THE UNIVERSITY OF MANITOBA

EFFICACY OF TILE DRAINAGE SYSTEM AT AGRICULTURE CANADA, MORDEN, FOR REDUCING SOIL SALINITY

A Thesis

Submitted to

The Faculty of Graduate Studies

The University of Manitoba

In Partical Fulfillment

of the Requirements for the Degree

MASTER OF SCIENCE

by

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Winnipeg, Manitoba

October, 1974

ABSTRACT

The effectiveness of tile drainage system in reducing soil salinity at the Morden Experimental Farm of Canada Department of Agriculture in Morden, Manitoba was studied over a period of twenty months. The study was carried out on an area of 47,040 square meters at the North-east corner of the farm which is most saline. Soil samples were obtained from 30 sampling sites in the area for soluble salt analysis. The samples were taken at 30 cm. intervals to a depth of 3 meters. Seven and a half centimeters diameter eave trough pipes were installed in the drilled holes for monitoring the groundwater table. Of the thirty wells, twenty four were installed across lateral drainage tile lines E-E, F-F and G-G (Fig. 2). Four wells were installed on either side of the lateral drainage tile lines at intervals of 1.5, 4.5, 10.5 and 22.5 meters, respectively, from the lateral drainage tile lines. A nest of three piezometers and a number of thermocouples were installed at site G-G in order to measure the groundwater hydraulic head and soil temperature respectively.

During the fall and winter the groundwater table was deeper than 3 meters below the soil surface. In the middle of April when soil temperature rose and the ice crystals in the soil pores melted, the melting snow together with rain

in case of heavy rainfall, infiltrated to the sub-soil; thus raising the groundwater table. In May 1973 however, it rose to about 120 cm below the soil surface. The groundwater table rose to about 7 cm below the soil surface in May 1974. In the middle of May 1974 when the groundwater table was below the lateral drainage tile lines and if the pumps at the sumps were operating, a groundwater table draw down curve was observed in lateral drainage tile lines E-E and F-F. A convex draw down curve of the groundwater table was observed in the lateral drainage tile lines when the pumps at the sumps were off.

The dominant soluble salts ions in the soils of the study area were sodium, magnesium and sulphate. Since the area was a discharge region as indicated by the hydraulic head data and accumulation of surface runoff water, the soluble salt dissolution was attributed to the dissolution of sulphate minerals in the sub-soil glacial till. The tile drainage system was installed in 1967. It was almost six years before the start of the investigation. The chemical analytical data when compared to data obtained before the tile drainage installation, indicates that the tile drainage system had not effectively reduced soil salt concentration. This fact has been attributed to many factors including the large distance (120 meters) between lateral drainage tile lines and the ocassional break down of the pumps at the sumps which resulted in the soils near the tile lines being fed with soluble salts.

ACKNOWLEDGEMENTS

The author wishes to extend his sincere thanks to the members of his committee; Dr. C.F. Shaykewich, Associate Professor of Soil Science, University of Manitoba for serving as chairman; Dr. M.A. Zwarich, Associate Professor, University of Manitoba for initiating the project; and especially to Mr. J.G. Mills, Department of Soil Science, University of Manitoba for his constant help in the course of study of the project.

The author would like to thank Mr. R.G. Eilers, Pedologist of the Canada Manitoba Soil Survey, University of Manitoba; for his helpful suggestions and installation of the wells across lateral drainage tile lines; also for carrying out the topographical survey of the wells, manholes and drainage tiles of the study area.

Sincere thanks are extended to Dr. Putt, Director of C.D.A. Experimental Farm in Morden, Manitoba, who allowed us to carry out the investigations in the farm and cooperated fully with us in the course of the study.

The author also would like to thank the Ministry of Water Development and Power of the Tanzanian Government for allowing him a two year leave from his duties as a Soil Surveyor so that he could take up the M.Sc. studies at the University of Manitoba.

Special thanks are extended to the Swedish International Development Authority for offering the author a fellowship which enabled him to carry out his studies at the Department of Soil Science of the University of Manitoba. Finally the author would like to thank the Department of Soil Science, University of Manitoba for providing him with transportation and equipment that were necessary for carrying out the study.

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CHAPTER I

INTRODUCTION

Investigation of the effectiveness of tile drainage in reducing the concentration of soluble salts was conducted at the North-east corner of the Canada Department of Agriculture Experimental Farm in Morden, Manitoba. The farm occupies the whole of Section 4, Township 3, Range 5, West of the Principal Meridian. It is located directly East of the town of Morden of the South side of Number 3 Provincial Highway. The investigation was carried out on an area of 2,221,560 square meters.

Since 1960, the Superintendent, Dr. J.W. Morrison of the Morden C.D.A. Experimental Farm noticed an increasing salinity in the North, East and South-west quarters of the farm. An indication of an increase in salt concentration of the soils of the farm, was at first a decrease in growth rate of the spruce trees; as years went by (1960-1966) many trees died.

In addition to the tree damage and the damage of orchard stands, which mainly occurred in the North-eastern corner of the farm, an unusually high water table was noticed.

The loss of trees and decrease in yield was explained by the fact that plants absorbing available water from a shallow source of saline groundwater will be affected by the high salt concentration of the groundwater. Hence, plants with a low salt tolerance will not survive in a saline soil and high water table environment. It was not easy at the time to explain the unusually high water table at the experimental farm. A suggestion was made that the rise of the water table in the farm was due to underground water flowing from Lake Minnewasta which was at a higher elevation within the Manitoba escarpment than the experimental farm.

As a result of a meeting held in 1966 where ways of solving the problem were discussed, a tile drainage system was constructed and installed in the farm in 1967 (Fig. 1). The system was designed in such a way that a network of drainage tile lines was concentrated in the North and South-west quarters of the farm. This design was aimed at lowering the water table in these quarters which are saline.

The effectiveness of the tile drainage system in lowering the groundwater table depends upon many factors, including: pattern of groundwater flow, soil texture and type, diameter and spacing between tile drainage lines. The tile drainage system was installed in 1967. Since then, no study has been made to evaluate the effectiveness of the system in reducing soil salinity. Therefore, it

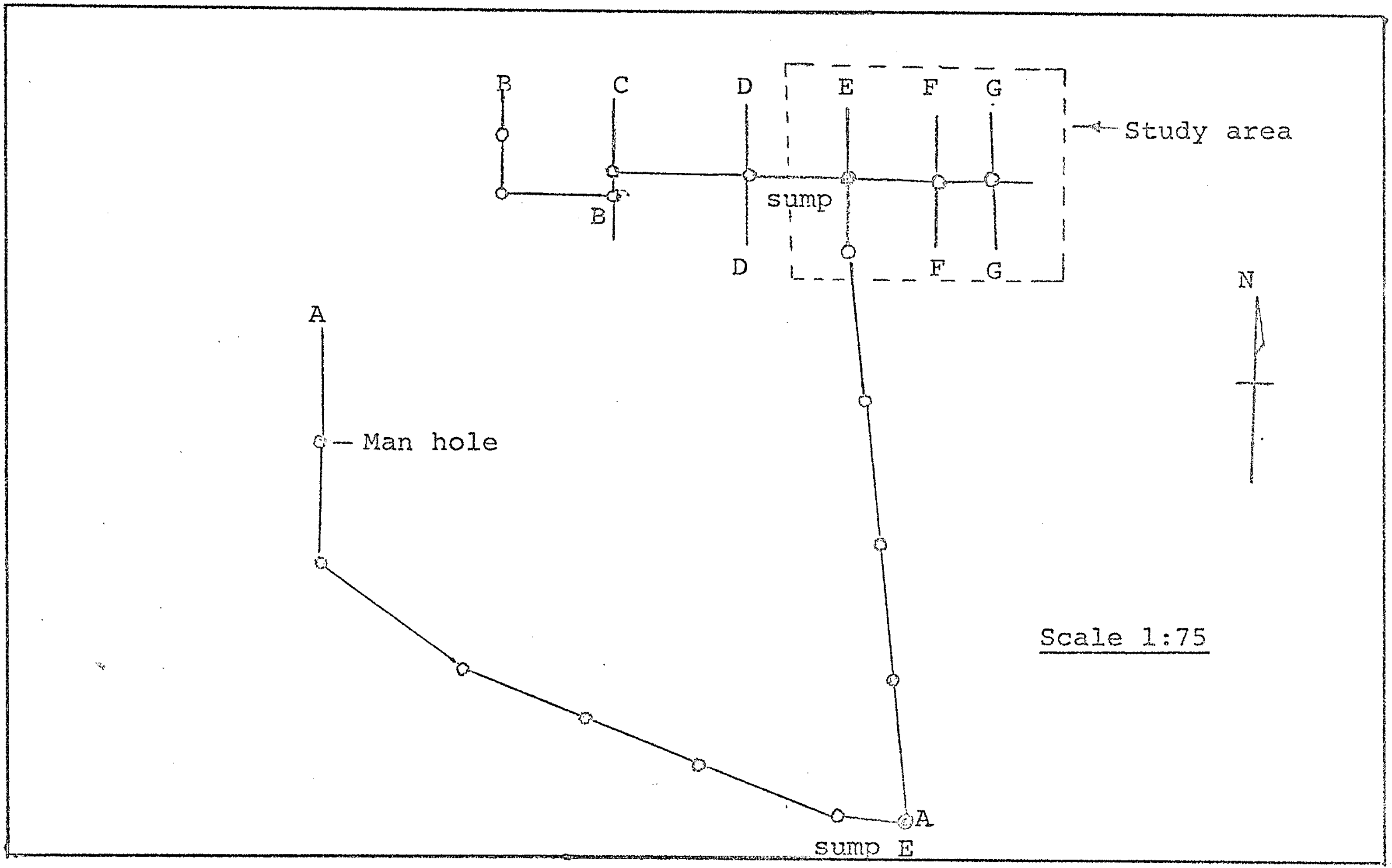

Fig. 1 The study area within the tile drainage network of Morden Experimental Farm.

was felt that a useful project would be to carry out a short term study of the system to evaluate its effectiveness. The main objective of this thesis, therefore, is to describe the effectiveness of chosen lateral drainage tile lines E-E, F-F and G-G of the tile drainage network in lowering the groundwater table, decreasing soil salt concentration and determining the distance to which the tile drainage line is effective in reducing soil soluble salt concentration. In order to achieve the objective, three wells were drilled to the North and South of the main lateral drainage tile line (Fig. 2). Also, four wells were drilled on either side of the lateral drainage tile lines E-E, F-F and G-G at intervals of 1.5, 4.5, 10.5 and 22.5 meters from the tile lines (Fig. 3). They were drilled to a depth of 3 meters and soil samples were taken at 30 cm. intervals for anion, cation and electrical conductivity analysis. Seasonal groundwater fluctuation was also monitored between October 1972 and June 1974.

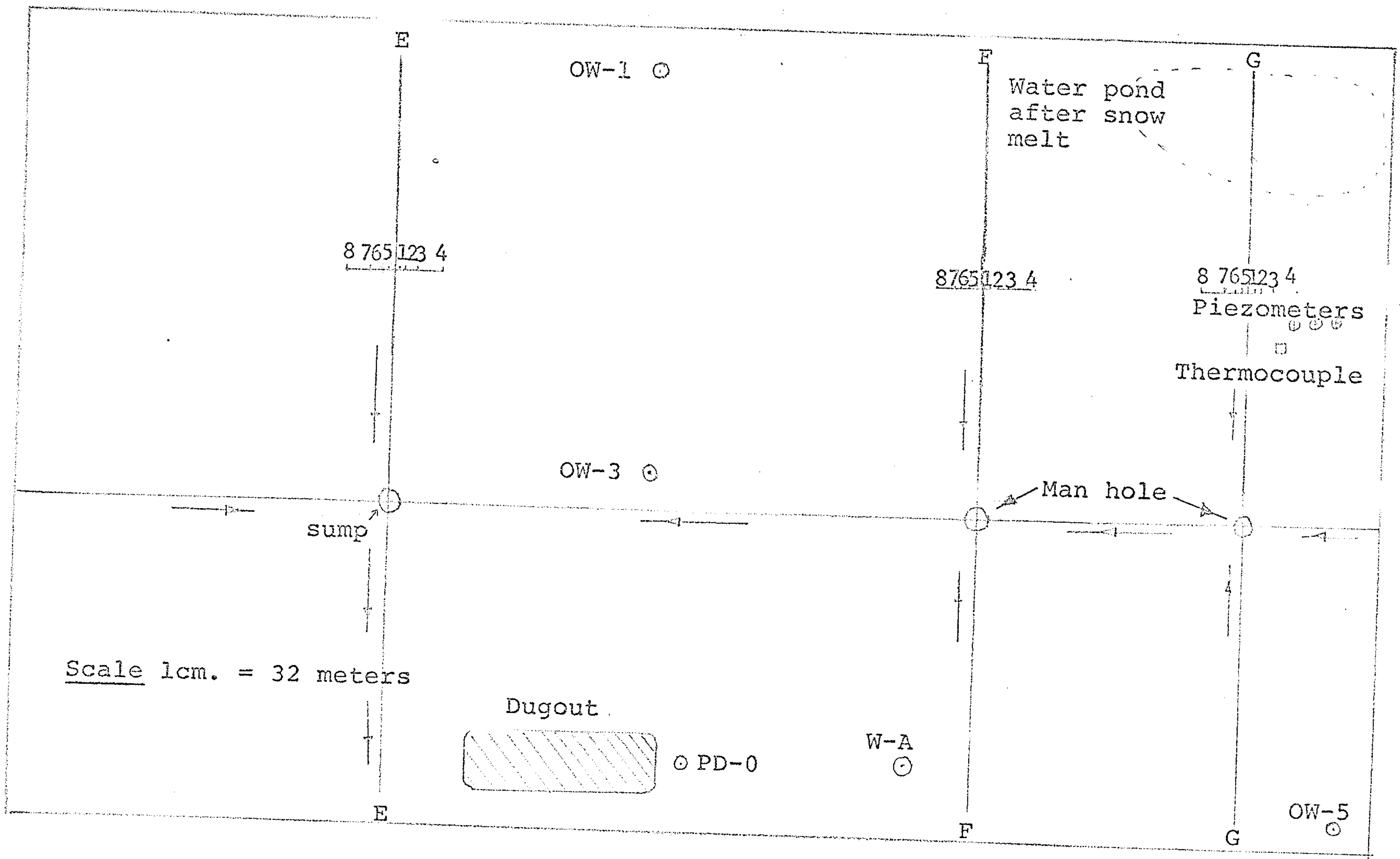

Fig. 2 Map of the study area.

CHAPTER II

REVIEW OF LITERATURE

A. SALINE SOILS

Richards et. al. (1954) defined saline soils as those soils having an electrical conductivity which is greater than 4 mmhos /cm at 25^{o}C ; the exchangeable sodium percentage of these soils is less than 15 and their pH value always being less than 8.5. Milne et. al. (1968) reported that these soils are very common in Western Canada.

Studies conducted by Milne et. al. (1968) revealed that these soils generally have good structure. Their permeability to water and tillage characteristics are like those of non-saline soils. They are generally recognized in the field by spotty growth of crops and often by white crusts of salts on the soil surface.

Many researchers have been investigating the causes of soil salinity. They include Milne et. al. (1968) who reported that the major cause of soil salinity was almost always due to a high water table. Mineralized groundwater in upland areas when moving down slope to low-land areas (Fig. 3) deposits salts in the sloping land or in the lowland depression. This movement or seepage

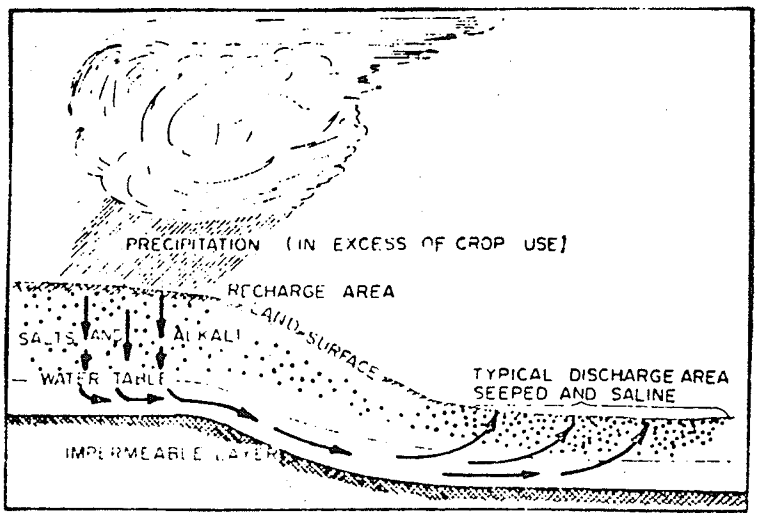

Fig. 3 An example of conditions under which saline soils may form as a result of groundwater discharge (After Montana U.S.D.A. Committee for Rural Development Subcommittee on Seeped and Saline Soils, March, 1971).

usually occurs where permeable soil (sand or gravel) overlies impermeable material (clay or bedrock) in the subsurface.

Where the water table is less than 1.5 meters below the surface water moves upwards by capillary action. This action is greater in fine textured soils than in coarse textured soils. Rose (1969) reported that capillary action is greatest in soils which have small pore diameters (clay, clay loam and loam) and is least in coarse textured soils which have large pore diameters (sand and gravel). This phenomena can be illustrated by equation (1) below (Fig. 4).

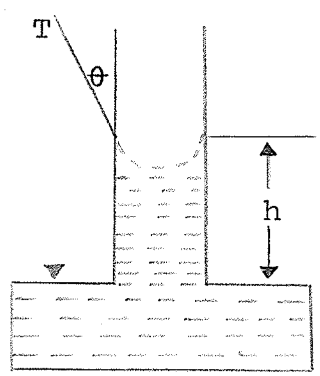

Fig. 4 Upward movement of groundwater by capillary action.

$$h = \frac{2\ T\ \text{Cos}\ \theta}{r\ d\ g} \qquad \text{.....................(1)}$$

where h = height of water rise in the soil pore.

T = surface tension.

T Cos θ - vertical component of surface tension force.

r = redius of soil pore.

d = density of water.

g = acceleration force due to gravity.

In semi arid regions soil salinity develop in some years and tend to disappear in others. Joffe (1949) reported that during wet periods the water table may rise and cause the salinity to increase while during dry periods the water table falls and movement of salts to the surface decrease. During the dry periods any rain that falls, tends to leach the salts downwards. The effect of the salts is seen in crop response but the amount is determined only by soil test.

Studies carried out by Richards _et_. _al_. (1954) revealed that some soils become saline after they have been irrigated with waters containing large quantities of soluble salts. As the irrigation water percolates through the soil pores, the soluble salts are absorbed by the soil particles. After many years of irrigation, the salt content of the irrigated soils become so high that the soils become saline. Milne _et_. _al_. (1968) reported that sometimes lands are being irrigated with waters that do not have large quantities of soluble salts but insufficient water is applied to leach the small amount of salts that accumulate in the topsoil during irrigation. Thus, salts deposited by the water accumulate in the root zone.

B. CLIMATE

The Morden area being in the temperate zone is characterising by hot summers and cold winters. The climatic data pertaining to the study area was obtained from the records of the climatological station located on the Experimental Agricultural Station in Morden.

The yearly total precipitation is shown in Fig. 5. The 34 year average precipitation (1940-1973 inclusive) is 42.06 cm with relatively wide fluctuation about this mean. The highest annual precipitation 72.72 cm occured in 1968; the lowest 31.8 cm occured in 1952.

The monthly mean precipitation over the same 34 year period is shown in Fig. 6 . The mean February precipitation of 2.21 cm is the lowest and the mean June precipitation of 7.62 cm is the highest.

The 34 year mean annual temperature from 1940-1973 inclusive is 4.4°C Fig. 7 shows the 34 year monthly normal temperature where in the lowest monthly mean temperature of -16.7°C occurs in January and the highest monthly temperature of 20°C occurs in July.

The average evaporation as determined in evaporation pans on the Experimental Farm during the interval from May through September (1963-1972) is 30.18 cm

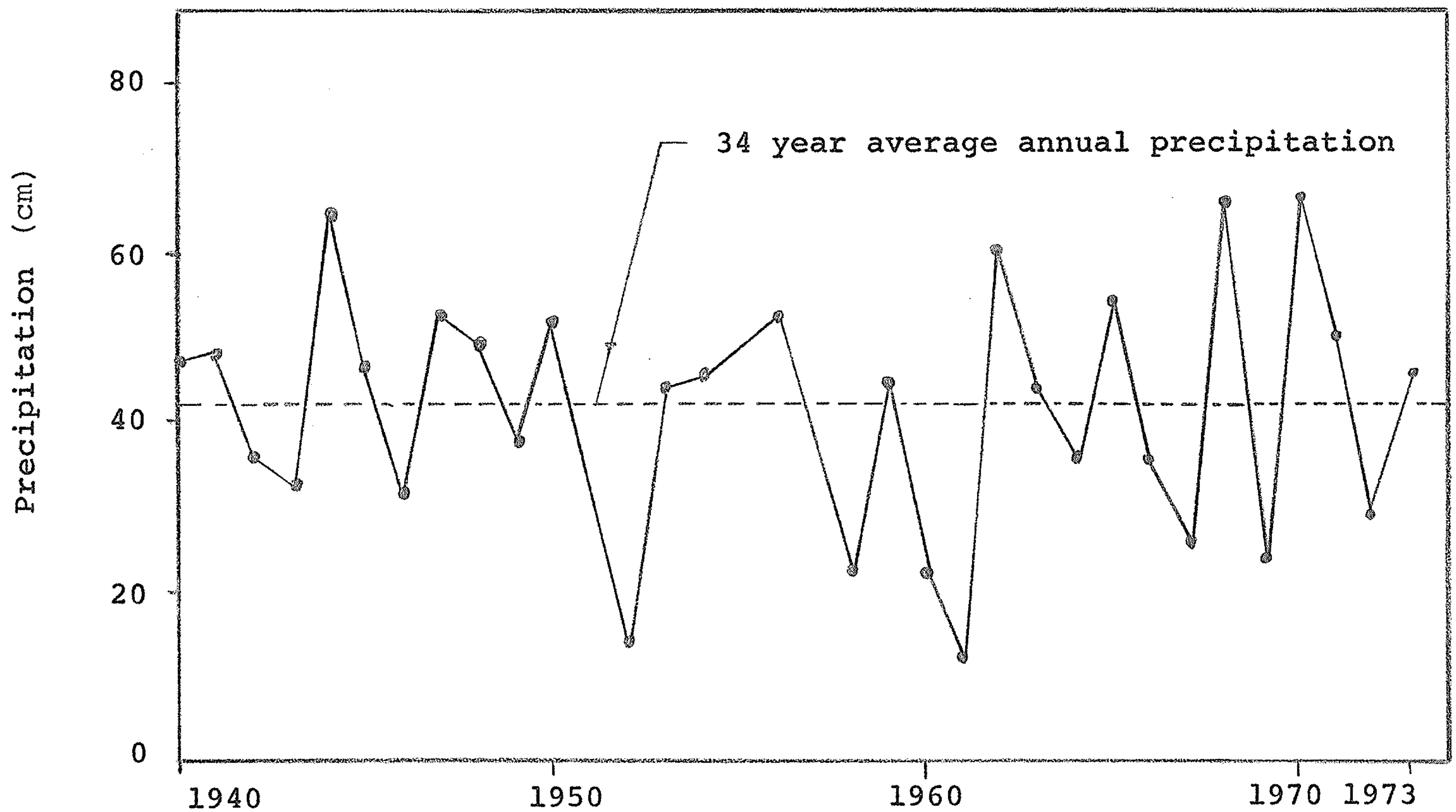

Fig. 5 Total annual precipitation at Morden, Manitoba, 1940-1973.

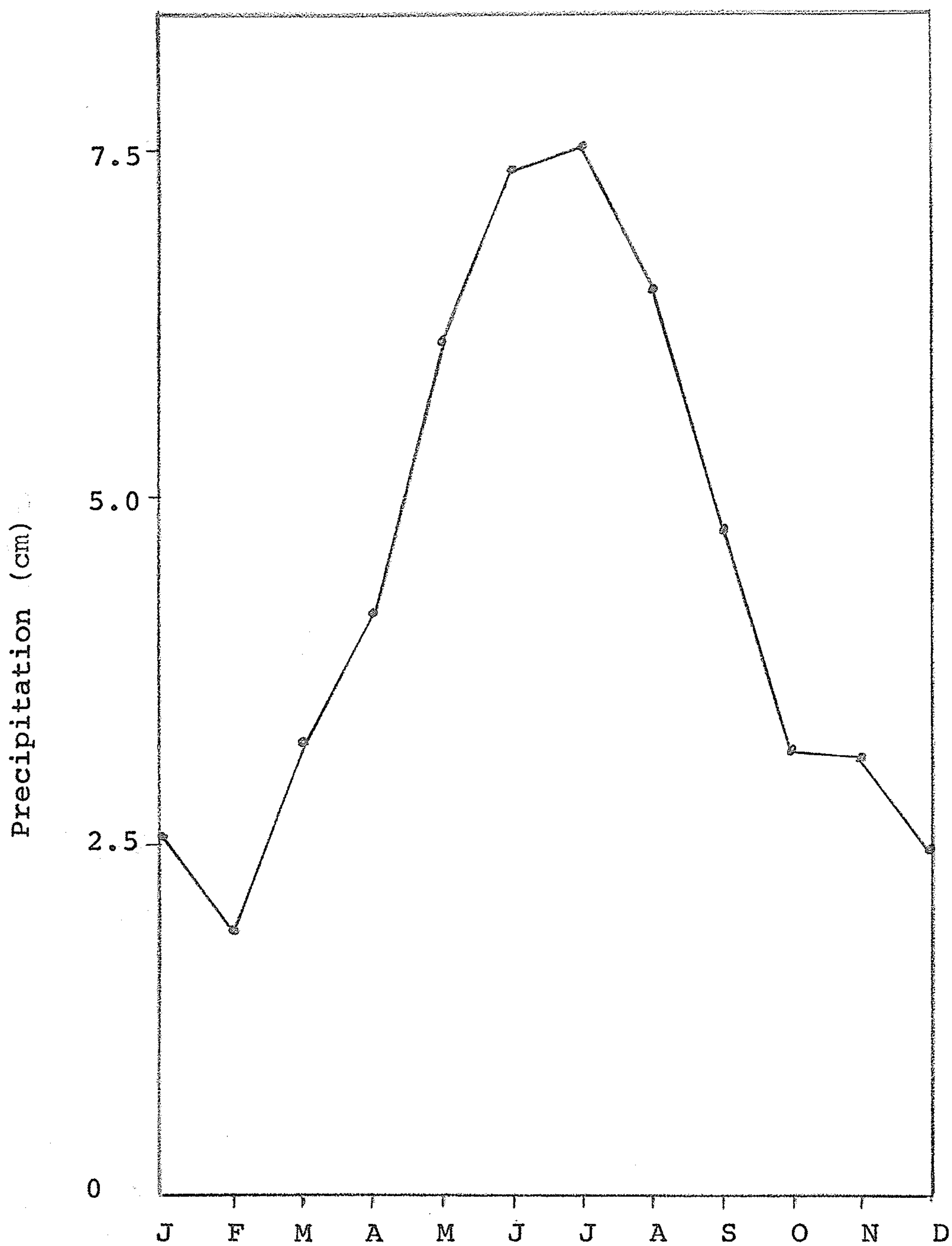

Fig. 6 Average monthly precipitation at Morden, Manitoba, 1940-1973.

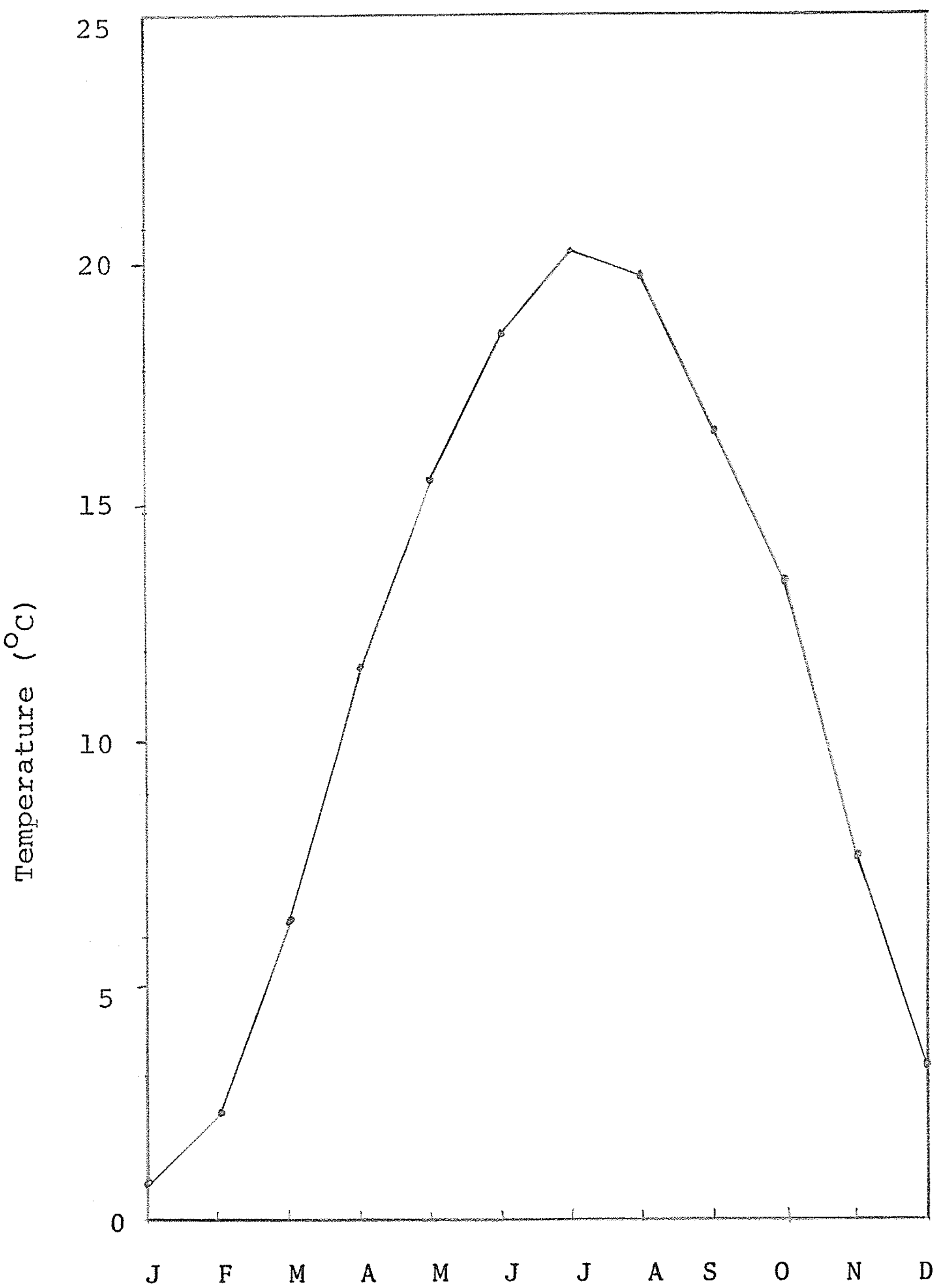

Fig. 7 Average monthly temperature at Morden, Manitoba, 1940-1973.

approximately 5.08 cm more than the average annual precipitation. The measurements were made by using a U.S. Weather Bureau Class A Evaporation Pan. Table 1 shows the monthly pan evaporation amounts from May to October during the periods from 1963 to 1972 inclusive.

Maximum monthly pan evaporation from May to October during the period from 1963 to 1972 inclusive, occured in June, July and August of the different years. The maximum total evaporation during the period 17.33 cm. of record was measured in July 1967. The lowest monthly evaporation seems to occur during September.

C. SURFICIAL GEOLOGY

The surficial deposits of the Morden area are shown in Fig. 8. All these deposits according to Sibul (1967) were laid down during the Pleistocene Epoch.

Elson (1958) reported that earliest glacial deposit in the area is the sandy till laid down by the retreating Red River Valley lobe. However, Lake Agassiz phase which followed the withdrawal of the ice to the North-east is responsible for all of the other deposits in the area.

Sibul (1967) reported that the ground moraine in the area is composed of sandy comminution till which is very hard and relatively stoney. The till has been modified locally to a coarse concentrate of gravel and cobbles

TABLE 1

MONTHLY PAN EVAPORATION
AT THE CANADA DEPARTMENT OF AGRICULTURE
IN MORDEN, MANITOBA
1963-1972

YEAR	EVAPORATION (cm)					
	MONTH					
	MAY	JUNE	JULY	AUG.	SEPT.	MEAN
1963	10.52	13.92	14.07	11.99	9.45	11.99
1964	16.65	13.13	15.60	13.03	9.45	13.46
1965	10.46	14.86	14.20	14.12	5.51	11.84
1966	14.20	14.50	12.50	10.89	6.32	11.66
1967	-----	15.27	17.32	15.90	13.16	12.42
1968	10.80	12.32	15.39	9.45	----	9.60
1969	12.98	12.70	12.52	15.72	9.55	12.70
1970	-----	15.14	16.61	16.38	9.04	11.43
1971	15.37	13.49	15.42	16.03	8.38	13.74
1972	14.40	19.02	15.37	14.83	----	12.73
MEAN	13.17	14.44	14.90	13.83	8.90	12.16

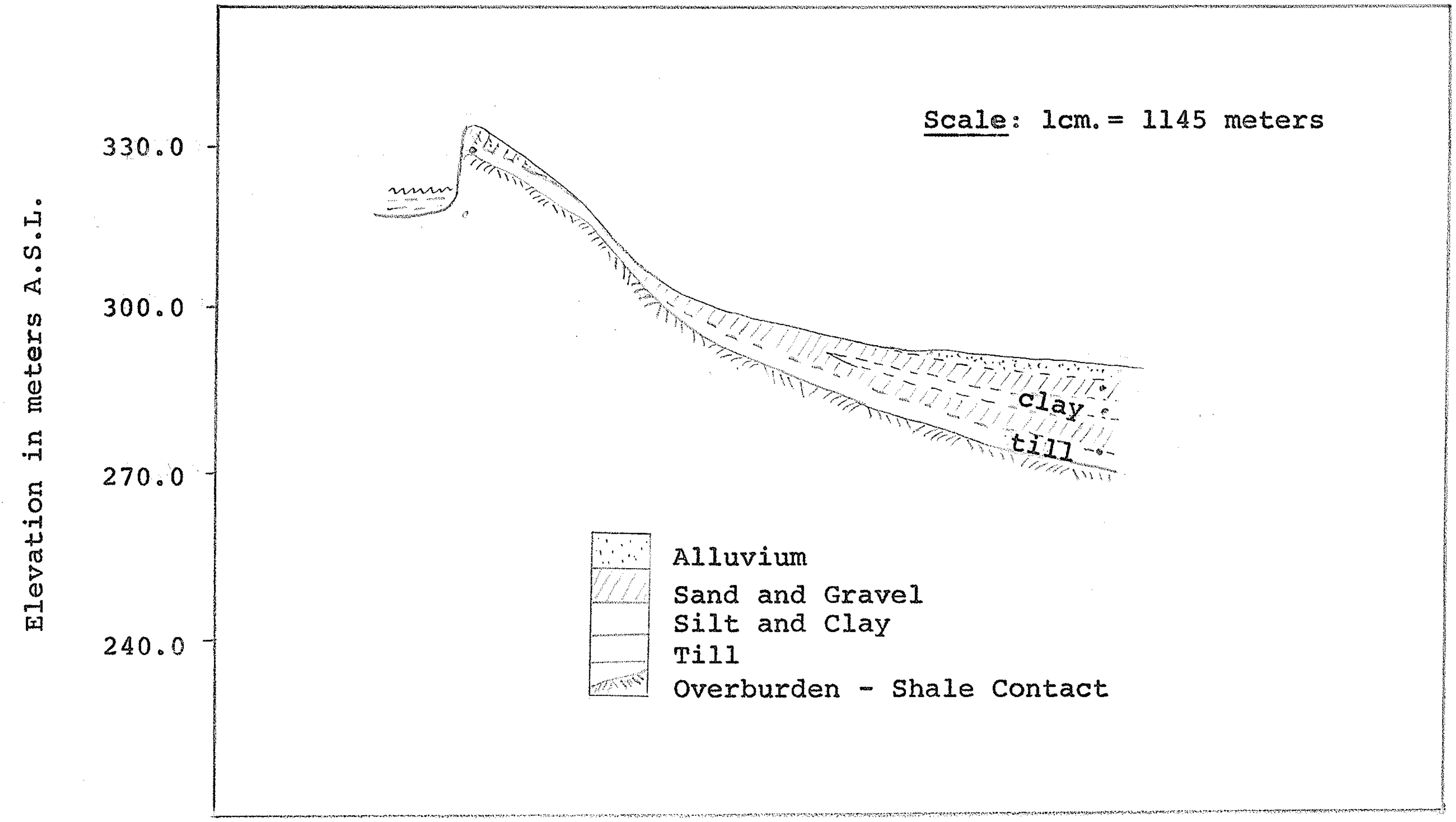

Fig. 8 Cross-section from Lake Minewasta to the Experimental Farm indicating surficial deposits. (After Sibul 1967).

which forms the surface. Except for the escarpment, most of the till plain is featureless. The till, where present, directly overlies bedrock shale.

The fine to medium grained sand covering the plain to the East.

Sibul (1967) reported that the alluvial deposits indicated in Fig. 8 are still being deposited at the present. They are confined to generally flat, broad alluvial fans that form at the foot of the escarpment as a result of the deposition of sediment by a stream eroding at high flows. The largest fan in the area is that formed by the Dead Horse Creek. Most of the alluvium is composed of an unsorted mixture of silt and clay derived from the bedrock of the escarpment. As a result of the alluvial material being fine grained, the deposit is relatively impermeable and consequently does not readily yield groundwater to dug wells.

D. PHYSIOGRAPHY AND SURFACE DEPOSITS

The Experimental Farm in Morden is located below the 300 meter contour line adjacent to the Manitoba Escarpment. The investigated area ranges from 291 meters A.S.L. from West to East. The farm slopes from West to East with an average fall of 3.0 meters per kilometer.

The surface deposits on which the soils are formed are variable due to the mode of deposition and subsequent erosion. According to Michalyna et. al. (1961) the underlying cretaceous shales were covered with till during the last glacial period. They also reported that the surface deposits of the soils of the investigated area consist of fine textured alluvial and lucustrine deposits are well drained soils developed from the alluvial and lucustrine deposits. These soils are mainly sandy in texture. A representative soil profile of the study area is 0-150 cm. of silt clay, 150-600 cm. sand and greater than 600 cm. is clay. Fig. 9 shows the geological formation of the soil of South Central Manitoba. When the ice retreated, the area was inundated with water of Lake Agassiz. Beaches and deltas were formed along the shore line 375 meters A.S.L. Wave action also modified earlier deposits. The emerged surface was modified by the action of streams from the Manitoba Escarpment.

Alluvial plains were formed by streams which emerged from the Escarpment. Dead Horse Creek has been one of the major contributors of alluvial deposits. The alluvial deposit is said to have originated from the fine materials eroded from the glacial till deposits. Some of the alluvial deposits originated from the shale beds of the Riding Mountains formation and the fine textured deposits (silt and clay) originated from the shale beds

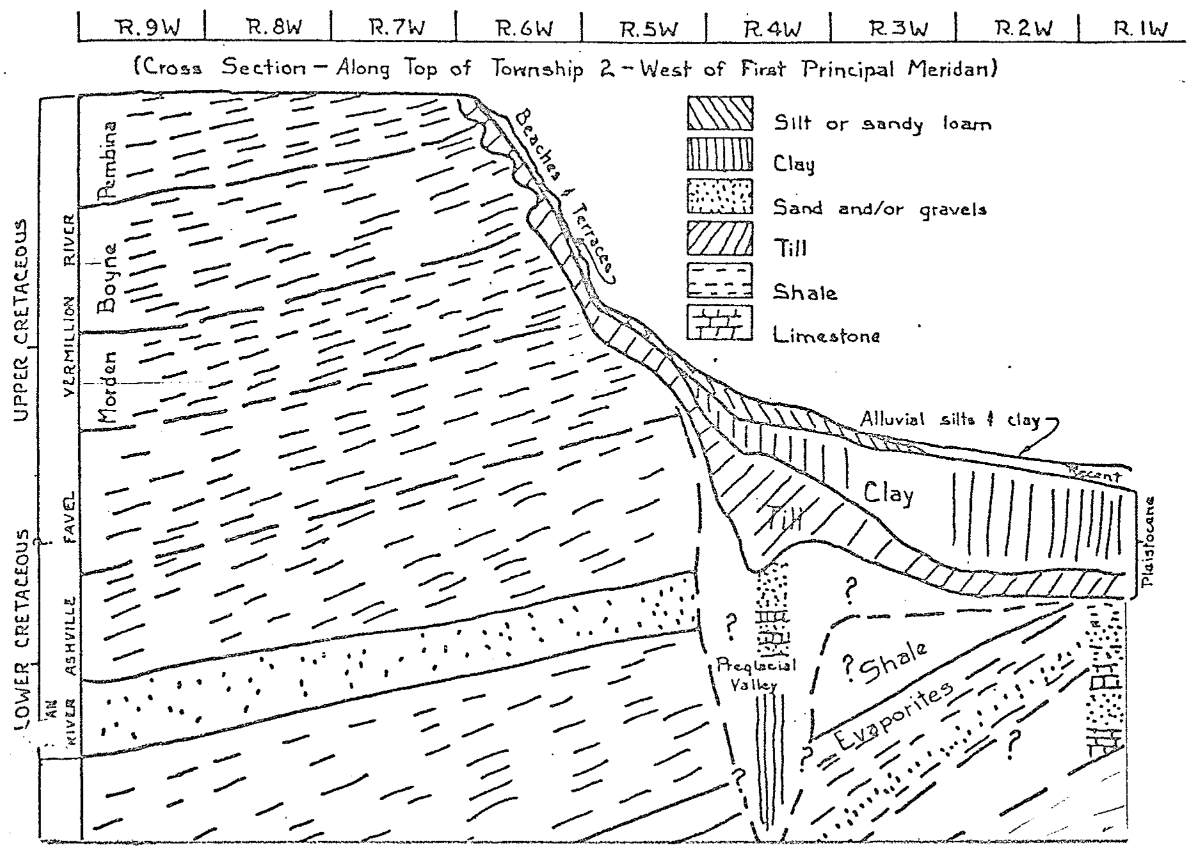

Fig. 9 Geological formation of the soils of south central Manitoba including the Morden Experimental Farm. (After Michalyna 1961).

and calcareous "chalk" of the Vermilion River Formations.

