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1968-5

THE GROUNDWATER REGIME NEAR RED DEER (DETERMINED FROM MAPPING NATURALLY OCCURING SURFICIAL PHENOMENA)

by: R. Clissold, June 1968

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ILLUSTRATIONS

minus 150 meters (-500 feet) occurs as if the flow medium is homogeneous.

Distribution of the chemical quality of groundwater is systematic on the highlands. From the distribution of the three main water quality types of groundwater in the highlands, the best quality (500 μ mho/cm) generally is associated with the west ridge and the poorest general quality (1,000 μ mho/cm) is associated with the east and southeast ridges. Possibilities for groundwater are most favorable in association with the west ridge and are least favorable in extensive low-sloping areas.

Individual supplies (few 10's of liters/min.) are available over the whole area; large supplies (few 1,000's of liters/min.) may possibly be obtained able in certain selected areas. ~~from areas outlined for test-drilling projects to develop large groundwater supplies~~.

THE GROUNDWATER REGIME NEAR RED DEER, ALBERTA

Determined from Mapping Naturally Occurring Surficial Phenomena

Introduction

Purpose

Groundwater mapping can be defined as the systematic examination of a region for groundwater information. The information may be obtained from two sources: first, from man-made features used to obtain or control groundwater; second, from naturally occurring surficial phenomena associated with the presence of groundwater on or immediately beneath the land surface within a drainage basin. The collection of data from this second source, that is, entirely from field observations, can be likened to a geologist studying an area with only outcrops available for interpreting the geology of the area.

The present project has a twofold purpose: first, to assess the value of field mapping of groundwater from naturally occurring surficial phenomena alone, both as a method of groundwater exploration and as a method for use in other aspects of science; and second, to provide a basis for a test-drilling project concerned with the development of a public groundwater supply from the area studied.

Basis for Study

Tóth (1966b) concluded from his investigations over a 90 square kilometer (35 square mile) area, that "A correlation between physiographic features and the direction of the natural movement of groundwater does exist." Therefore, the mapping of naturally occurring surficial phenomena is one possible method to study the groundwater regime. The method would be most useful for areas in which little or no hydrogeological information exists, or is available from man-made features for obtaining or controlling groundwater.

In order that a full assessment of the method of mapping could be obtained, the area studied was considered to be virgin land. This meant that no specific existing hydrological and geological information was used. The world maps showing the distribution of climates and vegetation were referred to, as this general information would be available for studies carried out in any part of the world.

Since one of the main purposes of this study is to determine the groundwater regime, only cursory attention was given to geology and weather. Geological investigations were restricted to noting geologic outcrops and their locations. Day-to-day weather was recorded only in terms of the number of days without rain and the sensible temperature of individual days.

The Red Deer area was selected so that the results of the second purpose could be utilized in the foreseeable future to evaluate fully the conclusions of this study. The extensive test-drilling program planned for the Red Deer area to supplement the present surface water supply for the city of Red Deer will provide an ideal opportunity for a full evaluation.

Scope and Techniques

In order to realize the proposed aims of this report, it was necessary to consider five phases of study, which are as follows:

- The collection of data pertaining to naturally occurring surficial phenomena throughout the area of study;
- A detailed investigation of pertinent phenomena;
- A study of the areal distribution of the different chemical types of water as determined from water samples collected on or immediately below the land surface;

- The distribution of areas of groundwater moving toward the land surface and groundwater moving away from the land surface;
- The preparation of hydraulic cross sections.

Information was collected in the field while on traverses. The traverses were made in one of two ways: first, in a vehicle and on foot; and second, by helicopter. Water samples were collected from locations where groundwater outflowed naturally onto the land surface, and from four-centimeter (1 1/2 inches) diameter auger holes to depths mainly less than three meters (10 feet).

Chemical analysis of water samples was mainly by field methods. Conductivity measurements of the waters were made with a Bechman RB3-portable solubridge with a manual temperature compensator. These measurements were used to approximate the total dissolved solids. Hardness, total alkalinity, chloride, and pH of the waters were determined with Hach kits. Sulphate was determined by a microtitration method (Fritz and Yamamura, 1955). The laboratory analyses were done by the Provincial Analyst.

An electric analog simulator employing Teledeltus paper and one variable potential boundary has been used to prepare the hydraulic cross sections.

Work Done and Acknowledgments

Field work was carried out during the summer months of 1966 and 1967. During the winter of 1966-67 the previous summer's work was written up as an M.Sc. thesis. The preparation of this report was delayed by four months because of other duties.

The writer is very grateful to Dr. J. Tóth for his association with the present project. His enthusiasm and encouragement have done much to improve the

quality of the results. Mr. D. Walker assisted with the processing of information in the office; Miss C. Shandro provided field assistance during the summer of 1967. My wife ably provided both field and office assistance during many times of need.

Description of the Area

Location

The area which has been mapped is within 52°05' to 52°20' north longitude and 113°40' and 114°20' west longitude (Fig. 1). In terms of the legal description of land in Alberta, this is ranges 26, 27, and 28 west of the 4th meridian and 1, 2, and 3 west of the 5th meridian in townships 36, 37, 38, and 39. The total area mapped is approximately 820 square kilometers (340 square miles). The elevation in the area ranges from 840 meters (2,750 feet) to 1,060 meters (3,450 feet) above mean sea level.

Drainage and topography

The only major drainage channel is occupied by the Red Deer River. The present-day valley of the river is approximately 30 meters (100 feet) deep and mainly less than two kilometers (1 mile) wide. The valley passes obliquely through the area mapped. The western boundary of the area is the Medicine River. It is a low order perennial stream, occupying a slightly incised valley within a broad valley with gently sloping flanks. Four intermittent streams are present in broad bottomed valleys with only slight longitudinal gradient.

Situated east of the foothills and west of the flat prairies, the area has moderate relief. The highlands are in the form of digitated ridges; the lowlands are broad with very little transverse or longitudinal gradient.

