RELATIONS BETWEEN HYDROGEOLOGY AND SOIL CHARACTERISTICS NEAR DELORAINE, MANITOBA

A Thesis

Submitted to

The Faculty of Graduate Studies and Research

University of Manitoba

In Partial Fulfillment

of the Requirements for the Degree

MASTER OF SCIENCE

by

ROBERT G. EILERS

February, 1973

ABSTRACT

The influence of hydrogeologic factors on genetic soil distributions near Deloraine in southwestern Manitoba was studied during a two year period. Emphasis was placed on determining the detailed hydrogeologic characteristics along a narrow 25 mile long strip of terrain between Turtle Mountain and the Souris Plain. To characterize the hydrogeology, 15 nests of piezometers were installed in the Quaternary and bedrock deposits. Hydraulic head data and samples of the groundwater were obtained from the piezometers. The hydraulic head data, chemistry of the groundwater and knowledge of the stratigraphy were used to interpret the patterns of groundwater flow. Seven hydrogeologic areas were established. The hydrogeological characteristics of each area were described and related to the pedological characteristics of the soils. In addition, a detailed sampling of the soil and sub-soil was conducted to evaluate the degree and source of salinity in the soil.

The pedologic, hydrogeologic, and geochemical data indicate that the general soil salinity pattern is controlled by a complex configuration of the groundwater flow system. Saline soils occur in areas of dominant groundwater discharge. Leached soils occur in areas of dominant groundwater recharge. On a micro-scale local groundwater flow systems and the vertical and lateral distribution of salinity are governed by micro-relief and micro-stratigraphy of the surface deposits. In some areas thin sand and gravel lenses above and slightly below the water table strongly influence the distribution

of soluble salts in the soil. The major source of soluble salts in the region was attributed to the dissolution of sulphate minerals in the glacial till.

ACKNOWLEDGEMENTS

The author wishes to extend his sincere thanks to the members of his committee; Dr. M.A. Zwarich, Assistant Professor of soil science, University of Manitoba for serving as chairman; Mr. R.E. Smith, Pedologist and Head of the Canada-Manitoba Soil Survey, University of Manitoba; Dr. C.F. Shaykewich, Assistant Professor of soil science, University of Manitoba; and especially to Dr. J.A. Cherry, Associate Professor of Earth Science, University of Waterloo, who supervised the hydrogeologic investigation and provided much helpful advice and encouragement during the course of this study.

The author would also like to thank Mr. A. Kohut for his helpful suggestions during the field study. In addition, appreciation is also extended to the following: the Staff of the Soil Survey Laboratory for conducting the salinity analysis, the C.D.A. Research Station, Winnipeg for the financial contribution to the drilling program, Mr. R. Thomlinson, PFRA, for surveying the piezometer elevations, the drafting section of the Soils and Crops Branch, Manitoba Department of Agriculture and the Department of Earth Sciences, University of Waterloo for the drafting of maps and diagrams, Miss. B. Stupak for typing the thesis, and to the many other people who rendered assistance and gave advice from time to time during the course of this study.

Finally, to my wife, Jo-Anne, a special thanks for her patience and encouragement during the course of this study.

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CHAPTER I

INTRODUCTION

The classification of soils, based primarily on morphological and chemical characteristics, has led pedologists to concentrate their attention primarily on the upper 36 to 48 inches of the soil. As a result, references to groundwater in relation to soil development studies have been brief, usually including only the depth to water table level and degree of groundwater mineralization. On the other hand, hydrologists have generally studied groundwater phenomena without considering in detail the relations between the groundwater environment and the soil genesis zone near the ground surface. Consequently, the two disciplines evolved with little attention being paid to the relations which exist between genetic soil development and groundwater flow. This thesis attempts to clarify some of these relations occurring in an area of dominantly chernozemic soils in southwestern Manitoba.

I OBJECTIVE OF STUDY

This thesis evolved, for the most part, from attempts to characterize certain genetic soil distribution patterns encountered during the resurvey of the Southwest Map Area of Manitoba (49°00'-49°32' N. Lat. and 100°00'-100°22' W. Long.) which was conducted from 1965 to 1969. During the resurvey it was thought that the distribution of imperfectly drained saline and non-saline soils developed on the same parent material, could be due to subsurface groundwater flow rather than due to surface drainage. Therefore, it was decided to investigate the groundwater flow phenomena and to determine their relationships to soil formation as expressed by the distribution of soil profile types. The main objective of this thesis, therefore, is to describe the hydrogeology of a representative area of soils for the purpose of determining the relations between groundwater flow systems and the general distribution of genetic soil profiles. To achieve this objective the investigation included:

1. The installation of nests of piezometers arranged in a cross-section through the study area,

2. A compilation of preliminary soil survey data, and

3. A detailed soil inspection at preselected sites along the cross-section giving careful consideration to the local factors of micro-topography, micro-stratigraphy, soil parent material, and genetic profile distribution.

