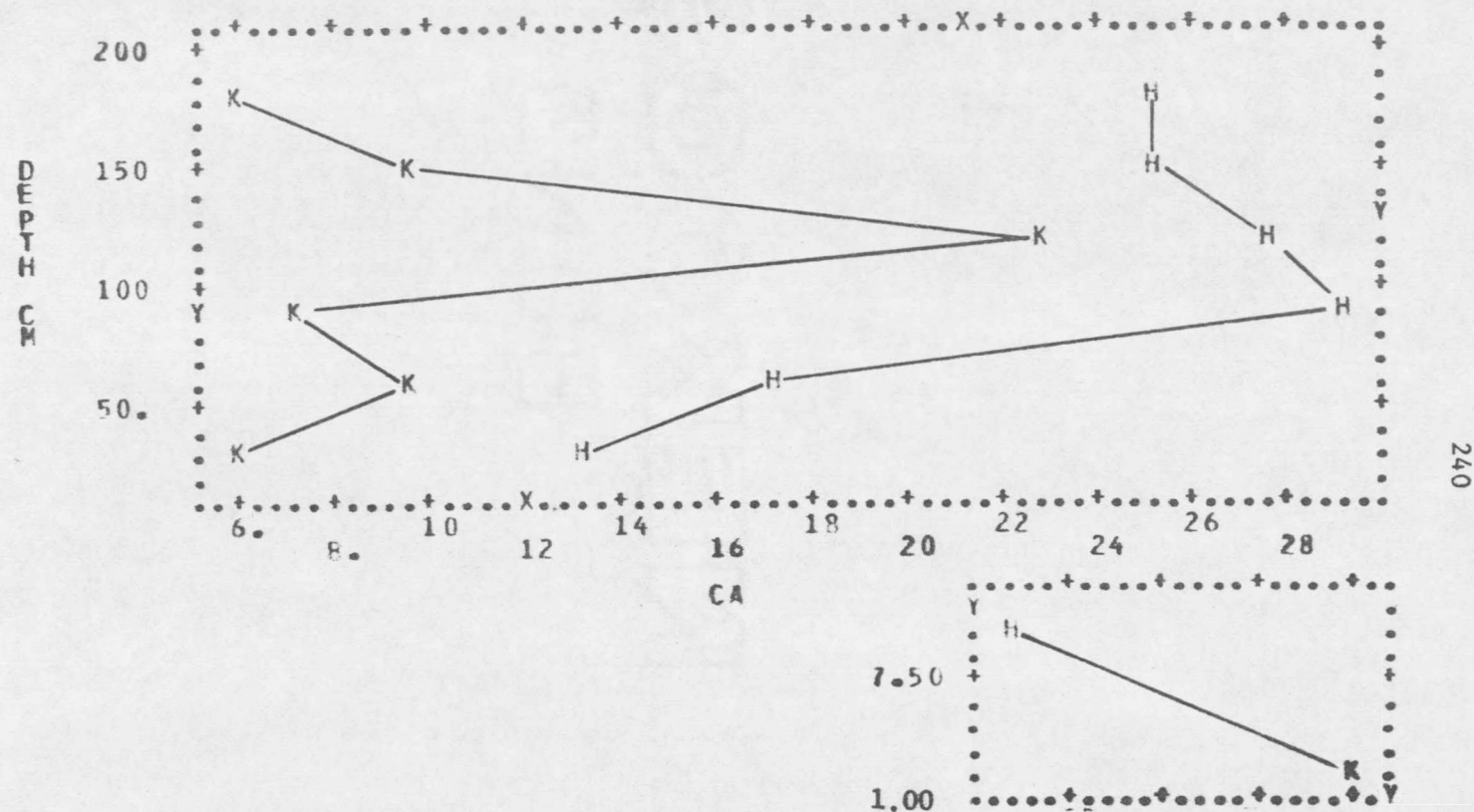


Fig. III-18. The large graph shows the distribution of Ca with depth of the soil profiles of streamline HK. The concentrations are in meq/l of the saturated extract. The small graph shows the 2-year groundwater means for the streamline sites. The concentrations are in meq/l. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

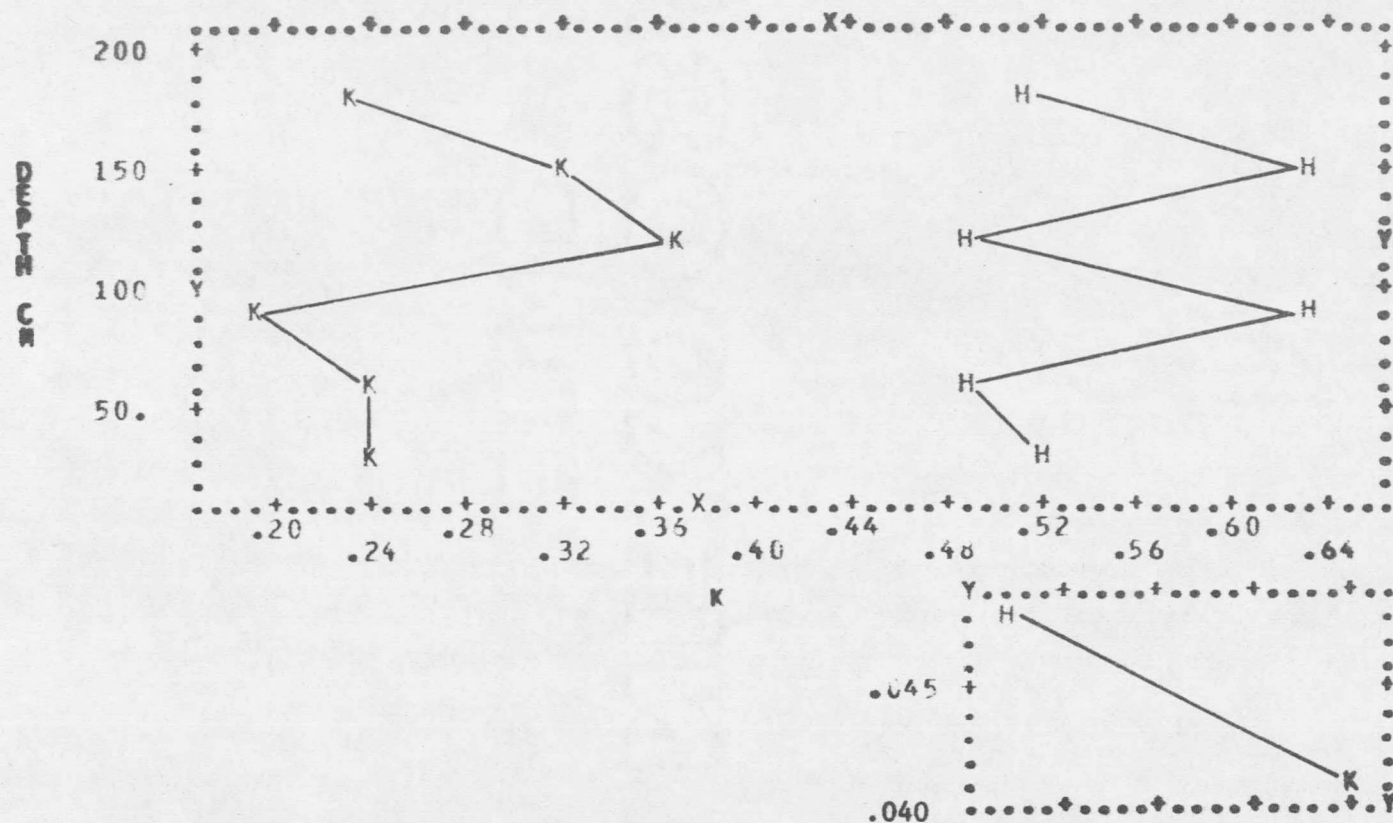


Fig. III-19. The large graph shows the distribution of K with depth of the soil profiles of streamline HK. The concentrations are in meq/l of the saturated extract. The small graph shows the 2-year groundwater means for the streamline sites. The concentrations are in meq/l. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

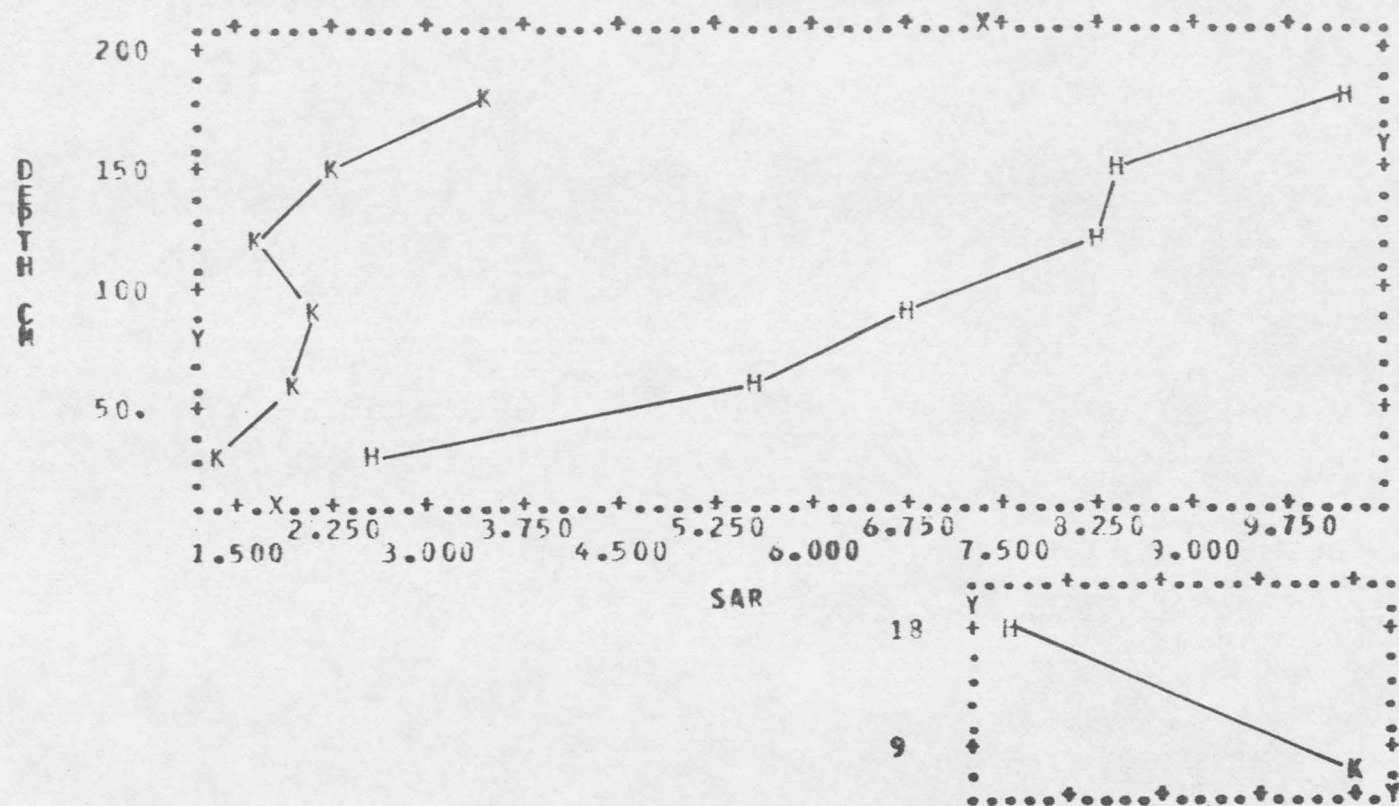


Fig. III-20. The large graph shows the distribution of SAR with depth of the soil profiles of streamline HK. The small graph shows the 2-year groundwater means for the streamline sites. The horizontal axis shows the relative positions of sites along the streamline from the main irrigation canal to the Yellowstone River.