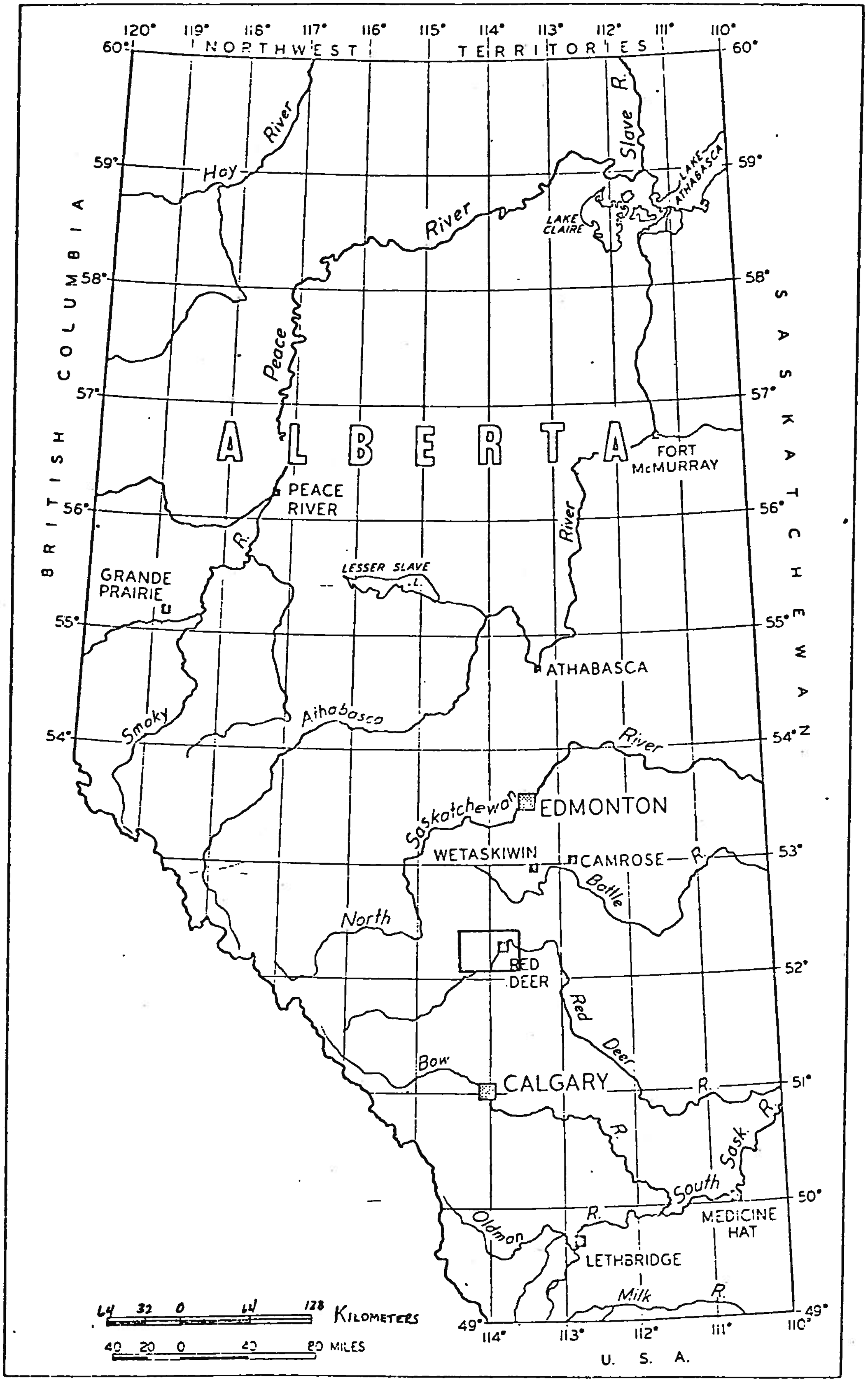

Figure 1: Location of the Red Deer area.

The relief between the highlands and the bottom of the Red Deer River valley is in the order of 125–150 meters (400–500 feet) over distances of 10-15 kilometers (six to ten miles). Therefore, regional gradients are in the order of 0.013 meters/meter (feet/foot). The relief between highlands and adjacent lowlands west of the Red Deer River is 45 to 90 meters (150–300 feet) over distances of three to six kilometers (two to four miles), resulting in gradients of approximately 0.015 meters/meter (feet/foot); east of the river, relief is 90–150 meters (300–500 feet) over distances of five to nine kilometers (three to six miles), giving gradients of around 0.018 meters/meter (feet/foot).

Sand dunes are present in the southwest corner of the area and also north, south and within the city of Red Deer. The dunes in some cases reach heights of 10 meters (35 feet).

Climate and vegetation

According to the Köppen classification (Trewartha, 1954), the Red Deer area lies in the Dfc climatic zone (cold climate, no dry season, short cool summers with humid winters) close to the BSkw climatic zone (mid-latitude steppe). The mean daily temperature is close to 2°C (36°F) and annual precipitation is approximately 430 millimeters (17 inches) (McKay, 1967).

The area of study lies in the "Coniferous Forest" vegetation zone close to the boundary with the "Prairie Grassland" vegetation zone, according to maps of the world distribution of vegetation (Trewartha, 1954). However, the most commonly observed tree vegetation in unfarmed areas is the Aspen variety, with coniferous trees being secondary, though unmistakably present.

Geology

The bedrock exposed in outcrop is mainly sandstone and shales. The different rock types are lenticular, having been deposited in a continental environment. At several locations the rocks exposed, both sandstones and shales, are noticeably fractured. Overlying bedrock, preglacial gravels are exposed at two locations along the Red Deer River valley. However, over the majority of the area there is a veneer of glacial and postglacial deposits. On the highlands the veneer is thin and mostly ground moraine. The lowlands have a relatively thick accumulation of deposits in most places. The deposits are composed of a mixture of ground moraine, glacial fluvial, glacial lacustrine, and aeolian deposits.