II GEOGRAPHIC SETTING

The area studied lies immediately to the west of the town of Deloraine in Southwestern Manitoba (Figure 1). This area was chosen for three reasons: firstly, it included representative areas of each of the major soil subgroups and catenas in the Southwestern Area of Manitoba; secondly, it included representative areas of each of the major soil climatic zones of southern Manitoba; and thirdly, it transected the total range in topographic relief for the area.

The layout of the study area is located along the regional

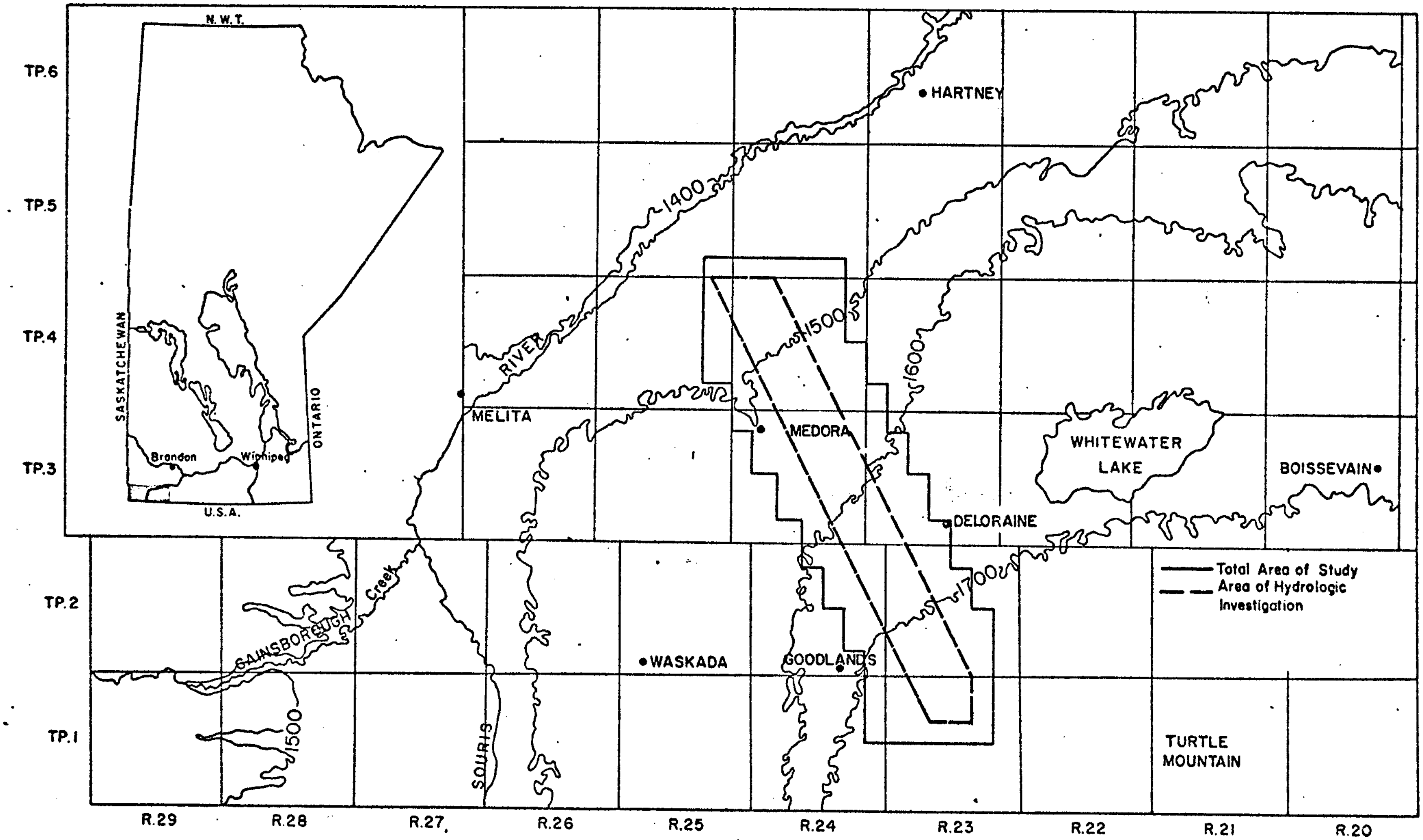


Figure 1. Location of Study Area near Deloraine in Southwestern Manitoba.