The SAR values of soil and groundwater of streamline HK are shown in Figure III-20. The SAR of the groundwater is greater than the profile at both sites. This is the result of elevated concentrations of Na. The lowest SAR of the profile at Site H is marginal for the heavy textured soil with a high proportion of expanding clays at this site. An SAR of this magnitude can disperse the clay enough to cause permeability to be severely reduced.

The coarse texture and low SAR at Site K allows for more leaching of soil salts. This is supported by little variation in profile Na concentration and Ca and Mg peaks that occur at a deeper depth than Site H. This could account for the lower groundwater concentration of salts at K, and even though it is "down streamline," could be the effect of dilution from irrigation water leached through a soil profile which is relatively low in salts and very permeable. Another possibility is that Sites H and K are hydraulically isolated from one another. The access tube at K is in contact with the gravel layer whereas Site H groundwater samples represent only water that has passed through the soil at the lower depths above the gravel.

The surface hydrology in this area is irregular. The general flow is east but the topography is gentle and the drainage pattern irregular. The potential gradient of the groundwater is small. The monitoring stations in this part of the study could well be established in an isolated or non-typical area.

Summary

The Na of the groundwater is higher than that of the soil suggesting net leaching. The Ca and Mg peaks are prominent. Potassium distribution is atypical and groundwater levels are correlated with soil concentrations. The SAR of the groundwater is higher than that of the soil profile.

The salts of the soil and groundwater are distributed in a reverse concentration gradient becoming more concentrated at the canal. This could be a function of soil influences on groundwater at both sites or anomalies in groundwater flow.

Summary of Streamline Soil and Groundwater Quality

Soil and groundwater means for streamlines are shown in Table III-5. The groundwater mean cation concentrations and SAR of the streamlines increase from west to east. The maximum soil concentrations of sodium and magnesium are found in streamline EFI. The water table is relatively deep and the textures are heavy in this streamline. The soil Ca maximum is found in streamline HK. The groundwater K decreases from west to east although the peak soil concentration is in the middle streamline (EFI) and groundwater concentrations seem to be independent of soil concentrations. Potassium of the groundwater is distributed in a reverse gradient to the major cations.

In general, the salts and SAR of the groundwater increase within streamlines in the direction of the river and between streamlines from west to east (down river). The salt is leached from the soil along the length of a given streamline and is accumulated "down streamline." The increased concentrations of salt may then enter the soils above the saturated zone at lower streamline positions. This accounts for soils having more salt as the river is approached within a given streamline. In some cases the distribution of soil salts seems to be dependent on local soil properties.

TABLE III-5. SOIL AND GROUNDWATER MEANS FOR STREAMLINES. 1/

Streamline	Streamline Means (Soil/Groundwater)				
	Na	Mg	Ca	K	SAR
ABCD	<u>12.5</u>	<u>3.79</u>	<u>5.95</u>	<u>.38</u>	<u>5.30</u>
	8.50	2.72	1.75	.0813	4.72
EFI	<u>53.5</u>	<u>10.7</u>	<u>14.2</u>	<u>.57</u>	<u>11.7</u>
	19.7	4.13	3.62	.064	9.0
HK	<u>18.0</u>	<u>9.07</u>	<u>16.6</u>	<u>.40</u>	<u>4.5</u>
	39.0	8.80	6.10	.0455	12.5

1/ Cation concentrations are in meq/l. Soil values are those of the saturated extracts.

Discussion of Study Summary Statistics

Soil Cation and Cation Fractions

The summary statistics of concentrations of cations and cation fractions of the soil are shown in Table III-6. The first column contains correlation coefficients with EC. Absolute values of the cations considered have a significant positive correlation with EC. The means reveal that Na is the dominant cation of the soil. Calcium and Mg are about equal and about one-third the concentration of Na. The CVs of the Na and Mg concentrations are well above 100. The variation in concentrations across the study area of these two cations is large. The variation of Ca and K is less than half that of Na and Mg.

The cation fractions are summarized in the middle section of Table III-6. The fraction of Na increased significantly as EC increased whereas Ca and K fractions decreased. The Mg fraction was not correlated with EC. About half of the cation total is Na, one-third Ca, and one-fifth Mg. Cation fractions of the major cations are less variable than absolute concentrations.

The SAR of the study area increased with EC. The standard deviation of the SAR and EC is larger than the mean. The mean EC is above four and would be classified saline. The SAR of 8.42 is equivalent to an exchangeable sodium percentage (ESP) of about 10 according to the

TABLE III-6. SUMMARY STATISTICS OF SOIL CATION CONCENTRATIONS (MEQ/L) OF SATURATED EXTRACT) AND CATION FRACTIONS.

	Correlation with EC	Mean	Standard Deviation	CV
Na	.981**	37.8	64.4	170
Mg	.909**	11.7	20.8	178
Ca	.688**	12.0	10.0	83
K	.632**	0.52	0.385	74
<u>Cation Fractions</u>				
Na	.514**	0.48	0.186	38
Mg	.024	0.18	0.072	40
Ca	-.534**	0.32	0.164	51
K	-.390**	0.02	0.025	125
SAR	.926**	8.42	9.83	117
EC		4.15	5.73	138

N = 61

 $r_{.95} = .214^*$ $r_{.99} = .300^{**}$

relationship established by the Salinity Laboratory Staff (1954). This is approaching the sodic classification of 15 ESP.

The summary statistics of the groundwater ion concentrations and ion fractions are shown in Table III-7. The relationship of cation concentrations and cation fractions with EC are shown by their correlation coefficients. Increases in concentrations of the three major cations were responsible for increases in EC. However, the percentage of Mg, Ca, and K decreased with increasing EC. This is supported by an increase in SAR with increasing EC.

The mean values of cations show Na to be the dominant cation with Mg and Ca similar in concentration. The CVs of all cations are above 100. Sodium makes up well over half of the total cations present. Magnesium and calcium are both about one-fifth of the total. The percent Na has the least amount of variation and generally the cation fractions are less variable than absolute values.

The SAR and EC standard deviations are larger than the means. The groundwater SAR is similar in magnitude to that of the soil. However, the soil EC is three times that of the groundwater.

The summary statistics of groundwater anions are shown in Table III-7. Sulfate was correlated with changes in EC. It is by far the dominant anion. Bicarbonate is found in moderate quantities. Nitrate and Cl exist in small concentrations. The variation of all anions is high (standard deviations larger than means).

TABLE III-7. SUMMARY STATISTICS OF GROUNDWATER IONS (MEQ/L) AND ION FRACTIONS.

	Correlation with EC	Mean	Standard Deviation	CV
<u>Cations</u>				
Na	.942**	17.5	29.1	166
Mg	.782**	4.15	5.22	125
Ca	.546**	3.24	3.46	107
K	-.045	0.081	0.089	110
<u>Cation Fractions</u>				
Na	.455**	0.57	21.4	37
Mg	-.340**	0.22	11.0	50
Ca	-.396**	0.20	14.0	70
K	-.345**	0.01	0.0136	136
SAR	.873**	7.81	8.17	104
EC		1.37	1.83	133
N = 104				
$r_{.95} = .165$				
$r_{.99} = 2.32$				
<u>Anions</u>				
SO ₄	.850**	21.4	29.2	136
HCO ₃	.143	3.10	3.64	117
NO ₃	-.137	0.41	0.49	119
Cl	-.059	0.32	0.47	146
<u>Anion Fractions</u>				
SO ₄	.578**	0.68	0.28	41
HCO ₃	-.507**	0.26	0.24	92
NO ₃	-.463**	0.04	0.06	150
Cl	-.271*	0.03	0.05	167
N = 56				
$r_{.95} = .235$				
$r_{.99} = .328$				

The SO_4 fraction is about two-thirds and bicarbonate makes up about a fourth of the total anion concentration. The sulfate fraction was the least variable. As the total concentration of salts increases, so does the percentage of SO_4 whereas the other three anion fractions decrease. The groundwater below the three saline sites (H, I, and J) had a sulfate fraction of greater than .90. The dominant electrolyte at the saline sites is Na_2SO_4 . Appreciable bicarbonate (anion fraction >.50) was found only in the less saline sites. This could be due to the following reaction: $\text{CaSO}_4 + \text{Na}_2\text{CO}_3 \rightarrow \text{Na}_2\text{SO}_4 + \text{CaCO}_3 \downarrow$. Regression lines and data point distributions are shown in Appendix Figures 8-11.

The proportional makeup of the canal water, groundwater and soil are shown in Table III-8. It is apparent that the level of salt ranks soil >> groundwater >> canal water. The percentage of cations for the soil groundwater and canal show that: (1) sodium is clearly the dominant cation of the soil and groundwater and has a higher percentage in the groundwater; (2) the major cation percentages of the canal water are similar in size with Ca being slightly higher; and (3) the Ca percentage is higher in the soil than groundwater whereas the reverse is true of Mg.

The summary statistics of cation ratios are shown in Table III-9. The mean ratios of Ca/Mg show that Ca is about equal to Mg in the groundwater whereas Ca is twice the concentration of Mg in the soil.

TABLE III-8. CANAL, SOIL, AND GROUNDWATER CATION PROPORTIONS.