Principles and Method of Mapping

Introduction

A study of naturally occurring surficial phenomena to determine the groundwater regime is based on various water conditions existing on the land surface. Besides their existence, it is also necessary that the different water conditions can be recognized and interpreted either as a deficiency or a surplus of water relative to the water available from surface sources. The detection and interpretation will be possible if there is a shortage of surface water on or near the land surface during part of the frost-free months. However, the detection of relative amounts of water could conceivably be possible under other conditions, for example, in a humid area with pronounced relief. In this case, surface water would run off, and at least relative surpluses of water would be detectable.

The detection of relative water conditions is used to interpret the direction of groundwater flow. A deficiency of water is interpreted as indicative of groundwater moving away from the land surface, known as a recharge or negative potential area. (The term "negative potential" refers to the phenomenon of lower groundwater potentials with increased depth below the land surface.) A surplus of water is interpreted as being indicative of groundwater moving toward the land surface, known as a discharge or, in most cases, a positive potential area (Tóth, 1966a, p. 35). At locations where a deficiency or surplus is not evident, the interpretation may be that groundwater flow is parallel to the land surface; this is known as the area of parallel or hingeline flow.

Groundwater Flow

The movement of groundwater is governed by the fluid-potential gradient; Hubbert (1940), in his classical paper "The Theory of Ground-Water Motion," showed that movement is from regions of higher to regions of lower fluid potentials. The fluid potential, which is the mechanical energy per unit mass of fluid at a point P in the flow region, is given by Hubbert's general expression

$$= gz + \overset{p}{\underset{p_o}{\frac{dp}{}}} \qquad (1)$$

where = fluid potential, g = acceleration due to the earth's gravity field, z = elevation of the point P above a standard datum, p_o = pressure of the atmosphere, p = pressure in the flow region at any point, and = density of fluid. The measurement of groundwater potential at a point in the flow region, if the point is open to atmospheric pressure, can be obtained by the expression

$$= gh \qquad (2)$$

where h = elevation to which the fluid rises above standard datum ("h" is often referred to as the hydraulic head). This means that the potential at a point in the groundwater flow region can be obtained from the elevation of a water level in direct contact with the atmosphere times the acceleration due to gravity.

The potential field governing groundwater flow in a rigid, porous, unconfined medium under natural conditions is a conservative field of force. This means that there is no change in the mass of a unit volume with time. Therefore, the analysis of the potential field can be made by means of the Laplace equation:

$$^{2}h = 0 \tag{3}$$

where ^{2} is the Laplacian operator.

The distribution of the potential within the field results automatically in the determination of the path of groundwater flow. Flow will be from higher to lower potentials along lines of maximum potential gradient (that is, at right angles to lines of equal potential) if the permeability of the porous medium is isotropic.

Tóth (1962), using an analytic solution of the Laplace equation, derived an equation for the solution of the distribution of the potential in a mathematical model. The model simulates a small drainage basin with a linear slope in a region in which the water table is a subdued replica of the topography. Three of Tóth's conclusions are pertinent with respect to the study of groundwater from surface phenomena:

a) The drainage basin is composed of two areas. Upslope from the hingeline (or midline) is the recharge area; downslope is the discharge area (Fig. 2, modified after Tóth, 1962, p. 4380). The presence of discharge over the lower half of the basin results in only a small portion of the groundwater reaching the valley bottom.

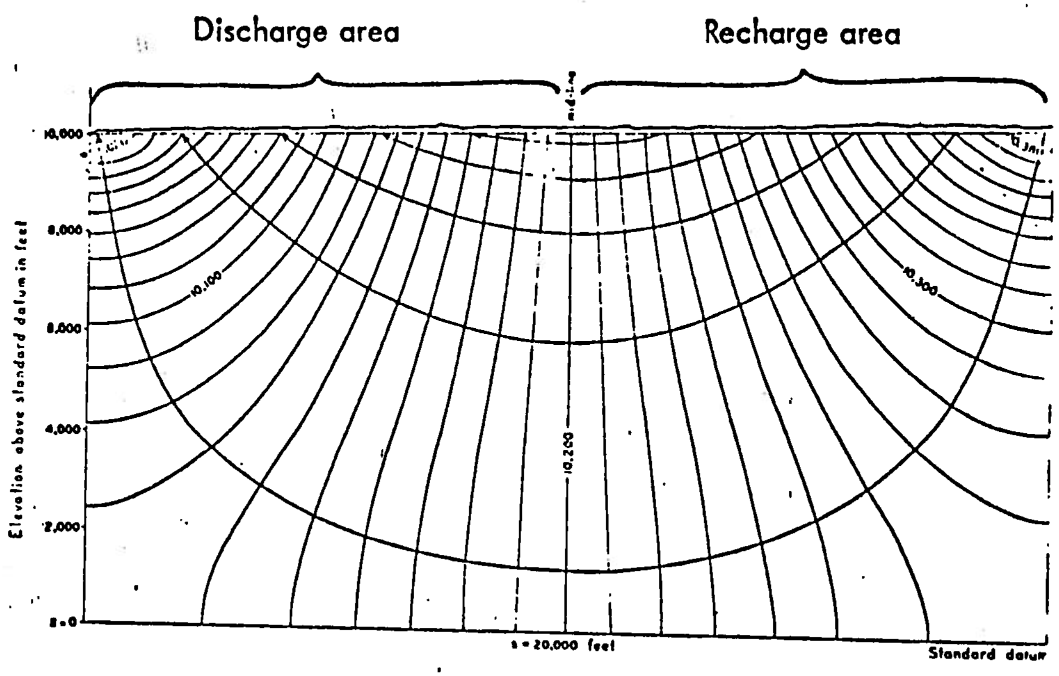

Figure 2: Distribution of recharge and discharge areas with respect to the hinge line (midline) [modified after Tóth, 1962, Fig. 3]

b) The belt of phreatic fluctuation is larger as the distance up the valley flank increases from the valley bottom.

c) Anomalies in the potential distribution will result from permeability inhomogeneities in the flow region.