slope of the surface topography. It was thought that in this location the area would be parallel to the slope of the regional water table and that the flow of groundwater would be parallel to the long axis of the study area. In this position, the various groundwater flow regimes within the area could be observed.

The study area occupies approximately 96,000 acres of land composed of glacial tills and thin lacustrine sediments. The tills are typically dead ice deposits characterized by knoll-depression topography. The topography varies from high relief on top of Turtle Mountain, which has very steep slopes ranging from 30 per cent to 60 per cent, to very low relief in the Boissevain Till Plain, having slopes generally less than 5 per cent. The Turtle Mountain Upland slopes steeply to the surrounding lowlands at approximately 250 feet per mile. The shallow glacial lake sediment in the Souris Plain and Whitewater Lake Basin areas is characterized by very low relief with slopes generally less than 2 per cent. Local variations in relief in the Souris Plain are commonly due to aeolian modification of the coarse lacustrine sediments.

The specific area of the hydrologic investigation, enclosed by the two dashed, parallel lines, as shown in Figure 1, constitutes approximately 38,400 acres.

Weir (1960) reports that the area has an average annual potential evapotranspiration of 21 to 65 inches and an average annual precipitation of 20 inches of which 12 to 14 inches fall during the growing season from May 1 to September 30. Weir (1960) also reports that the average annual January temperature ranges from

0.5° to 5°F while the average annual July temperature ranges from 63.5° to 68°F.

CHAPTER II

REVIEW OF LITERATURE

I HYDROLOGY

The hydrologic cycle as defined by Davis and De Wiest (1967, p. 15) is the "ever changing migration of atmospheric, surface, and groundwater as a complex interdependent system". Although the movement of groundwater is the main concern of this study, it is important that all aspects of the hydrologic cycle be understood in a general way in order that an accurate picture of the sub-surface portion of the cycle be achieved.

Using a two dimensional model (Figure 2), Toth (1962) showed that the theoretical groundwater flow system in an isotropic homogeneous porous medium with a uniformly sloping topography is composed of a recharge area and a discharge area. The recharge area which is upslope from the midline position is characterized by downward moving groundwater, that is, water movement away from the water table level. The discharge area, which is downslope from the midline position is characterized by upward moving water, that is, water movement toward the water table level.

In general, groundwater flow systems are influenced by three basic components: topography, geology, and climate. Topography in a broad sense determines the scale of the hydrological system. Hitchon (1969) in a study of the Western Canadian Sedimentary Basin, concluded that major upland topographic features are major recharge regions and that major lowlands are major regional discharge areas.