The parent materials of the study area include: glacial till and water worked till, till beach and deltaine deposits, alluvial and lucstrine deposits.

E. BEDROCK GEOLOGY

The most recent information on the geology of Morden has been published by Bannatye (1970). The bedrock geology of the study area is composed of the Vermilion River formation all of which were formed during the upper concretious age.

The Riding Mountain formation is composed of two members: an upper member (Odanah) composed of hard grey siliceous shale and a lower member (Millwood) composed of a softer greenish brown bentonite shale.

The Vermilion River formation is divided into the Morden, Boyne and Pembina Members. This classification was made after an out crop study conducted by Bannatye (1970). The study area falls between the Morden, Boyne and Pembina Members. The Morden member predominantly consists of a dark grey to black carbonaceous non-calcareous shale. Thin layers of bentonite occur within the Morden member. Pyrite is present in the shale beds as concretious, in irregular masses or as a layer of fine crystals. A considerable amount of gypsum is generally associated with pyrite; a coating of yellow material possibly jarosite ($K\ Fe_3\ (SO_4)_2\ (OH_6)$) is present in most shale exposures.

The Boyne member is about 43.5 meters thick. It is divided into an upper part and lower part. The upper part consists of buff and grey speckled calcareous shale. The lower part consists of dark grey carbonaceous and calcareous shales. It has also an abundance of small white specks of foraminifera fossils. The Pembina member overlies the Gammon Ferruginous and Boyne members. At the upper contact of the Pembina member, the chocolate brown, waxy carbonaceous Pembina shales grade upwards into the bentonite beds of the Millwood member. The lower part of the Pembina Member consists of interbedded yellow non-swelling bentonite and black lightly carbonaceous shale.

F. HYDROLOGY

The hydrologic cycle as defined by Gray et. al. (1970) is "a concept which considers the processes of motion, loss and recharge of the earth's waters." Davis and De Wiest (1967), defined it as the "ever changing migration of atmospheric, surface and groundwater as a complex of independant systems." The cycle may be divided into three principal phases: (a) precipitation, (b) evaporation and (c) run off surface and groundwater

(Fig. 10).

Topography, geology and climate influence groundwater flow systems. Topography mainly determines the scale of the hydrologic system. Groundwater movement studies carried out by Meyboom et. al. (1966) showed that the total fluid potential of any point on the land surface, where the pressure potential must everywhere be zero would equal the gravitational potential only, which because it is proportional to elevation would be lower in low lands than on high lands. Hence, because water flows towards areas of low potential, groundwater flow must converge towards local topographic basins which act as discharge areas. Studies on porous media with gently sloping topography conducted by Toth (1962) showed that the system is composed of a recharge area and a discharge area. (Fig. 11). He further found that the recharge area which is up slope from the middle line position is characterized by a downward movement of water away from the water table level and the discharge area which is at the bottom of the slope from the middle line position is characterized by an upward movement of water towards the water table level. Groundwater flow studies carried out by Hitchon (1969) on the Western Canadian sedimentary basin enabled him to conclude that major upland topographic features are major recharge regions and that major low

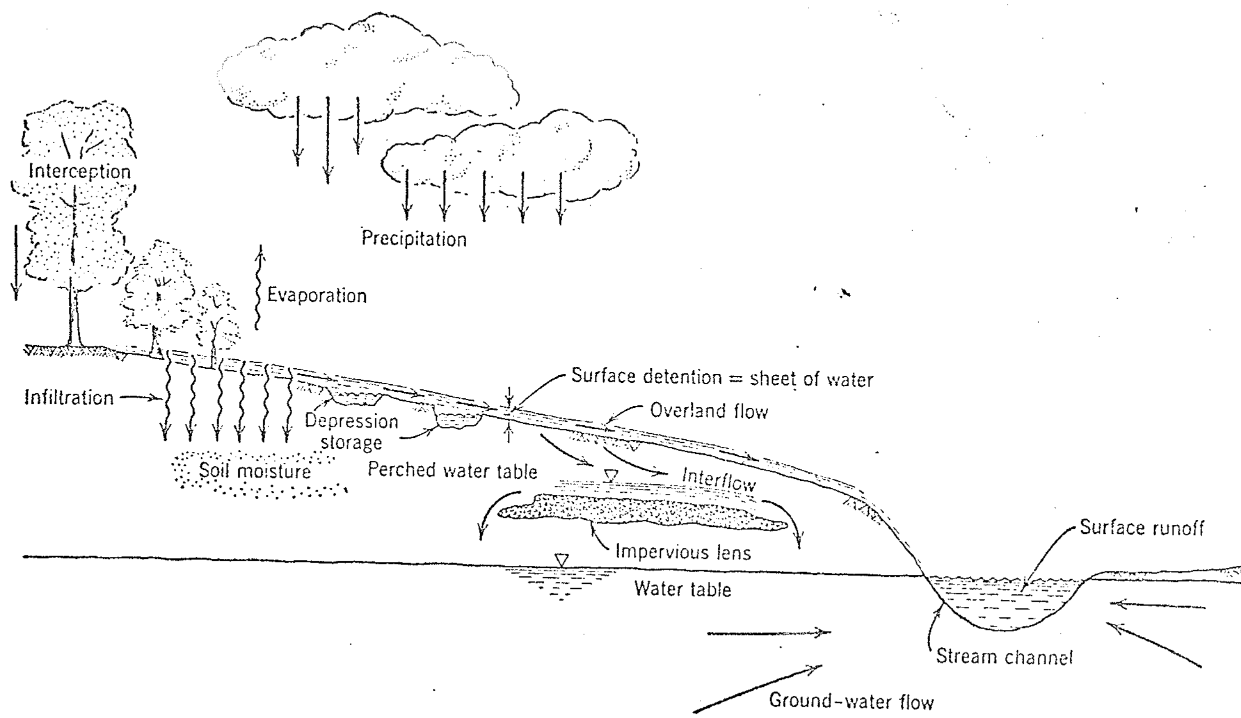

Fig. 10 Hydrologic cycle. (After Davies-de Wiest 1969).

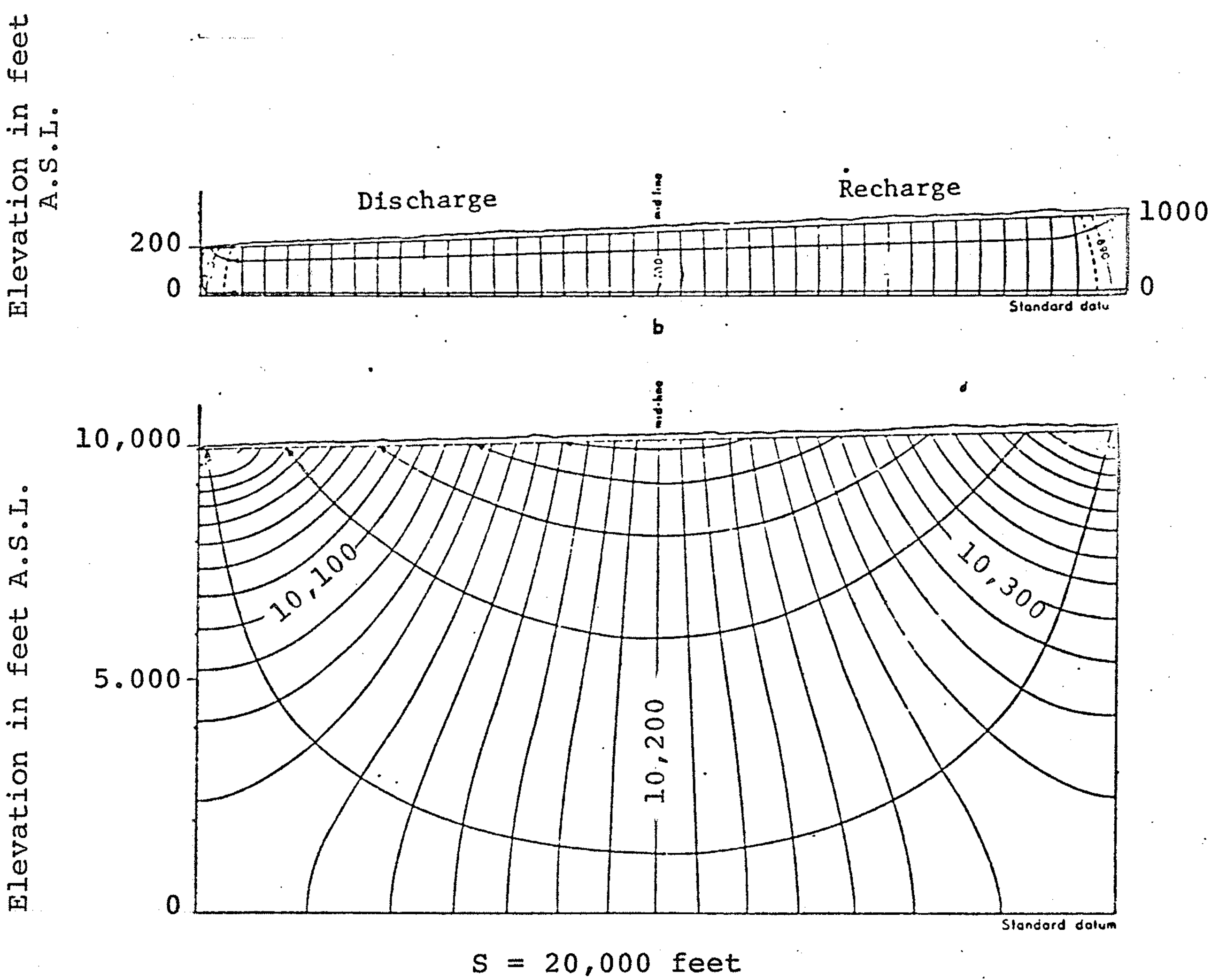

Fig. 11 Two-dimensional theoretical potential distributions and flow patterns for two different depths to the horizontal impermeable boundary. (After Toth, 1962).

lands are major regional discharge areas.

Groundwater flow systems are affected by the geology of the region through which the flow takes place. According to David et. al. (1967), pore space and grain size play a significant role in determining the characteristics of groundwater flow systems. Size of the pores and the size of grain, sedimentation and orientation of the rock structures; size and shape of the drainage basin are three aspects of geology which are important in determining the volume, rate and direction of groundwater flow.

Coarse texture geologic material, which have less micropores compared to fine textured material, but with relatively more macropores have higher saturated hydraulic conductivities than fine textured material which have a greater proportion of micropores and smaller proportion of macropores. Fine textured material like clay, although having a high porosity; has low saturated hydraulic conductivity while coarse sand with low porosity but with higher percentage of macropores than clay has high hydraulic conductivity. Baver (1963) showed that under saturated conditions, the flow of water in soils is in the order of sand - fine sandy loam - light clay - clay. Freeze and Wintherspoon (1967) have shown that lenses on contrasting permeability within homogeneous deposits alter the direction of normal groundwater flow and result in the occurence of discharge areas in the center of the regional flow systems.

Davis and De Wiest (1967) suggested that size and shape of the hydrologic basin determines the volume of surface and sub-surface water, the direction of water movement and the velocity of groundwater flow within the basin. In addition, the size and shape of the basin will determine the length of time that the water is in contact with the basin and thereby influence the quality of the water.

Davis and De Wiest (1967) pointed out that variations in climate affected the amount and distribution of recharge and discharge, the magnitudes of hydraulic gradients, the continuity of aquifers and the distribution of poor quality water within a given hydrologic environment. Precipitation and temperature which determine the amount of evaporation and evapotranspiration, have significant influence on the water budget of the hydrologic cycle. Climate dictates the type and quality of vegetation which may develop in a uniformly sloping land (Fig. 12). The type of vegetation growing on the land surface can promote or inhibit infiltration, evaporation and evapotranspiration; in this way, vegetation influences the processes of rechange and discharge. Rose (1969) pointed out that as soil temperature decreases, the groundwater viscosity increases.

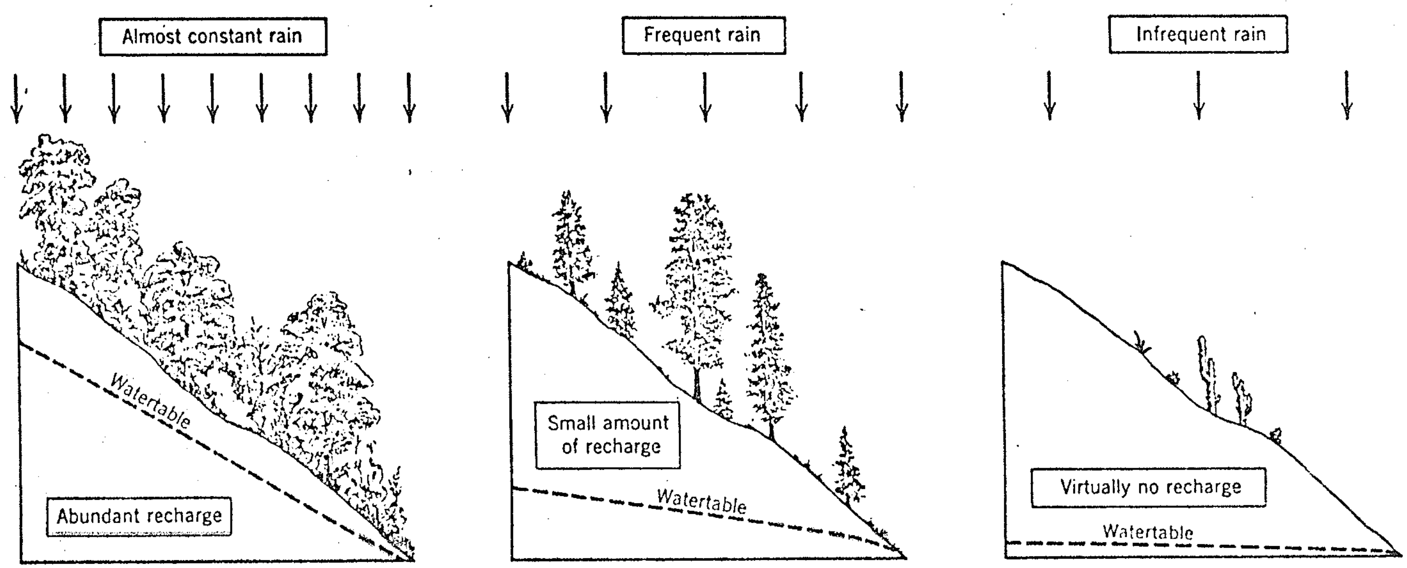

Fig. 12 The effect of varying amounts of recharge on the position of the watertable on vegetation growth. Permeability of the rocks in the three diagrams are identical. (After Davies de Wiest, 1969).

For the same hydraulic heads and the same area of flow, fluids with a lower viscosity will have a higher rate of flow than fluids with higher viscosity. Thus, it is evident that soil temperature fluctuations affect the rate of discharge in groundwater flow systems. Lissey (1968) pointed out that in temperate regions where snowmelt accumulates on the land surface during the winter, in the spring almost all the available water for recharge is derived from snowmelt. Freeze et. al. (1967) showed that except for very intense storms, summer rainfall does not contribute to recharge beneath local topographic highs. This is because any rain water that does not runoff tends to be concentrated in lowlands; and is used primarily to make up the soil moisture deficit in the upland topographical features. Meyboom (1966) carried out an investigation of the groundwater flow systems of sloughs in Saskatchewan, Canada. He showed that during the summer period surface water accumulating on upland depressions infiltrates through the ground beneath it as it had thawed. As a result the shape of the groundwater table beneath the depressions becomes convex (Fig. 13).

G. GROUNDWATER CHEMISTRY

Davis and De Wiest (1967) reported that "total dissolved solids in a water sample include all solid mater-

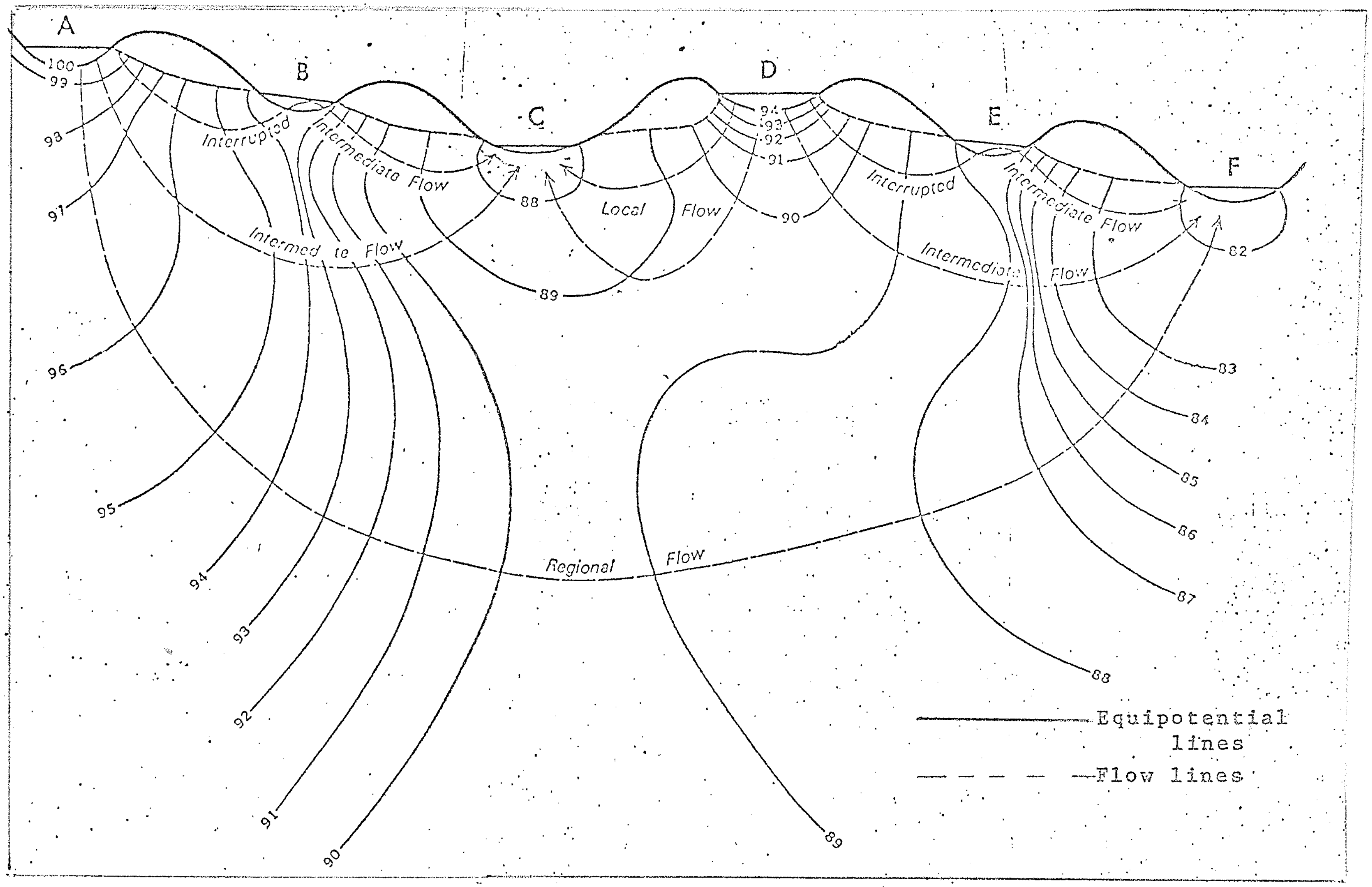

Fig. 13 Groundwater flow in depressions. (After Meyboom, 1966)

ial in solution, whether ionized or not. They do not include suspended sediment colloids or dissolved gases." They also reported that the chemistry of groundwater is basically determined by the composition of the geologic materials through which it flows. For instance, groundwater flowing through limestone and dolomite rocks will contain relatively large quantities of Ca^{++}, Mg^{++} and HCO_3 ions while groundwater flowing through coral shells will normally be dominated by Na^+ and Cl ions. Groundwater flowing through till deposits is generally dominated by Ca^{++}, Mg^{++}, Na^+, $SO_4^=$ and HCO_3^- ions (Rozkowski, 1967).

Studies made on drinking water showed that such undergroundwater contained large quantities of dissolved salts. Bradford (1963), Brown (1958), George et. al. (1951), Lohr et. al. (1954), Lohr et. al. (1954-b), Skougstad et. al. (1963), Taylor (1963) and White et. al. (1963) carried out investigations on the salt content of portable water from different states of the U.S.A. findings generally show that the salt concentration of undergroundwater used for domestic purposes is usually from 10.00 ppm to 100 ppm (Fig. 14). They also showed that natural waters range from less than 10 ppm of dissolved solids for rain and snow to more than 300,000 ppm for sea waters.

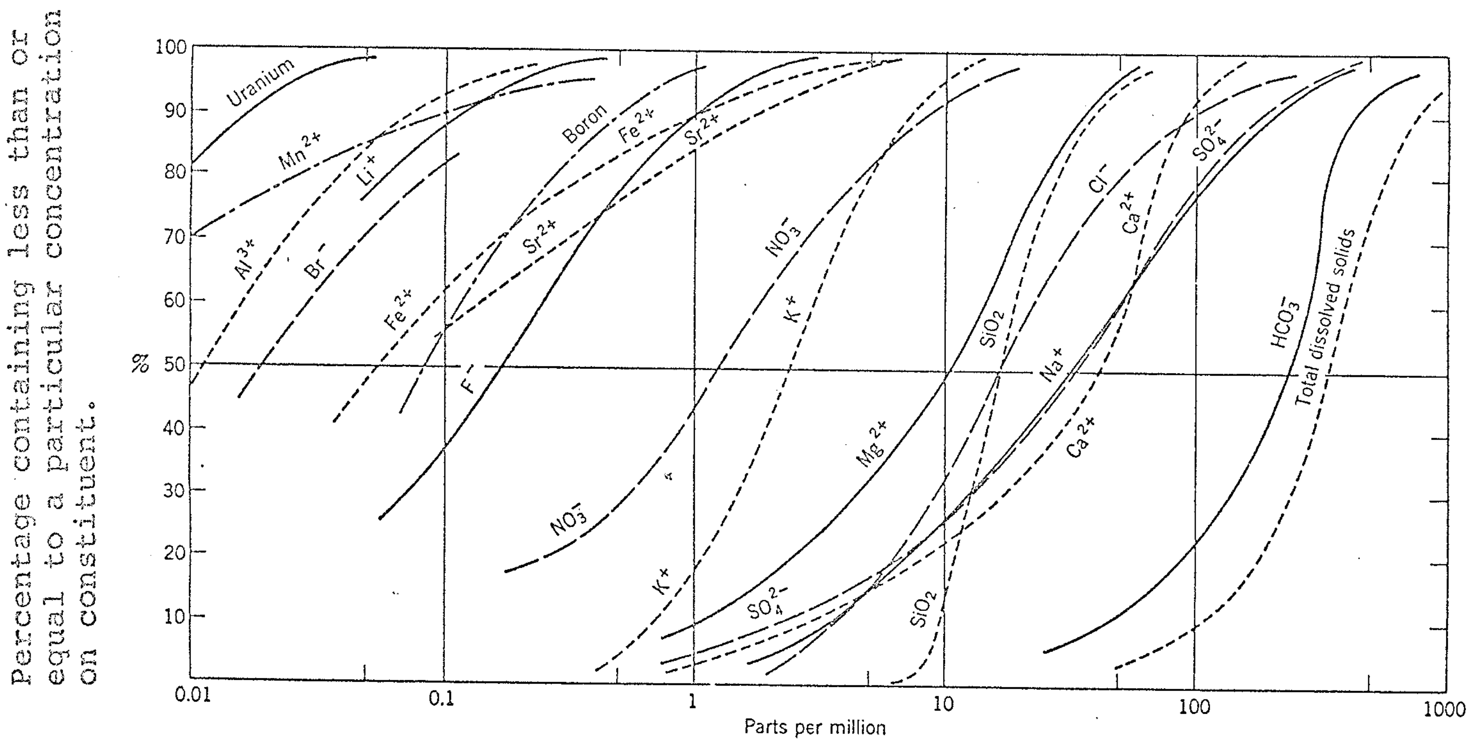

Fig. 14 Cumulative curves showing the frequency distribution of various constituents in potable water. Data are mostly from the United States from various sources (After Bradford (1963), Brown (1958), George et. al. (1951), Lohr et. al. (1954-6), Skougstad et. al. (1963), Taylor (1963) and White et. al. (1963).

H. GROUNDWATER MINERALIZATION

Discharge waters are generally more mineralized than recharge waters. This phenomena is explained by the fact that the mineralization of groundwater is dependent upon the rate of weathering of the rocks through which the groundwater flows. The rate of rock weathering is dependent upon among other things, temperature and pressure. The removal of salts from the weathering rocks and the addition of the removed salts to the underground flowing water, is dependent upon the interface between minerals and the ground flowing water, volume and time of water contact.

Obrejanu et. al. (1966) studied factors that affect the mineralization of groundwater. They studied the groundwater of the Danube Flood Plain. The study was carried out during the autumn season when the groundwater mineralization was not subject to the effects of floods or atmospheric precipitation, as their studies revealed.

The degree of mineralization decreases as the level of the groundwater table drops; at the same time there is a reduction in the content of chloride and sodium ions while calcium and sulphate is unchanged. This conclusion is very important for land reclamation (of saline soils) as it also indicates that groundwater has the most unfavorable effect on the soil when the water table is high. As the water level of the groundwater table drops, the effect on the groundwater on the soil profile is reduced.

Lebeduv (1963) and Kats (1963) as cited by Obrejanu (1967) have shown that the degree of mineralization of groundwater depends directly on the content of salts in the water bearing layer and indirectly on the subsurface flow. As the texture of the water bearing layer becomes finer there is an enrichment in chlorides, sulphates and sodium. However, the bicarbonate and calcium ion contents are reduced.

Obrejanu *et. al*. (1967) also reported that within the same hydrological sectors the groundwaters of diked areas were more strongly mineralized than in non-diked areas. As regards the salt composition there was an accumulation of chlorides and sodium ions in diked areas than in non-diked areas.

I. RECLAMATION OF SALT AFFECTED LANDS

Tile Drainage

Discharge from tile drains is one of the principal parameters for determining the distance between drains and the diameter of the drain pipes. Soovik (1967) reported that in designing drainage tiles one must make correct estimation of the hydrological characteristics of each drainage area. The hydrological characteristics of the soil, of course are determined by several climatic, biological and geological factors. The laws governing the effect of these factors on the hydrological characteristics of the soil are very complex and according to Soovik (1967) they have not been adequately studied yet. For this reason, existing methods of determining the design values of drainage discharge since they are based chiefly on factors governing the hydrological characteristics of the soil, do not always give satisfactory results.

In excessively wet soils, the water balance equation according to Soovik (1967) is:

$$DD = P - Tr - E - SR \pm GF \pm \Delta W \quad \ldots\ldots(1)$$

where

DD = Drainage discharge

P = Precipitation

Tr = Transpiration

E = Evaporation

SR = Surface runoff

GF = Groundwater flow (in layers located below the active zone)

ΔW = Decrease or increase in water storage within the active zone

All the terms in the equation express the volume q in litres for an area F in km^2 for a period of t seconds.

The rate of water discharged can be represented by the following equation:

$$q = \frac{DD}{F \times t} \text{ litres/sec}^{-1}\text{km}^{-2} \quad \ldots\ldots\ldots\ldots (2)$$

For soils having a shallow water table at one time of the year and a deep water table at another time of the year resulting in the formation of mottles, the rate of drainage discharge for such soil can be represented by:

$$q_{dr}^{-t} = F \; (g_i P_{dr\,ho}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where

q_{dr}^{-t} = Rate of drainage discharge for the period t

g = The numerical index of the degree of soil gleying

P_{drho} = Mean drainage discharge with water table "t" a depth "h_o" cm. below the surface in the middle of the zone between drains

Factors That Affect Flow of Water into Drainage Pipes

Luthin and Haig (1971) studied some factors that affect the flow of water into drainage pipes.

Their studies were carried out in the laboratory and then applied in the field. They reported that the groundwater discharge from the drainage pipes was related to the diameter of the pipes. Drainage pipes with larger diameters discharged more groundwater than those with smaller diameters.

Kirkham (1950) in his study of the factors that affect the flow of water into pipes found out by using theoretical analysis that encasing 1 foot pipe segments in gravel increased flow 180 percent. Luthin and Haig (1971) showed that decreasing the pipe segment length from 3 feet to 1 foot increased rate of flow into the pipe more than 2½ times. They also showed that drainage tiles are most efficient when they are completely open (Fig. 15).

If drainage tiles with holes are used, Luthin and Haig (1971) observed that maximum amount of discharge is obtained when the holes of the drainage tiles are at the bottom. The increase is due to the increased head drop between the water table level and the entry points in the pipe. In addition, locating the holes at the bottom of the pipe has the advantage of draining the soil to a greater depth.

Rogowski et. al. (1966) studied the effect of tile spacing on Webster till soils of Iowa State in lowering the groundwater table. Tiles were installed at 1.2 meters depth below the soil surface and they were spaced at 30 meters and 60 meters intervals. Groundwater table was monitored after a heavy storm which raised it to the

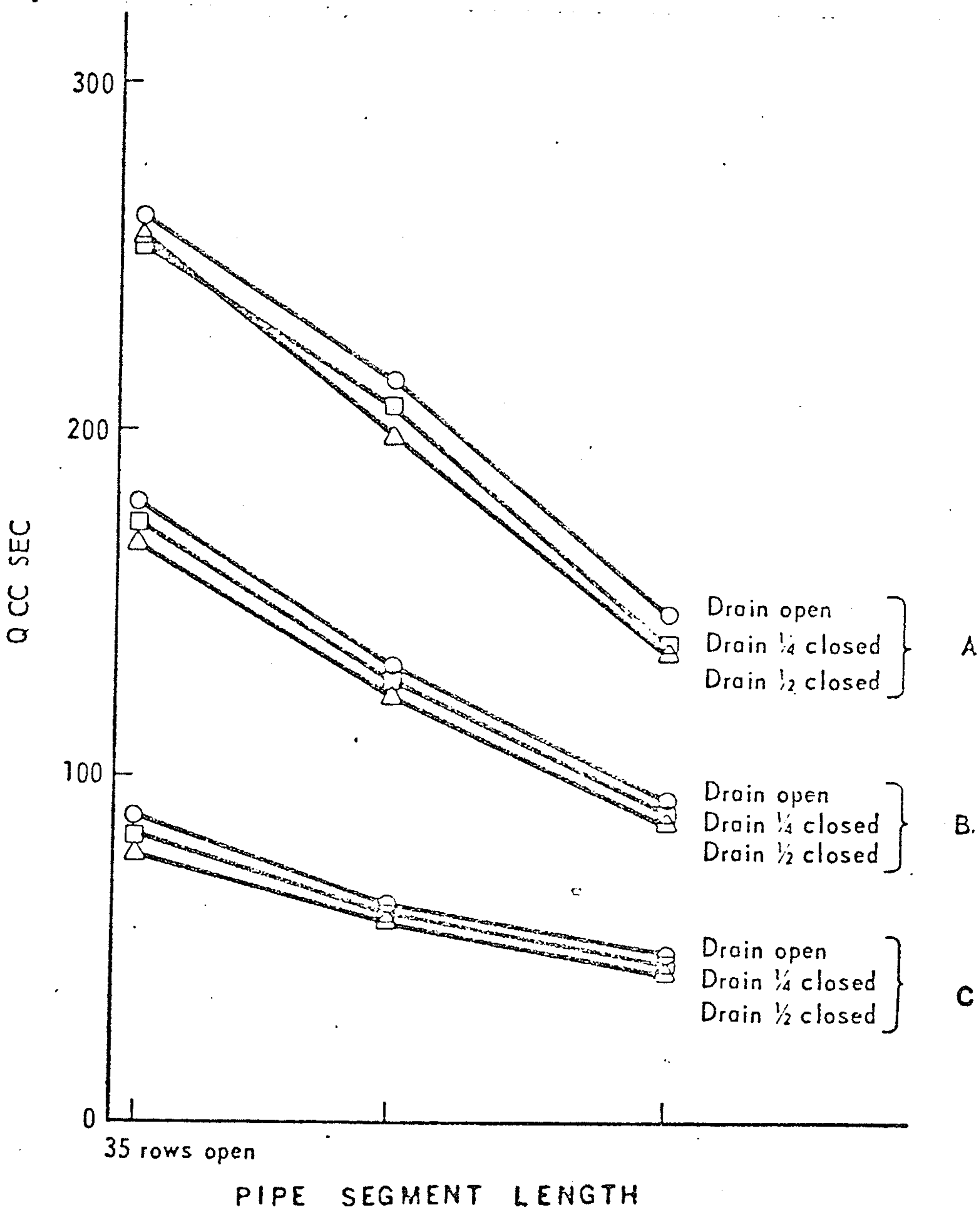

Fig. 15 Effect of pipe segment length on flow into drain. The "35 rows open" is a completely permeable drain perforated with 35 rows of holes. All drains were wrapped with glass fibers. The "drain open" is an empty drainpipe. One fourth and one half closed have weits to maintain the water level at one fourth and one half of drain diameter. A, B, and C = height of water in reservoirs. (after Luthin and Haig, 1972).

soil surface, They reported that after the initial 8 hours of draw down, the average fall of the water table on the 30 meters tile drainage spacing was twice the average fall on the 60 meter tile drainage spacing (39.2 cm. as compared with 19.6 cm.). They also reported that 32 hours after the groundwater table was at the soil surface, there was essentially no difference between the heights of the water table on either spacing. About 44.1 cm. of the water table was not appreciably affected by distance from the tile lines on either the 30 meter or 60 meter spacings. They suggested that this was due to deep seepage in the soils investigated which controlled the water table level.

Tile Drainage Discharge as Affected by Planted Crops

When Rogowski *et. al.* (1966) compared the amount of discharge groundwater in either of the two tile drainage spacings after the lands were planted with either corn or alfalfa, they found out that neither corn nor alfalfa affected the rate of flow of the groundwater into the tile tile drainage pipes. The draw down reported by Rogowski *et. al.* (1966) on the Clarion - Webster Experimental Farm, appears to be the result of deep seepage (translocation of water below the tile lines) and the translocation of water laterally through the surface layer on the soil under land by till (or sand deposits).

<u>Desalinazation of Soils with Tile Drainage System by Diking and Ponding</u>

Talsma (1966) reported that permanent reclamation of saline soils under condition of high water table is really not successful unless some form of drainage such as tile drainage is provided. He studied the desalinazation of tile drained soils under the condition of surface ponding and falling water table. His results indicated that during the ponding stage desalinazation proceeds more rapidly near the drainage tile lines than midway between, while during the falling water table stage desalinazation is more even over the whole area. Luthin (1950) from his studies of leaching tile drained land in the Imperial Valley, California, U.S.A., reported that in order to reclaim the saline soils of the valley, it is necessary that the valley be diked and then ponded alternately in order to enable the salts in the soils to be completely washed out and carried into the tile drainage system. He further pointed out that most of the flow of water through the soil to the tile line occurs in the soil above this line; it has been found that the soil above the tile line is leached free of salts where as the soil midway between the tile lines remains unaffected by the leaching procedure which would be by applying irrigation water, during a heavy storm or in the temperate countries during the spring when snow melts (Fig. 16). Luthin reported that in a ponded soil that is underlain by a tile drainage system, 50% of the total flow takes place within 3.3 meters of the tile line; 75% of the total flow takes place within 8.4 meters; 99% of the total flow takes place within 12 meters leaving only 1% of the total flow in the central 18 meters of the 60 meter tile drainage spacing (Fig. 16). Luthin's findings were also reported by Isherwood et. al. (1958) when they studied the effectiveness of tile drainage in soils with shallow groundwater table. When studying the effect of flood diking in leaching out soluble salts in the soil of the Imperial Valley, Luthin (1950) reported that the method is most effective when the diked areas lying midway between the tile lines are flooded first and then proceed towards the tile lines (Fig. 17).

Minashinn (1970) made an extensive study on the reclamation of the soils of Cotton Production Zone in the Soviet Union. He reported that when solving reclamation problems of soils having an excess of soluble salts, much attention has been paid to the study of groundwater by soil scientists working as early as 1910. Investigations in the Golodnaya Steppe in the Soviet Union showed that soil salinity depended on the shallow groundwater table. To reclaim such soils, tile drainage was introduced.

Bushuyev (1914)introduced the concept of "Critical

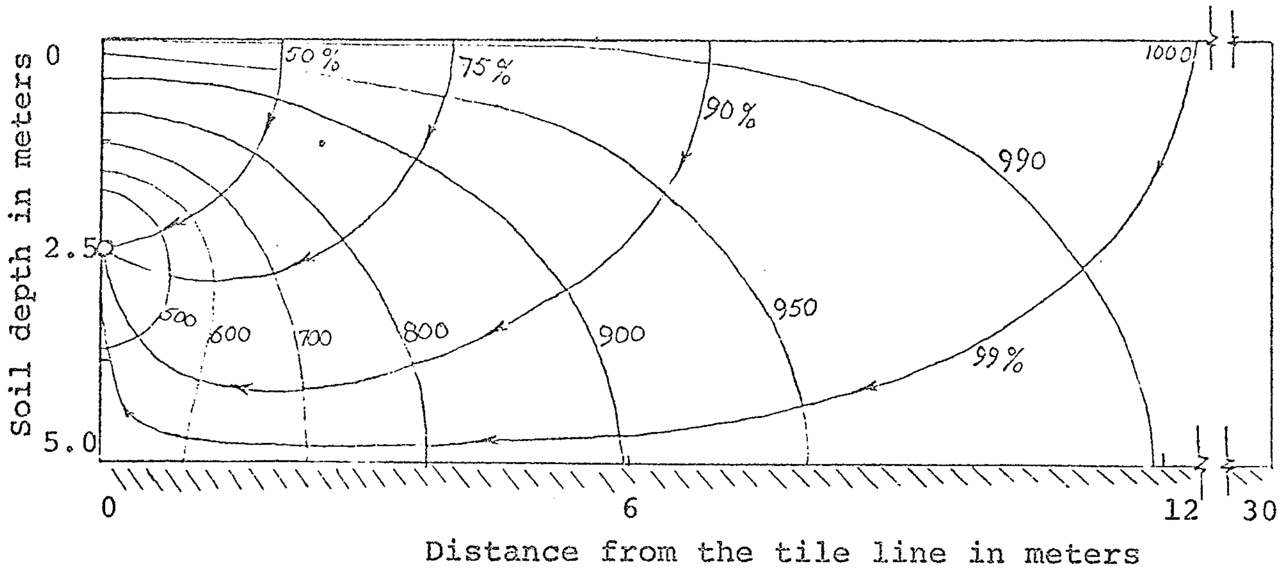

Fig. 16 Plot of hydraulic head for continious bonded case (After Luthin, 1950).

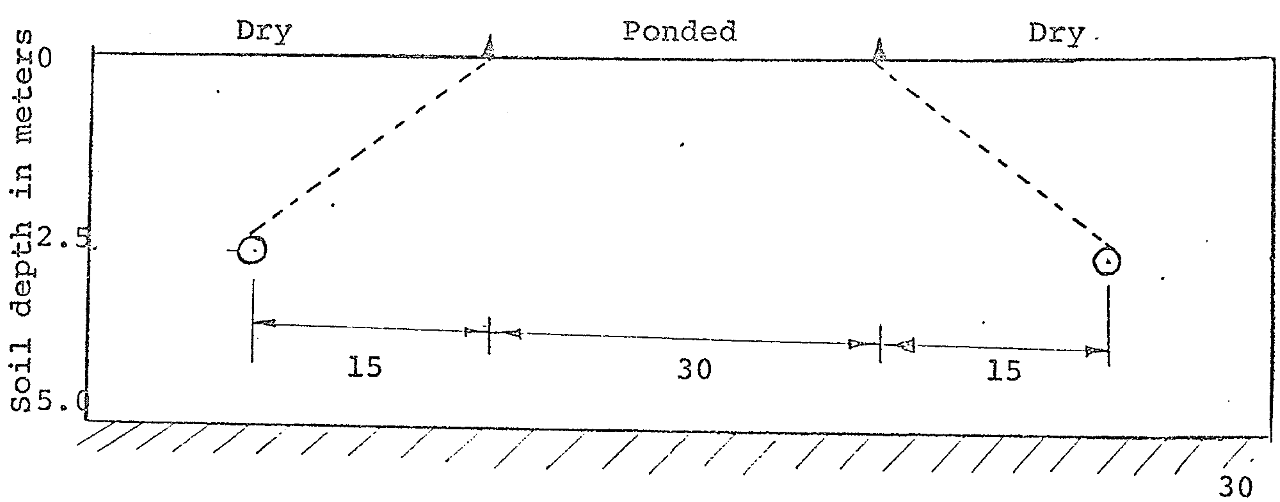

Fig. 17 Reclamation of saline soils by leaching (diking) and tile drainage. (After Luthin, 1950).