	Na	:	Mg	:	Ca	:	K
<u>Absolute values</u>	<u>-----meq/l-----</u>						
Canal	.63		.50		.67		.02
Groundwater	16.2		3.9		3.1		.08
Soil (saturated extract)	37.8		11.7		12.0		.52
<u>Cation fractions</u>							
Canal	.33		.27		.38		.01
Groundwater	.56		.22		.21		.01
Soil	.48		.18		.32		.02

TABLE III-9. GROUNDWATER AND SOIL CATION RATIOS FOR ALL SITES. 1/

GROUNDWATER 1975 & 1976					
<u>Correlation Coeff. w/EC</u>			<u>Mean</u>		
	<u>Mg</u>	<u>Ca</u>		<u>Mg</u>	<u>Ca</u>
Na	.294**	.441**	Na	4.06	6.32
Ca	-.221*		Ca	1.01	
N = 104			<u>Standard Deviation</u>		
$r_{.95} = .165$				<u>Mg</u>	<u>Ca</u>
$r_{.99} = .232$			Na	3.59	7.08
			Ca	.718	
SOIL					
<u>Correlation Coeff. w/EC</u>			<u>Mean</u>		
	<u>Mg</u>	<u>Ca</u>		<u>Mg</u>	<u>Ca</u>
Na	.141	.706**	Na	3.39	2.65
Ca	-.441**		Ca	1.98	
N = 61			<u>Standard Deviation</u>		
$r_{.95} = .214$				<u>Mg</u>	<u>Ca</u>
$r_{.99} = .300$			Na	3.09	2.70
			Ca	1.17	

1/ The vertical numbers of the tables are numerators and the horizontal numbers are denominators. For example: The mean of the groundwater ratio for Na/Ca is 6.32.

Sodium ratios are higher in the groundwater. These ratios illustrate the relative mobility of the major cations in a soil system. Sodium is the most mobile and Ca the least. The cation ratios of all sites and EC for the groundwater and soil at individual sites are shown in Table III-10. Groundwater at site A is not typical of the less saline sites in that it has elevated relative levels of sodium. The groundwater ratios at site A are similar to those of site I although site I has more than three times the EC. Site I has a high relative abundance of Na within the soil profile as evidenced by high Na ratios. The sodium ratios at site A are lower. This seems to suggest an outside source of groundwater Na at site A. Site B is the only site with all cation ratios near one. This is similar to those of the canal water. Site J and I contrast in that site J has the greatest difference in soil and groundwater salts. Site H has about the same level of salt in both. This suggests substantial leaching at site H and almost total upward flux of salt at J which is the most saline site. This is also supported by the high relative levels of Na and Mg of the soil at site J which are the most mobile of the cations (it has the highest Na/Ca ratio and the lowest Ca/Mg ratio).

TABLE III-10. MEAN CATION RATIOS AND ELECTRICAL CONDUCTIVITY FOR SOIL AND GROUNDWATER OF INDIVIDUAL SITES.

Site	Groundwater			Mean EC	Soil			Mean EC
	Mean cation ratios				Mean cation ratios			
	Na	Mg	Ca		Na	Mg	Ca	
A		4.69	14.5	(.860)		3.11	.990	(.860)
	Ca	.451			Ca	3.28		
B		.951	1.29	(1.05)		2.88	1.56	(1.1)
		.844				1.87		
C		2.67	5.84	(.539)		4.15	5.28	(1.3)
		.566				.957		
D		4.60	8.94	(1.35)		3.75	2.44	(3.9)
		.781				1.60		
E		.927	1.33	(.439)		1.13	1.62	(.88)
		.969				.906		
F		4.03	4.64	(1.14)		2.76	1.12	(3.2)
		1.70				2.80		
G		1.72	1.17	(.853)		5.38	1.64	(1.5)
		1.57				3.63		
H		4.26	6.44	(4.46)		1.99	1.29	(4.4)
		.764				1.53		
I		7.30	13.4	(2.87)		7.96	6.10	(13)
		.655				1.42		
J		6.04	6.48	(1.90)		2.60	8.01	(19)
		1.31				.373		
K		7.79	5.08	(.613)		1.74	.603	(1.2)
		1.56				3.00		

Contour Maps of Salt Distribution

Groundwater

Contour maps facilitate analysis of spacial distribution of salts. Groundwater contours are plotted on Figures III-21 and 22 for EC and SAR, respectively. The limited number of sites makes it difficult to construct detailed maps but general trends are apparent. The salt and SAR are highest in the eastern part of the study. The distribution of Na, Mg, and Ca of the groundwater is similar to the EC distribution. The EC and SAR contours are similar which supports the positive correlation of EC with Na.

Soil

The soil contour maps of EC and SAR are shown in Figures III-23 and 24, respectively. The soil salts and SAR are generally higher in the eastern part of the study. The similarity of the two maps show the relationship between SAR and EC. As with groundwater values the cation concentrations have a positive correlation with EC. The SAR and EC increase from the canal to the river and also down river. Soil Na and Mg are distributed similar to the EC map of Figure III-23. The soil Ca distribution is shown in Figure III-25. The calcium is more evenly distributed over a larger area than Na and Mg which are higher at sites I and J.

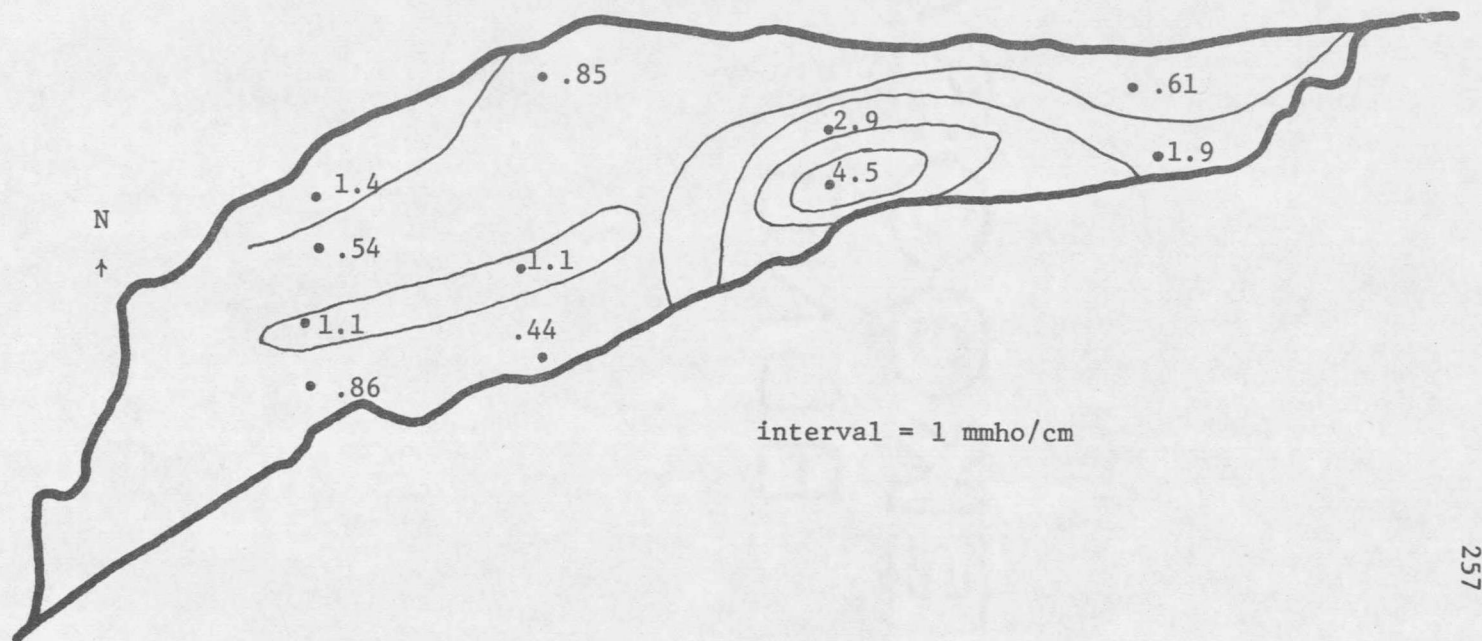


Figure III-21. Spacial distribution of mean groundwater electrical conductivity (mmhos/cm) for the two year study period.

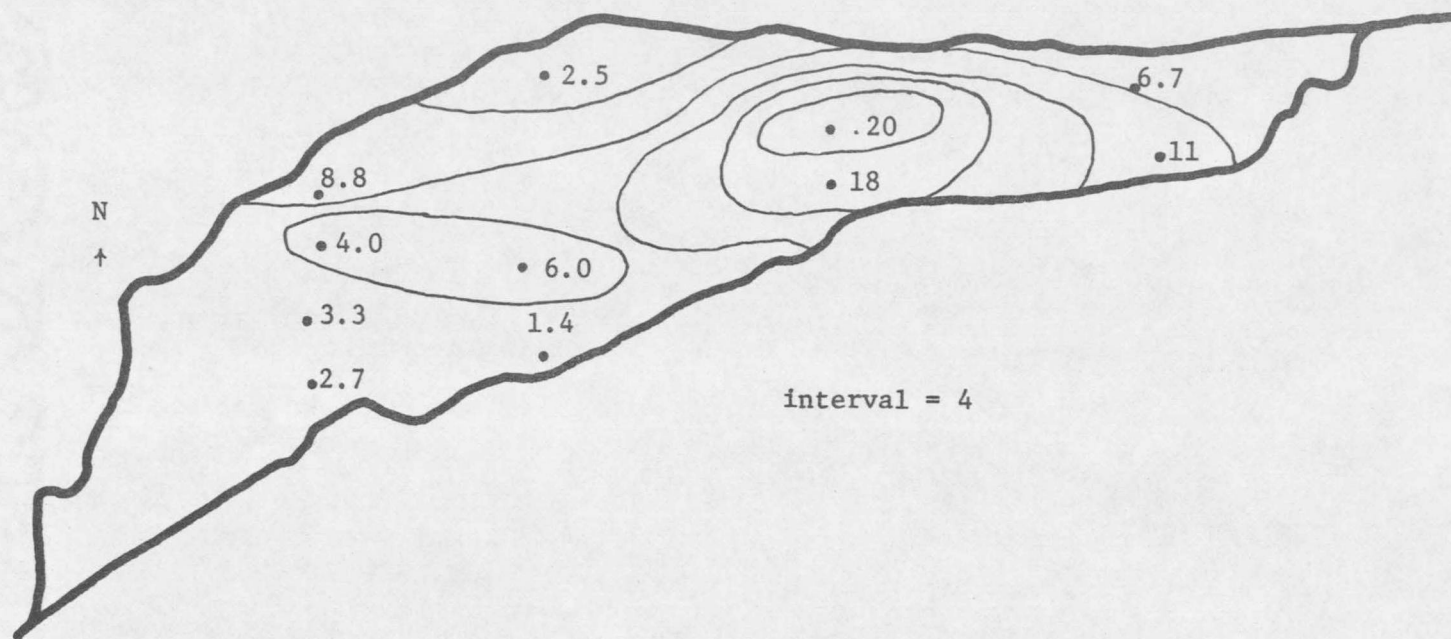


Figure III-22. Spacial distribution of mean groundwater sodium adsorption ratios for the two year study period.