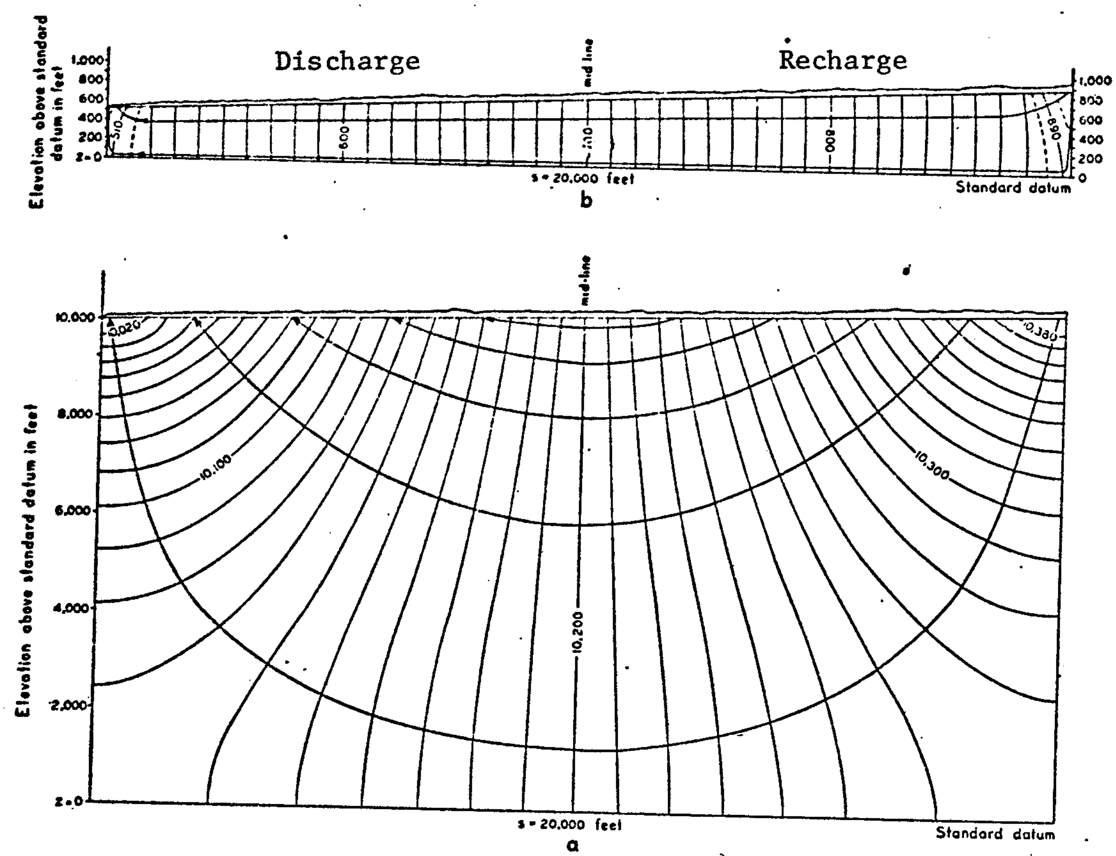


Figure 2. Two-dimensional theoretical potential distributions and flow patterns for different depths to the horizontal impermeable boundary (after Toth, 1962).

In his model he refers to the foothill region of Alberta as regional recharge and the exposed outcrops of sedimentary rocks near the contact of the Precambrian Shield to the east as the regional discharge area. On the other hand, Toth (1963) showed that minor irregularities in the surface topography resulted in local flow systems being superimposed on intermediate and regional flow systems (Figure 3). By applying Toth's (1963) theoretical flow systems (Figure 3) to the Western Canadian Basin, as discussed by Hitchon (1969) the area of the Turtle Mountain Upland and the Whitewater Basin is analogous to a local flow system superimposed on the regional discharge area for Western Canada. The terms regional, intermediate, and local defined in this sense therefore have little meaning for purposes of this study. For this study the term local flow system will be defined as the flow of groundwater from a slough or depression at a given elevation to an adjacent slough or depression of slightly lower elevation. This definition is analogous to the local flow systems as described by Lissey (1968) in the Oak River Basin of Manitoba.

Hitchon (1969) also states that the "dominant fluid potential in any part of the basin corresponds closely to the fluid potential at the topographic surface in that part of the basin". Therefore, topography determines the magnitude of the hydraulic potentials within the hydrologic system. He also concluded that variations in geology such as the presence of highly permeable beds, significantly affected the regional fluid potential distribution.

Geology, according to Davis and De Wiest (1967, ch. 10 and 11)