Groundwater Depth"; which is defined as that depth expressed in meters or centimeters above which saline capillarity solutions that rise from the groundwater table reach the soil surface (plow layer), produce accumulation in the soil, and stunt and kill plants. Gradbovskaya (cited by Minashina 1970) from his studies on the reclamation of saline soils introduced the concepts of "Critical Groundwater Mineralization", which is defined as the limiting mineralization value at which capillary water rising from the groundwater table salines the upper soil horizons and kills normal plants during hydromorphic soil formation.

During evaporation (spring and summer) salts are brought to the surface by capillarity to the plow layer. The salt balance equation according to Grabovskaya (1954) cited by Minashina (1970) for a critical "Groundwater Mineralization" can be written as:

$$V \ (C - C_i) = G X + N S \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where

V = The soil moisture content at a minimum moisture capacity level, minus the insoluble volume (hygroscopic water)

C = The concentration of soil solution at the end of growing season in the layer for which the computations are made

C_i = same concentration of soil solution at the beginning of the growing season

G = The amount of water evaporated during the growing season

X = The groundwater mineralization in (g/litre)

N = The amount of irrigation water for a non-leaching regime in (mm/hacter)

S = Mineralization of irrigation water (grams/litre)

Hence, it is possible to determine the "critical groundwater mineralization" for a possible increment of salt solution concentration for any depth of the root zone.

$$X = \frac{V(C - C_i) - NS}{G} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Equation (5) clearly indicates that the "critical groundwater mineralization" is determined by the salt increment in the spring and summer when the rate of evaporation of groundwater and irrigation water is highest. The critical groundwater mineralization is highest when the mineralization of the irrigation water is lower and also when the evaporation of groundwater is lower which in turn depends on groundwater depth, soil properties and aridity of the climate.

Graboskaya (1954) as cited by Minashina (1970) reported that the critical drainage at critical groundwater mineralization for removal of the salt increment during the growing season can be determined from the formula:

$$D_i = \frac{(C - C_i)\ V}{X} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The miminum amount of leaching water can be equated to the amount of critical drainage. The amount of salts supplied by the leaching water is $D_i.S$ and this requires additional drainage of

$$\Delta D = \frac{D_i.S}{X} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Substituting D_i we obtain

$$\Delta D = \frac{(C - C_i)\ V\ S}{X^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Thus the total annual critical drainage is obtained by the formula

$$D = D_i + D = \frac{(C - C_i)\ V}{X} + \frac{(C - C_i)\ V\ S}{X^2}$$

$$= \frac{(C - C_i)\ V}{X} \cdot \left(1 + \frac{S}{X}\right) \qquad \ldots\ldots (9)$$

It is evident therefore that the total annual amount of drainage, D, is higher when mineralization of irrigation water is higher.

The Effect of Tile Drainage System in Desalinization of Salt Affected Soils

Kinderis (1970) studied the amount of removed soluble salts in saline land of Lithuania in the Soviet Union. The land was reclaimed by installing drainage tiles at a depth of 1.0 to 1.1 meters below the soil surface. The recalimed soils had a loam subsurface texture. His study included groundwater discharge, chemical analysis and observation of the fluctuating groundwater table. Kinderis found that a higher average concentration of bi-carbonates in the drainage water was observed in the spring when the drainage discharge was high (14 65.4 - 1754.9 m^3/ha), the removal of bicarbonates reached 9.8 - 616.0 kg/ha. During the dry months when the groundwater discharge was low, the quantity of removed bicarbonates was also low (10.9k g/ha).

Considerable quantities of sulphates enter the soil with atmospheric precipitation. Kinderis (1970) reported that atmospheric precipitation brings 63.8 Kg of sulphates per hectare into the soil annually on experimental plots. He also reported that the content of sulphate and chloride in the drainage water depends on their addition to the soil with fertilizers. The concentration of these ions in the drainage water of the tile drained land was 8.2 - 176.3 Mg/litre in the case of sulphate and 2.8 - 112.4 Mg/

litre in the case of chloride. The removal through the tile drains amounted to 9.8 - 160.0 Kg/ha for sulphates and 6.1 - 76.0 Kg/ha for chloride annually.

Kinderis (1970) reports that the content of potassium and sodium in the drainage water was slight, ranging from 0.2 to 14.1 Mg/litre or K^+ ions and from 0.7 to 15.6 Mg/litre of Na^+ ions. On a yearly basis the tiles were able to remove 0.3 to 6.1 Kg/ha of K^+ ions and 1.6 to 22.9 Kg/ha of Na^+ ions. Nitrate ion removal ranged from 1.4 to 11.5 Kg/hactare annually.

Kinderis reported that the largest removal of soluble salts through the drainage pipes took place in the spring and early summer when the water table was highest and the soluble salt removal was lowest during the winter months when discharge was least or non-existent.

Molodtsov et. al. (1970) carried out research on the reclamation of saline soils of State Farm No. 5 in the Golodnaya Steppe of the Soviet Union. In this farm sub-soil drains were installed and reinforced during an irrigation leaching period. Temporary drains were created with a plow every 20 meters. The closed drains were 2.5 to 3.5 meters deep. The shallow drains within the farm were 0.8 to 0.9 meters deep at every 20 meter interval. The project was carried out on a 400 hactare area.

From the data obtained from the project, Molodtsov *et. al.* (1970) reported:

(a) Leaching of medium and strongly saline soils under rice and deep closed horizontal drains spaced 120 to 140 meters apart plus temporary drains extending 500 running m/ha and low water permeability of the soil (about 100 mm/24hrs.) can desalinize the top meter layer in a single season. The deeper horizons can be desalinized by using deep closed drains and growing crops on the land.

(b) Temporary drainage with major leaching of saline soils removes the bulk of the water and salts. Deep drainage plays a secondary role during the period of major leaching. The function of closed drainage is to maintain the groundwater table at the critical level and to remove the drainage water and salts when the leached lands are used to grow crops.

(c) Subsurface drainage is much more efficient than shallow, temporary drainage. In the particular project studied, it required an average of 80 m^3 of water to remove 1 metric ton of toxic salts during the leaching period campared with 300 m^3 water required by shallow drainage.

(d) Mineralization of the water in temporary drains is a reliable criterion of the salinity of the soil leached and it can serve as an indicator of when to stop the leaching. The topsoil (1 meter) does not have an excess of soluble salts when the mineralization of the drainage water is 4 to 5 grams/litre.

Averyanov (cited by Soovik, (1967)) reported that shallow open drainage does not produce positive results because it does not lower the groundwater table adequately so that the layer of secondary salination persists. Deep closed drainage keeps the groundwater table below the critical depth of salinization, ensures a downward flow that desalinizes the soil profile to a considerable depth, and, as a result, virtually eliminates the hazard of secondary salinization.

Reclamation studies carried out at the Rushets (Rumania) Experimental Station, showed that tile drains installed at a depth of 1.8 meters and spaced at 20 meter intervals desalted the groundwater and hence decreased the concentration of soluble salts below the limit of critical mineralization.

Pastukh and Shavrygin (1966) reported from their studies of salt affected lands of Northern Kuhunda in the Soviet Union that although the soils in this mountaineous region had a water table well below 2.5 meters, salts transferred from the groundwater table to the surface in a matter of hours. The critical groundwater depth for these solonetzic soils was reported to be 170 - 180 cm. in medium columnar solonetzes.

Pastuka and Shavrygin (1966) reported that the groundwater table in the summer of 1965 was much deeper below the soil surface in the ridges (2.62 - 2.95 m), on the slopes (2.95 - 2.24 m) and in the depressions (1.94 - 1.20 m). Their findings indicate that upland areas (recharge areas) have deeper groundwater tables below the soil surface than lowland areas (discharge areas). They also reported that areas with a shallow water table have more accumulated soluble salts than areas with a deeper groundwater table.

In addition to recommending tile drainage as a method to decrease the concentration of soluble salts, Pastukh and Shavrygin (1966) recommended that sweet clover should be sown in the area as it is salt tolerant and drought resistant. They also recommended that the land be plowed without a moldboard to a depth of 28-30 cm. with addition of up to 4-5 metric tons of gypsum/ha. Deep plowing to a depth of 40-45 cm. and layered plowing to a depth of 40-45 cm. were also strongly recommended.

J. PREVIOUS WORK DONE IN THE STUDY AREA

Pedological Investigations

Michalyna *et. al.* (1961) conducted a detailed soil survey of the Morden Experimental Farm to assess the suitability of the soils for irrigation. In conducting the survey, traverses 30 meters apart were made in a North-South direction throughout the section. Observations of the soils were conducted at intervals of 75 meters along each traverse for classification purposes. A topographical survey indicating the relief of the Experimental Farm was also made.

The system of soil classification used by Michalyna et. al. (1961) was that proposed by the National Soil Survey Committee (1965). In the Canadian Taxanomic Classification System soils can be classified into six categories: Order, Great Group, Subgroup, Family, Series and Type. In these groups the differentiating criteria is largely morphological features which reflect the effects of climate, vegetation, local moisture relations and age of the parent material. The basic unit in the field classification is the soil series. A soil series in a group of soils having horizons similar in differentiating characteristics and arrangement within the profile and developed from a particular kind of parent material. The similarity in the profiles reflects similar soil forming factors. Soils having similar features of significant agronomic importance are classified as phases. Examples of phases used are: saline phase, eroded phase and stony phase. When non-conforming substrate occurred within 120 cm.

of soil depth, the soil was identified with the series name and nature of the substrate phase, for example, Eigenhof-sand substrate phase, Plum Coulee-sand substrate phase.

The soils of the study area according to Michalyna et. al. (1961) can be grouped as moderately well and imperfectly drained. The impertectly drained soils of the study area have been developed from fine textured alluvial and lacustrine deposits (SiC, SC, C). They include the Winkler Series (Orthic Black (Wa)), Winkler Sandy substrate phase (Wb), Plum Coulee sand substrate phase (Pb). The moderately well drained soils which have been developed on moderately fine alluvial and lacustrine deposits (Cl, SiCL, SCL) occur to the North of the study area. They have been classified as the Eigenhof Sandy Substrate phase (Ed) (Fig. 18).

Imperfectly drained soils. The Winkler Series (Wa) is an Orthic Black soil developed on calcareous fine textured alluvial and lacustrine deposits. The drainage pattern of these soils varies from imperfectly to moderately well drained. The soil profile consists of 16 to 32 cm. of very dark grey Ah horizon and a well structured dark greyish brown Bm horizon. The lower portion of the Bm and the C horizons may be weakly developed with iron stains. There may also be an accumulation of gypsum in

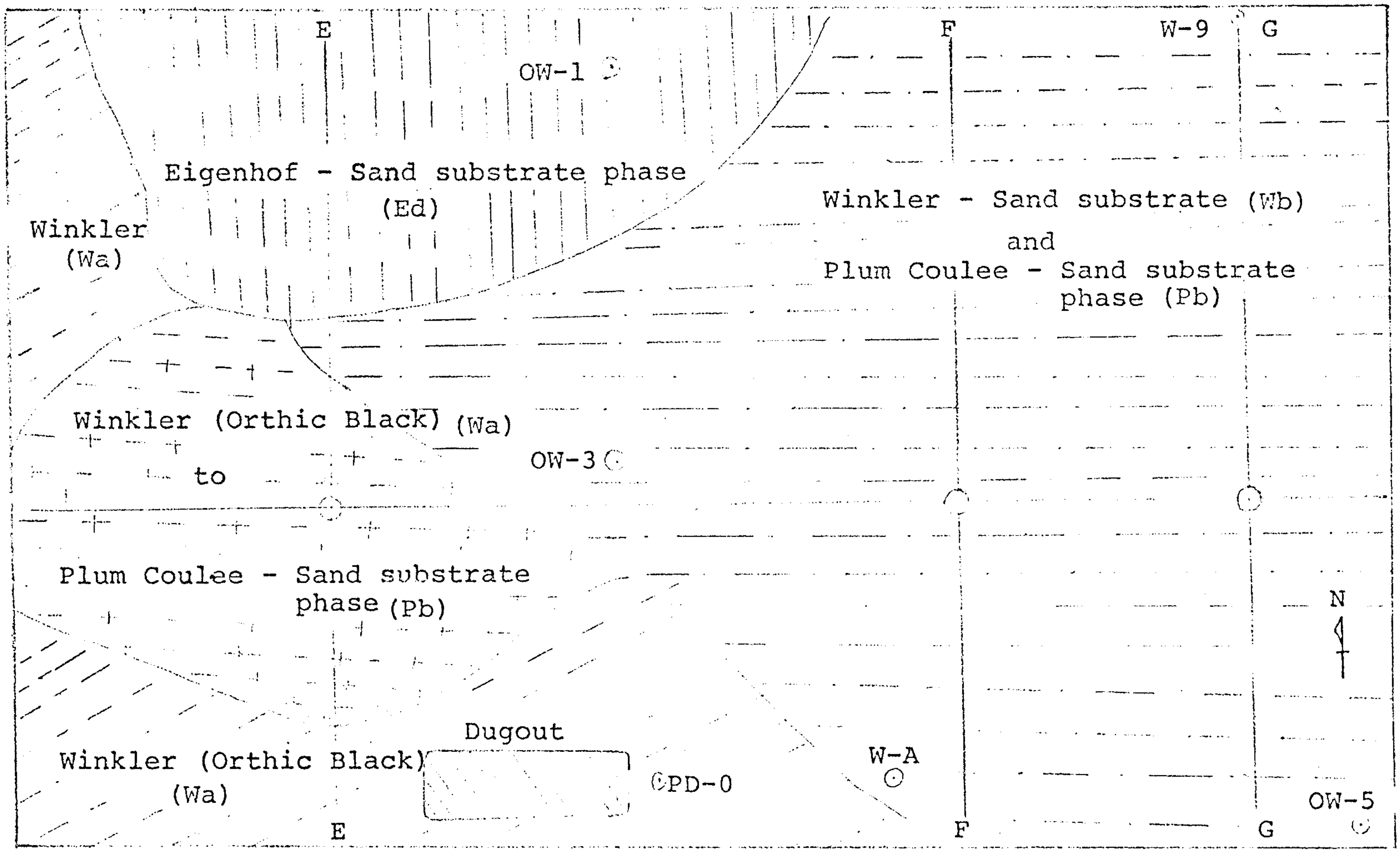

Fig. 18 Soil map of the study area. [After Michalyna et. al. (1961)]
Scale: 1 cm. = 32 meters.

the C horizon. A Winkler sand substrate phase (Wb) has also been mapped and included in the group of imperfectly drained soils. Like the Winkler series, they have slow permeability and a high moisture retention.

The Plum Coulee Series consists of imperfectly drained gleyed black soils developed on moderately calcareous, fine textured alluvial and lacustrine deposits. Michalyna *et*. *al*. (1961) reported that the profile of these soils has a moderately thick, very dark grey Ah horizon and a very dark greyish brown horizon with weak mottling. The deltaic sandy sediments which are found below the alluvial deposits are within 15.2 to 25.4 cm. below the soil surface of the soil profile. The Bmg horizon may be slightly solonetzic. The C horizon is characterized by mottles and may contain gypsum. These soils were mapped as Plum Coulee-sandy substrate phase (Pb).

Moderately well drained soils. Michalyna *et*. *al*. (1961) reported that the soils to the North of the study area have been developed on moderately calcareous, moderately fine textured alluvial and lacustrine. These deposits are stratified and may be underlain by sandy sediments within 91.4 to 152.4 cm. of the surface. The soil profile consists of a very dark grey Ah horizon 20 to 30 cm. thick, a dark greyish brown Bm horizon 20 to 34 cm. thick and light brownish grey C horizon. An accumulation of carbonates may be present in the upper C horizon. The C horizon is generally iron stained and gypsiferous. These soils have been classified as Eigenhof-sand substrate phase (Ed).

The surface texture in the areas mapped as Eigenhof clay loam range from a heavy loam to a light clay. The Eigenhof sand substrate phase (Ed) has sandy sediments within 91.4 to 152 cm. of the surface. The Eigenhof till substrate phase has till within 91.4 to 152.4 cm. of the surface. The soil has moderately slow permeability and a high moisture retention capacity.

Groundwater Flow

Sibul (1967) investigated the pattern of groundwater flow in the Morden area. His studied area also included the C.D.A. Experimental Farm. In studying the pattern of groundwater flow, he installed a number of nests of piezometers. He set up nests of piezometers at the top of the Manitoba Escarpment and he also set up piezometer nests along the plain from the escarpment. One of his nest of piezometers, was installed at the investigated area near lateral drainage tile line G-G (Fig. 2).

The collected hydraulic head data of Sibuls (1967) piezometers, showed that in general the top of the Manitoba escarpment is a groundwater recharge area. The plain below the Manitoba escarpment including the study area is a discharge area. The hydraulic head data of his deep piezometers, revealed that on the plain to the East of the escarpment, the groundwater discharge occurs only in the overburden; the bedrock displays recharge characteristics. He further reported that groundwater flow below and in the bedrock is downwards. This means that the area under the bedrock and in the bedrock is a recharge area. The general groundwater flow is from the West (Manitoba Escarpment) to the North-east including the study area. Although Sibul's study did not indicate that Lake Minnewasta is the major source of the discharge water on the plain of the escarpment, he concluded that it is possible that the Lake plays a significant role in providing groundwater for direct discharge in the vicinity of Morden, including the Experimental Farm (Table 2).

Groundwater Salinity

The groundwater table on the Morden Experimental Farm was reported by Michalyna (1965) to be the highest in the spring and early summer, and lowest during the winter months. He reported that by monitoring the water

TABLE 2

HYDRAULIC HEAD DATA
FROM THE NEST OF PIEZOMETERS
AT SITE G-G
DURING THE SPRING AND EARLY SUMMER, 1974

NO. OF PIEZOMETER	DEPTH OF PIEZOMETER IN CM.	WATER TABLE DEPTH IN CM. BELOW SOIL SURFACE			PIEZOMETRIC HYDRAULIC HEAD INTERPRETATION
		17.05.74	24.05.74	3.06.74	
P-1-122	122	109.0	88.9	94.0	Discharge
P-1-183	183	106.0	73.7	91.4	Discharge
P-1-244	244	101.6	62.2	85.1	Discharge

table of 13 wells drilled to a depth of 3 meters (using a Giddings drill) at various locations on the Experimental Farm, melting snow or heavy storms raised the water table considerably. The rise in groundwater table was attributed to infiltrating snowmelt or percolating rainfall water. During the winter months, the water table in the observed wells remained constant.

Michalyna (1968) in his study of the pattern of groundwater flow reported that although the land slopes eastwards with a gradient of 0.3 percent, the water table in the spring occurred at a greater depth at the western side of the farm and occurred at 0.3 meters below the soil surface in the eastern part of the farm (the study area). The level of soil salinity in the North-eastern side was highest at 11.0 mmhos./cm.

CHAPTER III

MATERIALS AND METHODS

The materials and methods used in this investigation can best be described in terms of three categories: hydrological, pedological and analytical.

A. TILE DRAINAGE NETWORK INSTALLATION AT MORDEN EXPERIMENTAL FARM

The tile drainage network (Fig. 1) was designed and installed in 1967. During the installation program, trenches were dug to an average soil depth of 1.5 meters. Segments of the lateral and drainage tile lines with 15.2 cm diameter were laid down the trenches. The lateral and main drainage tile lines were laid down in such a way that a 0.001 gradient was maintained so that the water flowing in them could empty at the manholes and at the sumps.[1] Having laid the tiles, the trenches were then back filled with soil.

B. SOIL PROFILE LOCATION, SOIL SAMPLING AND WELL SETTING ACROSS LATERAL DRAINAGE TILES G-G, F-F AND D-D

In the fall of 1972, 14 wells were drilled to a

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[1]The gradient and depth of tile lines below soil surface were obtained from Drawing No. 2, File No. 141/362-7/4-69-1. Site Groundwater Drainage System Phase 2. Research Station, Morden, Manitoba.

depth of 0.3 m (using a Giddings Drill) in the North-east corner of the C.D.A. Experimental Farm in Morden, Manitoba (Fig. 2). Eight of the thirteen wells were drilled across lateral tile drainage line G-G with 4 wells on either side of it. The well spacings are shown in Fig. 2.

Well W-9 was drilled to the extreme North of lateral drainage tile line G-G. OW-1 and OW-3 were drilled to the Western side of tile line F-F. Wells PD-0, OW-A and OW-5 were drilled to the Southern part of the main drainage tile line.

In the fall of 1973, using the same method and equipment, 16 wells were drilled across drainage tile line F-F and E-E (Fig. 2). At the time of drilling the wells, soil samples were collected at 30 cm. intervals to a depth of 3 meters. For every well pedological description were taken, noting mainly texture, mottling zone and parent material.

Having collected the soil samples 7.62 cm. diameter eave trough pipes were installed in the holes for the purpose of monitoring the groundwater table and measuring the electrical conductivity of the groundwater. The eave trough pipes were closed at the bottom and side slots were cut to allow the groundwater to enter the pipe. The purpose of the slots was to prevent soil aggregates from entering the pipes if larger holes were made (Fig. 19).

C. GENERAL FIELD DESCRIPTION OF SOIL SAMPLES

The textural description of the soils across the lateral drainage tile lines changes from topsoil clay, silt clay and sub-soil fine sand to very fine sand. In general 120 cm. from the soil surface of clay or silt clay. At this depth the soils are brownish black (10 YR 2/2) in colour. Below the clay layer is a thin silt clay layer which is greyish yellow brown (10 YR 4/2) and in some profiles is dominated by white salt crystals (gypsum). Below 150 cm. soil depth, the dominant soil texture is fine sand. Due to the fluctuation of the groundwater table in the summer and in the winter the sub-soil has been subjected to aerobic and anaerobic conditions. The oxidation and reduction processes in the summer and in the winter resulted in the sub-soil being dominated by mottles. The general colour of the fine sand is dull yellowish brownish (10 YR 4/3) when moist (Fig. 20).

The general colour of the mottles is dull yellowish brown (10 YR 5/4). The percentage of mottles changes from 1% at soil depth of 0-30 cm. to about 50% below 250 cm. The percentage of the mottles in general increases with increasing soil depth. Most of the mottles are in the soil saturation zone which is below the elevation of the

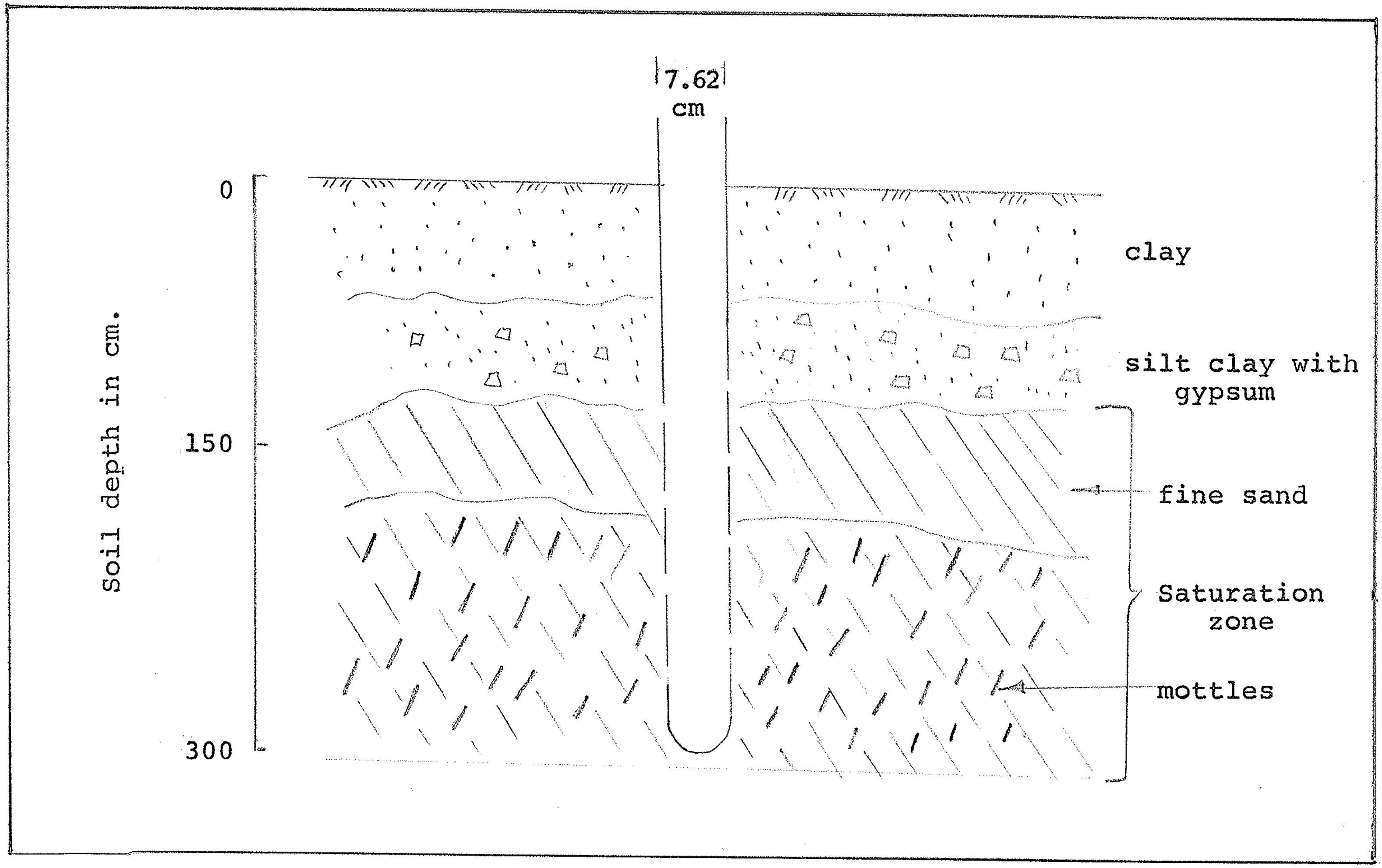

Fig. 19 Typical slotted well casing installed in the study area.

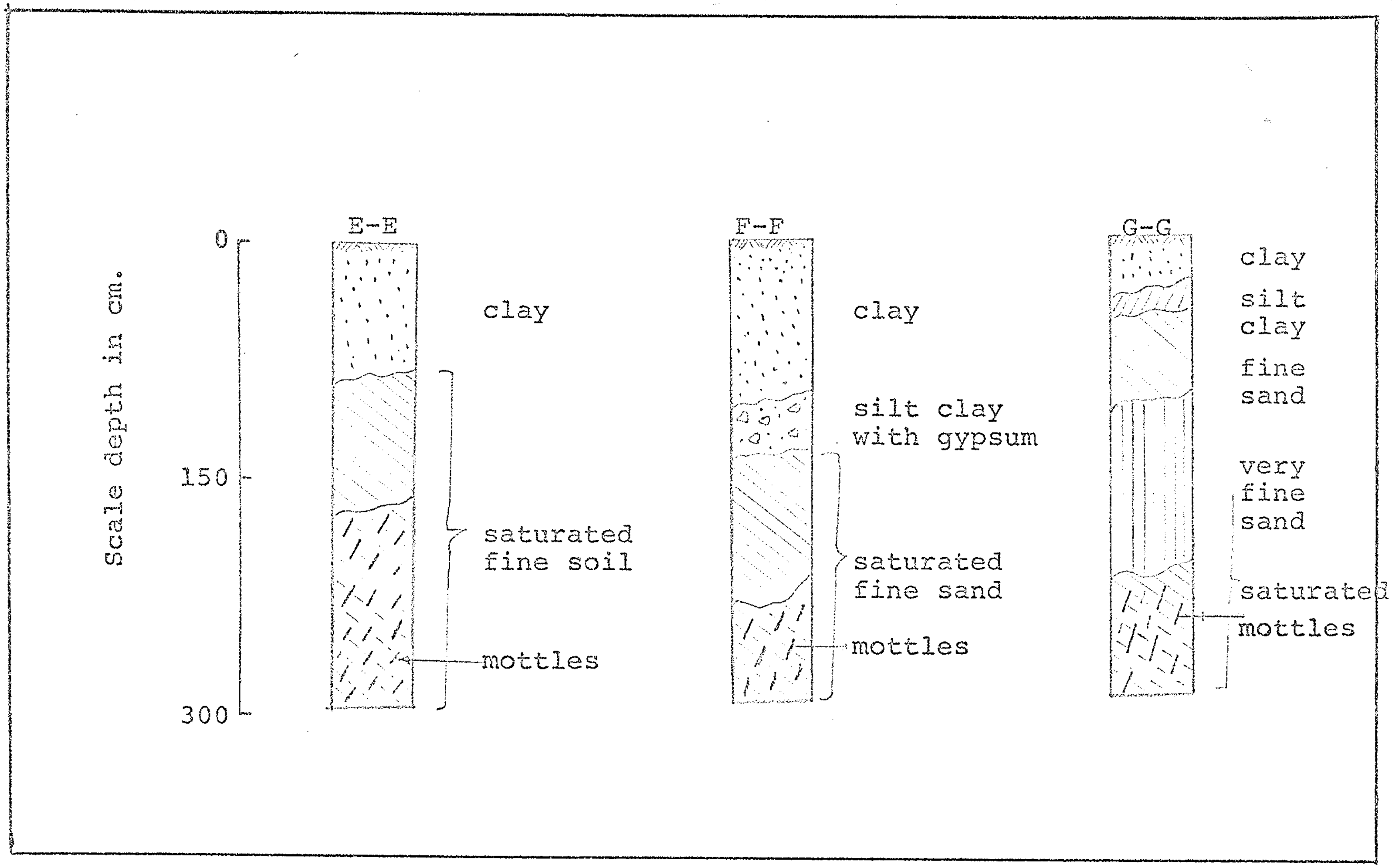

Fig. 20 Representative soil profile discriptions across lateral tile line E-E, F-F and G-G.

lateral drainage tile lines.

D. PIEZOMETER INSTALLATION

A nest of 3 piezometers were installed near well GG-3. They were of 2.0 cm. outside diameter, semi-rigid, polyvinylchloride (P.V.C.) tubing. When they were constructed, a 30.5 cm. section at the bottom of the piezometer was slotted and wrapped with fiber glass. The fiber glass was used to prevent the entry of fine textured soil (silt and clay) at the bottom of the intake zone.

Each piezometer was installed by boring a hole in the ground with a Giddings Drill to the desired depth. When the desired depth was reached, the piezometer was inserted. Coarse silica sand was added to the bottom of the bore hole to a thickness of about 76.2 cm. and 15.2 cm. of fine silica sand was added to the top of the coarse silica sand. The coarse silica sand at the bottom of the piezometer formed a small porous volume around the intake zone. The fine silica sand was added to prevent contamination of the intake zone by the cement grout. A mixture of water and portland cement was added to form a grout plug above the sand. The hole was finally back filled to the surface with the extracted soil.

The group of piezometers varied in depth from 1.20, 1.80 and 2.40 meters below ground level. The piezometers, enabled the study of the movement of water in a vertical direction by monitoring the hydraulic heads at different times of the study period (Fig. 21).

Since in 1972 and 1973 the water table was less than 2.40 cm. below the soil surface, the piezometers were not read during that period; however, in the spring and summer of 1974 the water table was generally higher than 150 cm. below the soil surface. During this period, the hydraulic heads of the piezometers were read once every two weeks.

E. THERMOCOUPLE INSTALLATION

In order to measure soil temperature a set of thermocouples was installed near well GG-3 in the fall of 1972 (Fig. 2). A 150 cm. hole was drilled in the ground with the use of an auger, a thermocouple which had wires fixed at depths of 2.5 cm., 5 cm., 10 cm., 20 cm., 50 cm., 100 cm., and 150 cm. below the soil surface was then inserted into the hole and the hole was then backfilled in order to form a good contact with the soil. Soil temperature measurements were taken at an average of once a month in the fall of 1972 and 1973. In the spring and summer times the soil temperature was measured at an average of once every fortnight.

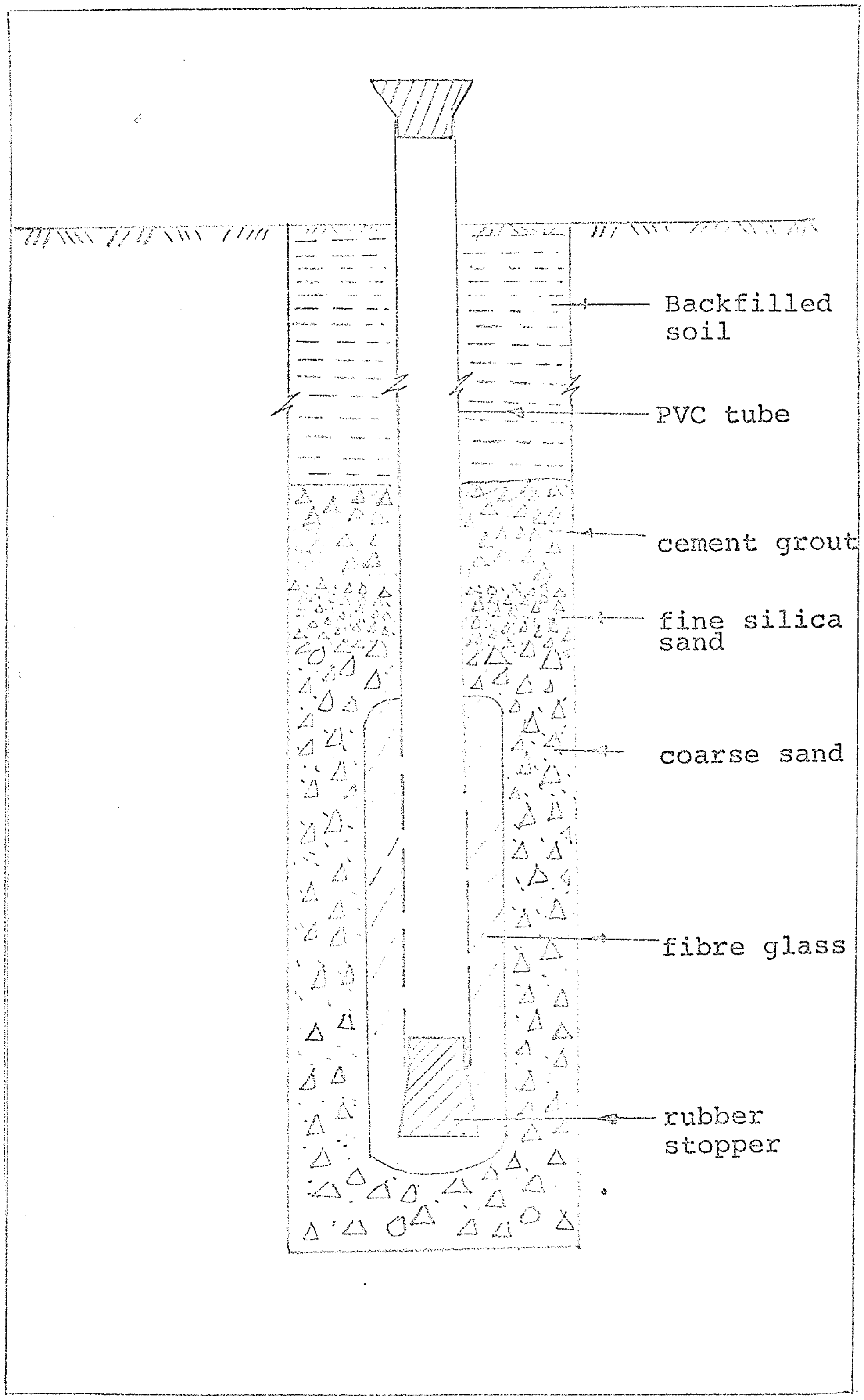

Fig. 21 Design of piezometer used to measure ground water hydraulic head.

F. WATER TABLE MONITORING

Groundwater table monitoring was carried out by inserting a 0.64 cm. diameter plastic tube (a hose) which was several feet long into the wells. By blowing through the hose, one could determine when the tube reached the groundwater table. Thus, it was possible to measure the depth of the water table from the top of the well.

Water table readings were taken between April and October 1973 at an average interval of once every two months. No readings were taken during the winter months as the wells were dry. In the spring of 1974, due to excessively heavy snow melt and heavy rainfall in the spring readings were taken frequently at an average of once every two days.

G. ELECTRICAL CONDUCTIVITY MEASUREMENT

The electrical conductivity of the groundwater table was read in the field by using a method developed by Beckman Company. The method involves the insertion of an electrical conductimeter bridge electrode into the groundwater in the well and reading off the electrical conductivity from the conductimeter bridge.

On the average electrical conductivity readings were taken once a month in the spring and summer of 1973 and 1974 respectively. Readings were not taken during the winter time as the wells were frozen or dry.

H. TOPOGRAPHICAL SURVEYING

An earlier topographical survey of the farm was carried out by the Manitoba soil survey staff in 1966. Due to the nature of the project, it was necessary to carry out a topographical survey of the study area in detail. With the use of an Abney Level, a staff and a known bench mark (elevation in meters A.S.L.), it was possible to survey the wells, manholes and the depth of the drainage tile lines below the soil surface. It was necessary to know the elevation of the pipes (of the wells) above sea level so that the measurements of the fluctuating groundwater table could be expressed as actual height above sea level.

I. LABORATORY ANALYTICAL METHODS

The analytical methods used in the laboratory for the determination of electrical conductivity, cations and anions are all standard procedures.

The soil solutions from which the different determinations were made, were extracted from saturation soil pastes which were prepared according to the method described by the United States Salinity Laboratory Staff

(1954). Electrical conductivity of the saturation soil paste extract was determined by using a pipette type conductivity cell and a conductivity bridge as described by the U.S. Salinity Laboratory Staff (1954). Sodium and magnesium were determined by using the atomic absorption apparatus as described by the Perkin-Elmer Corporation (1973). Calcium was determined by the E.D.T.A. Titration Method of Chang and Bray (1951). Sulphate and chloride were determined by using the centrifuge method. The method involved the mixing of 1 ml $NCaCl_2$ and acetone to 4 mls of soil paste extract in 15 ml centrifuge tubes. The contents were then centrifuged after flocculation had taken place. After decantation of the supernatant liquid the precipitate was dissolved in distilled water and titrated with versene using the method of Chang and Bray (1951) for the determination of calcium and magnesium. Chloride was determined by using a titremeter method. The method involved pipetting 2 ml aliquots of the soil extract in a beaker and diluted to 50 ml with distilled water. The solution was then titrated with standard $AgNO_3$ using an automatic titremeter.[2]

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[2]Sulphate and chloride were determined according to the method outlined by G.J. Beke of Canada Department of Agriculture Research Station, Pedology Unit, Winnipeg, Manitoba.

CHAPTER IV

RESULTS AND DISCUSSION

A. EVALUATION OF SOIL SALINITY

Changes in Electrical Conductivity with time

The tile drainage network was installed in 1967. Electrical conductivity data of the study area[3] before and after tile installation is available from three soil sampling sites: OW-1, OW-3 and OW-5 (Fig. 2). Sites OW-1 and OW-3 were all about 55 meters to the West of lateral drainage tile line F-F. Site OW-5 was about 30 meters to the South-east of lateral drainage tile line G-G. Soil samples were taken to 300 cm. soil depth and sampled at 30 cm. intervals. The samples were analysed for electrical conductivity in 1965 before the tile drainage network was installed. In 1969 and 1971 after the installation of the tile drainage network, soil samples were again taken at the same sites for electrical conductivity analysis. Since soil samples were taken at the same sites for chemical analysis at the start of the present study it is possible to compare the data of the three sites obtained in 1965, 1969, 1971 and 1972.

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[3]Electrical conductivity data of the 3 sites in 1965, 1969 and 1971 were obtained from unpublished data collected by Mr. R. Eilers of the Manitoba Soil Survey, University of Manitoba.

Fig. 22 shows that the electrical conductivity distribution in the soil profile of OW-1 was in general highest in 1965 before the tile drainage network was installed in 1967. The electrical conductivity data in 1969, 1971 and 1972 does not show a consistent decrease with time. It is probable that the tile line had very little influence on site OW-1 in reducing soluble salts. The variation in electrical conductivity in 1969, 1971, and 1972 can probably be attributed to changes in annual precipitation. In OW-3 like OW-1 electrical conductivity data was highest in 1965. There has been a significant decrease in electrical conductivity in the 100 cm. soil zone in 1969, 1971 and 1972 as compared to 1965. Data indicate that there was a slight removal of soluble salts in OW-1 and OW-3. This may have been due to the fact that they are both relatively close (10 m) from lateral drainage tile F-F.

The soil site OW-5, as shown by Fig. 24 shows no appreciable decrease in electrical conductivity with time. This suggests that the drainage tile lines were not effective in reducing soluble salts.