Tóth (1963) calculated the potential distribution in the mathematical model with a simple harmonic function, rather than a linear function, representing the valley flank. From the results of this study the following pertinent conclusions were obtained:

a) Within a small drainage basin, three orders of flow systems can be present (Fig. 3, after Tóth, 1963, p. 4807):

i) first order – local system

ii) second order – intermediate system

iii) third order – regional system.

b) The development of local systems is a direct result of local topography.

c) Under extensive flat areas, flow is retarded.

d) The result of local flow systems is that groundwater from any number of adjacent local topographic highs may be discharged in geographical proximity in one local topographic low.

Freeze (1966) used a numerical finite-difference approach to determine the potential distribution in the mathematical model. This method facilitated the calculation of flow patterns under a variety of conditions not feasible by the analytical method. With the numerical approach, a more versatile configuration of the upper boundary is possible; inhomogeneity and anisotropicity of the medium are not restricted to simple cases; and the third dimension can be included.

The flexibility of the numerical method of analysis enabled Freeze to calculate mathematically the potential distribution in the flow region caused by permeability inhomogeneities. The effect on the potential of a higher permeability lens, as shown on figure 4 (Freeze, 1966, p. 149), is the same as a local topographic high; that is, on a linear surface, a recharge and a discharge area are present as a result of a permeability variation.

In summary, in areas in which the water table is a subdued replica of the land surface, topographic relief establishes the potential distribution of groundwater. The potential distribution is modified by geologic conditions (herein the reference to geology is to the change in permeability of the rocks rather than to changes in actual rock types).

Manner of Groundwater Discharge

The observable existence of groundwater discharge onto the land surface is caused by groundwater moving toward the land surface at a rate which exceeds the rate of evapotranspiration. Since groundwater discharge is not observed at every point in the general discharge area, there are certain conditions which result in the development of high rates of groundwater flow over restricted areas. The high rates of groundwater flow result from inhomogeneities in the flow medium. The inhomogeneities can be either variations in the permeability of, or the configuration of, the flow medium. High rates of groundwater flow in most cases are associated with decreases in the cross-sectional area of stream tubes*.

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*stream tube – a volume of flowing fluid bounded by a group of streamlines

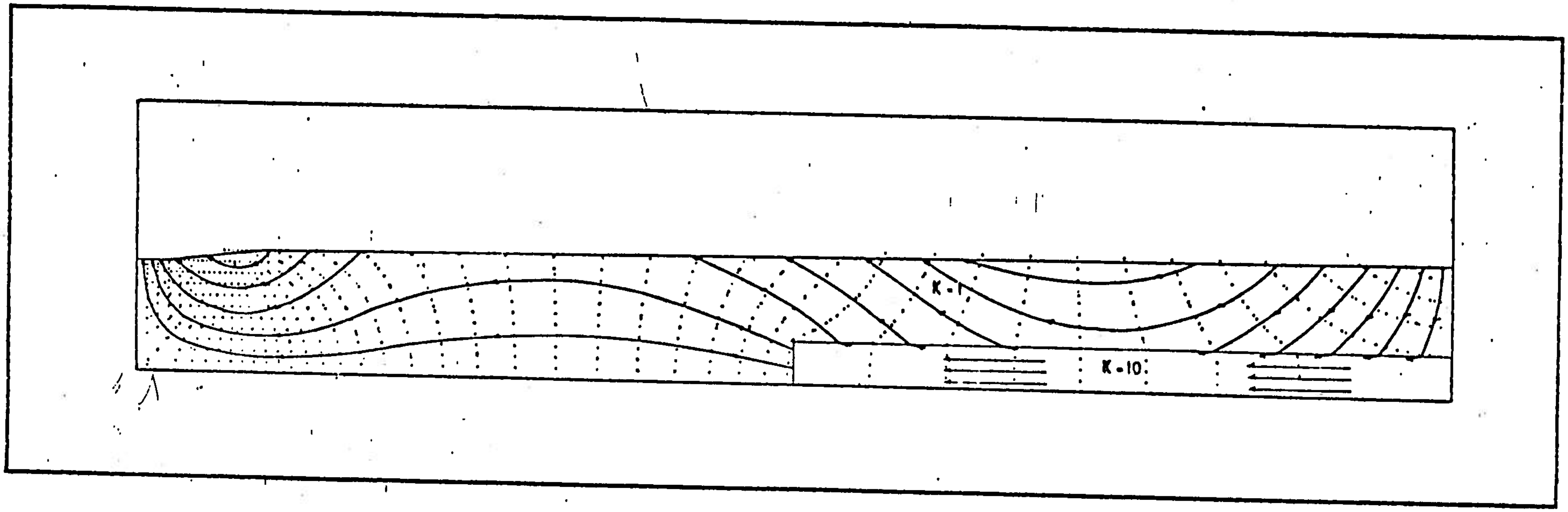

Figure 4. Flow pattern resulting from the presence of a higher permeability lens on a uniform slope [After Freeze, 1966, Fig. 20L]

As was noted under the section of groundwater flow, the effect of a large higher permeability lens was to concentrate flow through the lens (Fig. 4). Since the physical laws governing groundwater flow are the same for all microscopic* variations in permeability, the same "channeling" effect of groundwater results when a small area of higher permeability material (lens) is present. The effect of the lens in a general discharge area is to decrease groundwater discharge over a large area and concentrate it over a small area (Fig. 5). Water which would normally discharge around the lens is routed through the lens. The area above the lens, where groundwater is drawn downward before having reached the land surface because of the influence of the more permeable lens, is called a "microrecharge area".