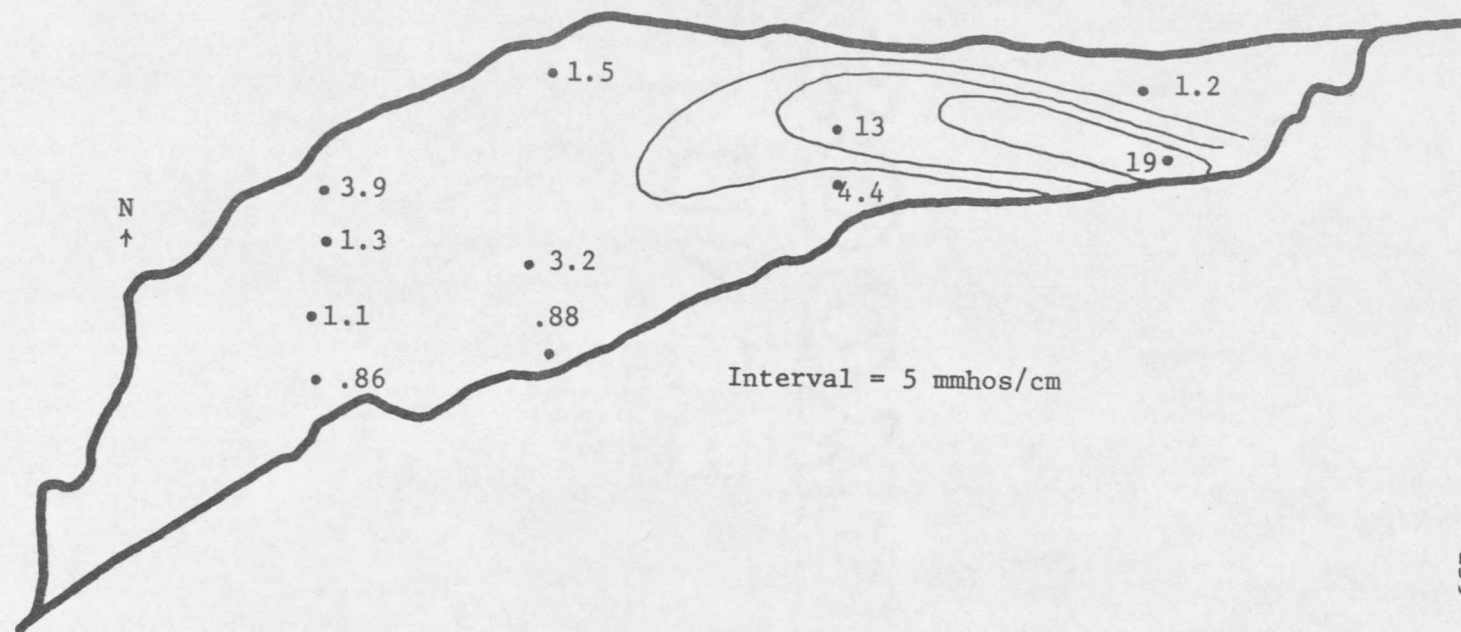


Figure III-23. Spacial distribution of mean soil electrical conductivity (of saturated extract in mmhos/cm).

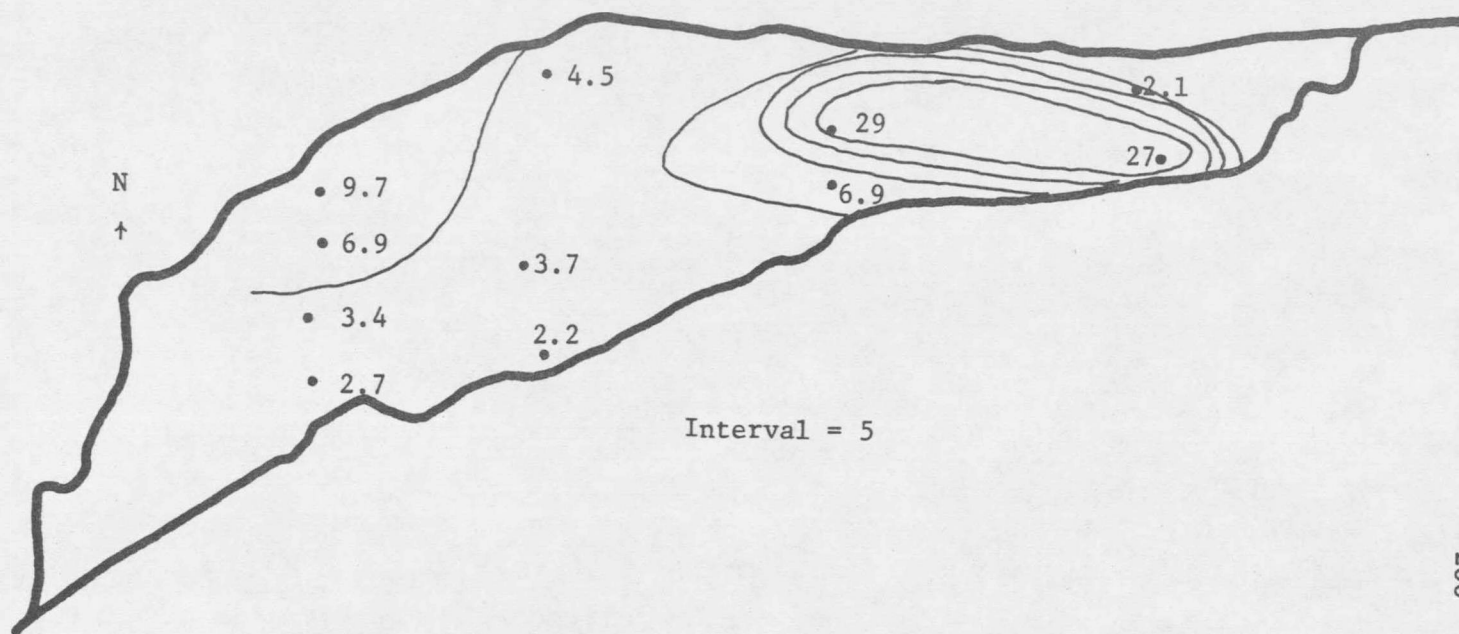


Figure III-24. Spacial distribution of mean soil sodium adsorption ratios.

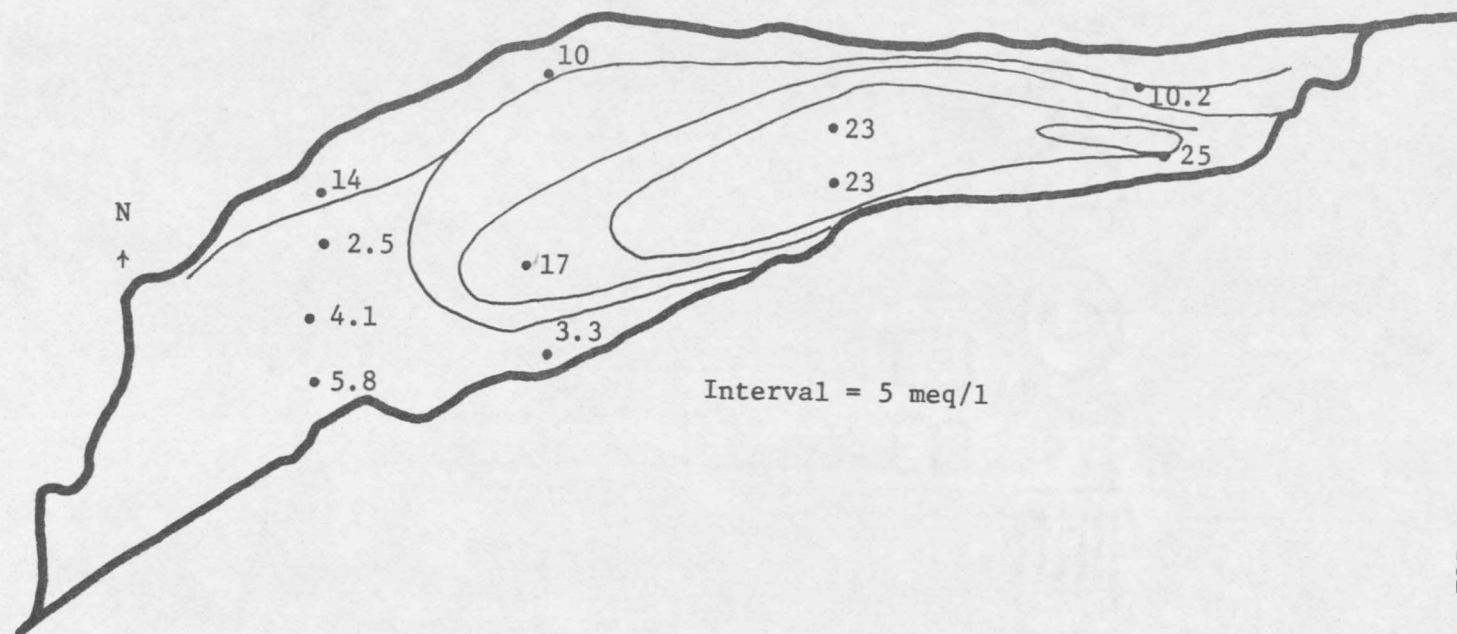


Figure III-25. Spacial distribution of mean soil Ca concentrations (of saturated extract in meq/l).

Potentiometric Change

The change in piezometric head over time can be used to determine the local effects of discharge and recharge of an aquifer. Changes in piezometric head can be caused by changes in barometric pressure, deformation of aquifers, and changes in groundwater storage. Changes in groundwater storage are usually responsible for large changes in piezometric head.

Changes in piezometric head within the study area during the summer are mainly due to irrigation activity (canal seepage and irrigation). These changes are superimposed on natural background changes due to seasonal fluctuations. Yearly trends are shown in the individual site discussions. Generally the piezometric head maximum is during early summer and the minimum in mid-winter.

The piezometric change over the study area during selected time intervals is shown in Figures III-26 through III-30. The time intervals of the first two figures (III-26 and III-27) are during canal water termination in the fall of 1975 and 1976, respectively. It takes from two to three days for the water to drain out of the canal after terminating flow at the point where it is diverted from the Yellowstone River. This is why during canal termination in 1975 when the canal was turned off on October 1, the interval for potentiometric change did not register in the piezometers until October 3, 1976 (Fig.