<u>The Pattern of Electrical Conductivity near the Lateral Drainage Tile Lines</u>

The investigated area slopes from West to East with

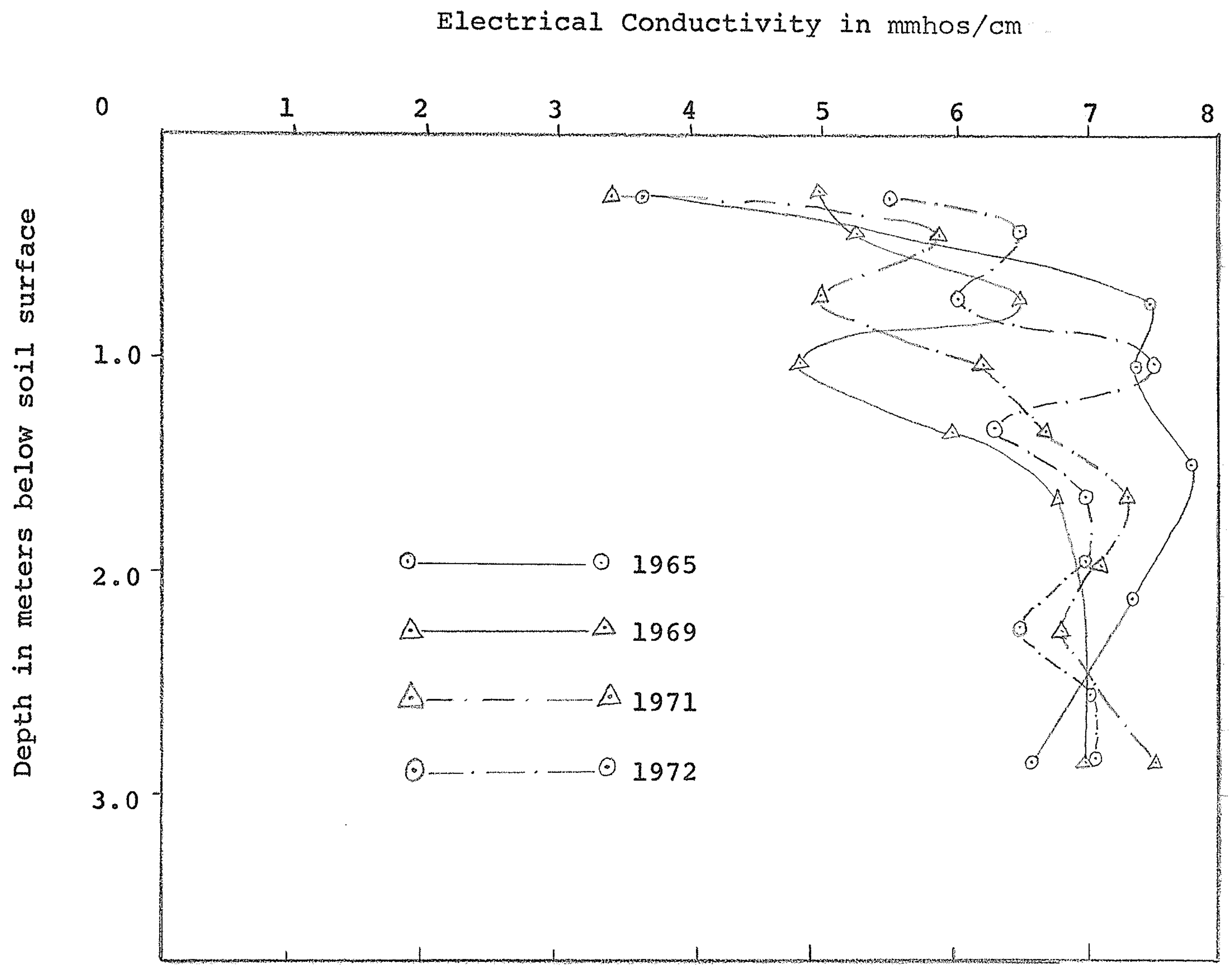

Fig. 22 Electrical conductivity of soils in soil profile OW-1 in 1965, 1969, 1971 and 1972.

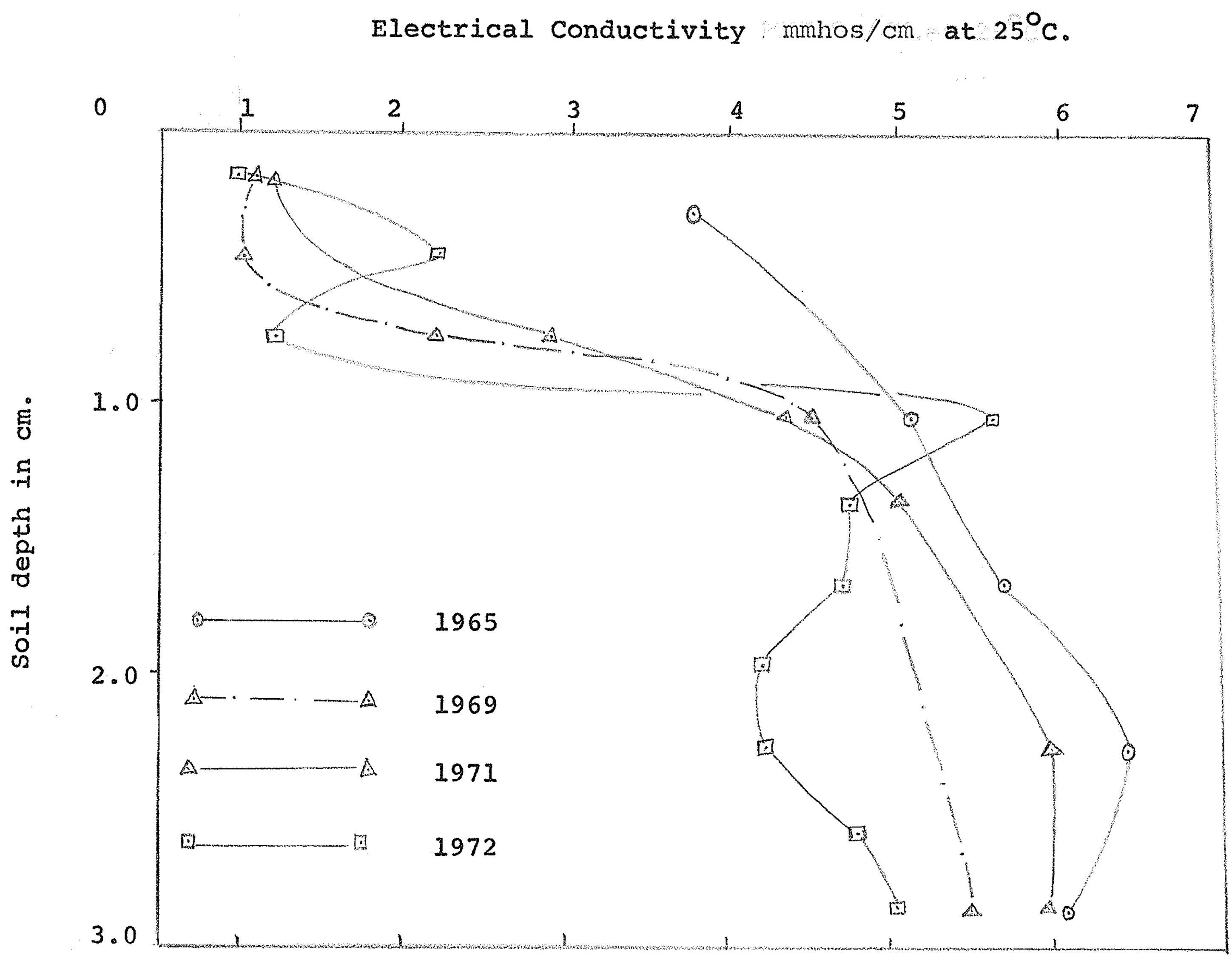

Fig. 23 Electrical conductivity of the soils in soil profile OW-3 in 1965, 1969, 1971 and 1972.

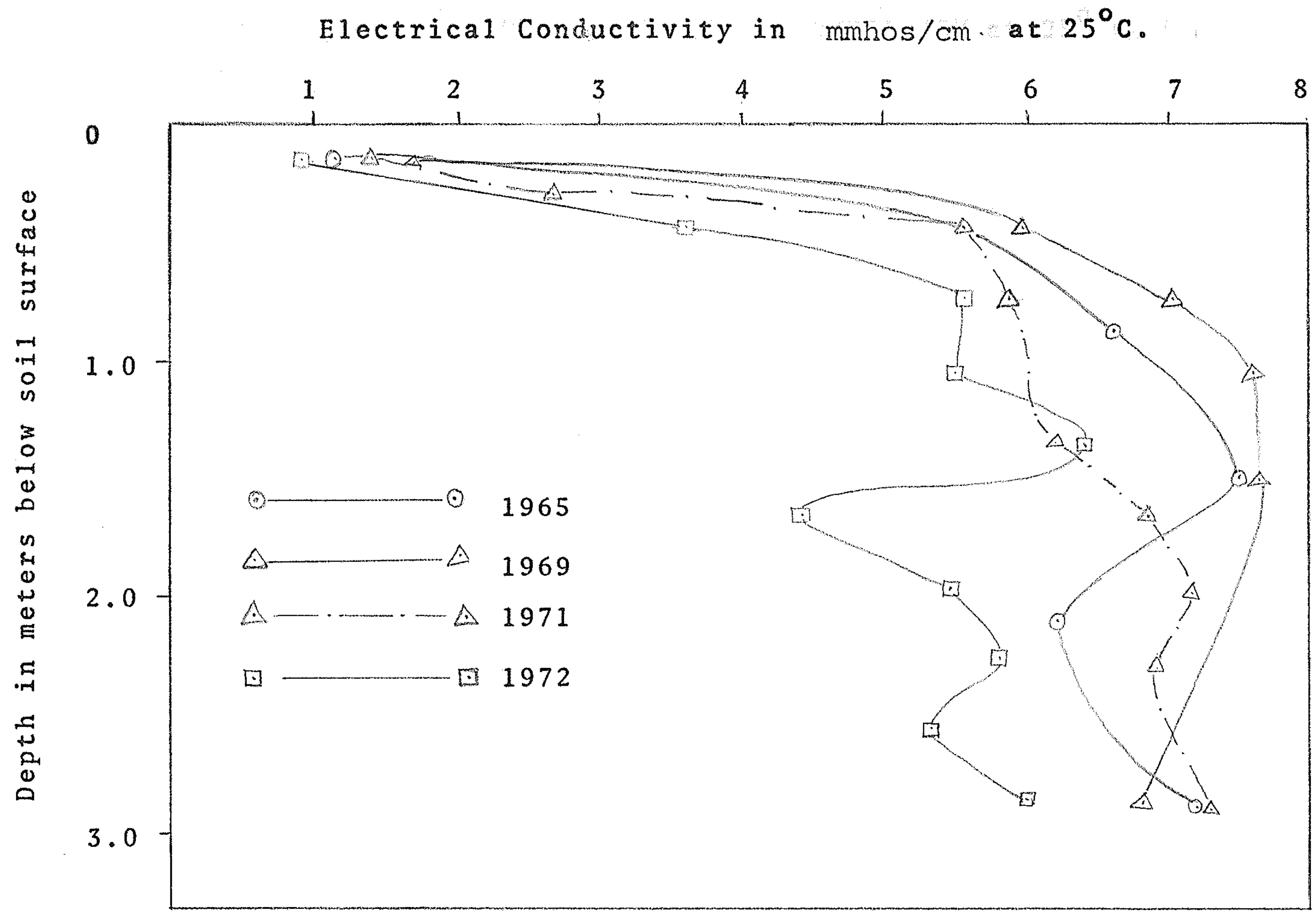

Fig. 24 Electrical conductivity of the soil in soil profile OW-5 in 1965, 1969, 1971 and 1972.

a general slope of 1:220 (Fig. 25). During the spring when snow melts, surface water flows from West to East and it is intercepted by a network of surface drainage ditches. In late April 1974, temporary water ponds were observed to the Western side of tile line E-E near the sump (Fig. 26). A water pond was also observed to the North-east of the study area at lateral drainage tile line G-G.

The electrical conductivity of the investigated soils across lateral drainage tile line E-E (Fig. 27) shows that the soils on the Western side of the tile line are less saline than those of the Eastern side. The electrical conductivity ranges from 1 to 4 mmhos/cm in the soil dept 0 - 180 cm. On the Eastern side, however, the electrical conductivity varies from 1 to 4 mmhos/cm in the 0 - 60 cm. The depth to the tile line in both cases is 180 cm.

A possible explanation for this fact is that during the spring or after a heavy rainfall, the ponded soil water (Fig. 26) which occurs on the West side of tile line E-E leaches the soluble salts down to the tile line. This resulted due to the fact that the ground elevation rises slightly from EE-5 to EE-2 (within the windbreak) which is located to the East of tile line E-E within the windbreak. The windbreak is located about 5 meters to the East of tile line E-E. It is likely that leaching of soluble salts due to infil-

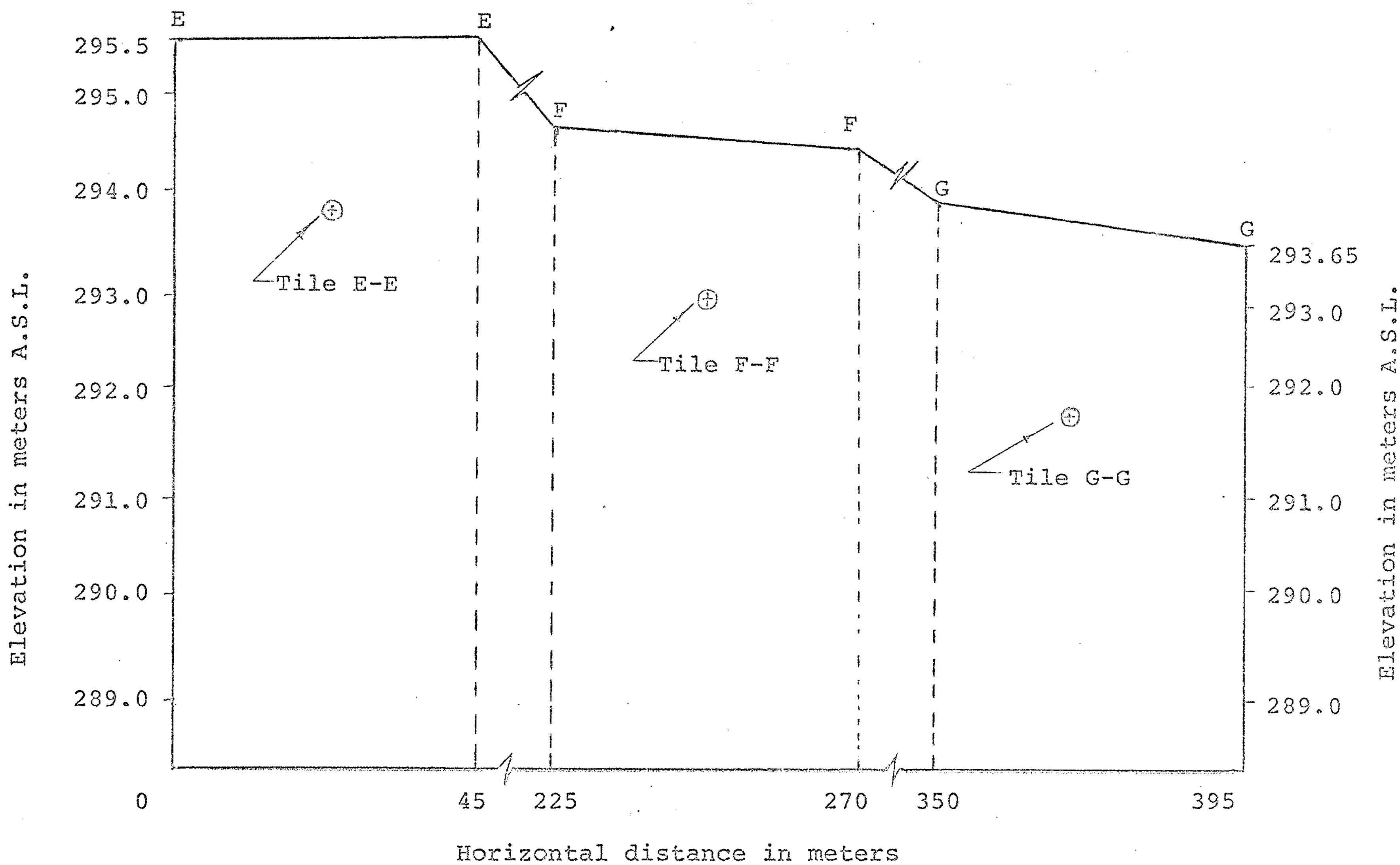

Fig. 25 Cross-section of the study area from lateral drainage tile lines E-E to G-G. (Average slope = 1:200)

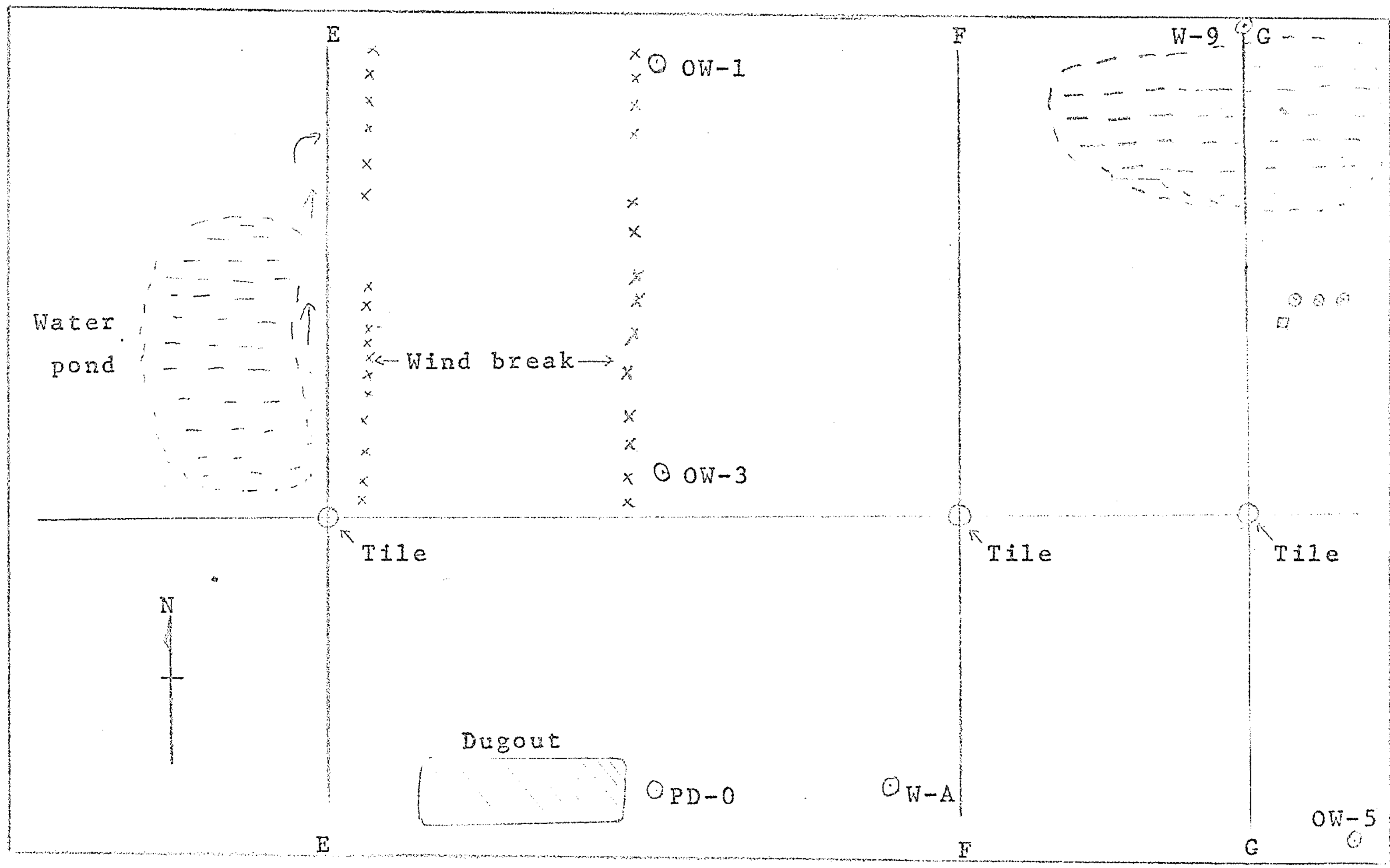

Fig. 26 Surface water flow in mid-April 1974 when most of the snow was melting in the study area. (Scale: 1 cm. = 32 meters).

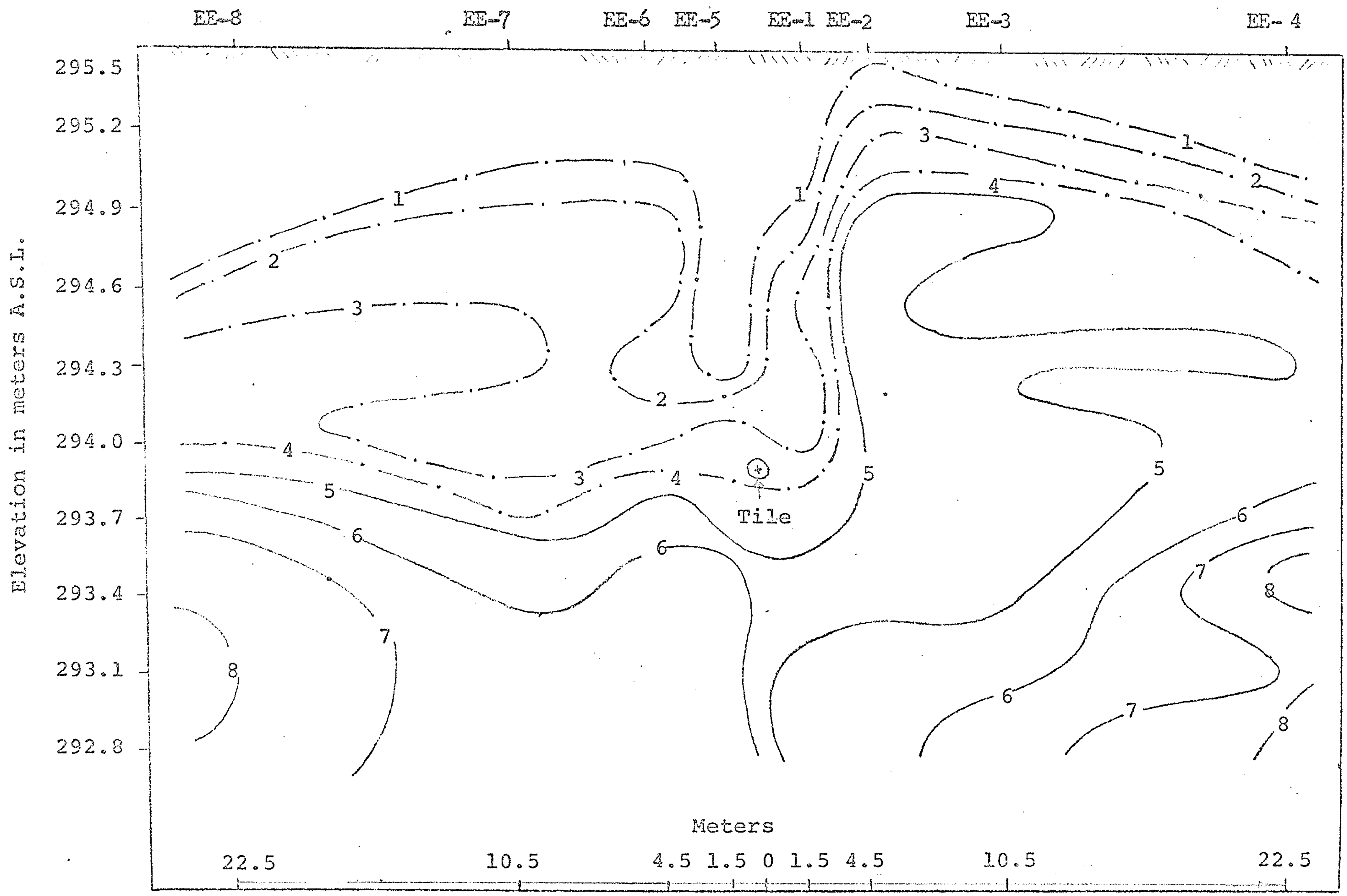

Fig. 27 Electrical conductivity of the soils in the profiles across lateral tile line E-E.

tration of the standing water will be more effective to the Western than to the Eastern side of the lateral drainage tile line.

The regional groundwater flow is from West to East (Sibul, 1968). It is most likely that the groundwater flow is perpendicular to the lateral drainage tile lines E-E, F-F and G-G. The low salt concentration on the Western side of the lateral drainage tile line E-E is probably contributed by the groundwater flow. Dissolved soluble salts in the groundwater moving from West to East drain into tile line E-E and empty at the sump. On the Eastern side of tile line E-E, however, salts dissolved in the groundwater tend to move Eastwards with the groundwater instead of draining into tile line E-E. As the process was repeated year after year, the Western side of the lateral drainage tile line had its soluble salts washed to the water table. It is possible that only small amounts of soluble salts moved with the groundwater on the Eastern side of tile line E-E.

Fig. 28 shows that the soil surface near tile line F-F up to a depth of 60 cm is not saline. Electrical conductivity varies from 1 to 4 mmhos/cm. The electrical conductivity increases with increasing soil depth. It increases from 4 mmhos/cm at 60 cm to about 8 mmhos/cm

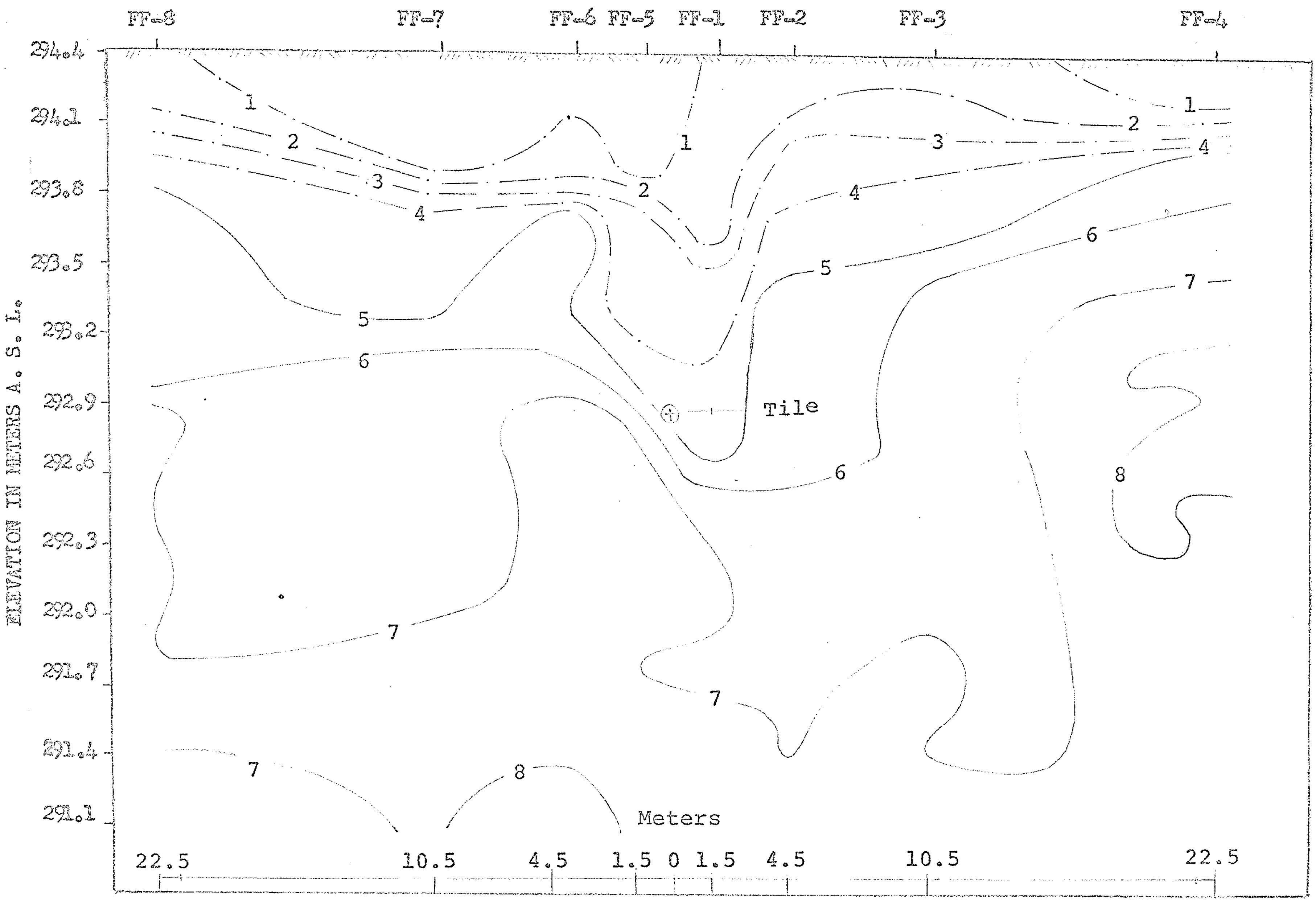

Fig. 28 Electrical conductivity of the soils in the profiles across lateral tile line F-F.

at 300 cm. soil depth. When lateral tile line F-F was installed, a trench probably as wide as 300 cm. was dug. After the tile line had been laid, the trench was backfilled with the excavated soil. The soil structure about 150 cm. on either side of the tile line and above the tile line was disturbed at the time of tile installation. It became more porous than the soils around the tile that were not disturbed. Standing rainfall water and snowmelt, infiltrates easily through the disturbed soil around and above the tile line. As it infiltrates, it washed away the soluble salts and drains with it into the tile line which then carries the water containing soluble salts into the manholes. It is probable that the decrease in soluble salts in the soils around and above the tile line is due to the increase in soil porosity of the disturbed soils rather than due to the influence of the drainage tile line.

For tile line G-G, the top 60 cm. of soil is again not saline, that is, has a conductivity less than 4 mmhos./cm. Like the soils in lateral drainage tile F-F, the soils directly around and above the tile line G-G are not saline. The decrease in soluble salts is probably due to an increase in soil porosity when a 300 cm. trench was excavated and backfilled when the tile line was installed. Electrical conductivity increases with increasing distance from lateral drainage tile line G-G (Fig. 29). Electrical conductivity between 2 to 11 mmhos./cm. were analysed between the soils near the tile line (GG-1 and GG-5) and the soils 40 meters (GG-4 and GG-8) from the tile line (Fig. 29).

The electrical conductivity values of between 11 and 12 mmhos./cm. in lateral drainage tile line G-G at an average distance of 14 meters on either side of the lateral drainage tile line and at a depth of 160 cm. below the soil surface indicates an accumulation of soluble salts (Fig. 29). This accumulation may be attributed to the fluctuation of the groundwater table between the spring and winter seasons and the movement of salts to the topsoil by capillary action during the summer season. The electrical conductivity data of the investigated cross-sections shows with the possible exception of tile E-E that the tile lines have not significantly reduced topsoil salinity beyond 450 cm. on either side of the tile lines.

From the electrical conductivity data obtained from the analysis of soil samples across the lateral drainage tile lines E-E, F-F and G-G it is possible to make general remarks. The topsoil (0 to 60 cm.) is in general not saline (electrical conductivity less than 4 mmhos./cm.). The soils directly above and around the lateral drainage

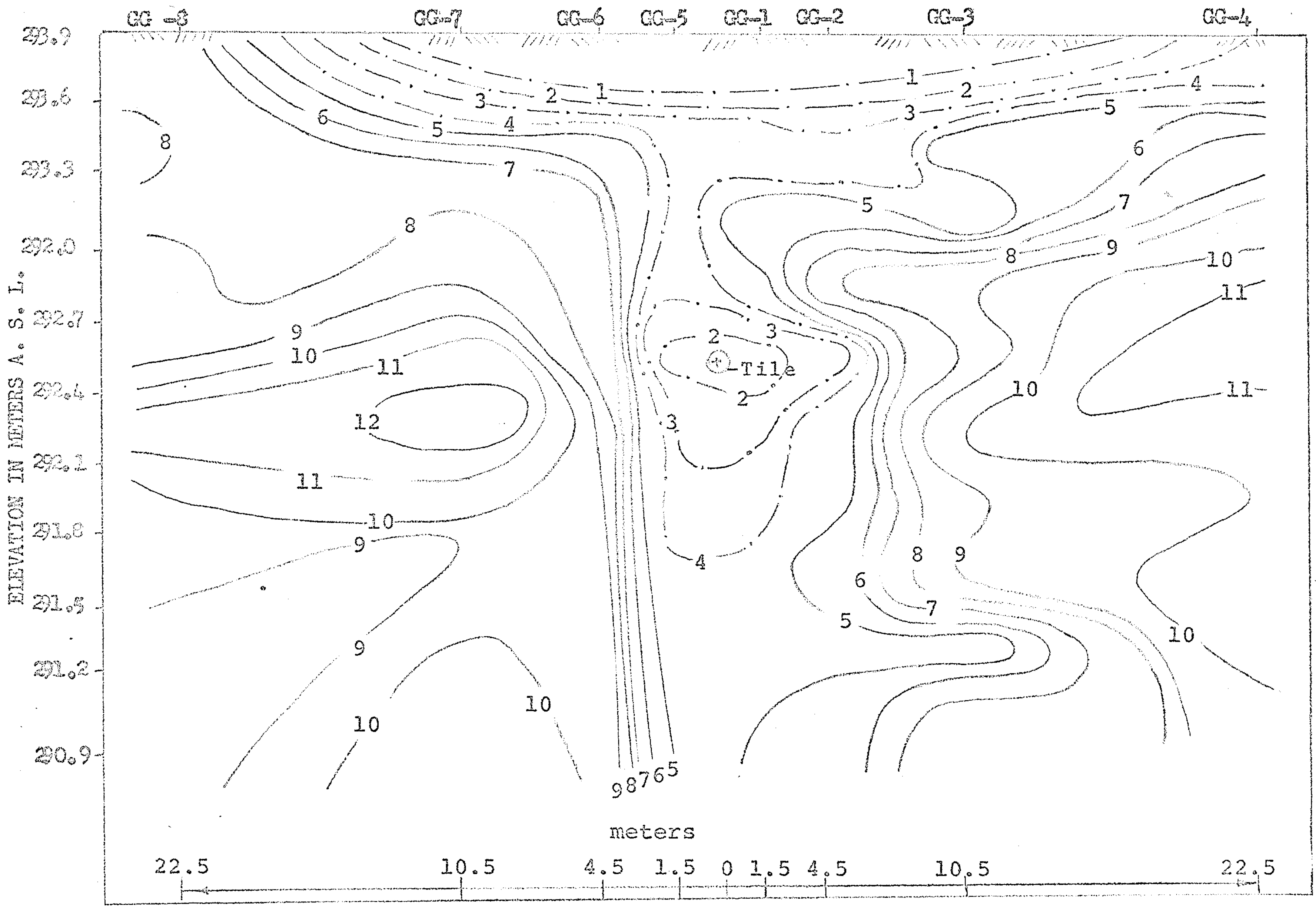

Fig. 29 Electrical conductivity of the soils in the soil profiles across lateral tile line G-G.

tile lines are not saline. A possible explanation to this fact is that standing water resulting from snowmelt or heavy rainfall is able to infiltrate more easily in these strips since their porosity has been increased during the tile installation operation. Snowmelt or heavy precipitation is able to infiltrate to the tile lines easily, thus leaching the soluble salts to the drainage tile lines. With the exception of the Western side of tile E-E, soluble salt concentration increases with increasing distance from the tile lines. Thus the tile drainage network may have had absolutely no effect in reducing the concentration of soluble salts.

In general the electrical conductivity is highest at the soils along cross-section G-G compared to the soils along cross-section F-F and E-E.

Specific Cations and Anions of the Soils Across E-E And G-G

The groundwater contains Ca^{++}, Mg^{++}, Na^{+}, $SO_4^{=}$ and Cl^{-} ions (Michalyna, 1968). The high concentration of these ions in the groundwater resulted in the precipitation of sulphates and chlorides of the cations. The sulphates and chlorides of sodium are more soluble than those of magnesium which in turn are much more soluble than those of calcium.

If the tile drainage network has been effective in reducing the concentration of soluble salts in the 1.5 meters soil depth (average tile drainage depth), we should expect a reduced concentration of sodium, magnesium and chloride. These salts should have been leached into the water table and drained away into the lateral tile lines; which carry the mineralized water into the sumps. Calcium sulphate being least soluble should not change very much, i.e. calcium and sulphate concentrations should increase slightly from the soils that are around and above the tile lines to the soils 6.0 meters from the tile lines.

Sodium. The sodium concentration of the soils across lateral drainage tile line E-E varies from 1 to 35 m.e./l. It increases with increasing soil depth as well as with increasing distance from the lateral tile line. Sodium concentration is lower on the Western side than the Eastern side of the tile and its distribution follows the pattern of the electrical conductivity (Fig. 30).

For the soils across lateral drainage tile line G-G the sodium concentration in the soils that are 1.5 meters on either side of the tile line is about 20 m.e./l. In general it increases with increasing distance from the tile line. A concentration as high as 100 m.e./l. has been analysed for the soils that are 6 meters from the

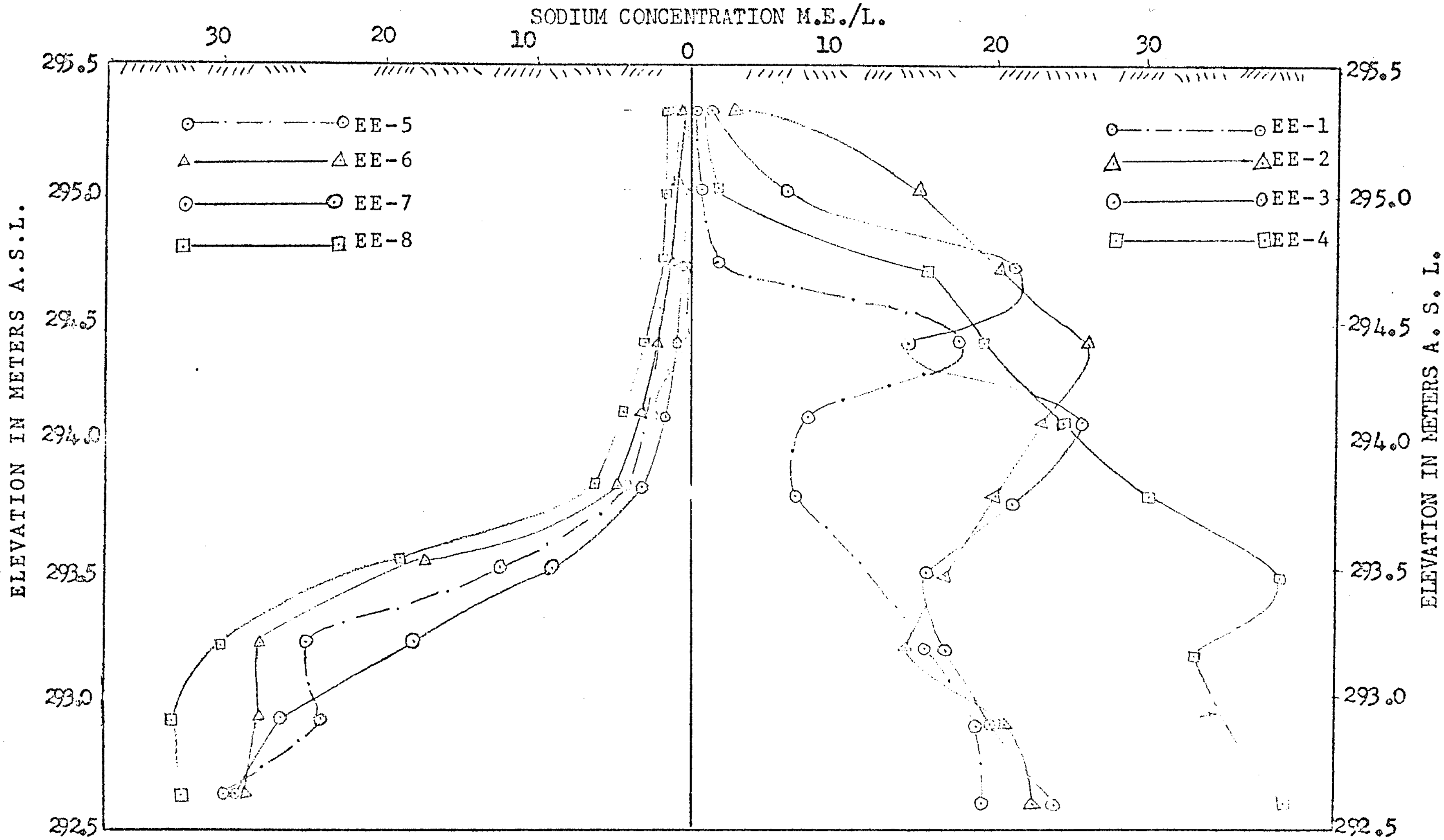

Fig. 30 The concentration of sodium in the soil profiles across lateral tile line E-E.

tile line. As in the case of lateral tile E-E the distribution of sodium follows the pattern of the electrical conductivity (Fig. 31).

The distribution of sodium in the soils across lateral tile lines E-E and G-G can probably be explained by the effect of infiltrating standing snowmelt or heavy rainfall water and regional groundwater flow as proposed on section two of this chapter which deals with the pattern of electrical conductivity near the lateral drainage tile lines. Sodium being most soluble of the three cations, is strongly affected by the two major processes.

Magnesium. Magnesium concentration varies between 1 and 90 m.e./l. in the soils across lateral drainage tile line E-E. Magnesium concentration is lowest on the Western side of the tile line and is highest on the Eastern side of the tile line (Fig. 32). In general magnesium concentration increases with increasing soil depth. The soils immediately below the level of lateral drainage tile line have much higher magnesium concentration than those above the tile line. This phenomenon is clearly apparent to the Western side of the tile line and it is only slightly apparent to the Eastern side of the tile line.