The concentration of groundwater caused by the configuration of the flow medium is best illustrated by the slope of the water table. First, if the water table is observed from a plan view, it can be seen that any flexure in the water-table contours will result in groundwater being concentrated toward the transverse axis of the convex upslope part of the flexure. For example, if a flexure in the water table exists in a discharge area, then the surface trace of flowlines approaching the surface shows that the width of the stream tubes decreases. Consequently, there is a concentration of groundwater flow in the area in which the water-table contours are convex upslope, at the expense of locations in which the contours are convex downslope (Fig. 6).

If the profile of the water table is considered in cross section, once again the concentration of groundwater is possible. In the case in which a steep slope is adjacent to a slope which is significantly less steep, a fluid potential distribution can result which causes particular stream tubes to decrease in cross sectional area

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*microscopic – refers to the scale in which a fluid element is large enough that irregularities of flow due to the medium need not be considered, only the statistical

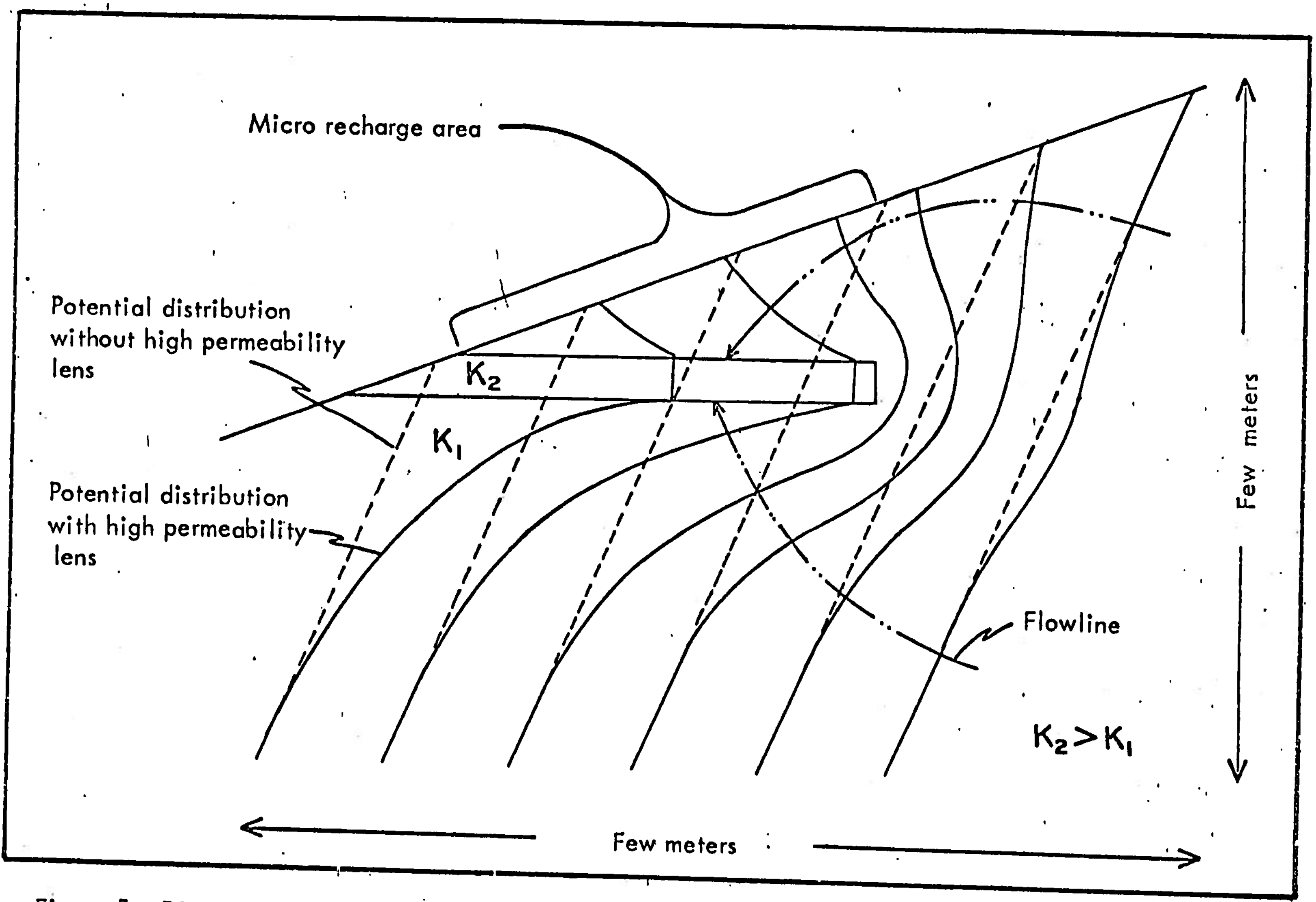

Figure 5. Diagrammatic representation of the fluid potential distribution associated with a small, high permeability lens in a general discharge area.

and hence concentrate groundwater flow (Fig. 7). Because of the concentration of groundwater flow caused by the water table configuration in this case, it is possible to develop a line of concentrated discharge along a steep slope in a homogeneous and isotropic medium. If,superimposed upon this condition, small flexures in the contours are present it would be possible to have a line of points of concentrated discharge along the slope at approximately the same elevation. If the points of discharge were springs, and if they were observed in the field, the springs would immediately be classified as contact springs, yet they could conceivably be formed in a homogeneous and isotropic situation.

Because individual features indicative of groundwater discharge on the land surface are finite in areal extent, and because their size is not large in comparison to the size of the basin, the features are believed to result from inhomogeneities in the flow medium which are small compared to the size of the basin. Therefore, the appearance of discrete occurrences of groundwater discharge in the field is not consistent with the solutions given by the mathematical model. This is because the small inhomogeneities giving rise to the discrete occurrences of groundwater on the land surface are too small to be consideredon the scale of the models.