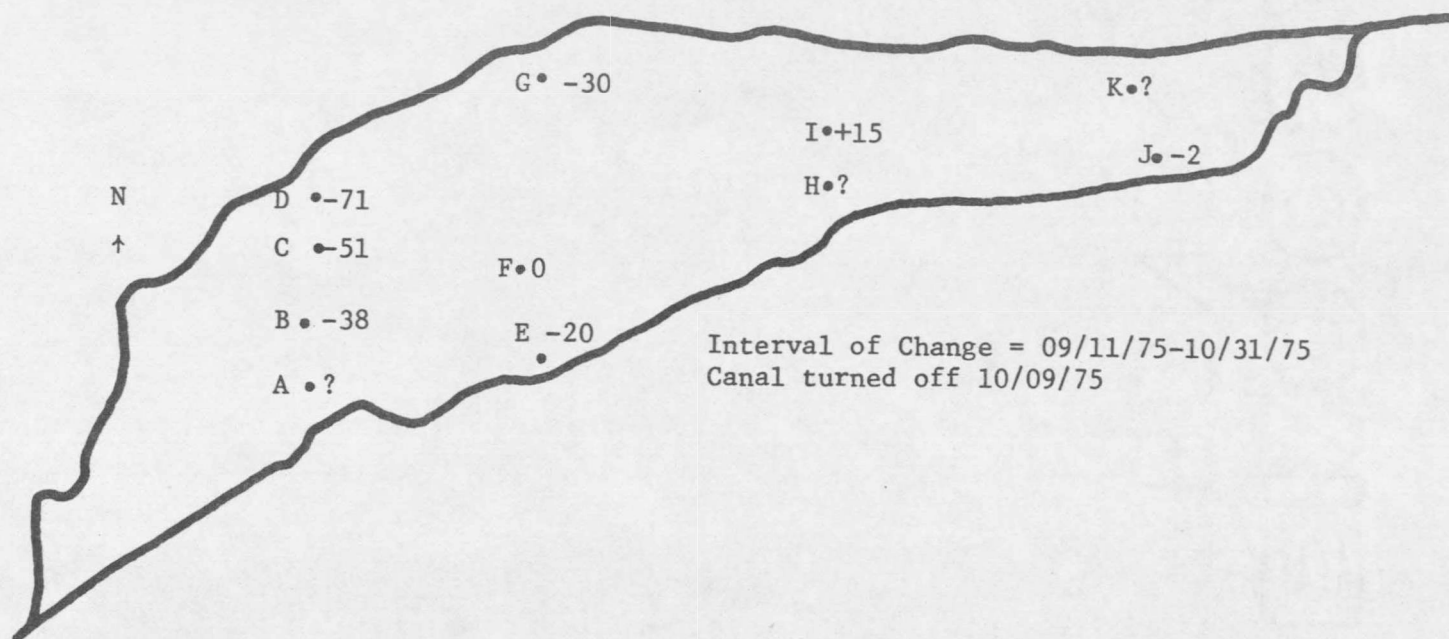


Figure III-26. Potentiometric change during canal water termination, fall of 1975 (values are in cm). The piezometers at site A were destroyed by tillage operations. Data for 10/31/75 are missing for site H. The pieziometric head at site K was below all piezometers on both dates.

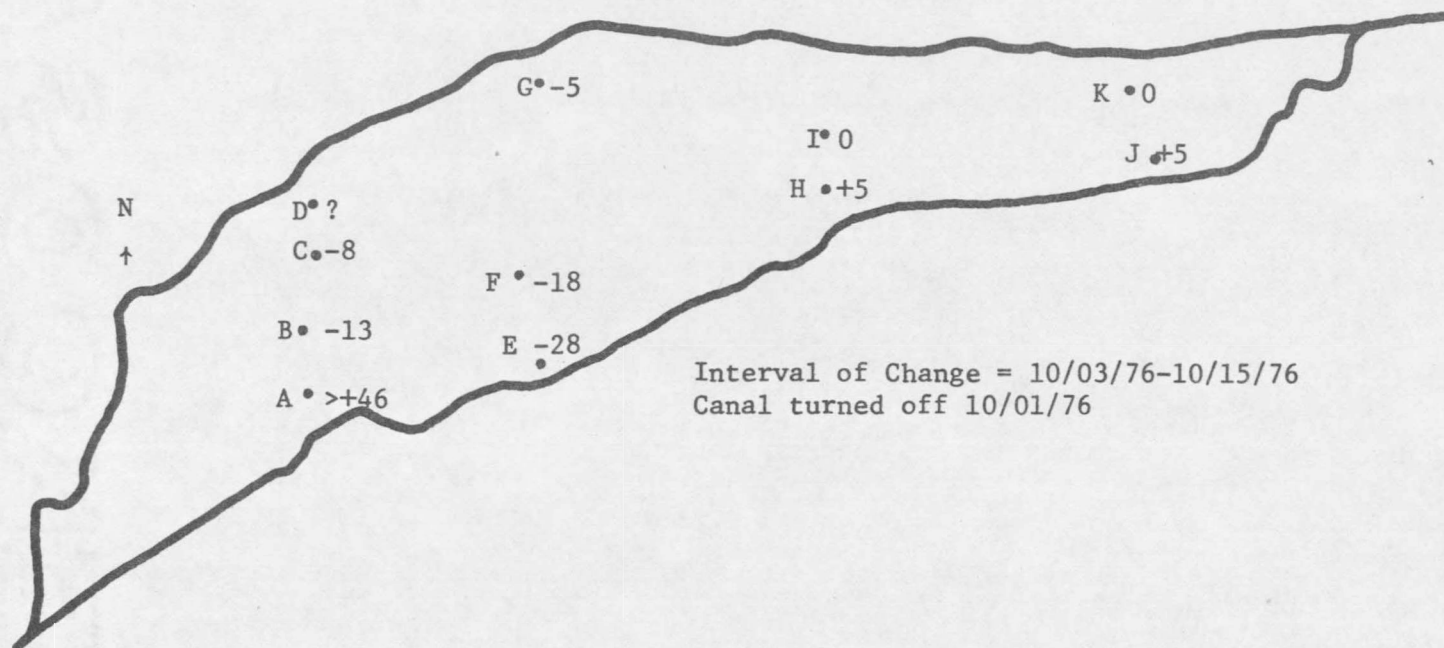


Figure III-27. Potentiometric change during canal water termination, fall of 1976 (values are in cm). Site D had a trace of water in the piezometer on 10/03/76 and more on 10/15/76. Site A did not have water in the deepest piezometer on 10/03/76.

III-27). In some instances head measurements were only possible on one of the two dates of the time interval under consideration because the piezometric head fell below the depth sampled by the deepest piezometer of the nest at that particular site. In this case a "greater than" sign appears in front of the change value. If, for various reasons, piezometer readings are unavailable for either date of the change interval, a question mark appears at the site concerned.

Both figures with time intervals during canal termination generally show a drop in piezometric head. This would seem to indicate that the drop is due to the curtailment of canal leakage and percolated irrigation water entering the groundwater. Site A does seem to follow the trend of most sites. The changes in piezometric head at Site A seems to be associated with an aquifer that is, in part, isolated from the main gravel aquifer underlying the study. Piezometric changes in the eastern half of the study are of limited value in assessing canal leakage because of lack of good connection with the gravel aquifer and responsiveness in the heavier textures of this area. Site E seems to be highly responsive to canal activity.

In order to assess the background change in head due to seasonally induced changes in groundwater flux, time intervals from after canal termination in the fall to mid-winter and from mid-winter to before canal initiation in the spring were plotted. These are shown in Figures III-28 and III-29. The potentiometric change in the spring

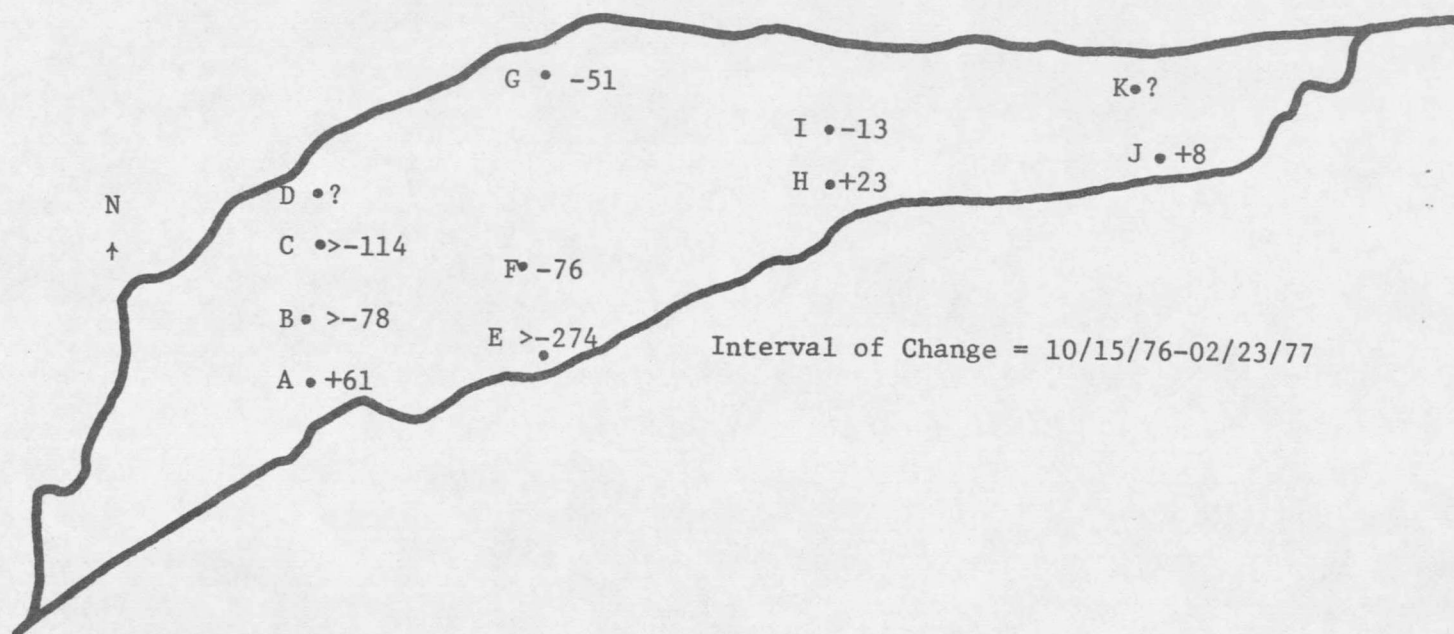


Figure III-28. Potentiometric change from fall to mid-winter (values are in cm). At site D the depth of the piezometer in contact with the gravel was above the saturated zone both dates. The piezometers at site K were destroyed by tilling operations. The sites with greater than (>) had piezometric heads below the deepest piezometer at one date.