The distribution of magnesium in the soils across tile line E-E can probably be explained by the mechanisms

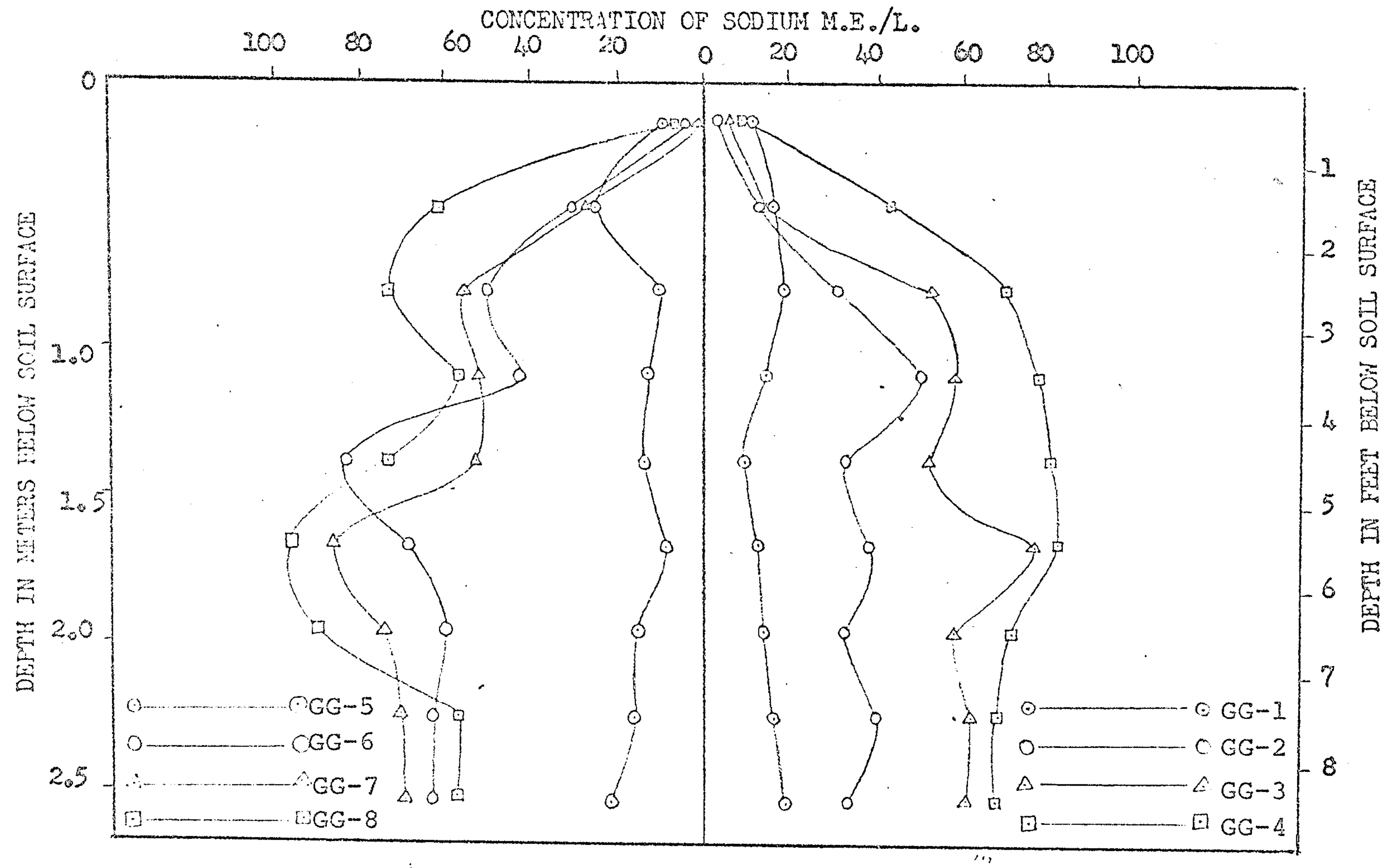

Fig. 31 The concentration of sodium in the soil profiles across the lateral tile line G-G.

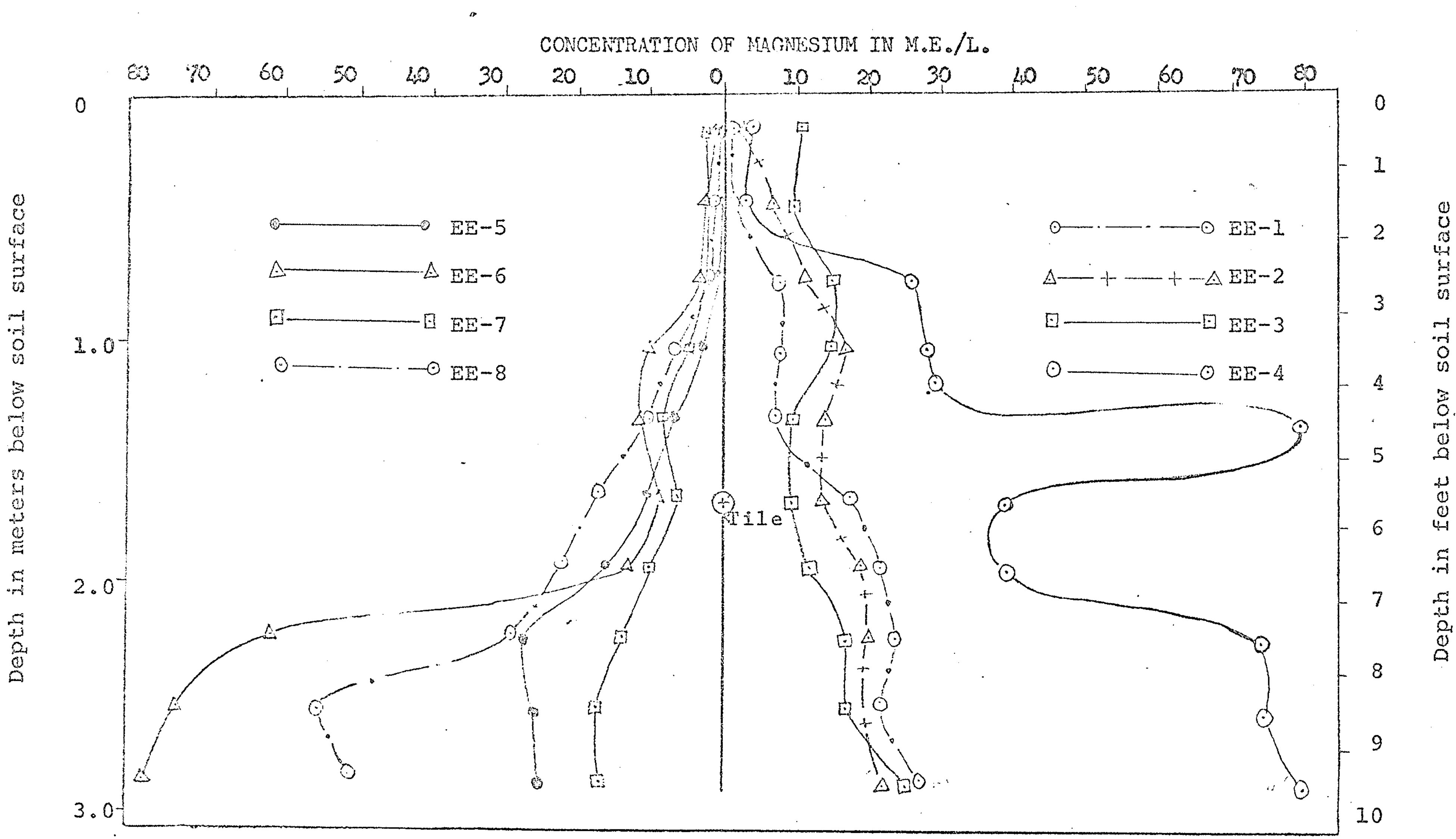

Fig. 32 The concentration of magnesium in the soil profiles across lateral tile E-E.

which affect the distribution of sodium, namely infiltrating standing water and regional groundwater flow. However, magnesium salts being less soluble than sodium salts, it is noticed by comparing Fig. 30 and Fig. 32 that although the distribution of magnesium is similar to that of sodium, the sodium concentration on the Western side of the tile is in general less than that of magnesium. Like sodium, the magnesium distribution follows the pattern of the electrical conductivity.

Magnesium concentration of the soils across lateral drainage tile line G-G varies between 1 and 4 m.e./l. for the soils that are 1.5 meters from the tile line to about 40 m.e./l. for the soils that are about 6 meters away (Fig. 33). In general magnesium increases with increasing soil depth. As in tile E-E, the distribution of magnesium follows that of the electrical conductivity.

The decrease in magnesium content in the soils near and above the tile line can probably be explained by the same kind of processes explained earlier which resulted in the distribution of sodium namely, infiltrating standing water and regional groundwater flow.

Calcium. The calcium concentration within the soils in the cross-section across lateral drainage tile line E-E varies from 1 to about 40 m.e./l. In general the calcium concentration increases with increasing distance from the

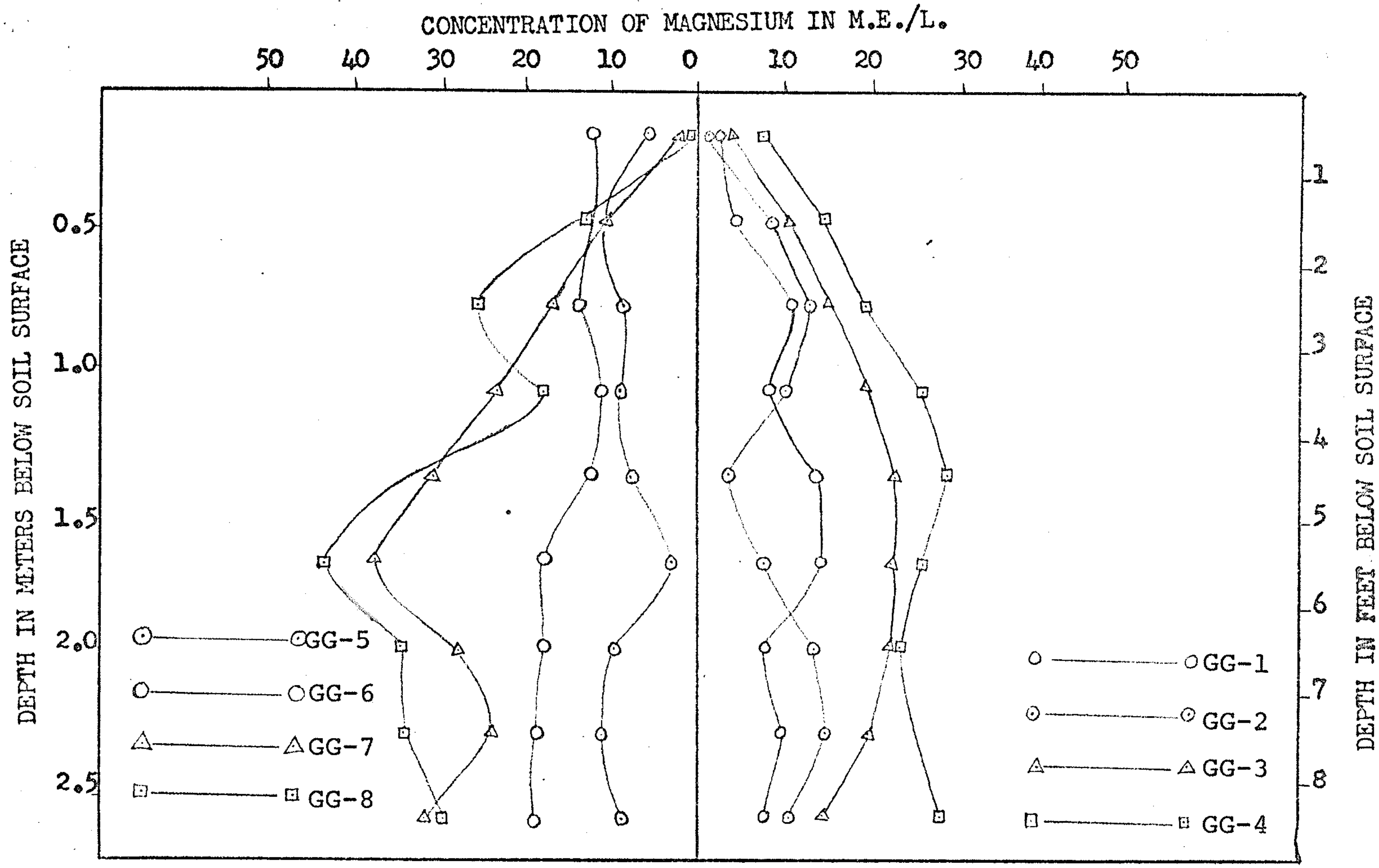

Fig. 33 The concentration of magnesium in the soil profiles across lateral tile line G-G.

lateral drainage tile line. Also, it generally increases with increasing soil depth. Although the calcium concentration is in general slightly higher on the Eastern side of the tile line E-E than the Western side, the difference in concentration is not as apparent as it was in the case of sodium and magnesium. In general, the calcium concentration distribution up to the level of the tile line is higher than that of sodium and magnesium (Fig. 34).

Calcium being the least soluble of the three cations (Na, Mg and Ca), it is expected that even if the salts are leached out by infiltrating standing water and regional flowing groundwater, the calcium concentration will not change very much. It is possible that the soils across lateral tile line E-E are dominated by $CaSO_4$.

The calcium concentration across lateral drainage tile line G-G varies between 5 to 10 m.e./l. in the soils that are 1.5 meters on either side of the lateral drainage tile line. The calcium concentration of the soils from 1.5 meters to 6 meters away from the tile line rises to about 55 m.e./l. (Fig. 35). The pattern of calcium distribution is similar to that of sodium. In general calcium increases with increasing distance from the lateral drainage tile line.

Due to the fact that calcium salts are least soluble,

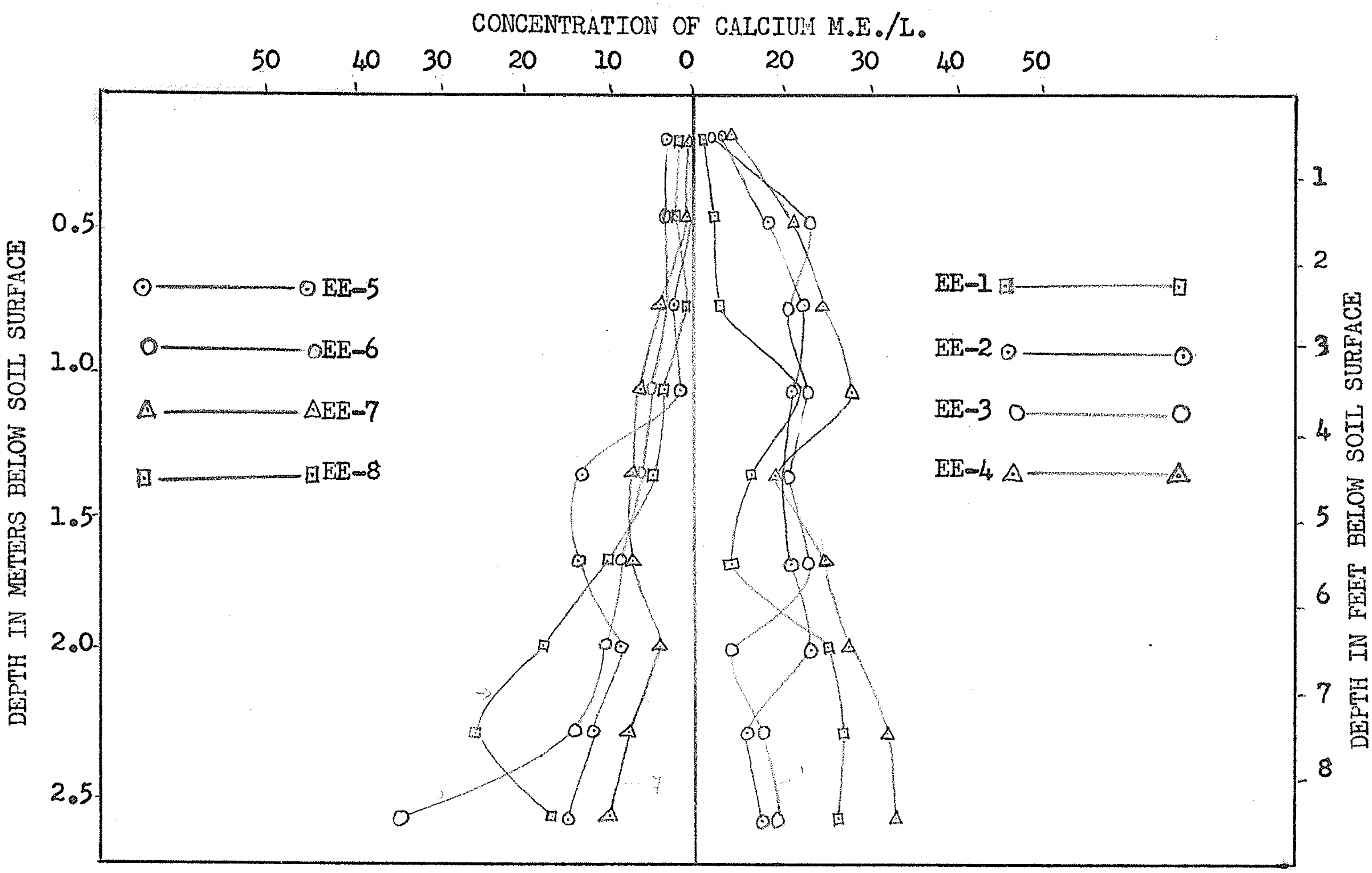

Fig. 34 Concentration of calcium (m.e./l.) of soil profiles across lateral tile E-E.

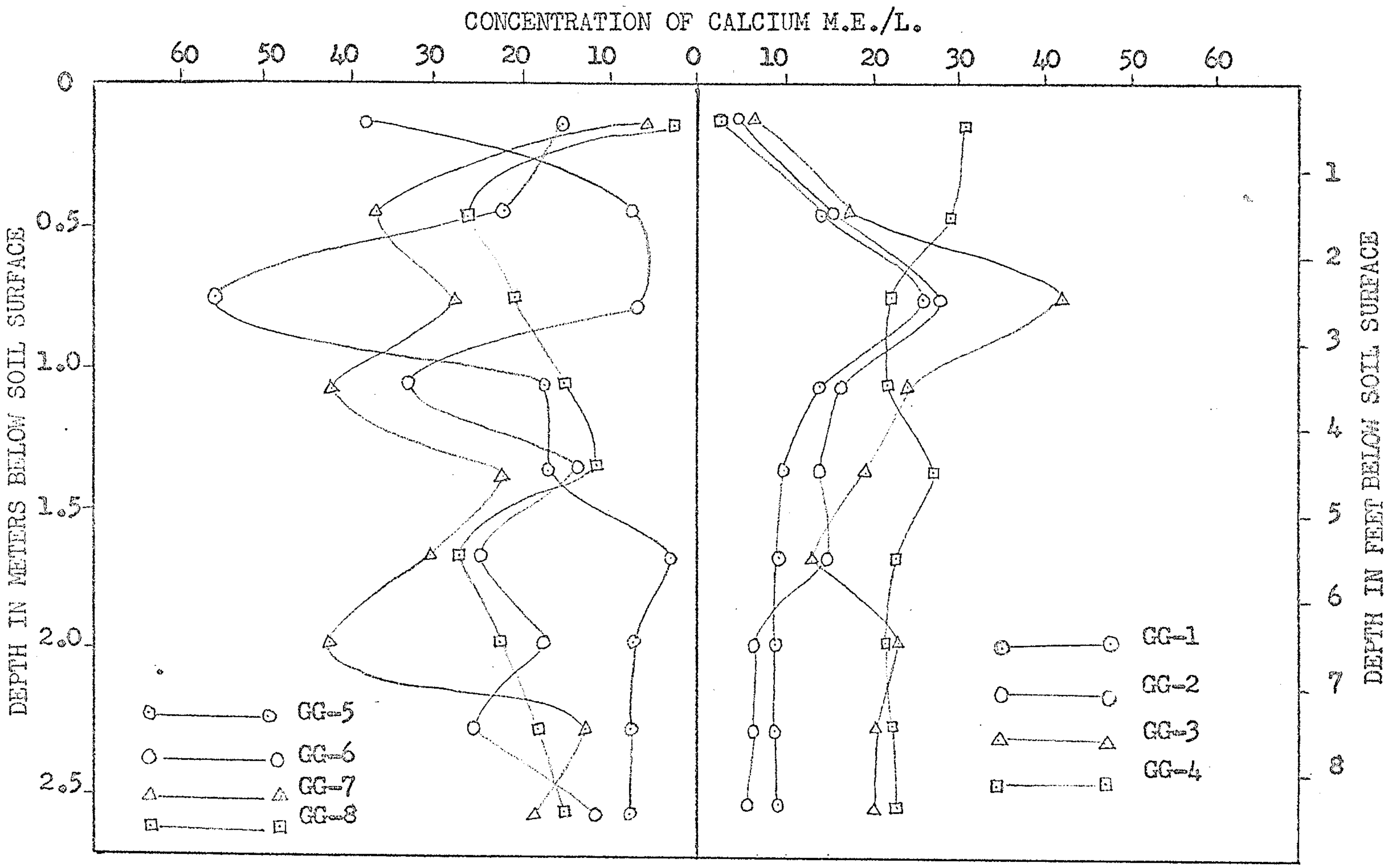

Fig. 35 Concentration of calcium (m.e./l.) of soil profiles across lateral tile G-G.

infiltrating standing water probably did not change the concentration of calcium very much. Leaching of calcium had probably taken place in the soils above and around the tile line. These soils being more porous than the surrounding soils, rainwater and snowmelt was able to infiltrate much faster, thus washing the soluble salts into the water table.

Sulphate. In the soils across lateral drainage tile line E-E as in G-G sulphate is the dominant anion. The sulphate concentration changes from 2 to 160 m.e./l. Generally the sulphate concentration increases with increasing distance from the lateral drainage tile line (Fig. 36). The sulphate concentration is slightly lower on the Western side of the tile E-E than the Eastern side (Fig. 36).

Comparing the calcium and sulphate distribution, it is apparent that the distribution curves are similar. It seems that both calcium and sulphate were not leached adequately on the western side of the tile line. It is obvious therefore that calcium sulphate dominates the soils on either side of lateral tile E-E. Calcium sulphate is less soluble compared to sodium and magnesium sulphate. Thus infiltrating standing water and regional groundwater flow were able to remove magnesium and sodium sulphates from the Western side of the tile line. Probably only

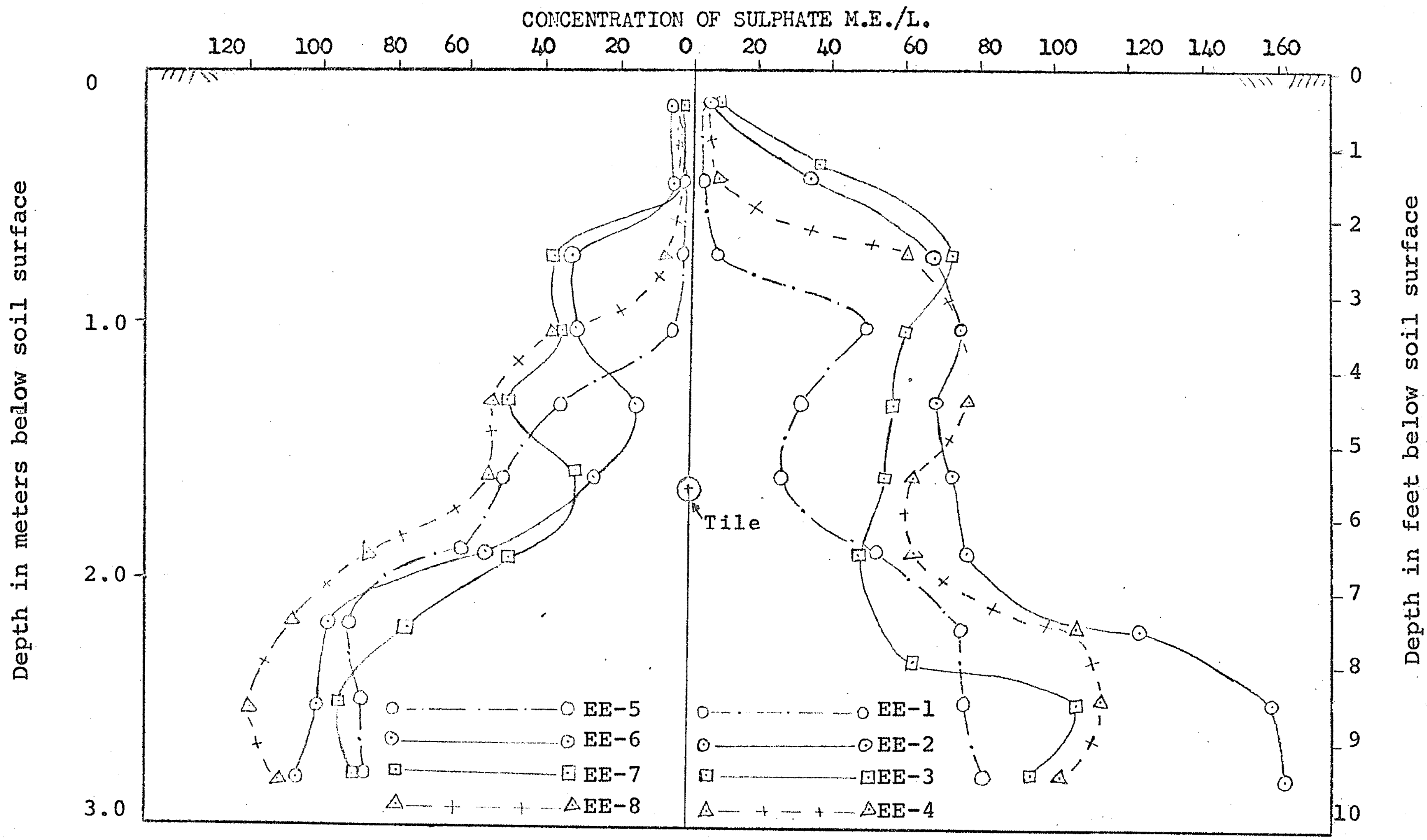

Fig. 36 The concentration of sulphate in the soil profiles across lateral tile E-E.

small amounts of calcium sulphate were washed down into the water table.

In the study area, sulphate is the dominant anion. In the soils across lateral drainage tile G-G the sulphate concentration varies from 21 and 25 m.e./l. in the soils that are 1.5 meters away from the tile line (Fig. 37). The sulphate concentration varies from 138 to 148 m.e./l. in the soil profiles that are 6 meters from either side of the lateral drainage tile line. Sulphate concentration generally increases with increasing soil depth and increases with increasing distance from the lateral tile line.

When the groundwater table is below the elevation of the tile line, dissolved salts in the water can move either laterally with the groundwater or vertically by capillary action. During the period of investigation, the groundwater was below the tile line. As long as the water table does not reach the level of the tile line, the salt concentration in the groundwater increases from season to season due to the addition of soluble salts leached from the topsoil by snowmelt or heavy rainfall. In general the soils across tile G-G have high amounts of the sulphates and chlorides of calcium, magnesium and sodium.

Chloride. The chloride concentration in the soils across drainage tile line E-E is low compared to that of

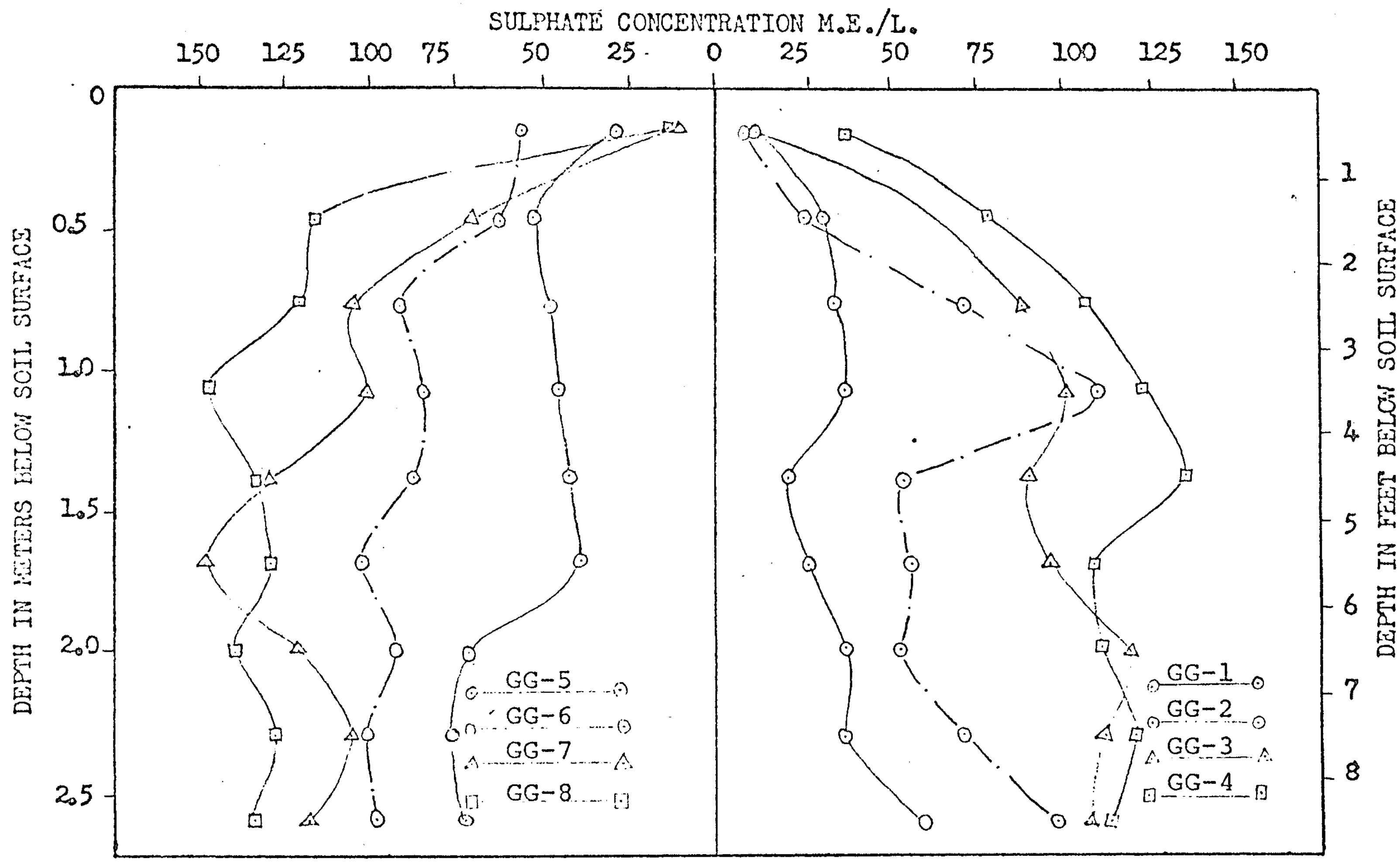

Fig. 37 The concentration of sulphate (m.e./l.) in the soil profiles across lateral tile G-G.

sulphate. However, chloride concentration is much lower on the Western side of the tile line E-E (about 0.5 m.e./l. up to the tile depth) than the Eastern side. A possible explanation is that infiltrating standing rain or snowmelt water together with regional groundwater flow were responsible for the removal of chloride on the Western side of the tile. Chloride being more soluble than sulphate is easily leached from the topsoil into the groundwater. As the groundwater rises above the tile line, it drains into the tile and it flows into the sump (Fig. 38).

The concentration of chloride on the soils across lateral drainage tile G-G vary from 1 to 27 m.e./l. In general chloride increases with increasing distance from the lateral drainage tile line. The decrease in chloride concentration in the soils which are near the tile lines is probably explained by the fact that the disturbed soils around and above the tile line had an increase in porosity during the tile installation program. Infiltrating standing rainwater or snowmelt waters have washed out the soils decreasing their soluble salt concentration considerably. The decrease in chloride concentration within the soils below the tile line can also probably be explained by the fact that flowing rainwater or snowmelt in the tiles flows out of the tile segment joints washing out the soluble salts in the soils around and below

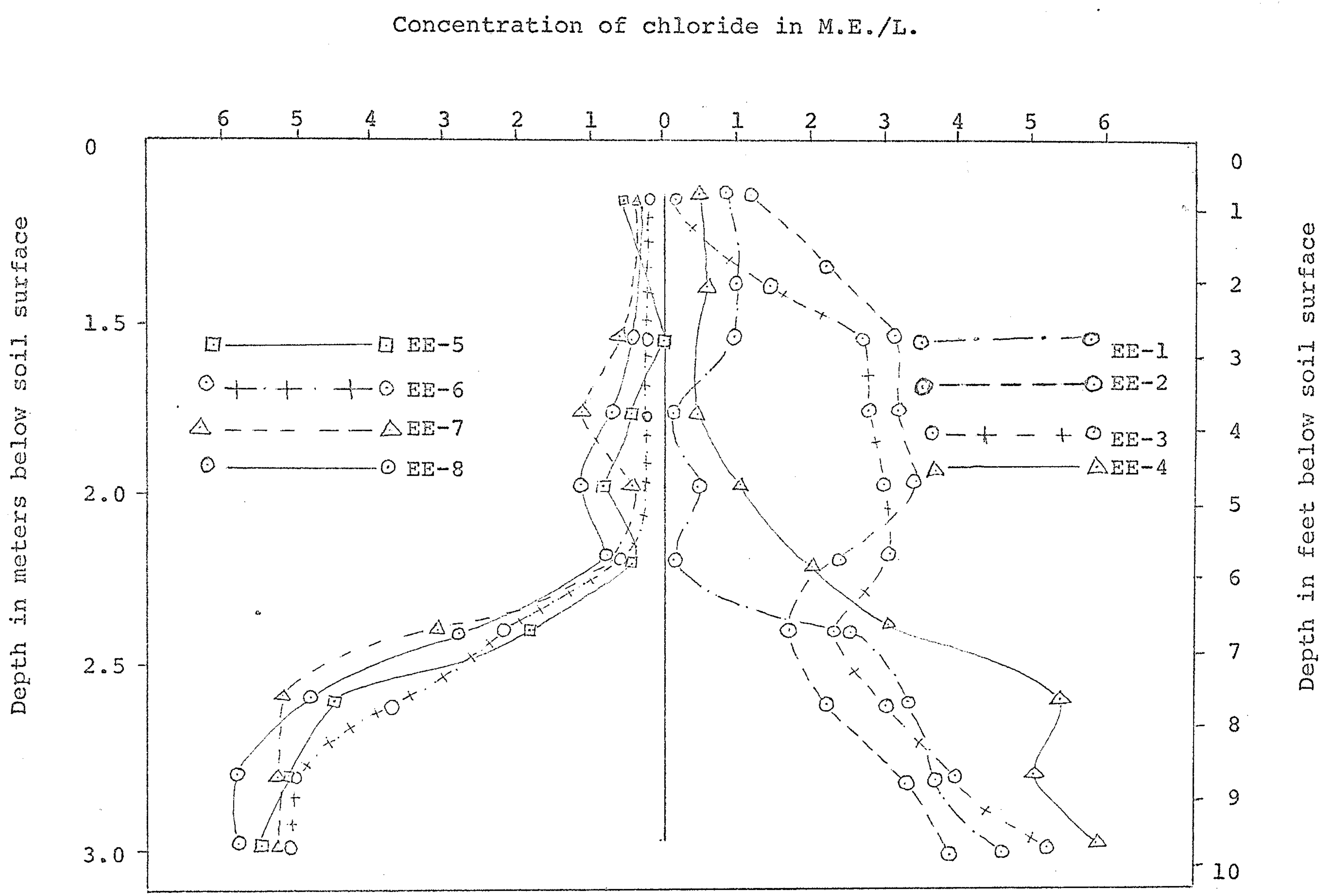

Fig. 38 Concentration of chloride in (m.e./l.) in the soil profiles across lateral tile E-E.

the tile line (Fig. 39).

Specific Cations of the Soils at W-9, OW-1, OW-3, W-DO W-A and OW-5

The soluble salt concentration of the soils of profiles W-9, OW-1, OW-3, W-DO, W-A and OW-5 are reported in the Appendix. In general the concentration of soluble salts is higher in profiles W-9, OW-1 and OW-3 which are to the North of the main drainage tile line, than those to the South of the main line. Probably due to better drainage as a result of the presence of the dugout. The dominant cations in these soils are sulphate, calcium and sodium.

B. WATER TABLE ELEVATIONS

The groundwater fluctuation of the study area was measured in three different seasons: summer 1973, winter 1973 and spring 1974. The data of the elevations of the water table will be discussed under the following headings: seasonal and daily fluctuation in water table elevations, water table heights as affected by the operation of the pumping station, water table heights as affected by breakage of the pumping station, and soil salinity as affected by water table fluctuation and drainage (pump operation).

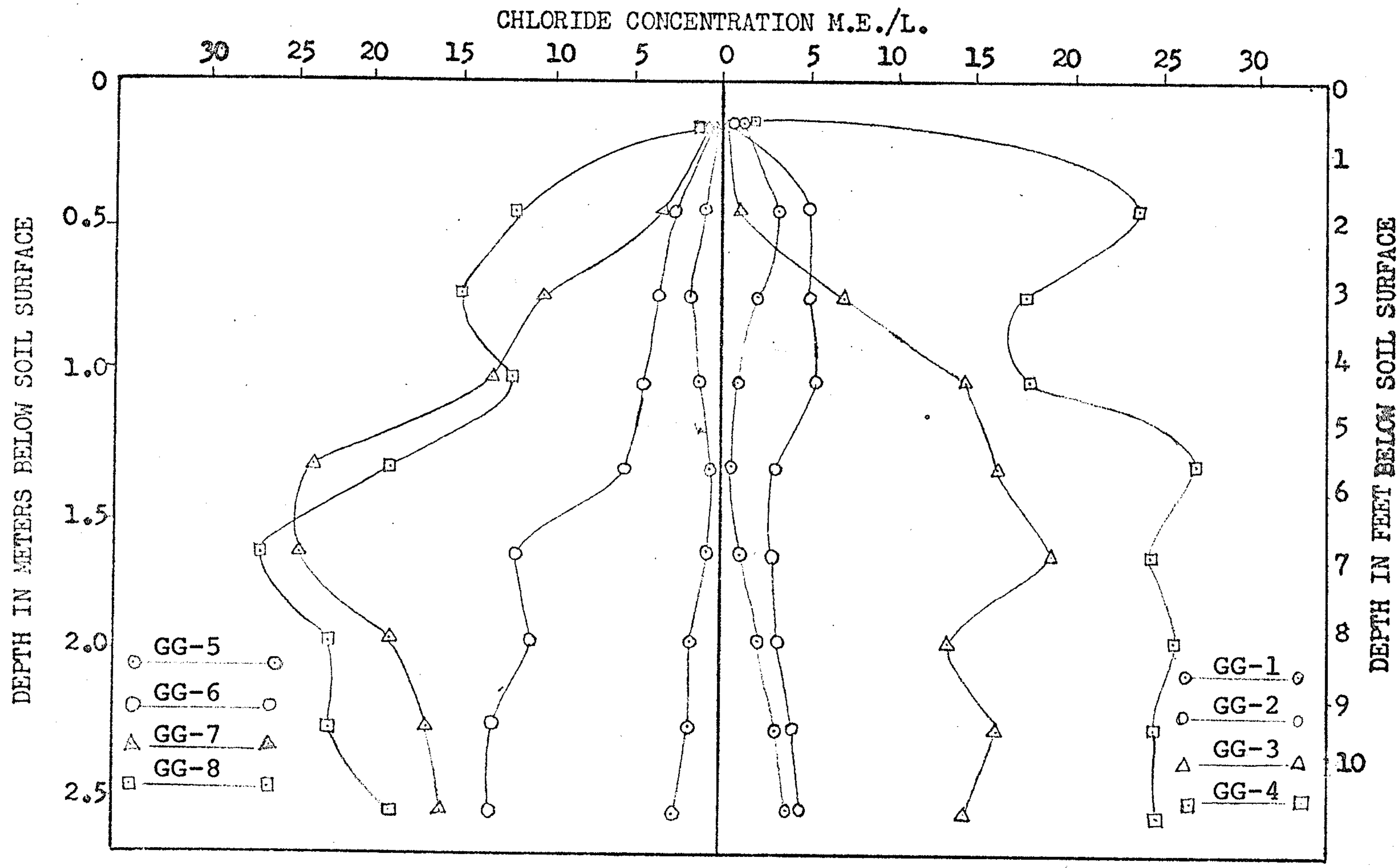

Fig. 39 The concentration of chloride in the soil profiles across lateral tile G-G.

Seasonal and Daily Fluctuation in Water Table Elevations

In temperate regions, seasons of the year have a profound influence on water tables. During a normal year the groundwater table is generally highest in the spring when most of the snow melts and is lowest in the winter time.

The groundwater table did not change much between spring and summer of 1973. It was in general 1.8 meters below the soil surface. The water table did not rise very much due to the fact that 1973 was a dry year. Amount of rainfall between January and May of 1973 was 6.1 cm. while snowfall over the same period was 23.6 cm. On the other hand in 1974 during the same period there was high amounts of rainfall (26.14 cm.) and high amounts of snowfall (82.6 cm.)

The groundwater table of all the investigated wells started to rise in early spring 1974. (E.g. Fig. 40, 41, 42, 43 and 44). It rose rapidly in mid-April when the soil temperature started to rise. Fig. 45 shows that the surface soil temperature rose from -2^{o}C. in mid-April to +13^{o}C. at the end of April. The rapid rise in the water table can be explained by the fact that although soil surface snow cover starts to melt in early April, the snowmelt is unable to infiltrate to the groundwater table due to the ice crystals that have blocked the soil pores.