In summary, the movement of groundwater toward the land surface is continuous when studied on a small scale. However, when the scale is large, as in the case of field observations, movement toward the land surface is along preferred paths caused by inhomogeneities in the flow medium. The inhomogeneities can result from variations in permeability in the flow medium, or from the configuration of the flow medium.

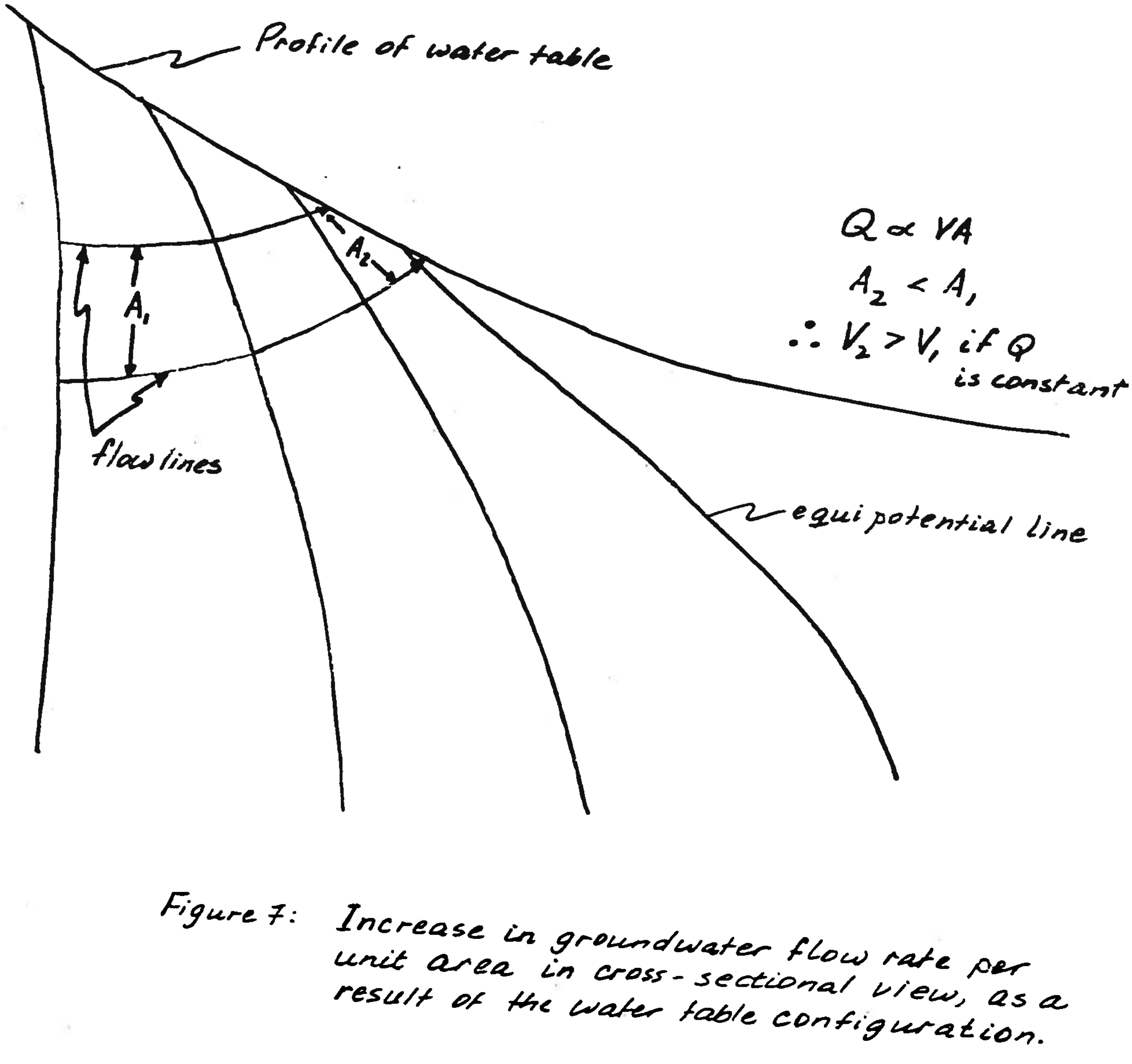

Figure 7: Increase in groundwater flow rate per unit area in cross-sectional view, as a result of the water table configuration.

Chemistry of Groundwater

The chemical composition of groundwater is in a state of constant change. In the words of H. Schoeller (1962, p. 372): "La composition chemique d'une eaux souterraine est quelque chose de tres vivant." Changes in the chemical composition of groundwater result from an interaction between the groundwater and the medium through which it flows. Because of its motion, groundwater is unable to reach an equilibrium with its (surroundings) and consequently is in a state of constant change.
(environment)

The rate of change of the chemical composition of groundwater is a function of the chemical and physical properties of the medium, the rate of groundwater flow and the path of flow. The three main processes by which changes in the chemical composition of groundwater originate are as follows: a) solution of mineral matter, b) ion exchange, and c) sulphate reduction. Other chemical reactions between groundwater and the environment do occur, but for the most part they are not as significant.

Soluble salts establish the basic chemical quality of groundwater. The solubility of particular salts will govern to a large degree the amount of a salt which will be dissolved, though the availability, amount, and duration of contact between the groundwater and the salt will also be important.

Ion exchange modifies the chemical composition of groundwater. Ions in the water are exchanged for ions in the medium. Commonly the exchange is between cations (base exchange), though anion exchanges can also occur.

Sulphate reduction modifies the chemical composition of groundwater by reducing the amount of sulphate in solution. The removal of sulphate by reduction results in the formation of hydrogen sulphide gas and water ($SO_4^{=} + 10H^{+}$ $4H_2O + H_2S$). The hydrogen is obtained from organic compounds or through the metabolism of bacteria.