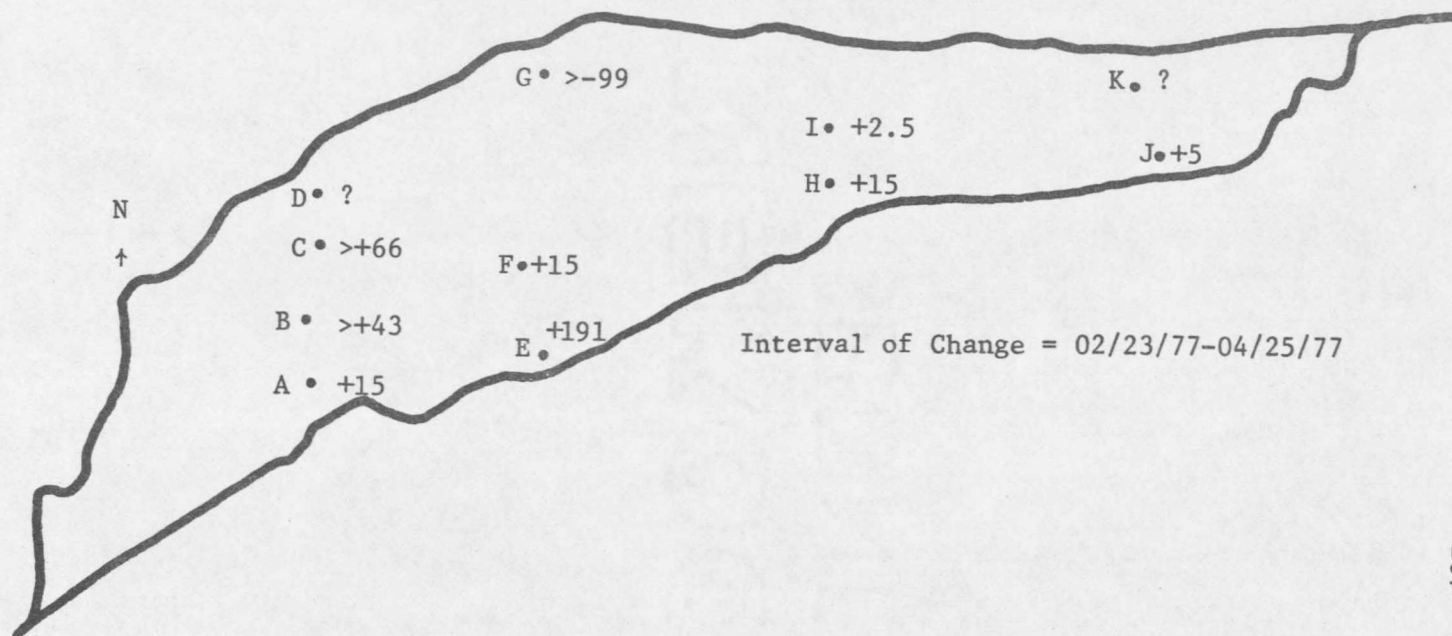


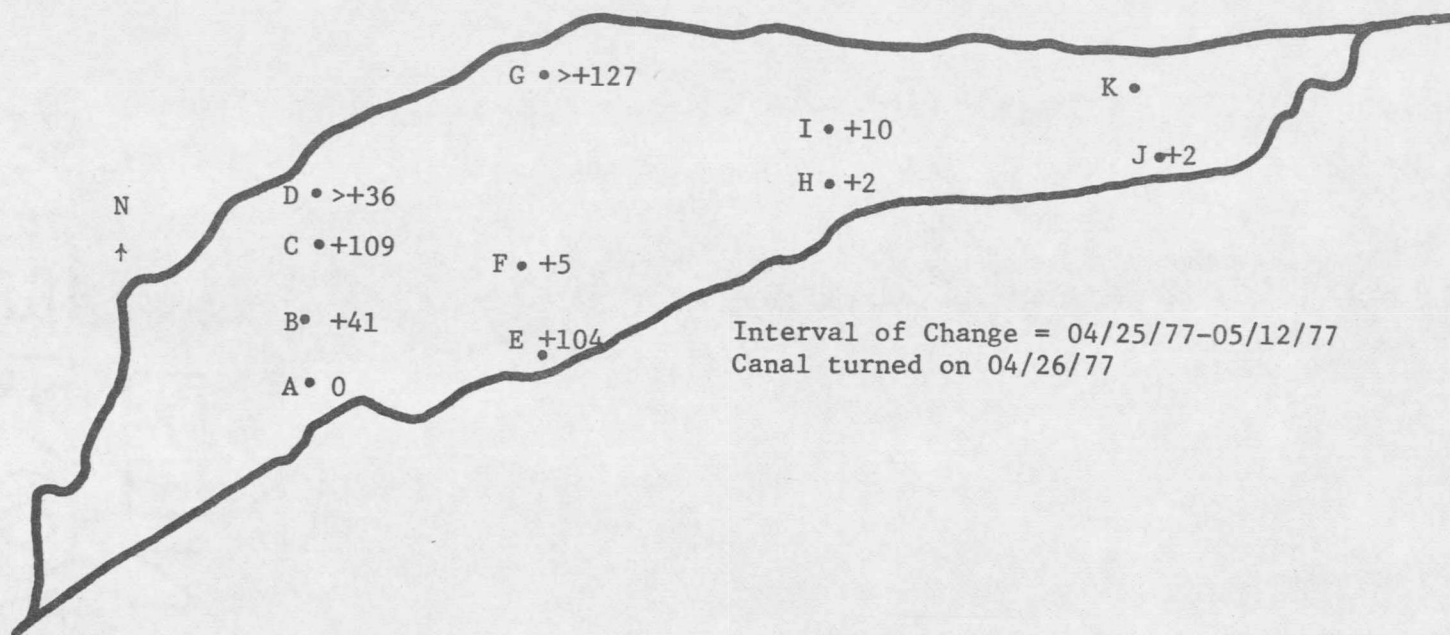
Figure III-29. Potentiometric change from mid-winter to spring (values are in cm). At site D the depth of the piezometer in contact with the gravel was above the saturated zone at both dates. The piezometers at site K were destroyed by tilling operations. The sites with greater than (>) had piezometric heads below the deepest piezometer at one date.

is generally positive and in the fall negative. This is independent of canal activity since the canal was inactive during these periods.

Figure III-30 shows changes in piezometric head during canal activation in the spring of 1977. Generally the change is positive. In some cases the change in this relatively short period (about 2 1/2 weeks) is almost as great or greater than that due to seasonal changes of the preceding three months. This would seem to indicate that the rapid change during the canal activation period is due to canal leakage and/or irrigation.

Summary

The piezometric change maps show a seasonally induced change in head. The maximum is in early summer and the minimum in mid-winter. The rate of change of piezometric head is highest during activation of the canal in the spring and deactivation in the fall. This is due to canal leakage and/or irrigation.



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Figure III-30. Potentiometric change during canal initiation, spring 1977 (values are in cm). The piezometers at site K were destroyed by tilling operations. The sites with greater than (>) had piezometric heads below the deepest piezometer at one date.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Individual Sites

1. The contrast between salt concentrations (saturated soil extract) above the saturated zone and in the unsaturated suggest the direction of net salt flux between the two. Generally, clay textured sites have higher salt concentrations above the saturated zone while the sandy loam to loam sites have higher salt concentrations in the groundwater. This suggests movement of salt from groundwater to soil in fine textured profiles and the reverse in coarse profiles.
2. Textural and structural boundaries in a given profile are associated with abrupt changes in ion concentrations. This is evidence of net salt flux dependency on local site profile horizonation.
3. The depth to groundwater affects the direction of salt movement through the profile. When the depth is sufficiently shallow to allow surface evaporation of the capillary fringe an upward net salt flux results. This is, of course, dependent also on texture.
4. The sequence of occurrence of maximum concentration of the various cations, vertically, in the soil profile in most cases agrees with their relative mobilities and assumed direction of net water flux.
5. Generally, Na, and to a lesser degree Mg, are responsible for temporal changes in groundwater EC.

Streamlines

The cation concentrations of soil and groundwater increase toward the river within streamlines. Concentrations also increase among streamlines from high to low water potential. The depth to groundwater is less as the river is approached within a given streamline. All sites in close proximity to the Yellowstone River have groundwater shallow enough to permit salt accumulation in the upper profile. The time required for groundwater to move from the canal to the Yellowstone River is estimated to vary from 1.1 to 6.1 years from west to east within the streamline defined.

Potentiometric Change

The piezometric change is seasonally induced being negative in the fall and positive in the spring. The rate of change of piezometric head is highest during activation of the canal in the spring and deactivation in the fall. This is due to canal leakage and/or to a lesser extent to irrigation.

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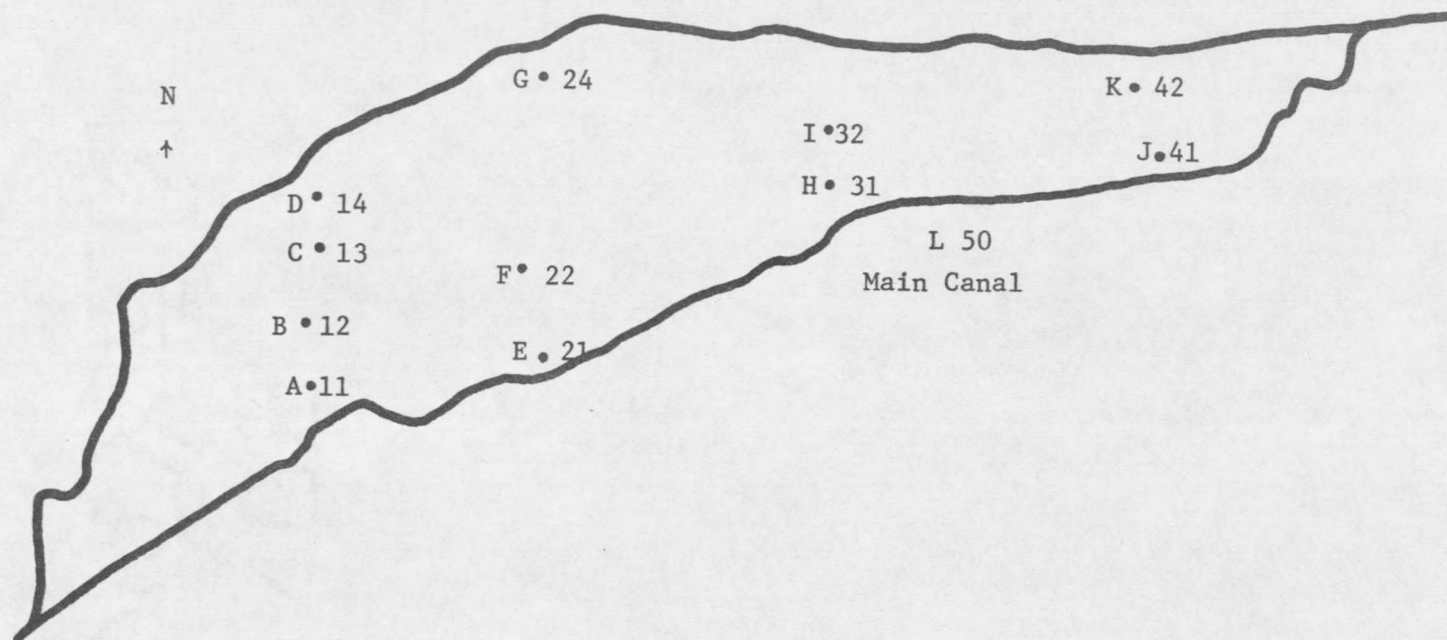
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APPENDIX



Appendix Figure 1. Appendix ID vs. text ID for groundwater monitoring stations. Groundwater monitoring sites are located on four north-south transects numbered from 1 to 4 from west to east. This is the first number of the two number site ID. Sites within transects are numbered sequentially from south to north. This is the second number in the site ID. The corresponding letters appear in the text whereas a numerical ID is used in appendix data.