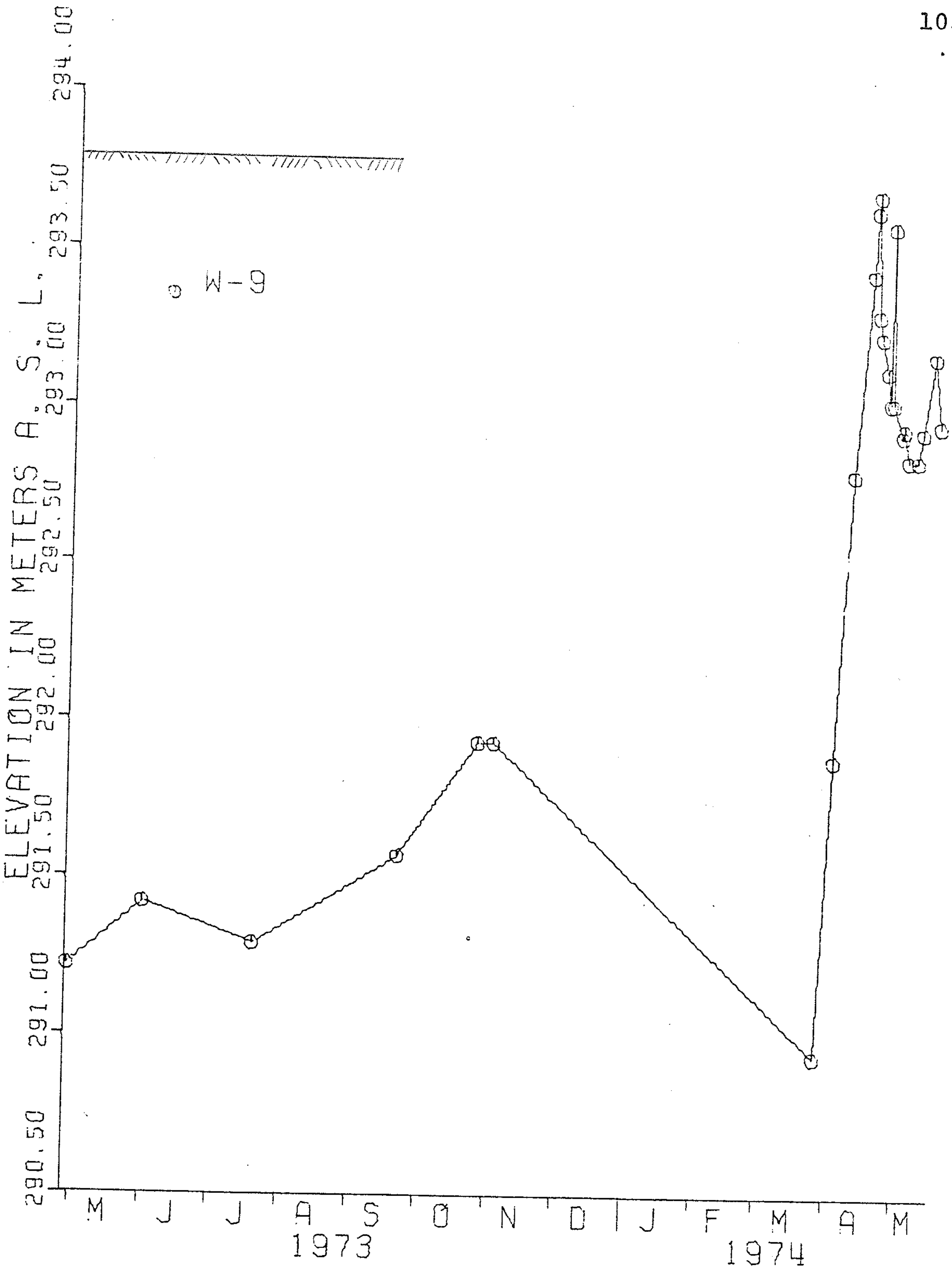

Fig. 40 Fluctuation of the water table in W-9 in 1973 and during spring and early summer 1974.

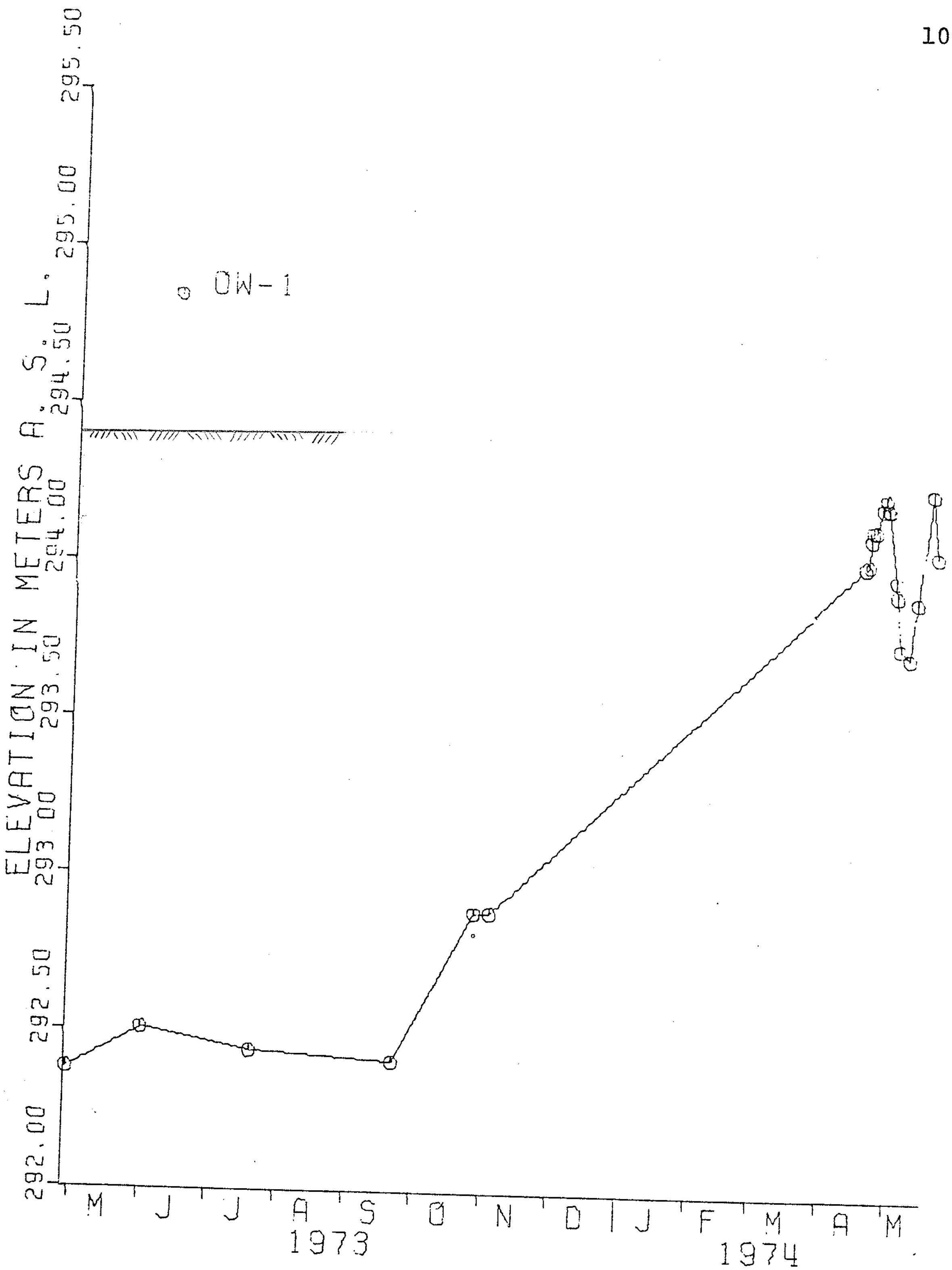

Fig. 41 Fluctuation of the water table in OW-1 in 1973 and during spring and early summer 1974.

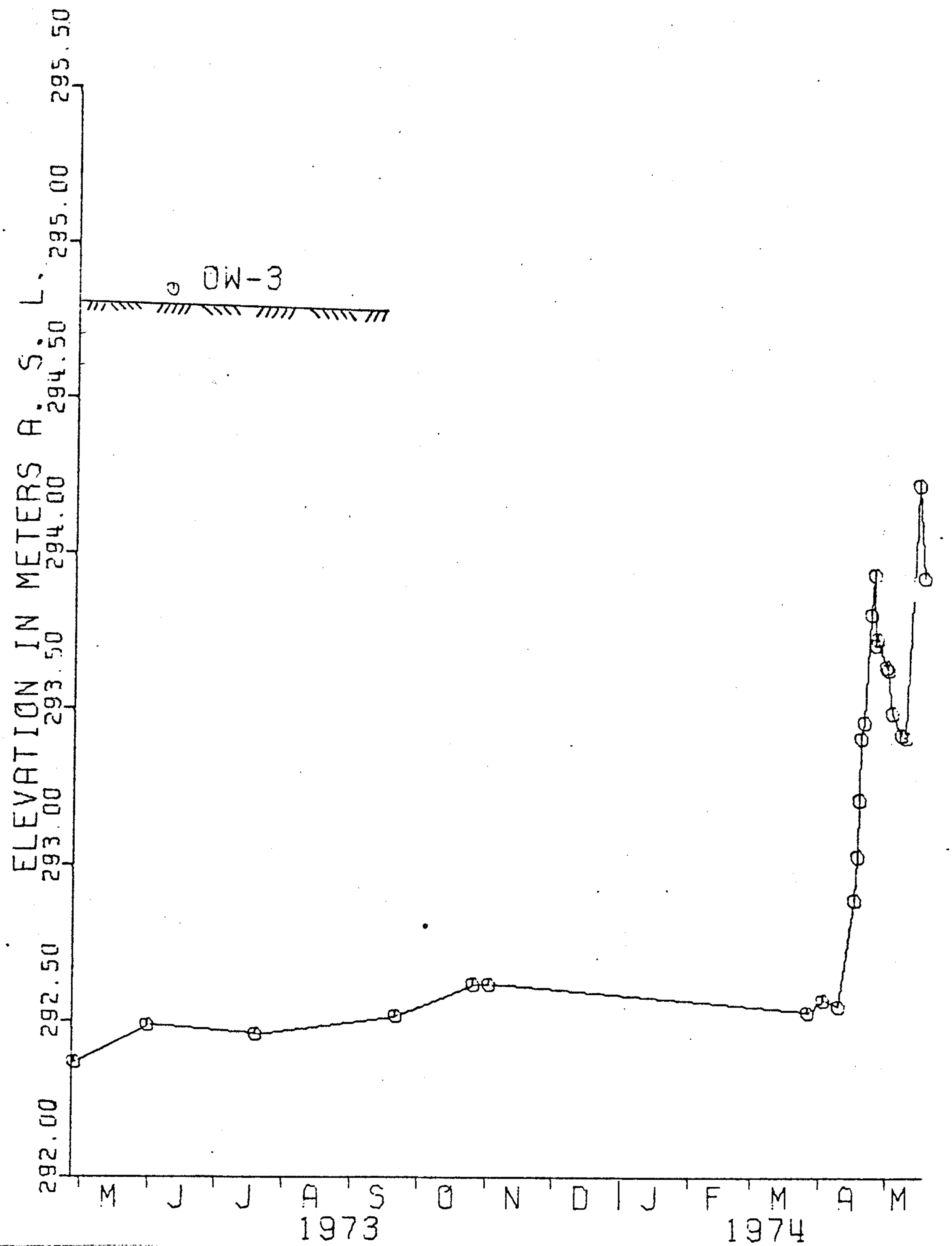

Fig. 42 Fluctuation of the water table in OW-3 in 1973 and during spring and early summer, 1974.

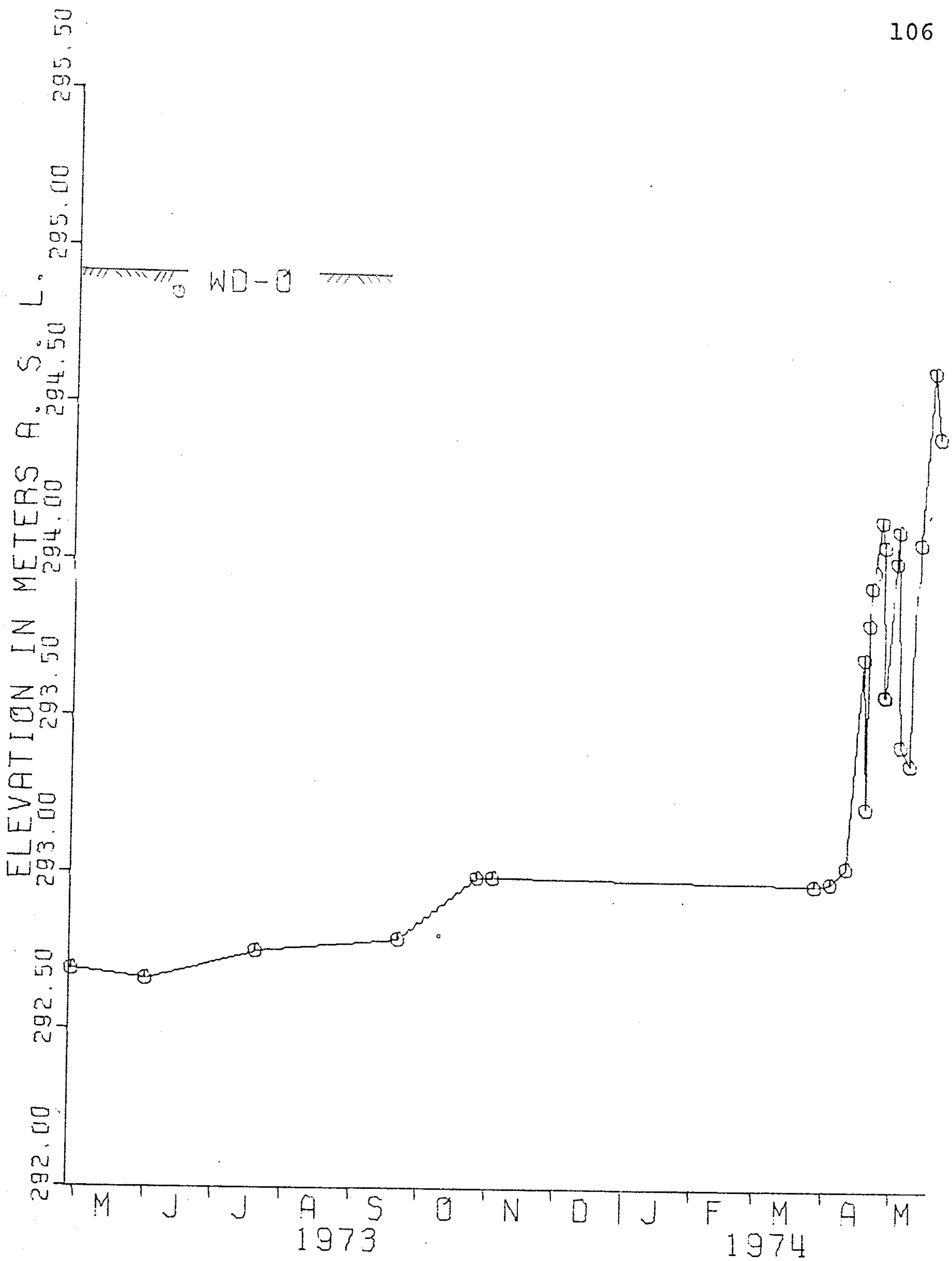

Fig. 43 Fluctuation of the water table in WD-0 in 1973 and during spring and early summer, 1974.

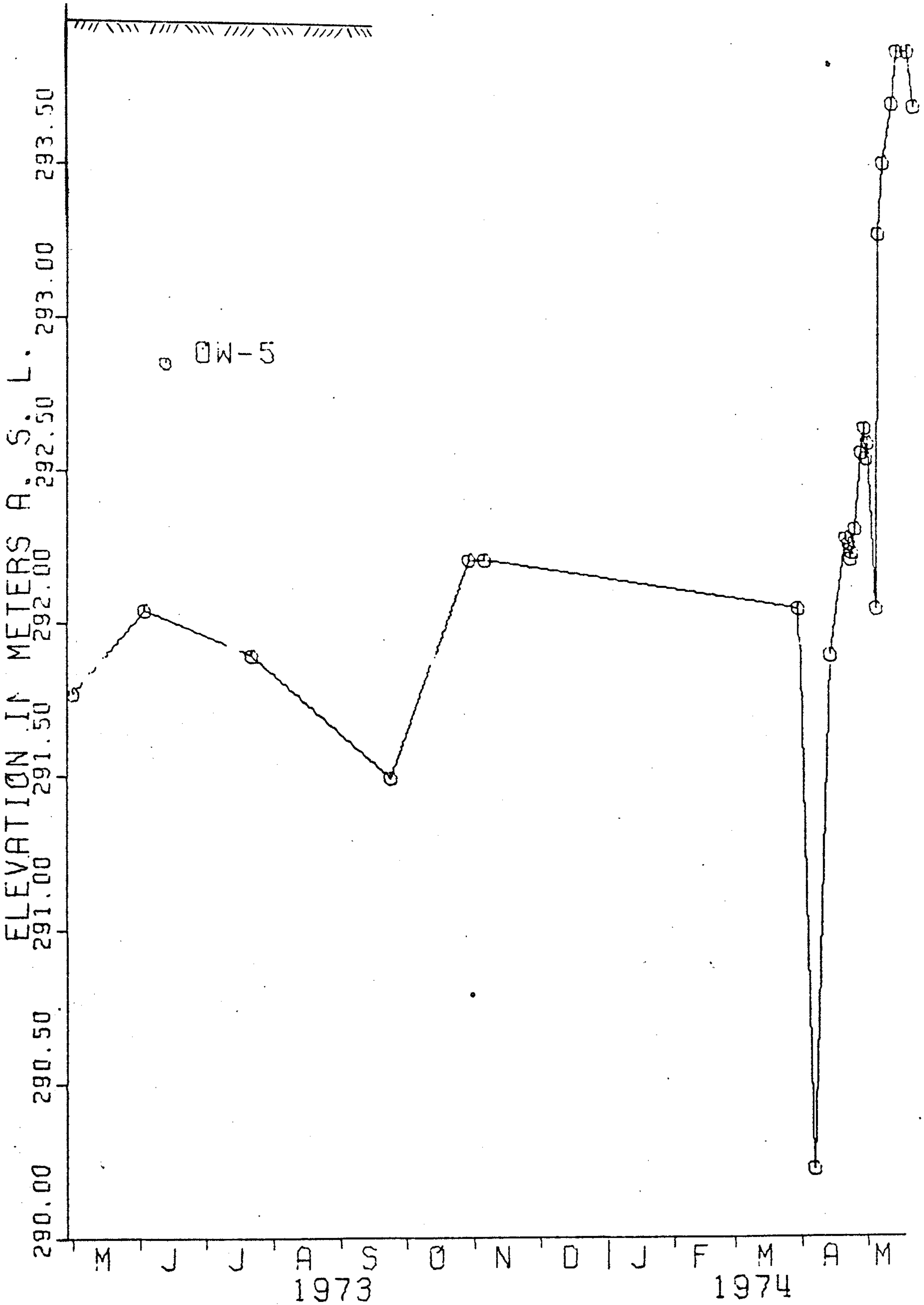

Fig. 44 Fluctuation of the water table in OW-5 in 1973 and during spring and early summer, 1974.

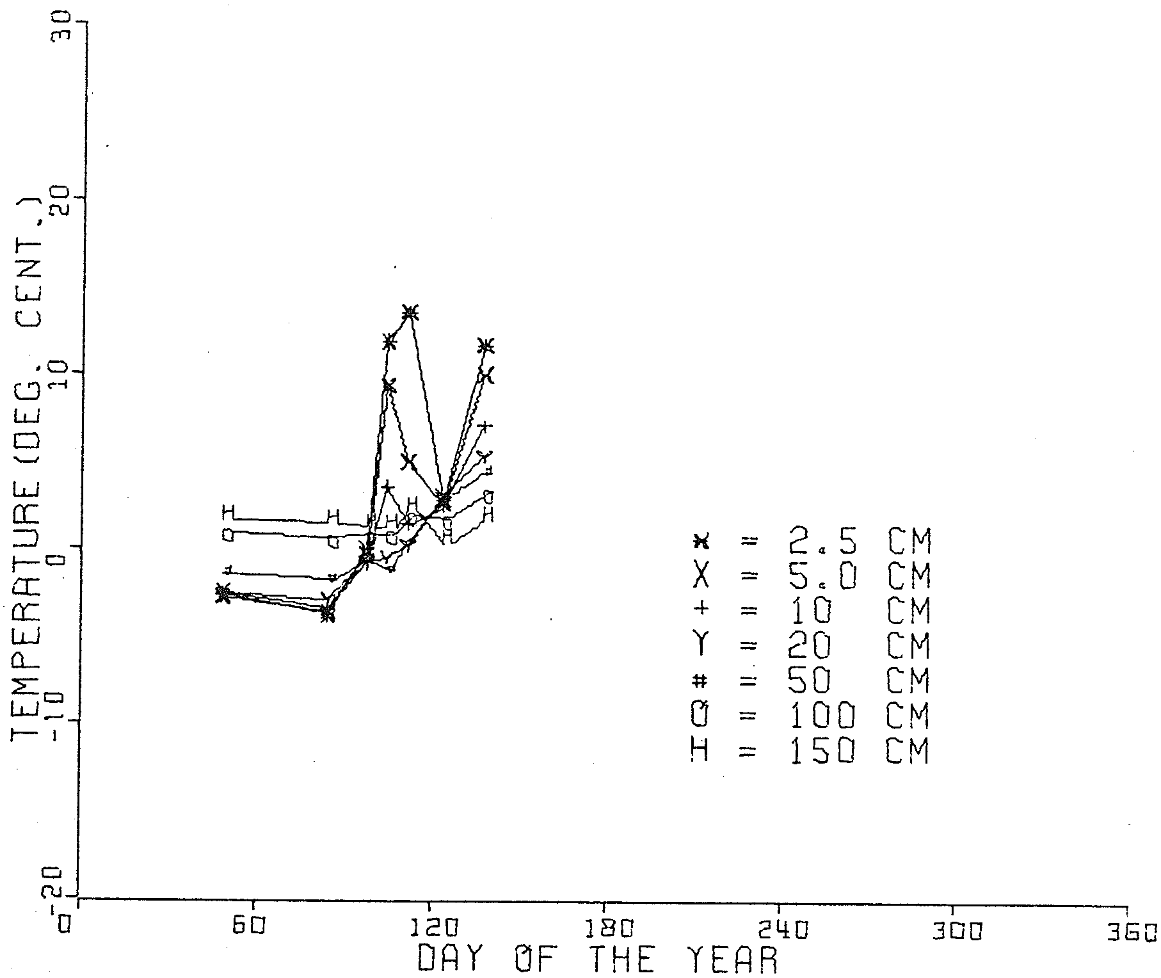

Fig. 45 **Soil temperature at site G-G between February and May 1974.**

In mid-April when soil temperature rises, the ice crystals melt enabling the snowmelt to infiltrate to the water table through the soil pores.

In the spring of 1974, the water table rose an average of 2.5 meters to about 0.6 meters from the soil surface. The groundwater table as monitored in wells OW-5 and W-9 which are situated at the North end of tile G-G and OW-1 which is situated to the North of the study area a few meters West of tile F-F was almost at the soil surface in the spring of 1974 (Fig. 40, 41 and 44).

An abnormally heavy rainfall (12.7 cm.) which fell on 12 May 1974 over a period of 48 hours caused the water table to rise about 15 cm below the soil surface at W-9, OW-1, WD-0, WD-0 and OW-5). After 48 hours, however, the water table fell to about 60 cm. below the soil surface. The rapid rise and rapid fall in water table indicated that after an abnormally heavy rainfall, rain water enters into the water table quickly and also flows out quickly. There are probably a number of explanations for the fast response of the water table. One of the possible explanations is that after an abnormally heavy precipitation, surface water collects and flows out through the ditches.

The Experimental Farm is surrounded by a network of ditches. The ditches run parallel to most roads in the farm. One of the ditches lies to the North of the farm and runs parallel to Provincial Highway No. 3. There is also a ditch running parallel to the road which lies along the Eastern side of the farm. The ditch runs from the C.P.R. Rail Line to Provincial Highway No. 3.

In general the topsoil stratigraphic unit is composed of clay and silty clay alluvium about 80 cm. thich. Sandy materials dominate the soils below 80 cm. depth. Sibul (1968) reported that at a soil depth of about 6 meters there is a thin layer of silt clay. Groundwater flowing from West to East will be confined to the coarse (sand) textured soil layer between the two fine textured soil layers (Fig. 46). A study of the soils of the farm (Michalyna, 1961) reported that the upper clay and silty clay layer is discontinuous. At many locations of the farm the sand layer is exposed to the soil surface. After an abnormally high rainfall, runoff water will infiltrate slowly in the clay and silty clay layers before it reaches the groundwater in the sand layer. On the other hand, runoff water will infiltrate much faster in the areas which have coarse textured (sand) soils at the surface.

Some of the ditches in the farm are deep enough (average depth is 60 cm.) to contact the sandy layer. Intercepted runoff water that flows in the ditches which are within the sand layer, infiltrates very rapidly, thus

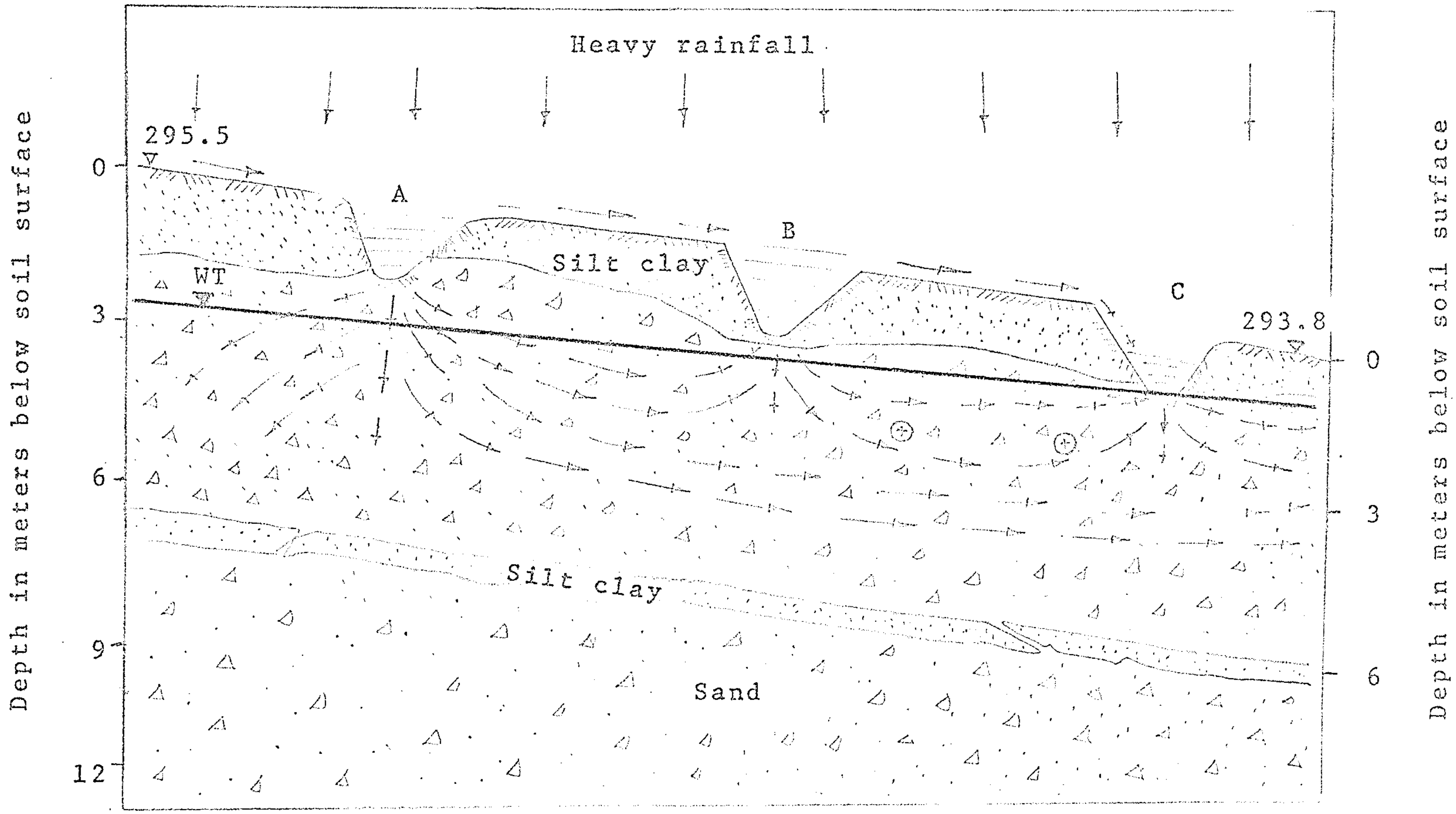

Fig. 46 Effect of ditches in the Experimental Farm in lowering the water table.

raising the water table (Fig. 46). Infiltration will be much lower in the ditches that are within the clay and silty clay layers as sand has higher saturated hydraulic conductivity. The water table will continue to rise as long as runoff water flows through the ditches. When rainfall stops and runoff water ceases to flow through the ditches, the groundwater table will fall as the groundwater flows out into the ditches that are at the extreme East of the farm which is the bottom of the slope (Fig. 46). As illustrated in the schematic diagram, ditches A, B and C are all filled up by flowing runoff. As soon as the rain stops, ditch A will start to drop first and ditch B next. The water from ditches A and B will flow through the sand and will come out at the bottom of the slope where ditch C is located.

Effectiveness of the Tiles in Lowering the Water Table

The water table was in general below the lateral drainage tile lines in early spring 1974 when the snow cover had melted but the subsoil had not yet warmed up. As the subsoil warmed up, snowmelt was able to infiltrate to the subsoil thus raising the groundwater table. When the water table rose above the lateral drainage tile lines water table draw down curves were noticed (Figs. 47 and 48). Such curves were observed in early May 1974 when

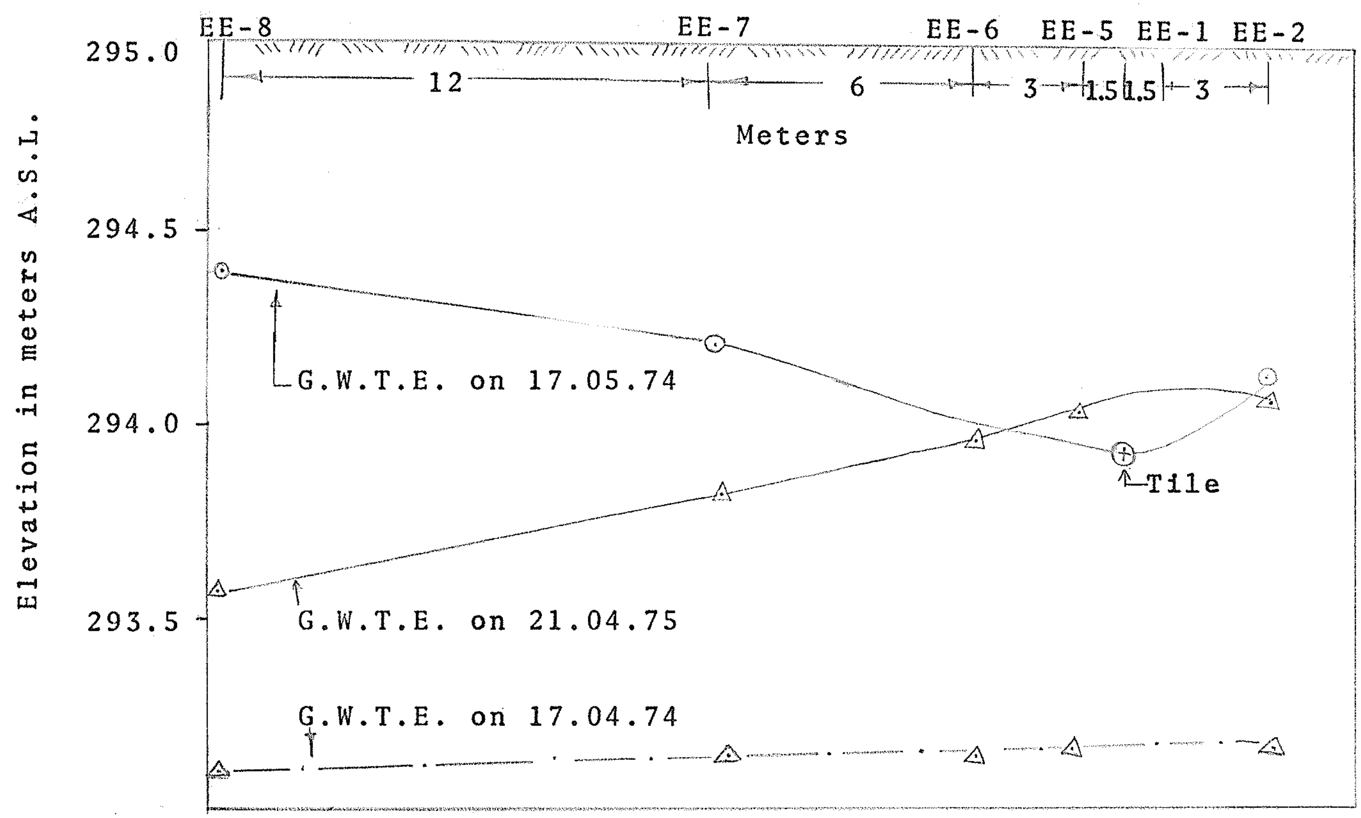

Fig. 47 Representative Groundwater table elevations across E-E in early spring, middle of the spring and early summer 1974.

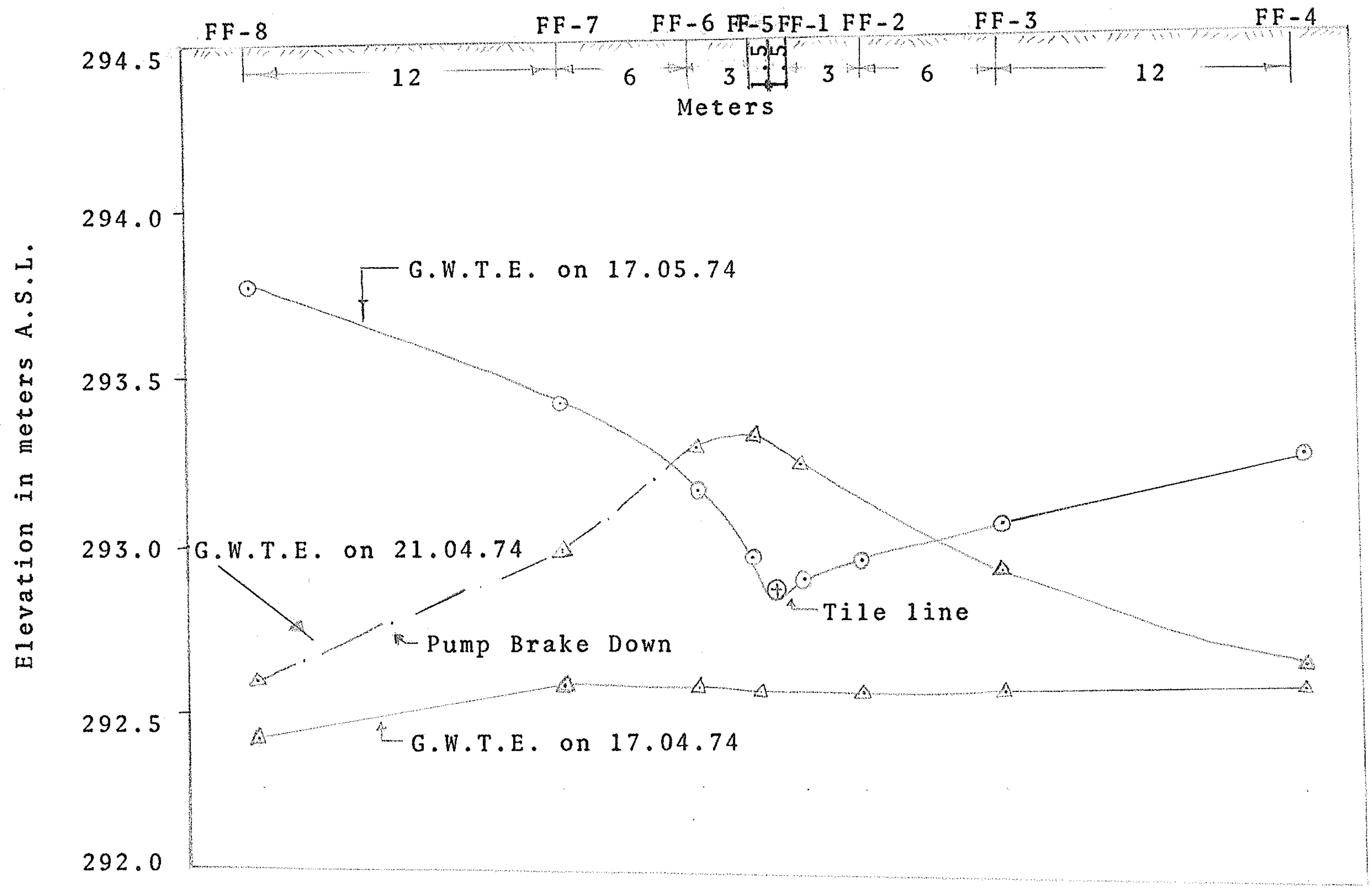

Fig. 48 Representative ground water table elevations across F-F in early spring, mid-spring and early summer.

the water table in the farm with the exception of site G-G was well above the lateral tile lines. Convex water table draw down curves were observed at site G-G where the water table was below the tile line at the time of investigation (Fig. 49).

A water table draw down curve was measured in the wells across lateral tile E-E at the end of April 1974 (Fig. 50) when water table in the wells across tile E-E was generally above the tile line. Figs. 51 and 50 show that with the exception of well EE-7 the water table was highest in EE-8 and lowest in EE-5. Wells EE-5, EE-6, EE-7 and EE-8; also EE-1, EE-2, EE-3 and EE-4 were located 1.5, 4.5, 10.5 and 22.5 meters to the West and to the East of the tile line respectively. The gradient of the draw down was low between the end of April and May 8, 1974. However, after a heavy rainfall which fell between the 8th and 12th of May 1974, the water table rose about 60 cm. resulting in a rise of the hydraulic head of the water table between the wells (Fig. 50). Since the rate of water flow between two points is governed by the magnitude of the hydraulic head, it is evident that the rate of groundwater flow into the tiles is accelerated by the rise in water table after an abnormally heavy rainfall.

The groundwater draw down curve of the wells across tile F-F were observed in mid-May 1974. The water

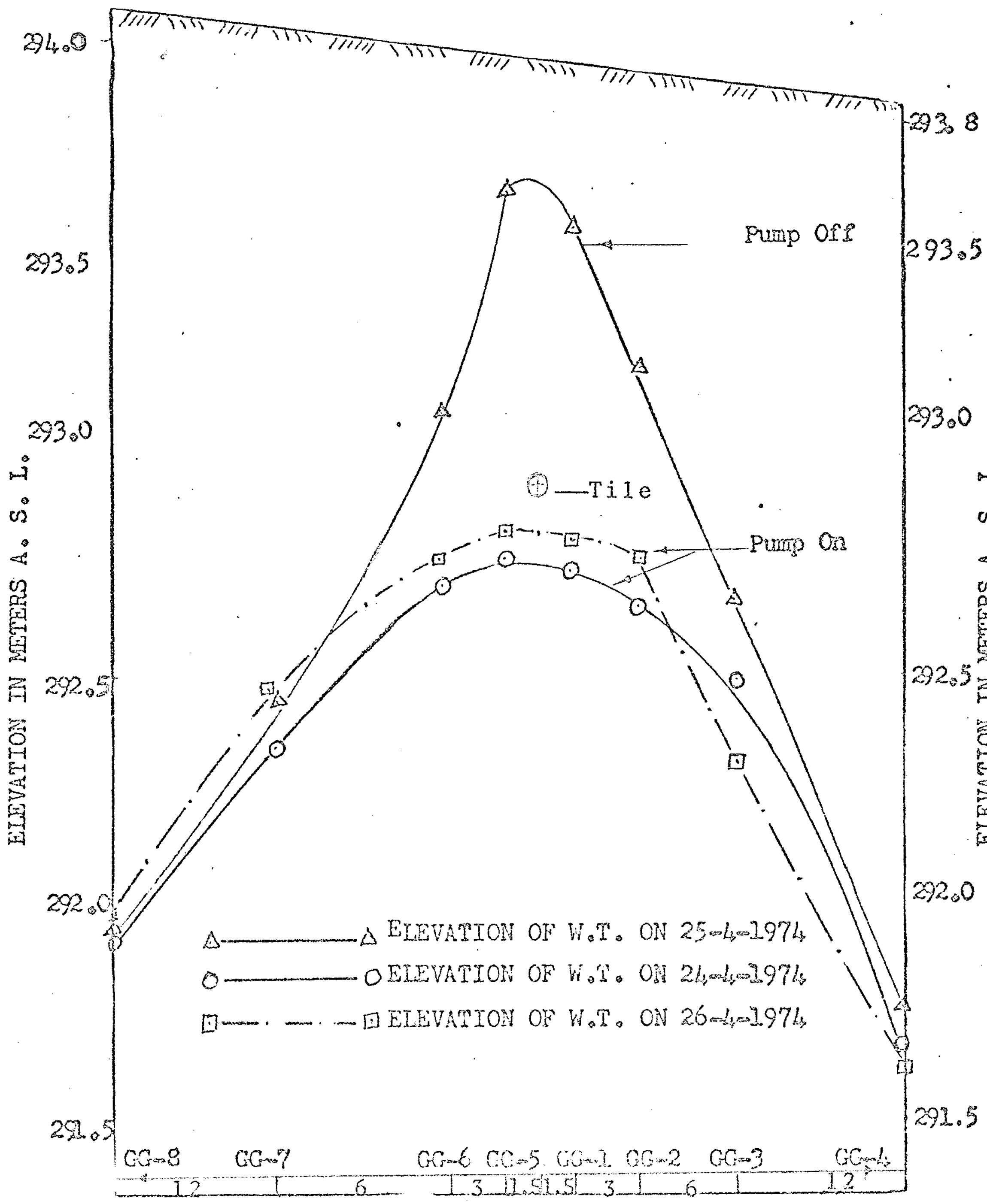

Fig. 49 The effect of groundwater table lowering and rising in lateral tile G-G as a result of whether the groundwater flowing in the main drainage tile is pumped out or not.