Even though the chemistry of groundwater is strongly dependent on the environment, systematic studies have shown that the changes in groundwater chemistry can be utilized to study both the flow of groundwater and the medium through which it travels.

Schoeller (1962) has given the total dissolved solids and the ratios of rSO_4[*] to rCl and rCa to rMg as indicative of the direction of groundwater movement. It was shown by Schoeller that total dissolved solids will increase and the ratios of rSO_4 to rCl and rCa to rMg will decrease in the direction of groundwater flow.

From the results of studying many groundwater analyses from all over the world, Chebotarev (1955) formulated a series of anion changes in groundwater which correspond to the length of flow paths. The series, from recharge areas on the left with the length of flow increasing to the right, is as follows:

$$HCO_3^- \quad HCO_3^- + Cl^- \quad Cl^- + HCO_3^- \quad Cl^- + SO_4^= \text{ (or } SO_4^= + Cl^-) \quad Cl^-$$

A cation series also exists and was illustrated by Bach (1960). The cation series is from predominantly calcium-magnesium waters in the recharge area to predominantly sodium-potassium waters toward the discharge area.

The methods of Schoeller, Chebotarev and Back are ways in which the direction of groundwater movement can be interpreted from the chemical quality of groundwater.

In mapping groundwater from the land surface, determination of the chemical distribution is obtained from water samples obtained from the end of flow paths. Even though most studies of the chemical composition of groundwater are conducted

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[*] r indicates concentration in epm

through the analysis of water samples obtained from within the groundwater system by means of wells, the same techniques for interpretation of changes in the water quality can be used when groundwater samples are obtained from on or near the land surface. This is because the flow length of successive flow lines increases as the distance downslope from the hingeline increases. The increase in flow length should, theoretically, result in a complete series of chemical changes being present at the land surface between the hingeline and the thalweg.

However, in many cases, the cation and anion series of changes are not complete. This is often the case whether or not the groundwater samples are taken from wells. The incompleteness of the series of expected changes may indicate a relatively short flow path. If, on the other hand, a deviation from the expected results occurs, an insight into the medium of flow might be obtained.

In terms of the quality of groundwater for different purposes, groundwater samples taken at the end of a stream tube represent for the most part the maximum degree of mineralization within the stream tube. Therefore, waters sampled at the end of the flow tube represent the poorest groundwater quality to be expected between the land surface and the same stream tube at depth.

The preceeding discussion of the chemical changes in groundwater is very limited. However, in most cases it is sufficient to permit two types of information to be gleaned from an areal distribution of chemical quality, apart from the actual distribution itself. The first concerns the general movement of groundwater; the second concerns the medium through which the groundwater has flowed. Also, it has been shown that groundwater samples collected from or near the land surface are useful in studies of the groundwater regime.

Method of Mapping

Map scale

To be able to use naturally occurring surficial phenomena to study the groundwater regime, it is necessary that a surplus or deficiency of water, relative to that which can be attributed to surface sources, be detectable on the land surface. Therefore, this method of mapping should involve only those flow systems in which the volume of waters, or the rate of flow, or both, are such that the required relative surplus and deficiency which develops are detectable. For the most part, the flow systems which will result in detectable relative water conditions are the ones circulating the majority of the groundwater exchange.

For any mapping project, the scale of field mapping should be commensurate with the detailedness of the investigation; the more detailed, the larger the scale. Since in groundwater mapping the most important flow systems are those circulating the greatest percentage of the groundwater flow in the area being mapped, the detailedness of mapping should focus attention on these systems.

If the water table is a subdued replica of the land surface in the area to be studied, the detailedness of the study can be determined from the topography. For example, the detail needed to study the groundwater regime on a long uninterrupted slope would not be as great as on the same slope with pronounced local highs present.

In summary, the scale of field mapping should be to focus attention on the flow systems circulating the greatest percentage of the groundwater exchange in the area being mapped.

Preparatory phase

In areas for which topographic maps are available, the initial stage of investigation is the use of topographic maps in the office. At the onset, a small-scale topographic map is needed. On the map, note should be made of regional and major topographic highs, as well as major stream channels both within the area of study and in the surrounding areas. The regional slope and any major trends in the topography within the area of study should also be noted. On larger-scale topographic maps, the area of investigation should be divided up into segments wherein similar environments of groundwater flow are present. (Environment is quantitatively definable by topography, geology, and climate.) In a particular environment, climate, topography and geology each must be uniform.

A uniform distribution of climate can be visualized by either an individual area of study being small, or by dividing a larger area into smaller areas. If the geology is also uniform, then for an area to have a similar environment of groundwater flow, it is only necessary for the configuration of the water table to be similar throughout, parallel to the maximum gradient of the highest and lowest areas of the water table. If the water table is a subdued replica of the topography, then the latter condition is satisfied if the distribution and areal extent of corresponding topographic expressions of the same relative magnitude are more or less constant and the corresponding forms occur in the same relative position within the drainage basin.

If the geology is not uniform throughout, it is still possible to analyze the environment of groundwater flow on the basis of topography alone. This condition presupposes that while the over-all geology is not uniform, the relative position of the rocks of similar permeability is the same in all parts of the area of similar topography and the rocks have approximately the same areal extent and thickness.

Geomorphic principles indicate a strong relationship between the permeability of rock types and subsequent land forms. Therefore, the latter set of conditions will suffice in many circumstances.

Delineation of different areas in which the environment of groundwater flow is similar should be followed by a study of the different types of local topographic expressions present within each area. The local topography should then be studied with respect to its position in the drainage basin and its areal extent.

In the absence of topographic maps, aerial photographs may be used to complete this part of a study. However, the interpretation may not be as fruitful as with topographic maps unless the observer is well versed in the use of aerial photographs.