DESCRIPTION OF TABLE COLUMNS

Table 1

<u>Column</u>	<u>Description</u>
1	Identification Number
2	Na (meq/l)
3	Mg (meq/l)
4	Ca (meq/l)
5	K (meq/l)
6	SAR
7	pH
8	EC (mmhos/cm)
9	PAR
10	NO ₃ -N (ppm)

Table 2

<u>Column</u>	<u>Description</u>
1	Identification Number
2	Na
3	Mg
4	Ca
5	K
6	SAR
7	pH
8	EC (mmhos/cm)
9	PAR
10	SO ₄
11	Cl
12	NO ₃

Appendix Table 1. Measured soil variables at groundwater monitoring stations. The soil ID numbers are preceded by a 3. The next two numbers of the ID represent site locations (Appendix Fig. 1). The last column of numbers in the ID is the depth increment in feet. The first seven variables are of the saturated extract. The second line for each depth increment contains the saturation percentage and ammonium acetate extractable K (ppm) in that order.

311	1	2.160	1.850	7.250	1.330	1.01	8.5	.786	.6235	.9
311	1	45.90	570.0							
311	2	2.100	1.850	7.250	.470	.98	8.7	.751	.2203	2.0
311	2	36.27	305.0							
311	3	3.020	1.850	6.000	.240	1.52	8.1	.681	.1211	6.4
311	3	19.68	175.0							
311	4	6.160	2.870	6.000	.250	2.93	8.6	1.120	.1187	5.8
311	4	30.39	160.0							
311	5	6.480	1.440	3.630	.170	4.07	8.7	.772	.1068	1.4
311	5	35.56	314.0							
311	6	9.940	1.230	4.880	.200	5.69	8.8	1.050	.1144	2.0
311	6	34.85	232.0							
312	1	4.100	2.670	4.880	.790	2.11	8.6	1.050	.4066	.9
312	1	56.89	739.0							
312	2	6.160	2.670	6.000	.660	2.96	8.4	1.230	.3170	.9
312	2	52.64	447.0							
312	3	6.260	2.870	4.880	.340	3.18	8.6	1.110	.1727	.9
312	3	47.89	394.0							
312	4	7.130	2.670	3.630	.520	4.02	8.6	1.310	.2930	.9
312	4	34.71	260.0							
312	5	5.180	1.230	2.500	.330	3.79	8.3	.751	.2416	.9
312	5	19.65	155.0							
312	6	5.400	1.230	2.500	.360	3.95	8.6	.872	.2636	.9
312	6	22.29	95.0							
313	1	3.460	2.670	3.630	.340	1.95	8.3	.752	.1916	19.1
313	1	36.43	310.0							
313	2	16.960	4.310	3.630	.210	8.51	8.6	2.010	.1054	8.8
313	2	30.23	110.0							
313	3	20.520	4.310	2.500	.180	11.12	8.7	2.050	.0975	3.0
313	3	30.16	110.0							
313	4	13.280	1.640	1.250	.170	11.05	8.6	1.420	.1414	.9
313	4	27.49	105.0							
313	5	5.720	1.640	2.500	.160	3.98	8.6	.688	.1112	.9
313	5	24.35	136.0							
313	6	6.160	1.850	1.250	.220	4.95	8.6	.766	.1767	.9
313	6	22.80	100.0							
314	1	4.970	1.030	2.500	.210	3.74	8.5	.781	.1581	2.5
314	1	29.74	210.0							
314	2	48.710	15.790	20.500	.690	11.44	8.3	5.010	.1620	2.0
314	2	31.33	180.0							
314	3	52.380	14.150	16.880	.320	13.30	8.6	5.490	.0812	2.0
314	3	28.74	120.0							
314	4	38.770	11.480	16.880	.270	10.30	8.3	4.270	.0717	1.4
314	4	32.25	110.0							
321	1	2.480	2.670	3.630	1.380	1.40	8.6	.632	.7775	10.0
321	1	33.96	491.0							
321	2	4.320	3.280	4.880	1.360	2.14	8.6	.891	.6733	13.3
321	2	28.33	412.0							
321	3	5.830	5.320	4.880	.440	2.58	8.1	1.410	.1948	13.3
321	3	26.65	241.0							
321	4	5.080	4.100	3.630	.340	2.58	8.5	1.010	.1729	4.7
321	4	27.57	213.0							
321	5	3.670	3.280	1.250	.390	2.44	8.3	.711	.2591	7.0
321	5	28.85	251.0							
321	6	3.240	3.080	1.250	.320	2.20	8.7	.619	.2175	3.0

Appendix Table 1. continued.

321	6	29.35	251.0							
322	1	1.940	2.670	3.630	.230	1.09	8.7	.642	.1296	3.9
322	1	45.73	456.0							
322	2	3.070	1.230	1.250	.110	2.76	7.4	.553	.0988	.9
322	2	45.45	350.0							
322	3	3.130	7.590	29.000	.290	.73	8.3	2.890	.0678	.9
322	3	46.15	368.0							
322	4	24.300	8.610	29.000	.360	5.60	8.0	3.540	.0830	.9
322	4	41.96	305.0							
322	5	25.920	7.590	27.750	.300	6.17	8.3	3.490	.0714	.9
322	5	33.48	185.0							
322	6	17.930	2.670	9.630	.150	7.23	8.1	8.210	.0605	.9
322	6	26.14	130.0							
324	1	3.780	2.260	8.380	.990	1.64	8.4	.788	.4292	7.0
324	1	33.39	320.0							
324	2	4.640	1.640	6.000	.310	2.37	7.7	.751	.1586	7.6
324	2	27.46	130.0							
324	3	21.170	6.970	24.130	.790	5.37	8.5	3.420	.2003	5.2
324	3	23.59	60.0							
324	4	5.620	2.260	9.630	.300	2.30	8.5	1.090	.1230	3.9
324	4	21.40	80.0							
324	5	13.820	3.820	2.500	.160	10.73	7.6	1.520	.1242	2.5
324	5	27.84	320.0							
331	1	8.860	10.660	13.250	.520	2.56	8.3	4.690	.1504	3.0
331	1	46.29	440.0							
331	2	21.170	12.100	17.250	.490	5.53	8.4	2.890	.1279	.9
331	2	46.18	380.0							
331	3	32.080	16.810	29.000	.630	6.70	8.3	4.120	.1316	.9
331	3	45.32	260.0							
331	4	38.230	15.790	27.750	.490	8.19	8.3	4.690	.1050	.9
331	4	35.98	230.0							
331	5	38.230	16.400	25.250	.630	8.38	8.2	4.570	.1381	.9
331	5	40.52	290.0							
331	6	46.980	17.220	25.250	.510	10.19	8.3	5.120	.1107	.9
331	6	42.89	320.0							
332	1	23.220	1.440	4.880	.180	13.06	8.8	2.110	.1013	5.2
332	1	46.00	210.0							
332	2	134.160	15.170	25.250	.690	29.84	8.4	11.500	.1535	6.4
332	2	53.67	230.0							
332	3	3208.550	30.750	26.500	1.070	38.98	8.2	16.900	.2000	.9
332	3	49.35	310.0							
332	4	4198.660	34.500	29.000	1.120	35.26	7.4	17.100	.1988	.9
332	4	48.01	340.0							
332	5	5168.130	32.750	25.250	.970	31.22	8.0	15.100	.1801	.9
332	5	53.89	70.0							
332	6	6129.860	25.250	25.250	.690	25.84	8.3	13.100	.1373	.9
332	6	50.11	280.0							
342	1	2.760	2.260	6.000	.240	1.36	8.6	.692	.1181	2.0
342	1	34.84	.0							
342	2	4.970	2.870	9.630	.240	1.99	8.4	1.190	.0960	1.4
342	2	33.07	200.0							
342	3	4.540	2.670	7.130	.190	2.05	7.9	1.140	.0858	.9
342	3	30.03	160.0							
342	4	6.370	6.970	22.880	.370	1.65	8.4	2.240	.0958	.9
342	4	30.10	180.0							
342	5	5.400	2.670	9.630	.320	2.18	7.3	.945	.1290	.9
342	5	32.52	180.0							
342	6	7.000	2.460	6.000	.230	3.40	8.6	.919	.1118	.9
342	6	27.48	140.0							
341	1	1112.230	36.500	25.250	1.530	20.20	7.6	13.100	.2754	.9
341	1	43.21	550.0							
341	2	255.420	102.500	27.750	1.280	31.65	7.4	22.200	.1586	.9
341	2	42.61	270.0							
341	3	3224.460	94.050	26.500	1.310	28.91	7.7	21.400	.1687	.9
341	3	45.37	270.0							
341	4	4210.700	85.600	21.250	1.310	28.83	7.9	20.900	.1792	.9
341	4	41.27	280.0							

Appendix Table 2. Measured groundwater variables at monitoring stations and the main canal. Groundwater and main canal ID numbers are preceded by a 4 for 1975 and 5 for 1976. The next two numbers of the ID represent site locations (Appendix Fig. 1). The last four columns of the ID contain the sampling date (month and day). All concentrations are in meq/l.