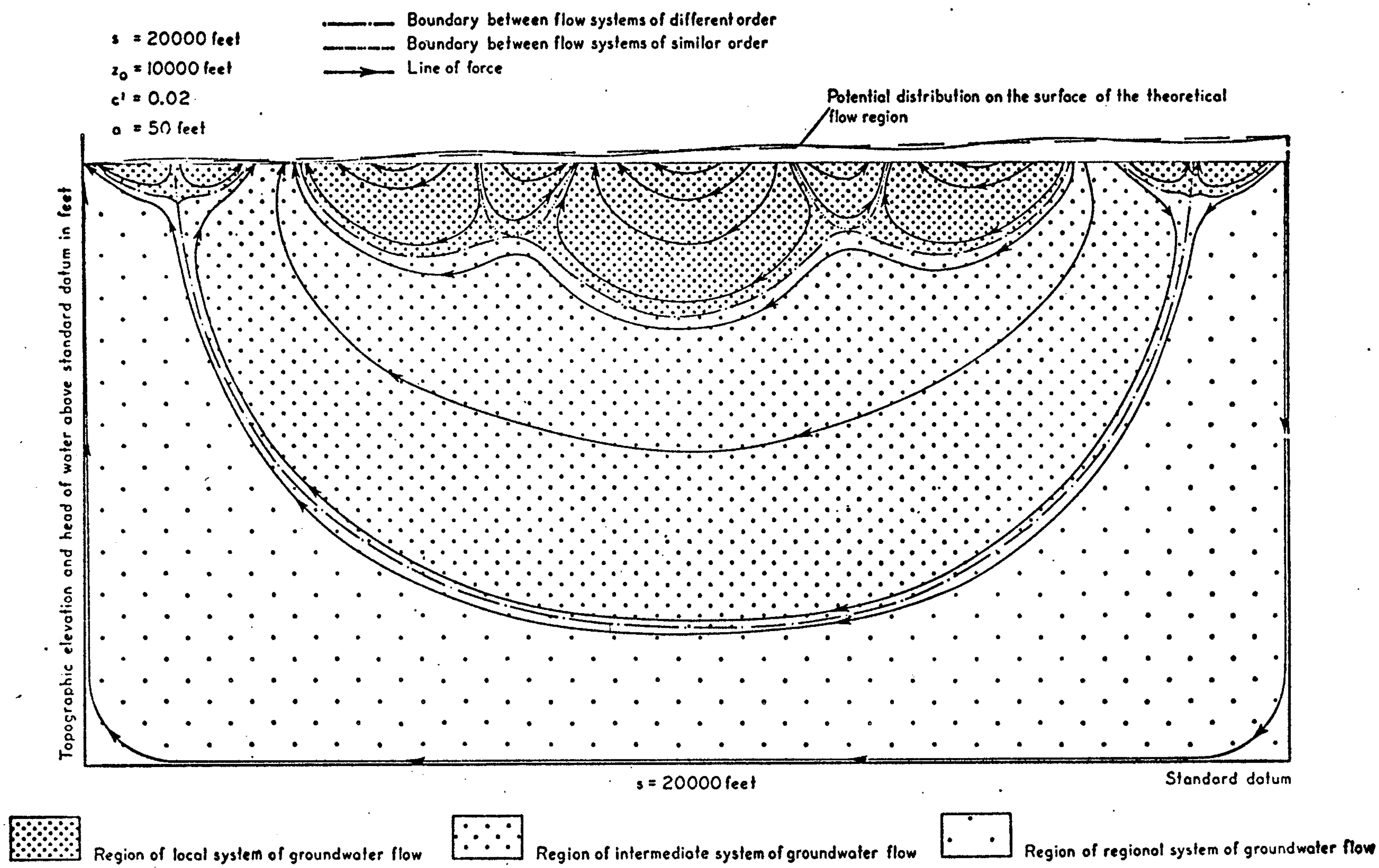


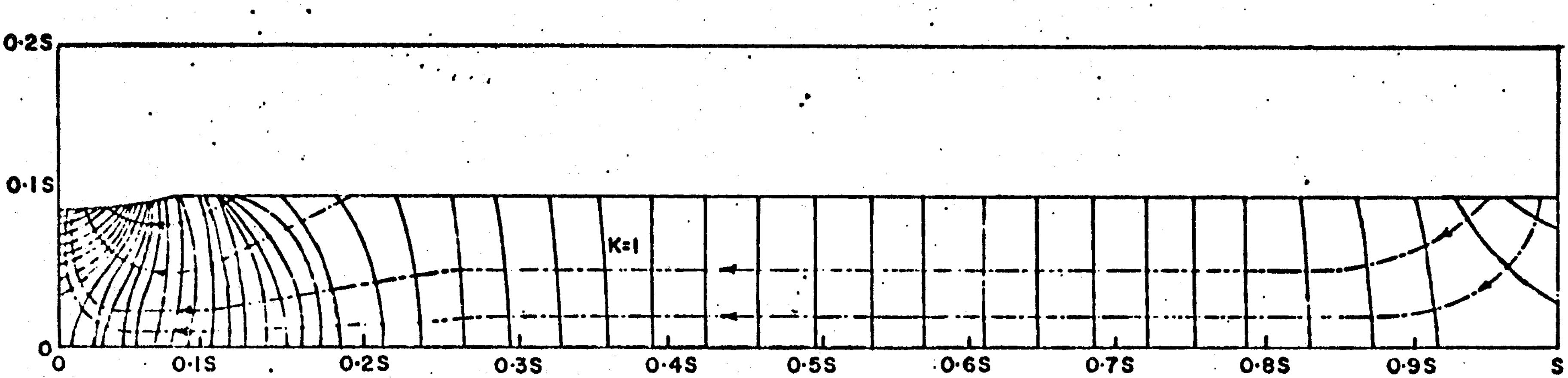
Fig. 3. Theoretical flow pattern and boundaries between different flow systems. (after Toth, 1963).

plays a significant role in determining the characteristics of groundwater flow systems. Pore and grain size, sedimentation and orientation of rock structures and the 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.