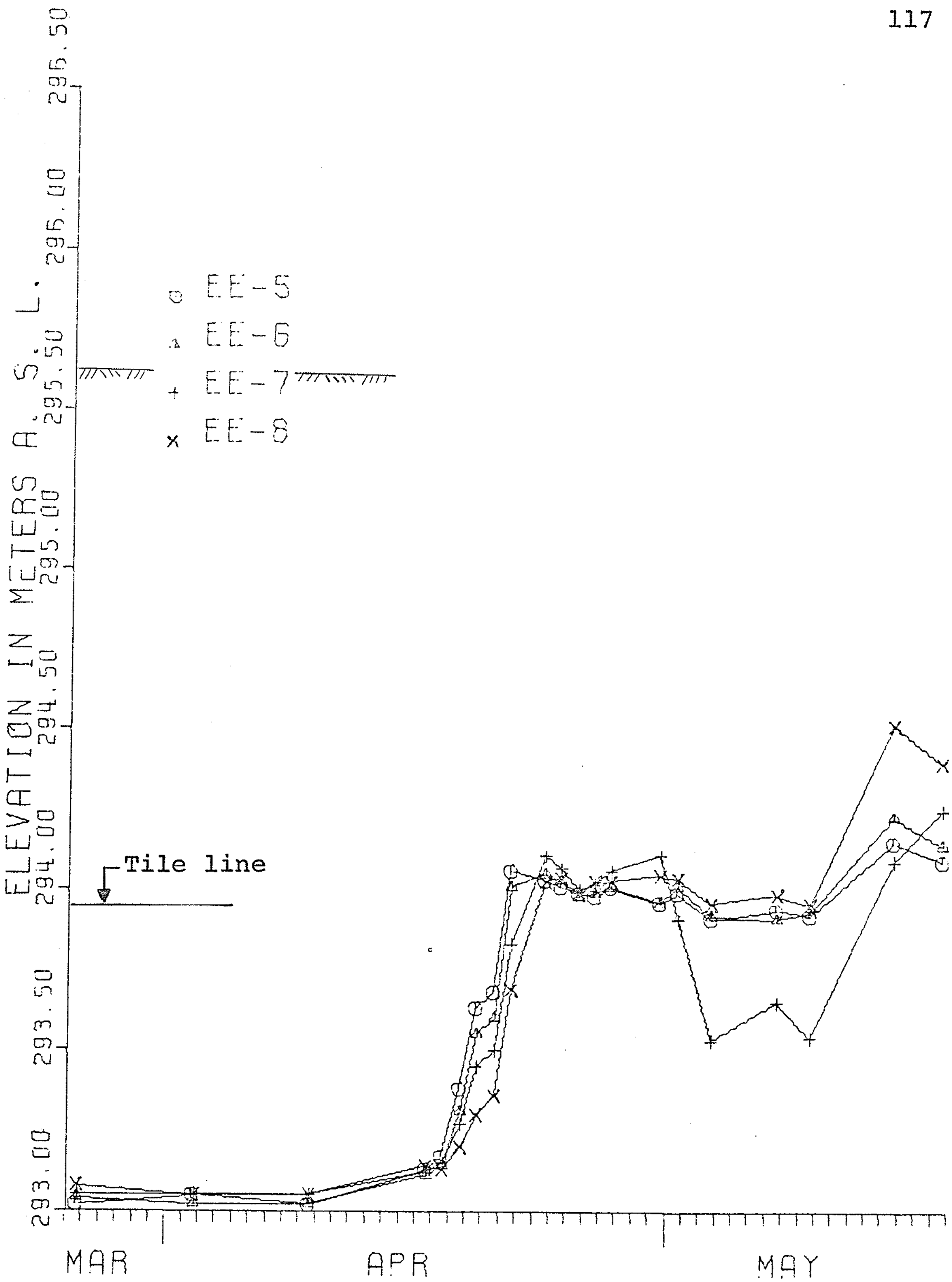

Fig. 50 Fluctuation of the water table in EE-5, EE-6, EE-7 and EE-8 during the spring and early summer 1974.

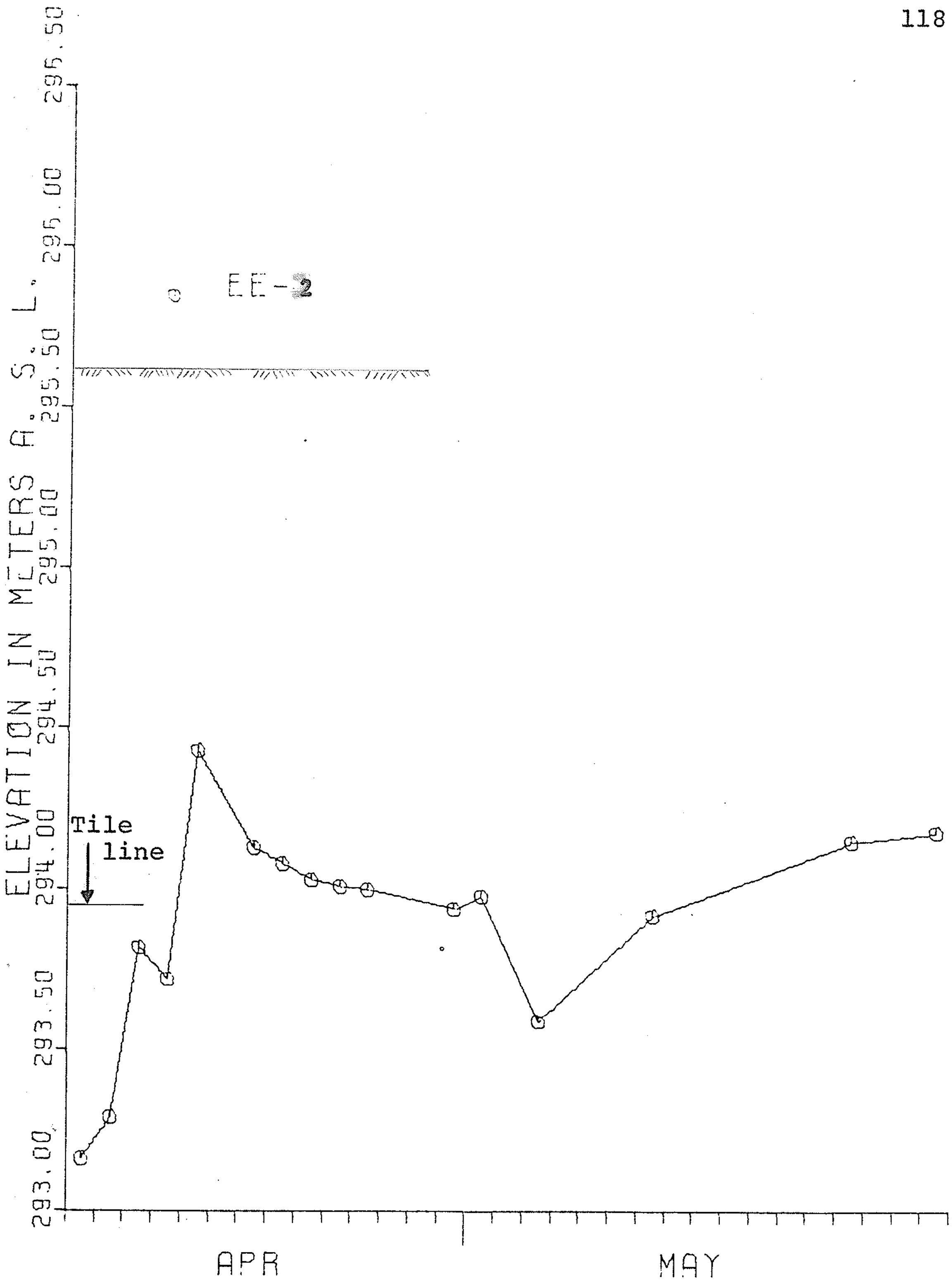

Fig. 51 Fluctuation of the water table in EE-2 during the spring and early summer 1974.

table was highest in FF-4 and FF-8 which were located 22.5 meters on either side of the tile line and was lowest in FF-1 and FF-5 which were 1.5 meters from the tile line. Figs. 52 and 53 indicate that after the area received a high rainfall of 12.7 cm., the water table rose. As the water table rose, the difference in hydraulic head between the level of the water in the tile and the level of the water table in the wells increased. This resulted in faster movement of the groundwater to the tile line.

The large differences in the hydraulic heads of the water table in the wells across tile F-F as compared to those across tile E-E is probably due to the general elevation of the water table relative to the depth of the tile lines below the soil surface. The deeper the tile line below the soil surface the larger will be the difference in hydraulic head of the water in the tile and the elevation of the water in the wells. Tile F-F is a few centimeters deeper in the soil surface as compared to the elevation of tile E-E below the soil surface.

The groundwater table was below tile line G-G during spring, summer and autumn of 1973. Figs. 54 and 55 show that due to the low water table elevations there was no draw down curve obtained. Unlike the water table elevation in the wells across tiles E-E and F-F, in the spring when the water table is highest it was still below

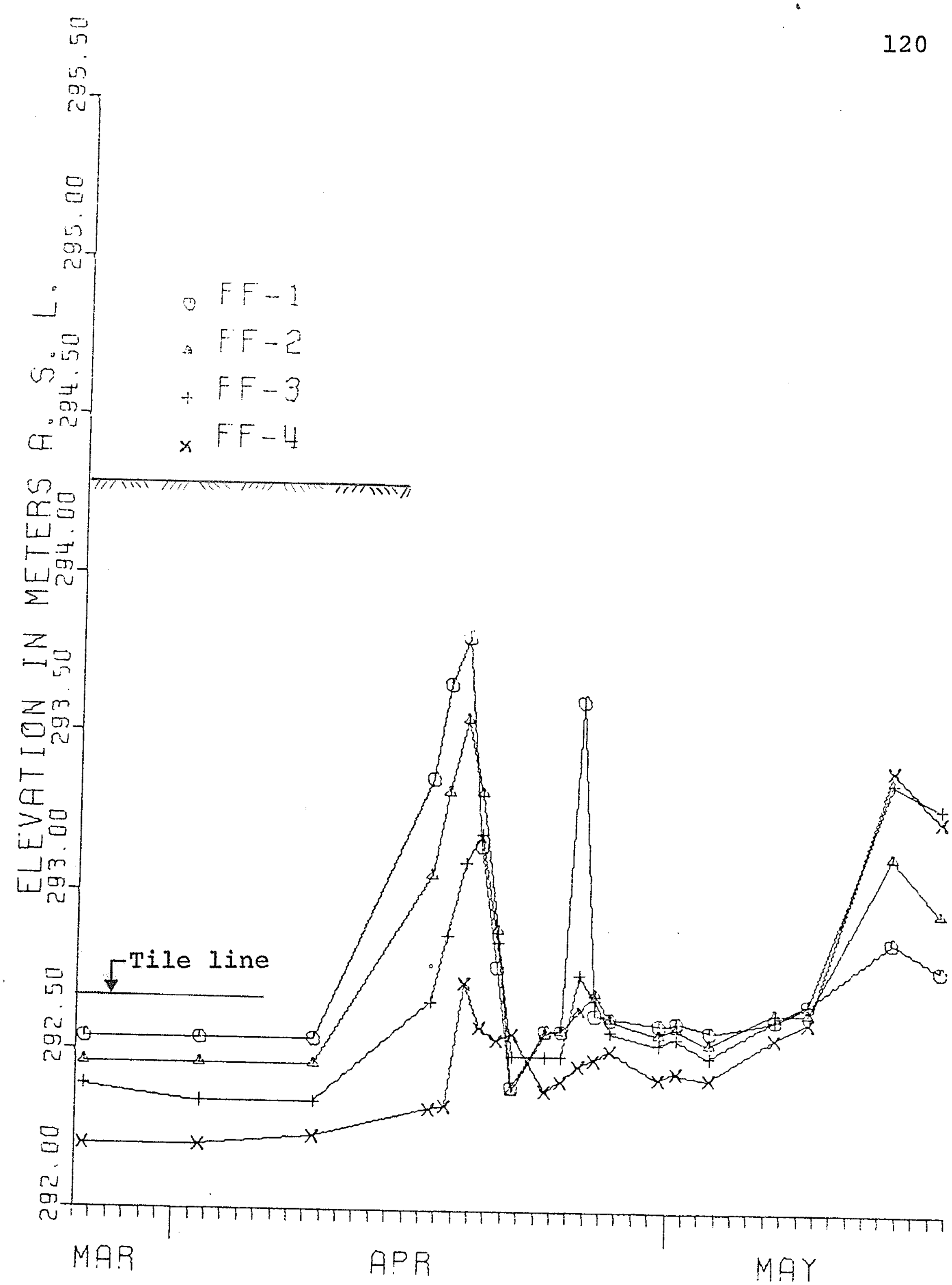

Fig. 52 Fluctuation of the water table in FF-1, FF-2, FF-3 and FF-4 during the spring and early summer 1974.

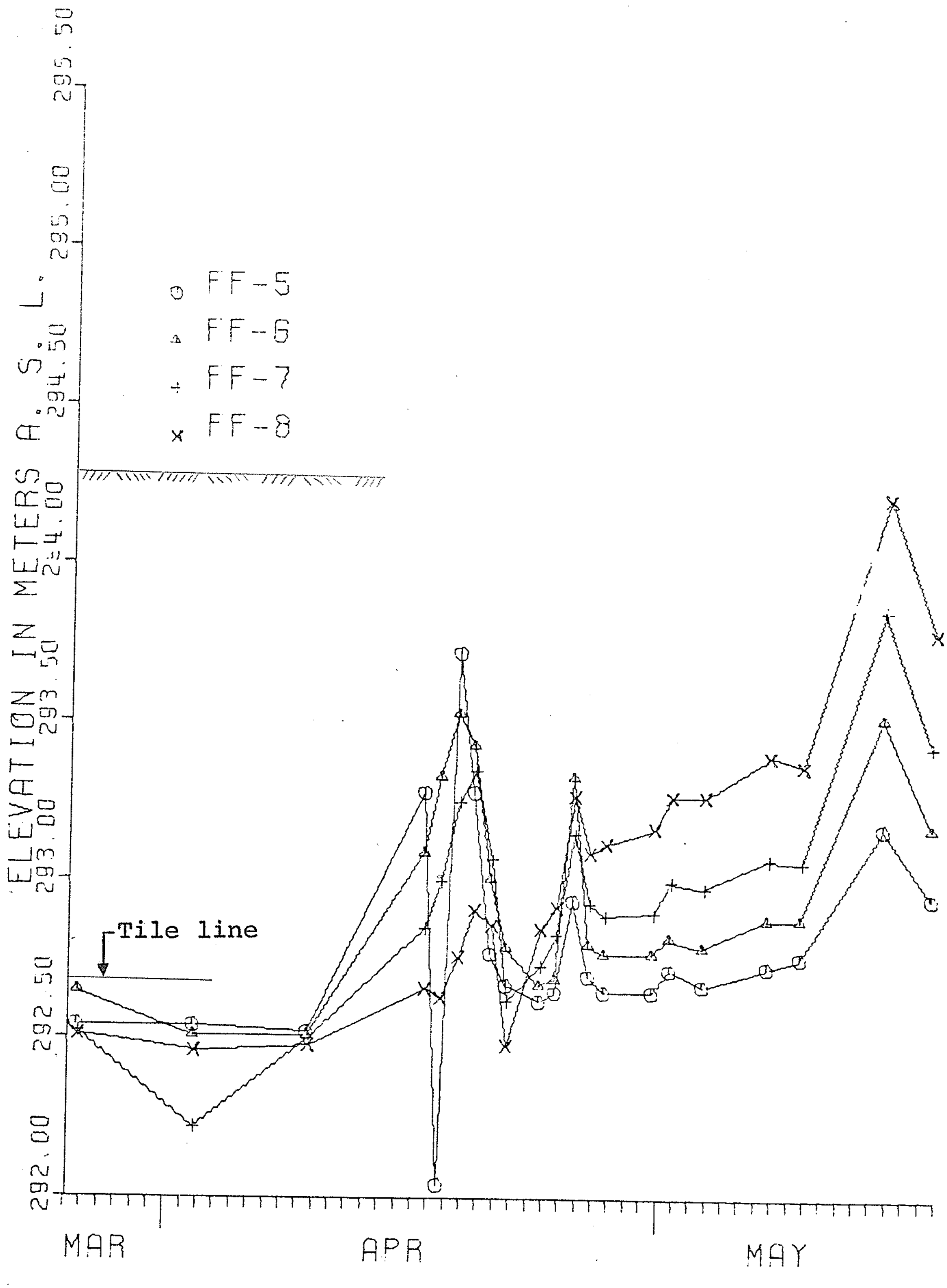

Fig. 53 Fluctuation of the water table in FF-5, FF-6, FF-7 and FF-8 during the spring and early summer 1974.

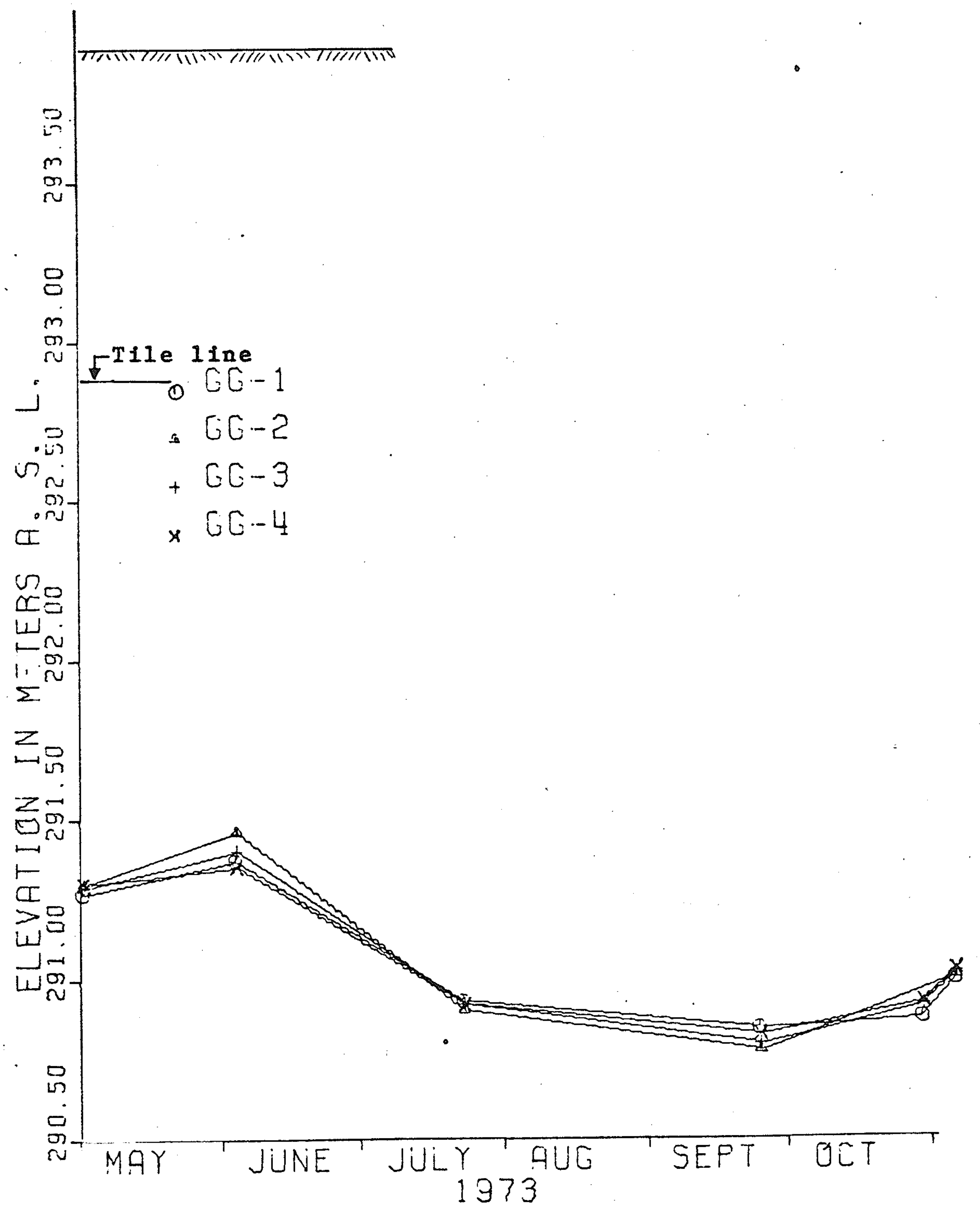

Fig. 54 Fluctuation of the water table in GG-1, GG-2, GG-3, and GG-4 in 1973.

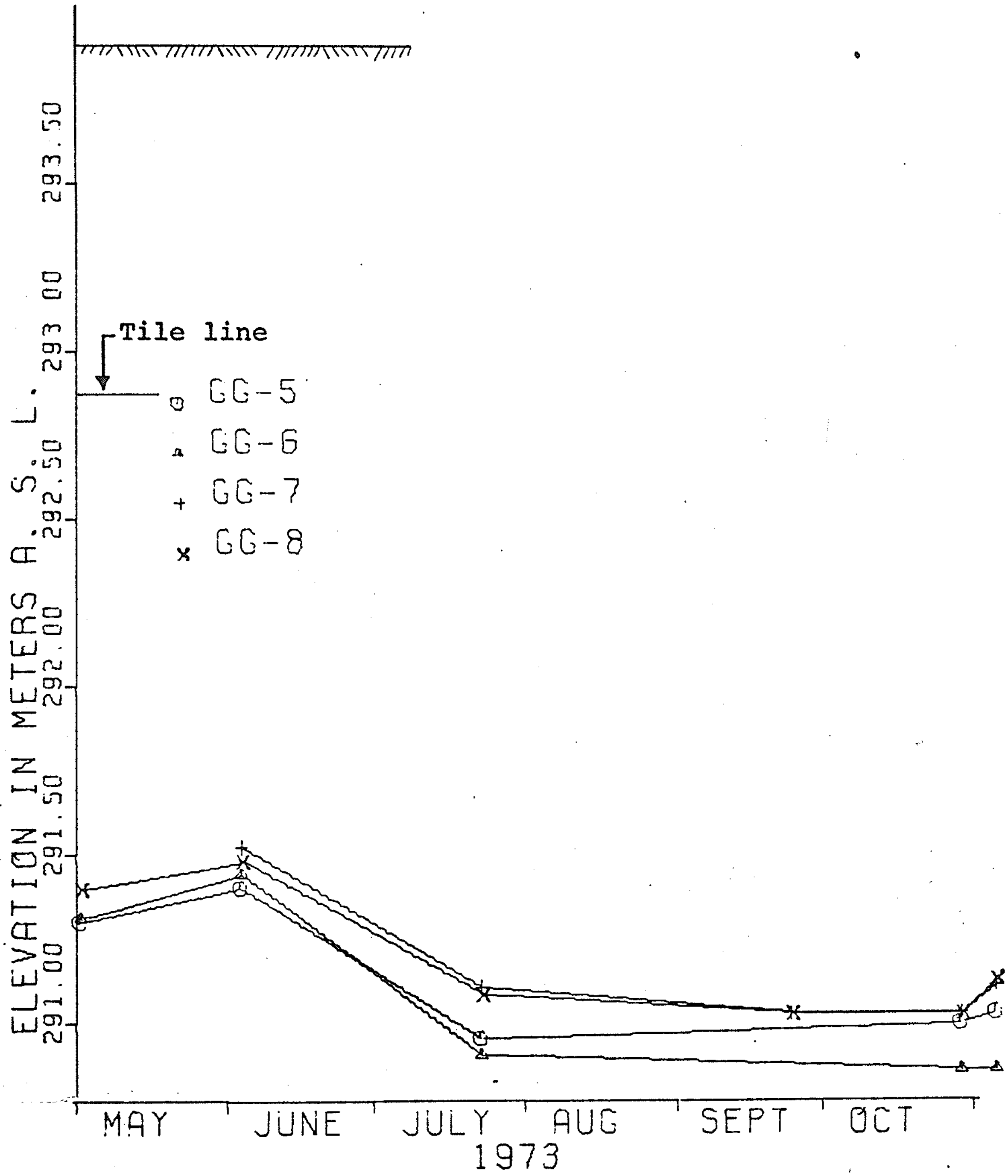

Fig. 55 Fluctuation of the water table in GG-5, GG-6, GG-7 and GG-8 in 1973.

the tile line. A convex water table was observed (measured) in the wells across the tile. The water table was highest in wells GG-1 and GG-5 and lowest in wells GG-4 and GG-8 which were 22.5 meters from the tile line on either side of it (Figs. 49, 56 and 57).

The fact that the water table was highest in the soils near the tile line and lowest in the soils that were 22.5 meters from the tile line, shows that the tile line feeds the soils near it with water. Water table elevation data collected from W-9 located directly to the North of G-G shows that during the spring and after a heavy rainfall the water table to the North of tile G-G is much higher than the general water table at site G-G. Due to the differences in water table elevation between the North of tile line G-G and site G-G is evident that groundwater is able to flow from the North of tile G-G through the tile line to the manhole. As the water was flowing in the tile, it came out of tile line segment joints thus raising the water table in the soils near the tile line (Fig. 49).

With the exception of tile line G-G it can generally be concluded that the tiles are effective to some degree in lowering the water table. The water table is generally, with the exception of tile G-G, high on the Western side of tiles E-E and F-F. This fact is probably due to the

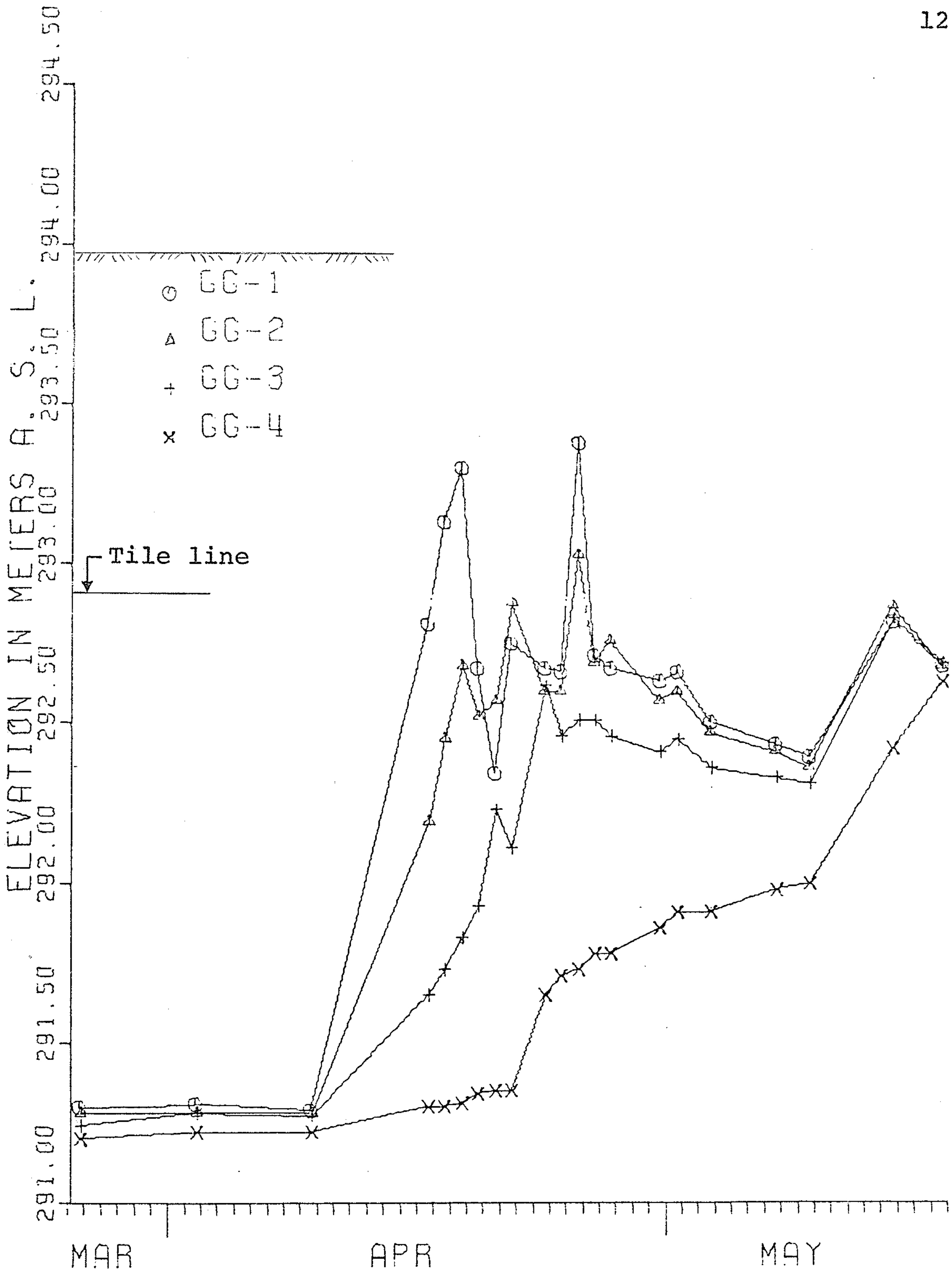

Fig. 56 Fluctuation of the water table in GG-1, GG-2, GG-3 and GG-4 during the spring and early summer 1974.

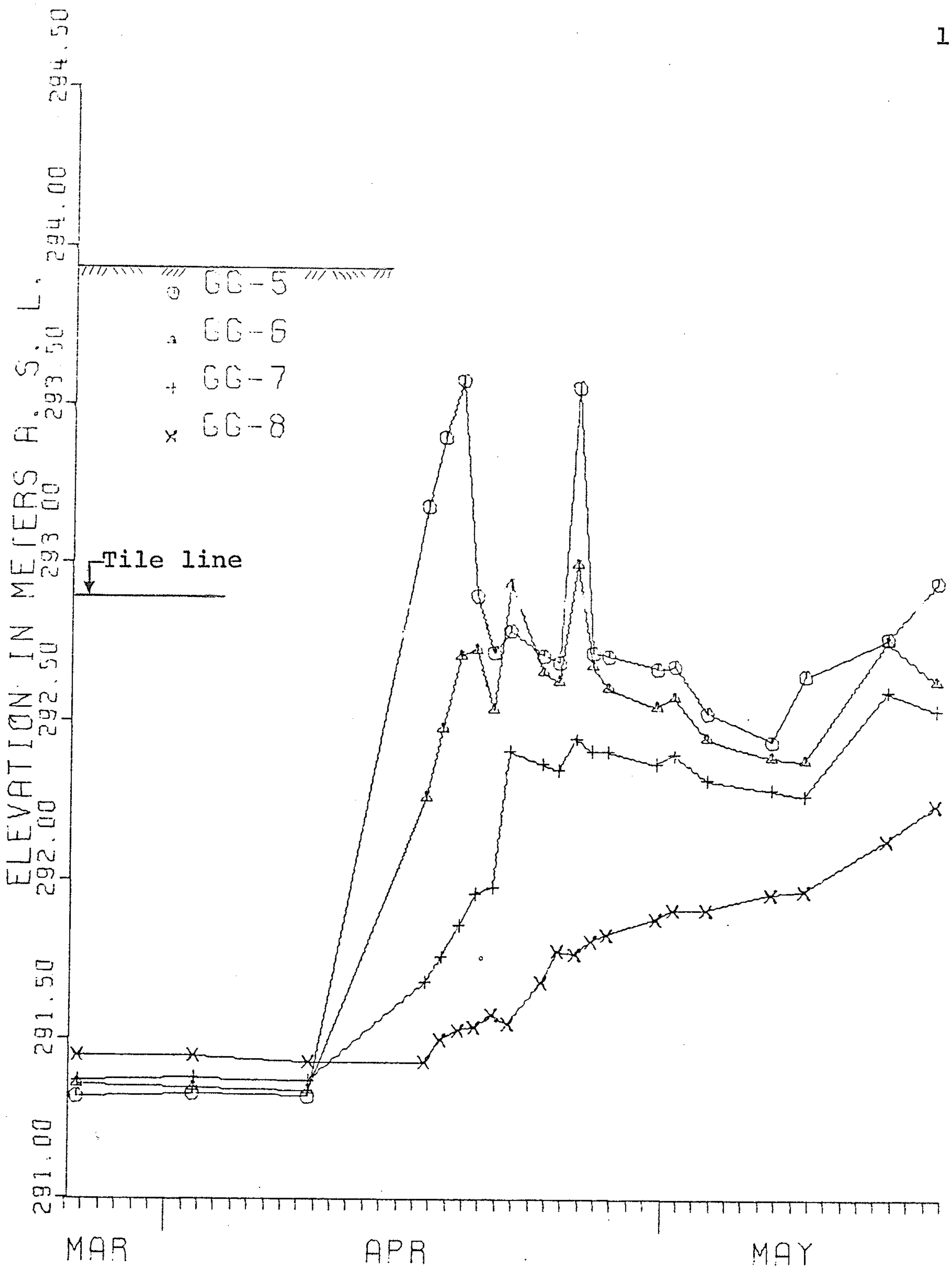

Fig. 57 Fluctuation of the water table in GG-5, GG-6, GG-7 and GG-8 during the spring and early summer 1974.

tile lines intercepting and draining the groundwater as it flows from West to East. For the tiles to continue lowering the water table, the water in the sumps should continuously be pumped out. In a later section of this chapter a detailed discussion on the effect of the breakdown of the pumping system on lowering of the water table by the tiles will be presented.

In the study area, the water table was in general above the tile lines from mid-April to early summer 1974. Since the objective of the tile drainage system is to lower the water table below the level of the lateral tile lines, it is possible to conclude that in general the tile drainage network was unable to effectively lower the water table.

Water Table Heights as Affected by the Breakage of the Pumping Stations

When the pumps are turned off the rising groundwater in the spring enters into the lateral drainage tile lines which carries it to the manholes and the sumps. When the system does not pump the drained water from the sumps, the sumps and the manholes get filled with the drained groundwater. The water in the manholes and sumps then starts to flow back into the lateral tile lines and the mains. As it flows back into the tiles, it goes out through the segment tile joints thus saturating the soils near the tiles and thus raising the water table. In general a concave shaped water table curve results.

The effect of breakdown of the pumping stations is clearly noted in the wells across lateral tile lines F-F and G-G (Figs. 48 and 49). The water table in well W-A (Fig. 58) which is located about 3 meters from tile line F-F and about 60 meters South of the main showed a sharp rise when the pump at the sump was off and a sharp decrease when the pump at the sump was on (Fig. 59).

The sudden rise in groundwater table as a result of the breakdown of the pumping station at the sump is clearly noticed in the water table hydrographs (Figs. 52, 53, 56, 57, 58 and 59). The hydrographs show that of the three well cross-sections only the water table in the wells across tile lines F-F and G-G responded to the breakage of the pumping system. The water table across tile E-E responded very slightly to the breakage of the system. A probable explanation is that tile E-E was installed at a higher elevation than the mains, thus as the sump became filled with unpumped drained water, the level of the drained water in the sump did not reach the level of tile line E-E instead it flowed into the mains which carried it to the manholes F-F and G-G.

When the pumping system breaks down, tile line G-G

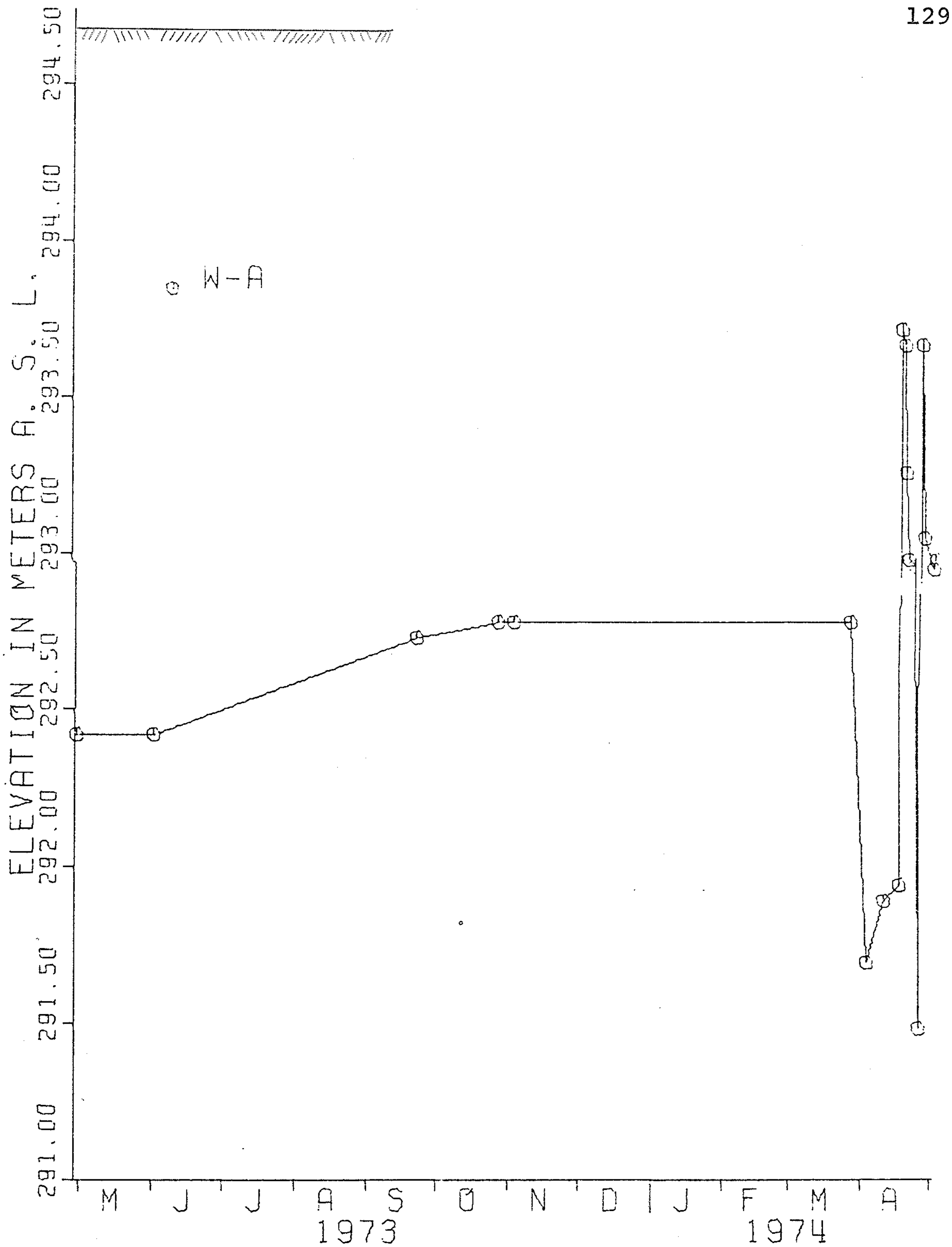

Fig. 58 Fluctuation of the water table in W-A in 1973 and during spring and early summer, 1974.

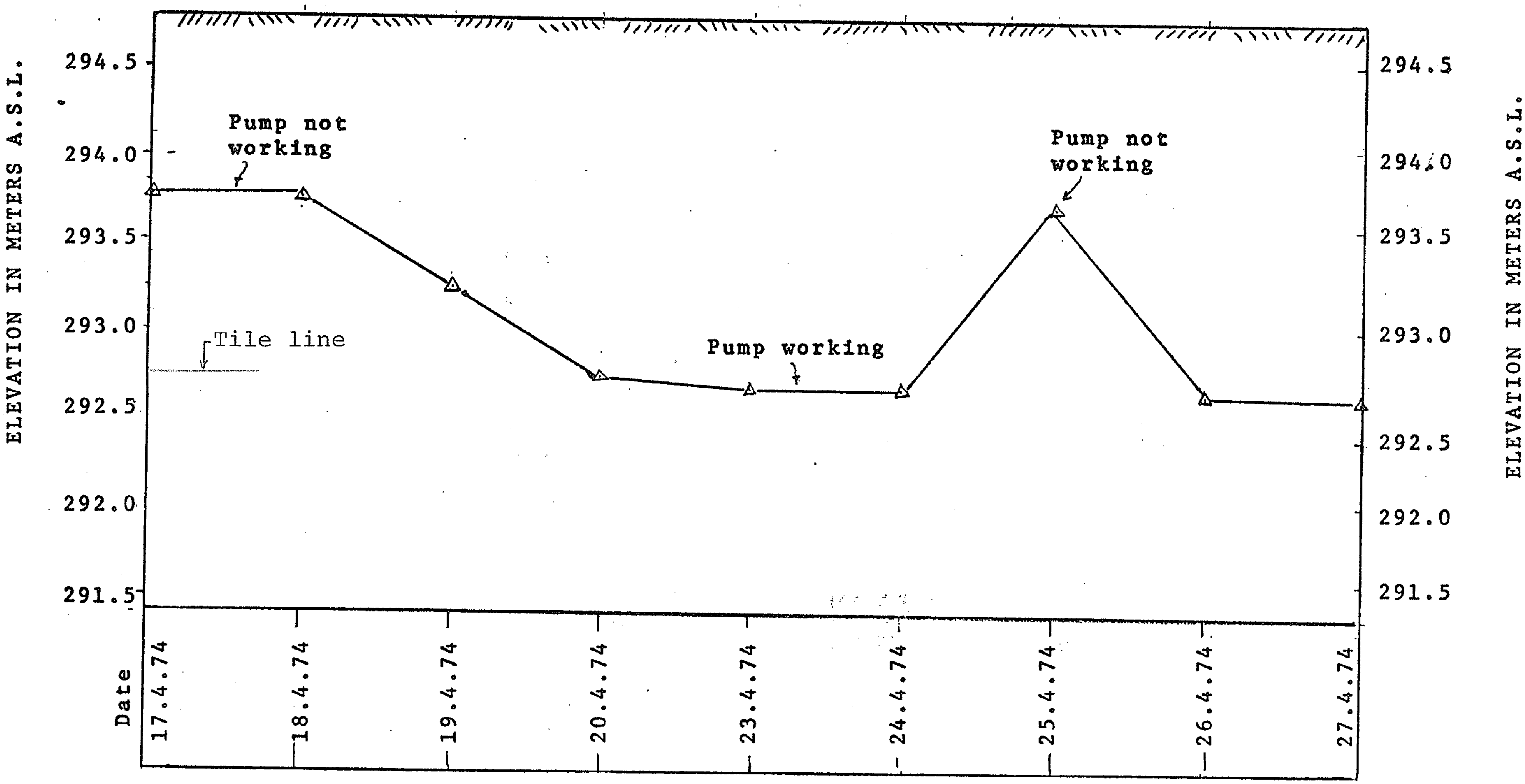

Fig. 59 Fluctuation of groundwater table in W-A which is 0.3 meters away from lateral drainage tile F-F.

being at the bottom of the slope is bound to be affected more than the other tile lines. This is due to the fact that as soon as the pump stops operating, drained groundwater will flow to the manhole of the tile line G-G after it has reached the level of the main at the sump. After the groundwater had backfilled tile line G-G, then it flowed back in tile line F-F and then tile E-E. Since tile E-E is at a higher elevation when compared to the elevation of tile F-F and G-G, it is unlikely that groundwater will backflow into tile line E-E.