4110701	6.816	2.056	1.882	.022	6.28	.580	.0157	6.079	.247	10.5
4110718	4.826	2.580	1.705	.041	3.30	.480	.0280	3.934	.141	12.4
4110911	6.276	2.402	1.485	.046	4.50	.450	.0320	4.787	.176	3.8
4110811	14.473	6.095	1.002	.036	7.68	1.800	.0191	16.447	.247	16.5
4110901	8.842	2.535	1.353	.031	6.34	1.200	.0222	5.787	.211	7.3
4120811	.968	.995	.647	.076	1.07	.280	.0839	.895	.529	1.0
4120901	2.128	2.446	2.335	.207	1.38	.450	.1339	2.331	1.164	11.3
4120911	1.468	2.808	2.475	.170	.90	.360	.1046	2.477	1.093	2.0
4120701	3.252	2.854	2.617	.636	1.97	.430	.3845	3.934	1.762	4.0
4120718	3.224	3.476	1.943	.287	1.96	.610	.1744	3.581	1.551	.5
4130811	1.908	2.184	.914	.027	1.53	.430	.0217	1.707	.000	11.0
4130701	4.004	3.329	1.090	.031	2.69	.290	.0209	2.352	.141	3.0
4130718	5.296	6.285	8.700	.270	1.93	.560	.0986	5.204	.000	23.3
4130901	9.032	3.136	1.178	.012	6.15	.450	.0082	10.305	.000	6.2
4130911	4.714	2.625	1.661	.012	3.22	.440	.0082	2.789	.000	8.6
4140811	16.883	2.270	6.911	.046	7.88	1.200	.0215	14.698	.353	1.8
4140901	16.005	2.535	1.397	.056	11.41	.930	.0399	12.679	.353	1.2
4140911	8.260	1.972	1.573	.036	6.20	.710	.0270	7.515	.176	1.6
4140701	17.322	3.775	2.713	.056	9.62	.900	.0311	23.755	.000	8.8
4140718	16.225	2.716	1.178	.061	11.63	2.000	.0437	16.218	.353	3.4
4210811	.859	.851	1.661	.173	.77	.240	.1544	.832	.600	11.6
4210901	.881	.575	.870	.118	1.04	.160	.1388	1.540	.070	4.8

Appendix Table 2. continued.

4210912	.686	.575	1.310	.081	.71	.110	.0834	.895	.000	5.3
4210630	4.539	6.668	2.100	.092	2.17	.440	.0439	11.950	.353	36.6
4210721	3.658	3.378	1.927	.031	2.25	.330	.0190	7.786	.387	6.4
4220811	15.129	2.314	2.713	.022	9.54	.950	.0139	18.217	.282	1.0
4220911	11.638	2.625	2.713	.031	7.12	1.200	.0190	14.948	.282	1.4
4220721	15.129	4.083	11.786	.027	5.37	1.600	.0096	28.044	.211	2.8
4220703	9.151	1.564	1.705	.012	7.16	.670	.0094	11.409	.211	4.4
4220901	14.692	3.427	1.705	.027	9.17	1.700	.0169	21.236	.282	.7
4240705	2.508	2.446	2.475	.071	1.60	.550	.0453	15.948	2.327	8.3
4240721	2.567	1.806	3.751	.150	1.54	.380	.0900	3.352	.176	20.0
4240911	4.539	1.330	2.016	.097	3.51	.430	.0750	.000	.000	10.0
4240901	1.425	.851	1.397	.156	1.34	.160	.1471	1.957	.000	1.4
4240811	1.732	.816	1.222	.123	1.72	.260	.1218	1.623	.000	2.4
4310701	98.710	32.380	14.410	.051	20.41	3.500	.0105	127.230	.282	1.4
4310725	31.420	15.940	12.660	.036	8.31	2.300	.0095	75.888	.000	1.6
4310811	35.770	11.820	7.810	.027	11.42	1.500	.0086	71.870	.000	1.0
4310911	20.620	8.240	10.900	.027	6.67	1.600	.0087	46.678	.000	1.6
4310901	27.690	10.520	9.580	.036	8.73	2.000	.0114	54.735	.000	2.0
4320912	29.740	6.860	3.530	.036	13.05	.200	.0158	36.434	.247	1.4
4320705	12.290	6.090	1.970	.031	6.12	1.800	.0154	65.811	.599	2.4
4320811	35.180	3.920	4.650	.056	16.99	1.900	.0271	50.696	.317	3.3
4320901	42.410	6.680	4.210	.051	18.17	1.600	.0219	57.088	.494	4.6

Appendix Table 2. continued.

4320725	94.300	13.610	14.410	.061	25.19	3.000	.0163	132.310	.494	16.5
4410711	900.700	154.450	22.430	.366	95.78	3.000	.0389	282.750	10.224	3.2
4410725	867.670	318.340	25.690	.593	66.16	7.000	.0452	282.750	15.513	3.9
4410811	845.670	276.570	19.710	.000	69.48	6.000	.0000	202.180	14.103	2.8
4410901	15.780	2.270	3.000	.219	9.72	1.200	.1349	25.358	.494	1.4
4410912	13.380	2.140	3.310	.249	8.11	.780	.1508	17.925	.353	1.8
4420710	17.980	2.220	3.380	.061	9.89	1.800	.0335	14.844	.141	1.8
4420912	10.040	.959	1.940	.027	8.34	.550	.0224	9.244	.088	1.0
4420901	10.840	.880	1.660	.017	9.62	.550	.0151	10.409	.071	2.2
4420725	19.780	1.030	1.520	.036	17.52	1.000	.0319	16.968	.071	.5
4420811	7.480	.780	1.000	.022	7.93	.340	.0233	13.928	.071	.7
4500912	.770	.643	1.040	.027	.84	.120	.0294	.916	.088	1.2
4500718	.420	.337	.730	.017	.58	.130	.0233	.333	.000	.7
4500811	.440	.378	.820	.003	.57	.086	.0039	.479	.000	.7
4500901	.940	.609	.780	.036	1.13	.067	.0432	1.623	.211	.7
5110712	12.400	2.970	1.670	.020	8.14	8.6	1.318	.0134		10.5
5110726	13.700	3.430	.684	.026	9.55	8.8	1.380	.0178		13.0
5110826	14.000	1.920	.469	.021	12.81	8.8	1.395	.0188		13.0
5110810	8.260	1.130	.313	.015	9.72	8.5	.838	.0180		6.5
5110914	25.300	2.670	.883	.031	18.98	9.0	2.125	.0230		.5
5120810	1.840	2.060	1.920	.251	1.30	8.6	.535	.1779		2.0
5120914	1.600	1.460	1.940	.056	1.23	8.5	.528	.0432		2.5
5120712	3.500	3.580	1.900	.143	2.11	8.5	.713	.0864		.0

Appendix Table 2. continued.

5120726	2.930	3.270	1.180	.123	1.96	8.7	.600	.0825	.5
5120826	2.340	1.920	2.540	.107	1.57	8.5	.650	.0717	.5
5130826	5.960	1.110	.449	.021	6.75	8.8	.650	.0232	1.0
5130914	7.610	1.330	.569	.021	7.81	8.8	.780	.0210	6.5
5130712	.383	1.250	.744	.020	.38	8.6	.653	.0204	.5
5130726	4.920	1.390	.609	.015	4.92	8.8	.580	.0153	.5
5130810	4.920	1.190	.783	.020	4.95	8.8	.555	.0205	.5
5140726	2.170	.872	.664	.020	2.48	8.6	.353	.0232	.5
5140914	16.500	4.350	.803	.026	10.28	9.1	1.800	.0159	.5
5140810	9.530	2.970	.983	.036	6.78	8.9	1.043	.0255	6.0
5140712	39.200	7.720	5.090	.107	15.49	8.6	3.525	.0423	25.0
5140826	6.700	2.970	.983	.010	6.19	8.8	1.060	.0073	2.5
5210826	1.980	3.120	1.630	.082	1.28	8.7	.647	.0521	1.0
5210726	1.740	2.970	1.370	.041	1.18	8.3	.528	.0278	5.5
5210810	2.530	3.120	2.350	.102	1.53	8.5	.673	.0617	5.0
5210914	3.520	4.350	1.530	.205	2.05	8.7	.825	.1196	7.5
5220914	13.700	2.810	.923	.097	10.03	8.9	1.540	.0711	1.0
5220712	1.600	2.810	13.000	.061	.57	8.4	1.160	.0218	.5
5220726	4.520	2.810	6.440	.056	2.10	8.4	1.060	.0262	.5
5220810	7.000	2.210	2.350	.067	4.64	8.5	.847	.0440	.0
5220826	4.330	.821	1.670	.015	3.88	8.5	.635	.0137	.0
5240914	6.390	3.730	6.090	.179	7.88	8.5	1.222	.0808	.5
5240826	3.920	4.510	4.690	.286	1.83	8.5	1.010	.1322	5.5

Appendix Table 2. continued.

5240726	2.730	2.810	7.440	.194	1.21	8.4	.980	.0857	8.5
5240712	11.000	4.820	6.640	.143	4.60	8.5	1.700	.0597	6.0
5240810	11.700	6.740	8.230	.297	4.28	8.5	1.840	.1086	13.0
5310810	115.000	25.200	10.400	.077	27.26	8.8	8.800	.0182	.5
5310826	74.200	8.560	8.230	.026	25.61	8.6	5.800	.0088	.5
5310914	158.000	26.600	12.400	.167	38.90	8.810	.200	.0263	.5
5320810	53.400	5.610	1.410	.036	28.50	8.9	4.250	.0191	1.0
5320826	74.200	10.400	8.630	.046	24.05	9.2	5.350	.0149	1.0
5320712	45.300	5.450	3.710	.067	21.17	8.5	3.520	.0311	.0
5320726	23.400	1.770	1.280	.041	18.95	8.9	2.260	.0331	.0
5320914	59.600	9.540	3.320	.041	23.50	8.7	4.850	.0161	.5
5410712	.805	.609	1.040	.092	.89	8.4	.229	.1014	.5
5410726	.474	.263	.332	.056	.87	8.4	.120	.1032	.5
5410810	.331	.162	.254	.026	.73	8.3	.125	.0561	.5
5410826	12.000	.706	1.020	.123	12.92	8.5	.308	.1324	.5
5410914	163.000	23.600	7.830	.133	41.12	8.710	.600	.0336	.5
5420914	1.170	.577	1.060	.051	1.29	8.5	.300	.0565	1.0
5420826	.761	.530	.823	.067	.93	8.4	.236	.0809	15.5
5420712	8.050	.674	.883	.015	9.12	8.4	.850	.0173	.0
5420726	1.060	.641	1.060	.051	1.15	8.7	.265	.0554	.5
5420810	.722	.625	.664	.061	.90	8.1	.242	.0765	.5
5500712	.392	.373	.529	.010	.58	8.4	.130	.0152	.0
5500726	.174	.162	.196	.005	.41	7.1	.066	.0121	.0
5500826	1.130	.821	.529	.041	1.38	8.4	.269	.0498	.5
5500914	.783	.689	.733	.031	.93	8.3	.225	.0364	.5

The effect of irrigation on soil salinity

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