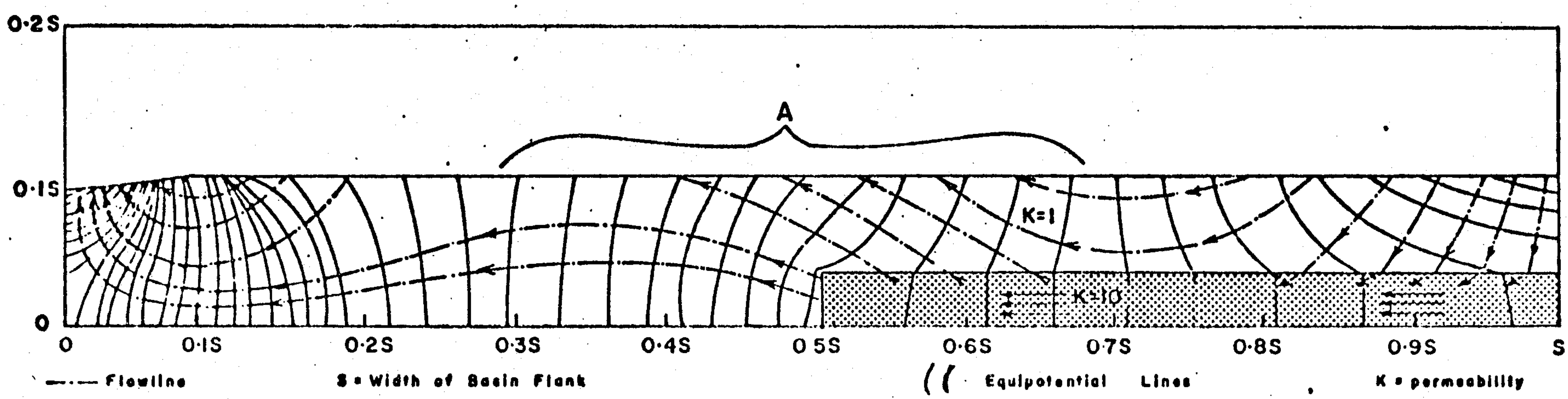
The pore and grain size of geologic material determine permeability or hydraulic conductivity. Sediments such as clay which have high porosities, generally have low hydraulic conductivities. Sands, on the other hand, with low porosities, generally have a higher percentage of macro pores than clays and consequently have higher hydraulic conductivities. Baver (1963, p. 252) has shown that under saturated conditions the velocity of water flow through soils decreases in the order of sand > fine sandy loam > light clay > and clay. Freeze and Witherspoon (1967) have shown that lenses of contrasting permeability within homogeneous deposits alter the direction of normal groundwater flow and result in the occurrence of discharge areas in the centre of regional flow systems (Figure 4).

Davis and De Wiest (1967, ch. 11) suggest that the 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.

Climatic factors such as the seasonal distribution of precipitation and temperature which determine the amount of evaporation



Hydraulic Potential and Flowline Network across one Flank of a Hypothetical Basin with a Homogeneous Isotropic Flow Medium.



Flow Network Altered by the Presence of Part of an Aquifer with a Larger Permeability than the Rest of the Flow Medium. The Midslope Discharge Area A is a Direct Result of the Aquifer Pinchout.

Figure 4. Theoretical Patterns of Groundwater Flow (after Freeze and Witherspoon, 1967).

and evapotranspiration have a significant influence on the water budget of the hydrologic cycle. According to Davis and De Wiest (1967, ch. 12) variations in climate affect the amount and distribution of recharge and discharge, the magnitudes of the hydraulic gradients, the continuity of aquifers and the distribution of poor quality water within a given hydrologic environment. In addition, Lissey (1968) reports that the influences of climate dictate, either directly or indirectly, the type and quality of vegetation which may develop in a basin. Vegetation then may influence the processes of recharge and discharge either by enhancing or inhibiting infiltration, evapotranspiration and evaporation. By the use of piezometers, Meyboom (1966) has shown that the vegetation on hummocky glacial drift in the Canadian Prairies influences the local groundwater flow systems and thereby influences the larger flow systems beneath.