<u>Soil Salinity in Relation to Pump Operation and Water Table Fluctuation</u>

Soluble salts move to the topsoil with rising groundwater table or by capillary action. In 1973, since the groundwater table was about 3 meters below the soil surface, it is probably that soluble salts did not move to the soil surface by rising water table. Soluble salts may have moved to the topsoil by capillary action. In the spring and early summer 1974, soluble salts were brought to the surface with the rising water table. The electrical conductivity of the water in the wells of the study area was usually greater than 5 mmhos./cm. (Table 3). If the soil profile sites sampled in the fall of 1972 and 1973 were resampled in the fall of 1974, it is possible

TABLE 3

ELECTRICAL CONDUCTIVITY OF GROUNDWATER
(MMHOS./CM. AT 25°C.)

No. of Wells \ Date	27.4.73	18.7.73	1.11.73	7.5.74	9.5.74	14.5.74
EE-2	-	-	7.5	7.0	6.0	6.5
EE-5	-	-	8.0	8.0	7.5	8.0
EE-6	-	-	7.9	8.0	7.0	8.0
EE-7	-	-	7.9	7.9	7.5	8.0
EE-8	-	-	8.6	9.0	5.5	6.5
FF-1	-	-	7.6	8.0	4.5	5.0
FF-2	-	-	7.3	7.5	6.5	7.0
FF-3	-	-	7.3	7.5	6.5	6.5
FF-4	-	-	7.6	8.0	7.5	8.0
FF-5	-	-	7.7	8.0	6.5	7.0
FF-6	-	-	8.2	8.0	7.5	7.5
FF-7	-	-	8.5	8.5	7.0	7.0
FF-8	-	-	9.0	9.0	7.5	7.5
GG-1	5.7	5.2	6.8	4.0	4.0	4.0
GG-2	7.5	7.2	8.2	7.5	7.5	8.5
GG-3	9.5	9.1	9.5	10.5	10.5	11.0
GG-4	10.5	9.0	9.5	11.0	12.0	13.0
GG-5	6.5	5.9	7.3	4.0	3.8	4.0
GG-6	7.6	Dry	Dry	9.5	10.5	10.0
GG-7	12.0	11.0	Dry	11.5	12.0	14.0
GG-8	13.0	12.1	Dry	12.5	13.0	13.5
W-9	14.0	11.7	10.0	11.0	11.0	11.0
OW-1	9.2	8.8	8.5	8.8	7.5	8.0
OW-3	5.4	6.5	6.7	6.5	5.5	6.0
WD-0	2.8	3.4	3.8	3.5	2.8	3.0
W-A	3.7	3.1	3.6	3.5	3.5	3.1
OW-5	7.5	6.7	7.0	6.5	6.5	6.5

that soluble salt concentration would be higher than it was in the first sampling.

As explained earlier, the purpose of the tile drainage network is to lower the water table. Since the water table was about 1 meter above the tiles in mid-April and early summer 1974 (except at site G-G) we can conclude that generally the tiles were not able to effectively lower the groundwater table. However, the tile drainage system of the study area was only able to lower the groundwater to some degree. From field observation when the pumps were on, lateral tiles E-E and F-F discharged more groundwater than tile G-G. Tile lines E-E and F-F were therefore active to some degree in lowering soluble salt concentration by lowering the water table.

When the drained groundwater flows back into the tiles when the pumps are off it saturates the soils with mineralized water. Instead of the tile drainage network decreasing soil salinity, it increases soil salinity when the pumps are off. Previous researchers who worked on the problem (including Bushayev, 1914) have pointed out that drained water flowing back into the tiles create a pressure in the tiles which could damage the tile line.

In evaluating soil salinity of the study area as it is affected by fluctuating groundwater table and operation of the tile drainage network we can make general remarks. Although the decrease of soluble salts by lowering the water table is a long term process, it seems obvious at the present time that the tiles are unable to reduce soil salinity because they are not capable of lowering the groundwater table. It seems that the rate at which groundwater flows into the farm is much faster than the rate at which the tiles are able to lower the water table. Probably the tiles are too widely spaced apart thus closer lateral tile drainage could be necessary so as to increase the quantity of drained water by the tiles. It is also possible that the tiles are unable to lower the water table fast enough due to the lengths of the segments. As discussed in the 'Literature Review' section, a tile drainage line with shorter segments discharges more water than one which has long segments. Since we are not sure of the lengths of the segments of the tiles used, it is possible that tile segment length has contributed to the ineffeciency of the tiles in lowering the water table.

As discussed earlier under no circumstances should the pumps be turned off at any time in the spring and early summer when the water table is above the tile lines. In case of pump breakage, repair should be made as soon as possible in order to avoid the possibility of the tiles feeding the soils with mineralized groundwater.

SUMMARY AND CONCLUSIONS

The main objective of this study was to evaluate the effectiveness of the tile drainage system in reducing soil salinity. The study was carried out at the North-east corner of the Morden Experimental Farm on an area of 2,221,560 square meters. The study area has an average West to East slope of 1:200.

The tile drainage network was installed in 1967. If it had been effective in lowering the groundwater table we would expect the water table not to rise above the tile lines during the spring and early summer when the water table was highest. We would also expect a consistent decrease in soluble salts in the soils approaching the lateral tile lines. The electrical conductivity should decrease in the soils with decreasing distance from the lateral tile lines.

With the exception of the soils to the West of the tile line E-E whose electrical conductivity varied from 1 to 4 mmhos./cm. up to the level of the tile line and up to a distance of 22.5 meters from the tile line, the electrical conductivity of the soils across the tiles was generally greater than 5 mmhos./cm. The electrical conductivity varied from 5 to about 12 mmhos./cm. Site G-G was the most saline area. Electrical conductivity as high as 12 mmhos./cm. was measured in the soils 10 meters from the tile and about 1.5 meters soil depth. The high amounts of dissolved soluble salts in the soils which resulted in high electrical conductivity values, is attributed to rising mineralized groundwater containing Na^{+}, Mg^{++}, Ca^{++}, Cl^{-} and $SO_4^{=}$ in the spring or after a heavy rainfall. The soluble salts in rising the mineralized groundwater are absorbed by the soil particles. When the water table falls in the winter they are left behind. In the summer they move upwards by capillary action.

The electrical conductivity was generally low in the soils around and above the tile lines. The decrease in electrical conductivity indicated a decrease in dissolved soluble salts. The decrease in soluble salts of the soils to the West of tile line E-E and of the soils above and around the tile lines is attributed to leaching of soluble salts by infiltrating rainwater and infiltrating standing snowmelt.

Due to the differences in solubility, the investigated soils are generally dominated by calcium and $SO_4^{=}$. The distribution of magnesium, sodium and chloride in the soil profiles across the tile lines follows the pattern of the electrical conductivity. The concentrations of magnesium, sodium and chloride are lowest up to the level of tile line E-E on the Western side. They are also low in the soils around and above the tile lines. Such a distribution is attributed to a leaching effect as a result of infiltrating standing snowmelt and rainwater. Calcium and sulphur being the least soluble, indicate a slight decrease in the soils around and above the tile lines also in the soils to the West of tile line E-E.

In general the tiles were not very effective in lowering the water table. The water table remained above the tile line (with the exception of the wells across tile line G-G), from mid-spring to early summer when the water table was highest. If the tile lines were effective in lowering the water table of the study area, we would have expected the water table generally not to rise above the level of the tile lines. There are two probable explanations concerning the inability of the tiles in lowering the water table. It is possible that groundwater flows into the farm much faster than the tiles can drain and pump out. In this regard, it is necessary to use lateral tile lines with large diameters since the larger the diameter the larger the quantity of water that can flow through them. It is also important that the capacity of the pumping system is improved so that the pump can handle large quantities of water. Tile spacing is very important on the effect of the tiles in lowering the water table. When tiles are closely spaced together, they become very efficient in lowering the groundwater table. The more widely they are spaced, the more inefficient they become in lowering the water table. It is suggested that more tiles be installed in order to decrease the tile spacing.

The water table data indicated a water table rise in the soils close to the tile lines when the pump was not working. When the pump broke down drained groundwater was forced to flow back into the main and lateral drainage tile lines. As it flowed back it raised the groundwater table in the soils near the tile lines and fed them with soluble salts, In order to make sure that the soils are not fed with mineralized groundwater, it is necessary that the pumps at the sumps are kept operating constantly during mid-spring and mid-summer when the water table is above the lateral drainage tile lines.

In order to hasten the reclamation process of the soils of the study area a number of methods can be applied. Some of them have already been discussed in detail in the 'Literature Review' section. We can just point out that diking, irrigation, summer fallow and deep plowing are practical methods that can be applied in the study area. They are effective methods that have been used in different parts of the world, including U.S.A. and Soviet Union, in reclaiming saline soils. If none of the suggested methods are adopted, it is certain that at the present rate at which the tiles remove soluble salts, it will take many years for the 120 cm. topsoil to have electrical conductivity less than 4 mmhos.

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APPENDIX A

ELECTRICAL CONDUCTIVITY AND WATER SOLUBLE CATIONS AND ANIONS IN THE SOIL PROFILES OF THE CROSS-SECTION ACROSS THE TILE LINES E-E, F-F AND G-G

TABLE A-1

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE EE-1

DEPTH OF SOIL SAMPLE IN METERS	E.C.	CATIONS M.E./L.			TOTAL CATIONS M.E./L. OF	ANIONS M.E./L.		TOTAL ANIONS M.E./L. OF
	MMHOS./CM	Ca	Mg	Na	Ca, Mg AND Na	SO_4	CL	SO_4 AND CL
0-0.3	0.42	1.50	0.82	0.87	3.19	1.45	1.08	2.53
0.3-0.6	0.50	1.90	0.90	1.04	3.84	3.28	TRACE	3.28
0.6-0.9	1.16	2.50	2.39	2.61	7.50	7.95	1.07	9.02
0.9-1.2	3.54	12.48	6.42	18.27	37.17	44.15	0.10	44.25
1.2-1.5	2.69	6.24	7.24	8.27	21.75	29.50	0.78	30.28
1.5-1.8	2.31	3.74	6.58	7.39	17.71	23.10	0.24	23.34
1.8-2.1	4.50	16.89	18.45	17.83	53.17	54.50	2.58	57.08
2.1-2.4	5.04	18.23	20.57	16.53	55.33	70.00	3.41	73.41
2.4-2.7	5.03	16.49	19.09	20.01	55.59	72.60	3.80	76.40
2.7-3.0	5.28	16.24	24.68	28.71	69.63	76.50	4.78	81.28

TABLE A-2

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE EE-2

DEPTH OF SOIL SAMPLE IN METERS	E.C. MMHOS./CM	CATIONS M.E./L. Ca	Mg	Na	TOTAL CATIONS M.E./L. OF Ca, Mg AND Na	ANIONS M.E./L. SO_4	CL	TOTAL ANIONS M.E./L. OF SO_4 AND CL
0-0.3	1.10	2.50	1.65	3.26	7.41	6.00	1.27	7.27
0.3-0.6	3.90	8.73	7.40	15.66	31.79	31.50	2.39	33.89
0.6-0.9	5.20	12.48	10.69	20.88	44.05	53.00	3.32	56.32
0.9-1.2	5.17	11.88	16.04	26.97	54.89	75.40	3.32	78.72
1.2-1.5	5.10	9.98	13.57	23.49	47.04	67.60	3.56	71.16
1.5-1.8	5.00	11.23	13.74	20.88	45.85	65.00	2.44	67.44
1.8-2.1	5.01	13.72	19.09	17.40	50.21	73.60	1.76	75.36
2.1-2.4	4.50	6.24	17.77	14.79	38.80	31.75	2.24	33.99
2.4-2.7	5.14	8.73	22.38	21.75	52.86	153.63	3.32	156.95
2.7-3.0	5.70	9.14	25.16	48.74	83.04	157.95	3.49	161.44

TABLE A-3

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE EE-3

DEPTH OF SOIL SAMPLE IN METERS	E.C. MMHOS./CM	CATIONS M.E./L. Ca	Mg	Na	TOTAL CATIONS M.E./L. OF Ca, Mg AND Na	ANIONS M.E./L. SO_4	CL	TOTAL ANIONS M.E./L. OF SO_4 AND CL
0-0.3	0.60	1.90	10.69	0.87	13.46	11.78	0.10	11.88
0.3-0.6	2.99	13.12	9.46	6.96	29.54	35.68	1.17	36.85
0.6-0.9	5.40	11.23	15.63	21.53	48.39	74.25	2.83	77.08
0.9-1.2	4.30	12.48	15.22	14.79	39.75	54.63	2.88	57.51
1.2-1.5	6.00	10.93	9.54	26.97	47.44	53.70	3.12	56.82
1.5-1.8	4.50	13.12	9.05	21.75	43.92	49.83	3.12	52.95
1.8-2.1	4.00	4.39	11.52	16.53	32.44	43.68	2.44	46.12
2.1-2.4	4.70	6.24	16.45	17.40	40.09	58.83	3.07	61.90
2.4-2.7	5.30	6.29	18.92	20.88	46.09	102.95	3.80	106.75
2.7-3.0	6.70	8.98	25.50	30.45	64.93	90.75	5.17	95.92

TABLE A-4

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE EE-4

DEPTH OF SOIL SAMPLE IN METERS	E.C.	CATIONS M.E./L.			TOTAL CATIONS M.E./L. OF	ANIONS M.E./L.		TOTAL ANIONS M.E./L. OF
	MMHOS./CM	Ca	Mg	Na	Ca, Mg AND Na	SO_4	CL	SO_4 AND CL
0-0.3	0.60	2.30	2.47	0.83	5.60	4.40	0.39	4.79
0.3-0.6	0.45	11.24	1.65	0.87	13.76	10.80	0.20	11.00
0.6-0.9	3.64	14.15	27.56	8.70	50.41	57.15	0.68	57.83
0.9-1.2	4.80	17.48	28.38	16.09	61.95	64.90	0.64	65.54
1.2-1.5	5.00	10.29	79.80	19.14	109.23	107.60	1.22	108.82
1.5-1.8	5.30	14.98	40.30	24.79	80.07	79.30	3.02	82.32
1.8-2.1	6.10	17.18	39.08	30.45	86.71	84.80	3.12	87.83
2.1-2.4	8.30	22.14	74.04	39.37	135.55	123.90	5.51	129.41
2.4-2.7	7.10	23.13	74.04	33.93	131.10	129.15	5.02	134.17
2.7-3.0	8.00	29.14	79.80	39.15	148.09	130.70	5.95	136.65

TABLE A-5

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE EE-5

DEPTH OF SOIL SAMPLE IN METERS	E.C.	CATIONS M.E./L.			TOTAL CATIONS M.E./L. OF	ANIONS M.E./L.		TOTAL ANIONS M.E./L. OF
	MMHOS./CM	Ca	Mg	Na	Ca, Mg AND Na	SO_4	CL	SO_4 AND CL
0-0.3	0.78	2.50	1.23	0.52	4.25	3.10	0.39	3.49
0.3-0.6	0.46	1.50	0.82	0.43	2.75	2.10	0.70	2.80
0.6-0.9	0.49	1.25	1.15	0.43	2.83	0.03	2.05	2.08
0.9-1.2	0.80	2.50	1.73	0.87	5.08	5.23	0.24	5.47
1.2-1.5	2.69	13.22	6.75	1.74	21.71	38.08	0.59	58.67
1.5-1.8	3.40	13.72	9.05	5.22	27.99	46.13	0.44	46.57
1.8-2.1	4.50	9.97	15.63	22.18	57.79	60.93	1.66	62.59
2.1-2.4	6.60	12.13	27.15	25.23	64.51	63.75	4.39	68.14
2.4-2.7	6.30	14.97	25.50	24.36	64.83	59.50	4.73	54.77
2.7-3.0	6.70	8.23	24.68	30.45	63.36	59.75	5.02	64.77

TABLE A-6

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE EE-6

DEPTH OF SOIL SAMPLE IN METERS	E.C. MMHOS./CM	CATIONS M.E./L. Ca	Mg	Na	TOTAL CATIONS M.E./L. OF Ca, Mg AND Na	ANIONS M.E./L. SO_4	CL	TOTAL ANIONS M.E./L. OF SO_4 AND CL
0-0.3	0.60	1.19	0.82	0.43	2.44	2.38	0.15	2.53
0.3-0.6	0.40	3.14	2.06	0.35	5.55	3.05	TRACE	3.05
0.6-0.9	2.50	2.18	1.65	0.43	5.26	33.65	0.39	34.04
0.9-1.2	2.30	5.14	9.71	0.91	15.76	31.88	0.98	32.86
1.2-1.5	1.50	6.67	10.45	2.17	19.29	15.85	0.20	16.05
1.5-1.8	2.30	9.18	8.64	6.52	24.34	26.80	0.39	27.19
1.8-2.1	5.50	10.11	52.33	17.40	79.84	72.10	2.83	74.93
2.1-2.4	6.90	23.14	61.69	27.84	112.67	92.20	4.98	97.18
2.4-2.7	6.90	35.14	74.86	26.97	136.97	130.00	4.93	134.93
2.7-3.0	7.00	28.14	78.97	29.58	136.69	130.50	5.07	135.57

TABLE A-7

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE EE-7

DEPTH OF SOIL SAMPLE IN METERS	E.C. MMHOS./CM	CATIONS M.E./L. Ca	Mg	Na	TOTAL CATIONS M.E./L. OF Ca, Mg AND Na	ANIONS M.E./L. SO_4	CL	TOTAL ANIONS M.E./L. OF SO_4 AND CL
0-0.3	0.30	0.14	0.41	0.09	0.64	1.10	0.10	1.20
0.3-0.6	0.40	0.78	0.82	0.13	1.73	1.60	0.29	1.89
0.6-0.9	2.78	4.73	5.76	0.43	10.92	19.63	0.39	20.02
0.9-1.2	2.82	5.14	6.17	1.30	12.61	38.10	0.49	38.59
1.2-1.5	3.10	6.17	7.40	3.04	16.61	45.65	0.29	45.94
1.5-1.8	2.00	8.14	5.76	3.04	16.94	28.00	0.05	28.05
1.8-2.1	3.75	4.14	9.46	9.13	22.73	50.10	1.95	52.05
2.1-2.4	5.50	8.14	12.50	18.27	38.91	76.60	3.41	77.01
2.4-2.7	6.70	10.18	16.45	27.84	54.47	93.25	4.78	98.03
2.7-3.0	6.70	6.99	15.63	30.45	53.07	90.20	4.88	95.08

TABLE A-8

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE EE-8

DEPTH OF SOIL SAMPLE IN METERS	E.C. MMHOS./CM	CATIONS M.E./L. Ca	Mg	Na	TOTAL CATIONS M.E./L. OF Ca, Mg AND Na	ANIONS M.E./L. SO_4	CL	TOTAL ANIONS M.E./L. OF SO_4 AND CL
0-0.3	0.40	0.18	0.82	0.09	0.99	0.75	0.10	0.85
0.3-0.6	0.30	0.53	0.74	TRACE	1.27	1.30	0.20	1.50
0.6-0.9	0.39	0.83	0.99	0.13	1.95	1.55	0.29	1.84
0.9-1.2	2.68	5.10	6.50	0.87	12.47	38.83	0.49	39.32
1.2-1.5	3.30	7.13	9.46	2.17	18.76	51.80	0.88	52.68
1.5-1.8	3.50	10.14	16.62	4.78	31.54	53.00	0.54	53.54
1.8-2.1	6.00	18.14	21.39	19.57	59.10	86.30	2.63	88.93
2.1-2.4	7.50	26.45	28.79	30.45	85.69	105.65	4.49	110.14
2.4-2.7	8.00	11.48	55.12	33.93	100.53	119.50	5.61	125.11
2.7-3.0	8.00	15.14	26.74	33.06	74.94	112.45	5.56	113.01

TABLE A-9

ELECTRICAL CONDUCTIVITY MMHOS./CM. AT 25° C.
OF SOIL PROFILES ACROSS TILE F-F

DEPTH OF SOIL SAMPLE IN METERS	WELL FF-1	WELL FF-2	WELL FF-3	WELL FF-4	WELL FF-5	WELL FF-6	WELL FF-7	WELL FF-8
0-0.3	1.55	1.40	1.95	0.87	0.80	0.42	1.32	1.40
0.3-0.6	1.86	3.80	3.60	5.50	0.80	1.55	0.75	4.15
0.6-0.9	1.55	4.80	4.70	6.60	3.10	5.90	4.15	5.80
0.9-1.2	3.25	5.40	6.40	7.20	3.60	4.90	4.32	5.80
1.2-1.5	4.00	5.50	6.20	8.50	4.30	6.60	6.00	5.40
1.5-1.8	4.90	5.50	6.50	7.30	7.00	8.80	6.40	7.50
1.8-2.1	6.70	6.30	6.40	8.30	7.10	7.20	6.20	7.00
2.1-2.4	7.30	6.50	6.50	7.60	7.50	7.50	6.70	7.20
2.4-2.7	7.00	6.80	7.40	7.50	7.00	7.70	7.50	7.00
2.7-3.0	7.60	7.00	7.20	7.70	6.90	8.10	7.40	7.20

TABLE A-10

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE GG-1

DEPTH OF SOIL SAMPLE IN METERS	E.C.	CATIONS M.E./L.			TOTAL CATIONS M.E./L. OF	ANIONS M.E./L.		TOTAL ANIONS M.E./L. OF
	MMHOS./CM	Ca	Mg	Na	Ca, Mg AND Na	SO_4	CL	SO_4 AND CL
0-0.3	0.51	2.50	1.23	11.41	15.14	11.15	0.32	11.47
0.3-0.6	3.53	17.76	8.14	16.52	42.42	30.73	3.13	33.86
0.6-0.9	5.56	24.95	12.34	19.13	56.42	38.60	2.27	40.87
0.9-1.2	4.42	17.47	10.69	16.09	54.25	42.83	1.94	44.77
1.2-1.5	1.60	10.28	3.29	10.43	24.00	21.65	0.59	22.24
1.5-1.8	2.70	9.98	7.40	13.04	30.42	27.00	1.13	28.13
1.8-2.1	3.90	9.48	13.16	14.78	37.42	39.00	2.59	41.59
2.1-2.4	4.30	9.78	14.40	16.52	40.70	39.10	2.70	41.80
2.4-2.7	4.30	9.48	10.69	20.00	40.17	36.48	3.83	40.31
2.7-3.0	5.00	8.48	9.05	31.74	49.27	60.70	4.37	65.07

TABLE A-11

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE GG-2

DEPTH OF SOIL SAMPLE IN METERS	E.C.	CATIONS M.E./L.			TOTAL CATIONS M.E./L. OF	ANIONS M.E./L.		TOTAL ANIONS M.E./L. OF
	MMHOS./CM	Ca	Mg	Na	Ca, Mg AND Na	SO_4	CL	SO_4 AND CL
0-0.3	0.80	3.49	1.89	3.26	8.64	10.38	0.38	10.76
0.3-0.6	2.32	5.99	4.94	13.05	23.98	21.25	5.02	26.27
0.6-0.9	5.70	25.95	11.52	31.32	68.79	73.90	5.72	79.62
0.9-1.2	8.00	13.97	8.06	51.33	73.36	110.50	5.40	115.90
1.2-1.5	2.52	14.97	13.49	33.93	62.39	54.73	3.78	58.51
1.5-1.8	4.60	15.97	13.90	39.15	69.02	56.88	3.78	60.66
1.8-2.1	4.90	8.73	7.40	33.93	50.06	52.25	3.89	56.14
2.1-2.4	5.90	6.99	9.05	41.32	57.36	72.20	4.64	76.84
2.4-2.7	4.50	5.99	7.32	34.32	47.63	95.70	3.89	99.59
2.7-3.0	5.50	8.73	9.87	43.50	62.10	74.20	7.24	81.44

TABLE A-12

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE GG-3

DEPTH OF SOIL SAMPLE IN METERS	E.C. MMHOS./CM	CATIONS M.E./L. Ca	Mg	Na	TOTAL CATIONS M.E./L. OF Ca, Mg AND Na	ANIONS M.E./L. SO_4	CL	TOTAL ANIONS M.E./L. OF SO_4 AND CL
0-0.3	0.71	5.47	3.18	4.78	13.43	10.30	0.00	10.30
0.3-0.6	5.20	16.22	10.28	16.53	43.03	63.25	1.67	64.92
0.6-0.9	4.00	42.42	37.02	53.07	132.51	89.75	7.13	96.88
0.9-1.2	9.00	20.46	17.69	59.16	97.31	102.10	14.31	116.41
1.2-1.5	8.00	20.46	14.40	53.07	87.93	89.88	15.77	105.65
1.5-1.8	10.30	13.97	23.86	78.30	116.13	96.88	18.90	115.78
1.8-2.1	8.80	23.95	23.86	59.16	106.97	120.00	13.72	133.72
2.1-2.4	9.50	20.46	22.21	63.07	105.74	114.80	15.66	130.46
2.4-2.7	4.50	20.46	20.57	62.64	103.67	108.38	14.47	122.85
2.7-3.0	7.30	14.97	14.40	60.03	89.40	85.30	15.13	100.43

TABLE A-13

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE GG-4

DEPTH OF SOIL SAMPLE IN METERS	E.C. MMHOS./CM	CATIONS M.E./L. Ca	Mg	Na	TOTAL CATIONS M.E./L. OF Ca, Mg AND Na	ANIONS M.E./L. SO_4	CL	TOTAL ANIONS M.E./L. OF SO_4 AND CL
0-0.3	3.30	30.94	7.82	7.83	46.59	35.75	2.27	38.02
0.3-0.6	7.90	29.94	13.98	43.50	87.42	68.20	24.19	92.39
0.6-0.9	9.50	23.45	19.33	70.47	113.25	106.40	18.36	124.76
0.9-1.2	11.00	21.96	26.32	79.60	127.88	124.40	18.63	143.03
1.2-1.5	11.70	28.44	28.79	79.17	136.40	136.85	27.11	163.96
1.5-1.8	10.20	23.45	26.32	81.78	131.55	108.80	25.38	134.18
1.8-2.1	10.00	23.45	22.21	72.21	117.87	108.80	26.14	134.94
2.1-2.4	10.50	21.25	-	69.60	90.85	122.20	25.87	148.07
2.4-2.7	10.40	23.45	28.79	69.60	121.84	113.00	29.27	142.27
2.7-3.0	9.70	23.45	18.10	53.68	95.23	99.80	21.49	121.29

TABLE A-14

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE GG-5

DEPTH OF SOIL SAMPLE IN METERS	E.C. MMHOS./CM	CATIONS M.E./L. Ca	Mg	Na	TOTAL CATIONS M.E./L. OF Ca, Mg AND Na	ANIONS M.E./L. SO_4	CL	TOTAL ANIONS M.E./L. OF SO_4 AND CL
0-0.3	0.50	16.47	6.17	10.00	32.64	29.85	1.40	31.25
0.3-0.6	3.70	22.46	11.52	26.09	60.02	54.53	1.67	56.20
0.6-0.9	4.10	56.39	9.05	11.36	76.80	49.65	1.84	51.49
0.9-1.2	3.80	18.46	9.05	13.82	41.33	45.35	1.30	46.65
1.2-1.5	1.49	17.47	8.23	13.48	39.18	43.88	0.54	44.42
1.5-1.8	3.20	2.50	3.29	8.26	14.05	41.80	1.08	42.88
1.8-2.1	3.60	7.49	10.04	15.22	32.75	37.63	2.05	39.68
2.1-2.4	4.60	7.49	11.68	17.83	37.00	47.23	2.27	49.50
2.4-2.7	4.20	6.99	9.62	20.44	37.05	44.40	2.59	46.99
2.7-3.0	5.70	8.48	10.69	34.80	53.97	61.23	4.97	66.20

TABLE A-15

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE GG-6

DEPTH OF SOIL SAMPLE IN METERS	E.C.	CATIONS M.E./L.			TOTAL CATIONS M.E./L. OF	ANIONS M.E./L.		TOTAL ANIONS M.E./L. OF
	MMHOS./CM	Ca	Mg	Na	Ca, Mg AND Na	SO_4	CL	SO_4 AND CL
0-0.3	1.20	39.92	12.34	4.78	57.04	57.00	0.22	57.22
0.3-0.6	5.50	8.98	10.16	30.45	49.59	65.10	3.51	68.61
0.6-0.9	7.40	7.49	14.40	51.33	73.22	90.60	3.78	94.38
0.9-1.2	7.20	34.43	11.52	43.50	89.45	86.50	4.64	91.14
1.2-1.5	7.50	14.47	12.34	84.52	111.33	88.30	5.94	94.24
1.5-1.8	9.40	25.45	19.74	69.60	114.79	104.40	12.10	116.50
1.8-2.1	9.00	17.96	18.10	50.03	86.09	98.20	11.34	109.54
2.1-2.4	9.30	26.45	19.74	63.07	104.26	103.00	13.18	116.77
2.4-2.7	9.30	11.48	19.66	63.07	94.21	99.70	13.07	112.77
2.7-3.0	9.60	4.99	0.16	63.07	68.22	103.00	13.77	116.77

TABLE A-16

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE GG-7

DEPTH OF SOIL SAMPLE IN METERS	E.C.	CATIONS M.E./L.			TOTAL CATIONS M.E./L. OF	ANIONS M.E./L.		TOTAL ANIONS M.E./L. OF
	MMHOS./CM	Ca	Mg	Na	Ca, Mg AND Na	SO_4	CL	SO_4 AND CL
0-0.3	0.63	5.99	1.65	1.30	8.94	12.30	-	12.30
0.3-0.6	6.00	38.92	11.52	29.58	50.44	70.65	3.94	74.59
0.6-0.9	8.80	26.94	17.28	56.55	102.77	106.10	10.26	116.36
0.9-1.2	9.00	43.41	23.86	53.94	121.21	102.70	13.55	116.25
1.2-1.5	11.50	22.46	31.26	53.50	167.22	132.40	23.76	156.16
1.5-1.8	12.50	30.94	38.66	87.74	157.34	149.00	24.30	173.30
1.8-2.1	10.70	43.91	27.97	74.82	146.70	123.25	19.11	142.36
2.1-2.4	9.50	12.97	23.86	70.47	107.30	105.00	17.28	122.28
2.4-2.7	10.00	18.46	32.08	69.60	120.14	120.40	16.85	137.25
2.7-3.0	10.70	22.95	32.08	70.47	125.50	117.60	18.04	135.64

TABLE A-17

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE GG-8

DEPTH OF SOIL SAMPLE IN METERS	E.C.	CATIONS M.E./L.			TOTAL CATIONS M.E./L. OF	ANIONS M.E./L.		TOTAL ANIONS M.E./L. OF
	MMHOS./CM	Ca	Mg	Na	Ca, Mg AND Na	SO_4	CL	SO_4 AND CL
0-0.3	8.50	2.50	1.65	6.52	10.97	11.35	0.54	11.89
0.3-0.6	8.00	27.94	23.86	63.51	51.80	117.10	12.10	129.20
0.6-0.9	8.70	21.46	26.08	74.82	122.36	121.80	15.44	137.24
0.9-1.2	7.50	15.97	18.10	57.42	90.49	149.10	12.85	161.95
1.2-1.5	9.00	12.50	.64	74.82	87.96	127.50	19.22	146.72
1.5-1.8	11.70	26.95	44.42	96.56	167.93	130.90	26.95	157.85
1.8-2.1	10.00	22.46	34.55	80.04	137.05	140.10	22.63	162.73
2.1-2.4	8.50	15.47	30.44	57.42	103.33	135.47	19.33	154.80
2.7-3.0	8.50	17.96	31.26	56.98	106.20	148.95	19.12	168.07

APPENDIX B

ELECTRICAL CONDUCTIVITY AND WATER SOLUBLE CATIONS AND ANIONS IN THE SOIL PROFILES OF W-A, OW-1, OW-3, WD-0, W-A AND OW-5

TABLE B-1

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE W-9

DEPTH OF SOIL SAMPLE IN METERS	E.C.	CATIONS M.E./L.			TOTAL CATIONS M.E./L. OF	ANIONS M.E./L.		TOTAL ANIONS M.E./L. OF
	MMHOS./CM	Ca	Mg	Na	Ca, Mg AND Na	SO_4	CL	SO_4 AND CL
0-0.3	0.80	94.81	3.29	1.74	99.84	90.50	0.22	90.72
0.3-0.6	2.00	74.35	18.92	9.57	102.84	102.00	1.19	103.19
0.6-0.9	3.30	29.44	13.16	7.39	49.96	44.25	0.81	45.06
0.9-1.2	4.10	55.89	18.10	11.31	85.30	85.60	0.86	86.46
1.2-1.5	3.90	54.89	15.63	13.05	83.57	60.58	0.86	61.44
1.5-1.8	6.90	59.88	17.28	52.20	129.36	169.00	0.97	169.97
1.8-2.1	7.30	78.71	17.19	11.31	77.21	126.85	0.93	127.78
2.1-2.4	7.50	37.81	14.23	29.58	81.62	135.40	0.84	136.84
2.4-2.7	8.10	53.10	18.94	33.93	105.97	90.40	0.87	91.27
2.7-3.0	8.50	42.83	16.73	34.50	94.06	80.60	0.89	81.49

TABLE B-2

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE OW-1

DEPTH OF SOIL SAMPLE IN METERS	E.C.	CATION M.E./L.			TOTAL CATIONS M.E./L. OF	ANIONS M.E./L.		TOTAL ANIONS M.E./L. OF
	MMHOS./CM	Ca	Mg	Na	Ca, Mg AND Na	SO_4	CL	SO_4 AND CL
0–0.3	5.50	19.96	8.23	52.20	80.39	77.30	13.39	90.69
0.3–0.6	6.50	23.95	21.55	60.90	106.40	85.40	22.14	107.54
0.6–0.9	6.00	21.46	37.84	34.80	94.10	84.40	6.26	90.66
0.9–1.2	7.50	23.95	27.15	40.02	91.12	87.60	8.32	95.92
1.2–1.5	6.30	20.96	27.97	38.28	87.21	53.70	8.86	64.56
1.5–1.8	7.00	19.96	27.97	40.89	88.82	74.30	9.29	83.59
1.8–2.1	7.00	20.96	31.26	40.89	93.11	106.60	9.29	115.89
2.1–2.4	6.50	18.96	24.68	36.54	80.18	99.70	8.10	107.80
2.4–2.7	7.00	21.46	31.67	40.89	93.92	81.50	9.29	90.79
2.7–3.0	7.00	19.46	31.67	40.45	96.58	107.60	9.40	117.00

TABLE B-3

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE OW-3

DEPTH OF SOIL SAMPLE IN METERS	E.C.	CATIONS M.E./L.			TOTAL CATIONS M.E./L. OF	ANIONS M.E./L.		TOTAL ANIONS M.E./L. OF
	MMHOS./CM	Ca	Mg	Na	Ca, Mg AND Na	SO_4	CL	SO_4 AND CL
0-0.3	1.00	12.48	3.46	6.09	22.05	22.85	1.08	23.93
0.3-0.6	2.20	9.48	3.29	12.17	24.94	25.18	6.70	31.88
0.6-0.9	1.20	45.91	28.79	40.86	115.56	110.72	8.75	119.47
0.9-1.2	5.60	38.42	20.57	40.86	109.85	98.73	4.75	103.48
1.2-1.5	4.70	34.93	11.60	37.39	83.92	72.18	4.86	77.04
1.5-1.8	4.70	17.96	10.69	39.13	67.78	70.11	4.10	74.21
1.8-2.1	4.20	19.46	9.05	32.17	60.68	60.12	3.83	63.95
2.4-2.7	4.20	11.98	9.87	34.78	56.63	54.38	4.64	59.02
2.7-3.0	4.80	16.97	12.83	31.73	61.53	48.98	4.64	53.62

TABLE B-4

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE WD-0

DEPTH OF SOIL SAMPLE IN METERS	E.C.	CATIONS M.E./L.			TOTAL CATIONS M.E./L. OF	ANIONS M.E./L.		TOTAL ANIONS M.E./L. OF
	MMHOS./CM	Ca	Mg	Na	Ca, Mg AND Na	SO_4	CL	SO_4 AND CL
0-0.3	0.70	4.99	2.14	0.87	8.00	7.14	1.62	8.76
0.3-0.6	1.50	15.97	4.74	0.87	21.58	20.17	0.43	20.60
0.6-0.9	3.00	31.26	7.18	1.30	39.74	40.23	0.81	41.04
0.9-1.2	3.00	20.46	3.12	1.30	24.88	24.18	0.65	24.83
1.2-1.5	2.80	27.45	6.42	1.30	34.17	35.15	0.65	35.80
1.5-1.8	2.60	25.95	3.29	0.65	29.89	30.12	0.32	30.44
1.8-2.1	2.50	26.45	2.63	0.66	29.74	33.14	0.27	33.41
2.1-2.4	2.50	27.45	3.29	0.65	31.39	29.10	0.38	29.48
2.4-2.7	2.60	25.95	3.70	0.65	30.30	30.15	0.43	30.58
2.7-3.0	3.20	22.46	8.23	4.35	35.04	38.14	0.49	38.63

TABLE B-5

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE OW-A

DEPTH OF SOIL SAMPLE IN METERS	E.C. MMHOS./CM	CATIONS M.E./L. Ca	Mg	Na	TOTAL CATIONS M.E./L. OF Ca, Mg AND Na	ANIONS M.E./L. SO_4	CL	TOTAL ANIONS M.E./L. OF SO_4 AND CL
0-0.3	2.60	40.92	9.87	7.39	58.18	56.14	1.35	57.49
0.3-0.6	2.50	22.46	10.69	7.16	40.31	40.15	0.54	40.69
0.6-0.9	3.60	47.41	10.86	10.00	68.27	71.14	1.35	72.49
0.9-1.2	4.60	49.90	20.57	13.92	84.39	75.24	10.69	85.93
1.2-1.5	3.70	27.94	16.29	15.22	59.45	61.24	2.54	63.79
1.5-1.8	3.40	26.95	19.05	12.18	48.18	55.28	1.73	57.01
1.8-2.1	3.70	20.45	15.63	10.44	46.52	64.58	2.16	66.74
2.1-2.4	2.80	26.95	13.98	8.70	49.63	61.70	1.73	63.43
2.4-2.7	3.10	26.45	12.83	9.13	48.41	56.58	1.13	57.71
2.7-3.0	3.30	30.44	12.34	10.44	53.22	51.38	1.19	52.57

TABLE B-6

CHEMICAL ANALYSIS OF WATER EXTRACTS FROM SOIL PROFILE OW-5

DEPTH OF SOIL SAMPLE IN METERS	E.C. MMHOS./CM	CATIONS M.E./L. Ca	Mg	Na	TOTAL CATIONS M.E./L. OF Ca, Mg AND Na	ANIONS M.E./L. SO_4	CL	TOTAL ANIONS M.E./L. OF SO_4 AND CL
0-0.3	0.90	13.97	4.99	3.04	22.00	29.85	2.81	32.66
0.3-0.6	3.60	57.39	20.57	15.56	93.52	92.14	2.54	94.68
0.6-0.9	5.60	45.91	31.26	27.40	104.57	111.40	2.27	113.67
0.9-1.2	5.50	56.54	31.26	33.06	120.86	123.90	2.92	126.82
1.2-1.5	6.40	41.92	31.26	35.67	108.85	126.01	3.13	129.14
1.5-1.8	4.40	27.94	20.57	23.49	72.00	68.14	1.94	70.08
1.8-2.1	5.50	57.39	25.67	27.84	110.90	113.90	2.38	116.28
2.1-2.4	5.80	44.91	31.26	31.32	107.49	118.00	2.81	120.81
2.4-2.7	5.30	44.91	15.63	27.40	87.94	108.15	2.75	110.90
2.7-3.0	6.00	43.41	32.91	31.32	107.64	119.85	2.70	122.55