Continuity Between Saturated and Unsaturated Systems

According to Moore (1939, as stated in Baver, 1963, p. 252) the same properties which affect water flow in the saturated soil zone also affect water flow through the unsaturated soil zone with the exception that the order of permeability is reversed. Freeze (1967) states that the unsaturated flow processes of infiltration and evaporation are in physical and mathematical continuity with the parallel saturated processes of recharge and discharge, that is, the terms infiltration and evaporation in the unsaturated soil zone are continuous with the terms recharge and discharge in the saturated soil zone, respectively.

Freeze (1967) states that "a given meteorological condition which gives rise to a certain flux at the ground surface will create different pressure head, total head, and moisture content profiles depending on the conditions of groundwater recharge and discharge which underlie the unsaturated soil". Freeze (1967) also states that "soil moisture conditions can therefore be expected to show areal variations even under homogeneous meteorological conditions and uniform soil type".

As a result of the continuity between the saturated and unsaturated soil zones, surface soil moisture conditions are a direct reflection of the depth to and the range of fluctuation of the water table level. Freeze (1967) shows that water table fluctuations result when the rate of groundwater recharge or discharge is not matched by the rate of infiltration or evaporation in the unsaturated soil zone and the end result is a water table which is almost never stable.

Groundwater Chemistry

According to Davis and De Wiest (1967, ch. 4) the chemistry of groundwater is basically determined by the composition of the geologic materials through which it flows. For example, groundwater from limestone aquifers has dominantly a Ca^{++} and HCO_3^- ion composition whereas groundwater in marine shales generally has a Na^+ and Cl^- ion composition. Rozkowski (1967) in a hydrological study of glacial tills in the Moose Mountain area of Saskatchewan reports that the most common ions found in groundwater of calcareous glacial drift are Ca^{++}, Mg^{++}, Na^+, $SO_4^=$, and HCO_3^-.

Since the degree of mineralization of groundwater is dependent upon: temperature, pressure, area of interface between minerals and groundwater, volume and time of water contact, it is expected that discharging groundwaters would be more mineralized than recharging groundwater. Rozkowski (1967) and Lissey (1968) applied this concept to their studies in glacial drift and found that the groundwater chemistry patterns substantiated the groundwater flow patterns which had been interpreted from hydraulic head data. It is apparent, therefore, that areal and vertical distributions of ionic concentrations in groundwater are a valuable aid for interpreting the characteristics and direction of groundwater movement.

II SOIL GENESIS

Soil genesis is basically a two-fold process which involves firstly the formation of the soil parent material and secondly the formation of the soil profile. The formation of soil parent material has resulted from the physical and chemical weathering of geologic materials and the subsequent redistribution of these products by water, wind, and ice.

The formation of the soil profile, on the other hand, has resulted from the dynamic interaction of the six basic factors of soil formation, namely: climate, vegetation, parent material, topography, time, and man. The result of this interaction is the formation of various layers or horizons within the parent material. These horizons constitute the soil profile. Horizon differentiation is the result of additions, removals, transfers and transformations within the soil system. Each of these processes depend greatly on the presence and movement of water through or within the soil.

The concept of an interrelationship between soil development and the movement of groundwater is relatively new. Studies in pedology have recognized the depth to groundwater as an important property of soil, however as Cairns and Bowser (1969) have stated, "the function of groundwater in the development of the soil profile is still not clearly understood".

Significance of Water in the Soil System

Water is the key element in the genesis of soil profiles. It is responsible for nearly all chemical reactions in the soil and provides a means of transport for all moveable soil constituents. The physics of water movement in the unsaturated zone has been studied at great length, however, the role of water movement as a factor in soil genesis has received little attention.

The development of soil profiles results from the flow of water in both the saturated and unsaturated soil zones. According to Toth (1962) groundwater is generally in a state of constant motion and is therefore capable of dissolving and transporting mineral matter from one part of a flow system to another, following flow trajectories defined by well known physical principles. He also shows that if the pattern of groundwater movement and its controlling factors were better understood, conclusions regarding both general principles and specific local features associated with the removal, transport and deposition of salts in soils, could be derived.