The division of an area into discrete parts of similar groundwater flow permits a rough estimate of the types of flow systems expected to commence or terminate within any particular part. This method of outlining similar environments of groundwater flow can be likened, for the purpose of analogy, to the initial stages of a geological study. In this case, the geologist, by examining the topographic map, attempts to delineate areas of major geologic structures and rock types before going into the field.

Reconnaissance phase

The first part of the field work should be a cursory traverse over the entire area and also to check to see if the areas of similar environments of groundwater flow, as outlined in the office, are realistic.

The second part of the reconnaissance survey should consist of a second, fairly rapid traverse across the whole area but, this time, each similar environment of groundwater flow should be considered separately. On this traverse, an idea of the more obvious features associated with recharge and discharge areas should be obtained. This includes both their distribution and density.

To obtain the best indication of the distribution of features on the reconnaissance survey, it is desirable to traverse along a line essentially parallel to the flow lines. A traverse parallel to the flow lines can most closely be approximated by following a line along the maximum topographic gradient. The traverse should either commence on the topographic high and terminate in the valley bottom, or vice versa.

The reconnaissance survey should provide an outline by which the detailed investigation is to be carried out. The outline should include the order in which individual environments of groundwater flow are to be mapped, when only the natural movement of groundwater is considered.

Detailed Investigation

The purpose of a detailed investigation is to obtain groundwater information from flow systems involving the major part of groundwater exchange. The information collected from naturally occurring surficial phenomena is related to whether or not there is a surplus or deficiency of water at a point, relative to that which could be attributed to surface sources. The possibilities are the following: a definite surplus; a definite deficiency; a possible surplus; a possible deficiency; or no indication of either a surplus or a deficiency.

A definite surplus of water is indicated in three possible ways: a discharge of groundwater upon the surface of the lithosphere, as in the case of a spring or a seepage; the development of phenomena related to surfaceward moving groundwater within the saturated zone, without the water actually being observed (for example, the presence of salt precipitates); or the observation of quasi-stable water levels either on or immediately below the land surface.

A definite deficiency of water is difficult to observe. However, one indication of a deficiency is obtained from "dry depressions" (Tóth, 1966b). These depressions lack the characteristic features associated with depressions which contain water for a duration sufficiently long enough to develop features characteristic of wet conditions. The two factors believed to be responsible for this condition are the quick infiltration of collected surface waters and the lack of groundwater being discharged into a depression. Therefore, these depressions are interpreted as being locations of a definite deficiency of water.

If there is an absence of features related to a relative surplus or deficiency at a location, the point can be omitted. The reverse case is not true; that is, when the interpretation could indicate either a surplus or a deficiency. In this case then, if there is no indication after all possibilities are considered, the best procedure is to record the location as questionable, and see how it is related to phenomena in the adjacent area.

An example of this latter condition might be given by a depression which contains water. There are three possibilities for the water being in the depression: first, the surface water is prevented from infiltrating by an impermeable bottom; second, the water cannot infiltrate because the groundwater potential below the land surface increases with depth due to the depression being in a discharge area;

third, there is a slow discharge of groundwater maintaining water in the depression.

Adding to the uncertainties of the interpretation of relative water conditions, there are locations which, because of their position in the basin, are local points of a surplus of water for part of the year and points of a deficiency of water for the remainder of the year. This type of situation was encountered by Meyboom (1966) in the Allen Hills, Saskatchewan.

At any observation point, it is necessary to collect information of two basic types, namely, descriptive and measured. The descriptive data refer to the presence, absence, type, and interrelation of individual phenomena present at an observation point. This will include the presence or absence of water, type and distribution of particular vegetation or soils, and land forms, both local and regional. The measured data consist of information to which a value is assigned, rates of groundwater discharge, chemical and physical properties of water, depth to water below the land surface and elevation of the observation point.

The data are obtained from field traverses, topographic maps and aerial photographs. Field traverses provide most of the measured and descriptive data. Both topographic maps and aerial photographs provide a small amount of descriptive data. Aerial photographs, besides being used to obtain basic data, are also valuable in the determination of variations in the physiography of the area. This variation helps to determine the route of field traverses.

The density of field traverses is determined by the topography, as was noted earlier. On each traverse, points or areas are visited which are either outlined from the aerial photographs or are encountered in a field traverse. At each observation point visited, both describable and measurable data should be collected.

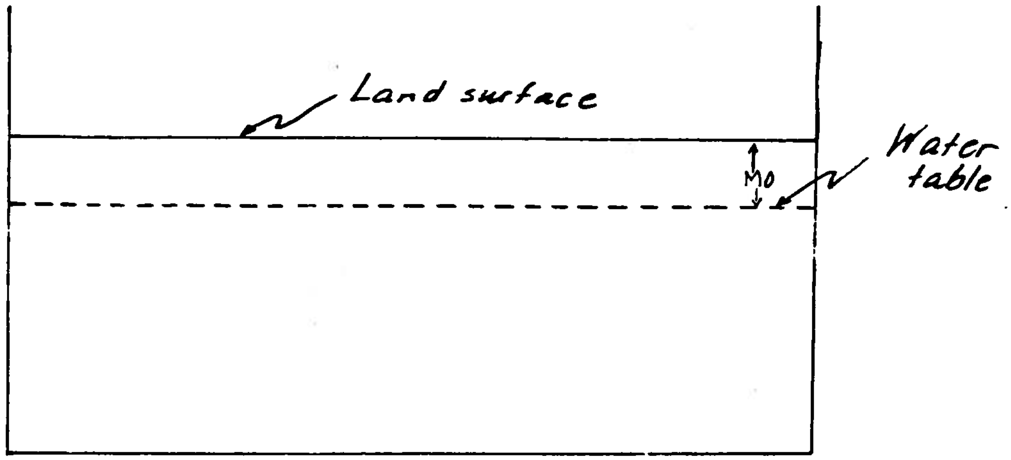

Figure 8a: Position of the water table in a hypothetical basin with a horizontal land surface.

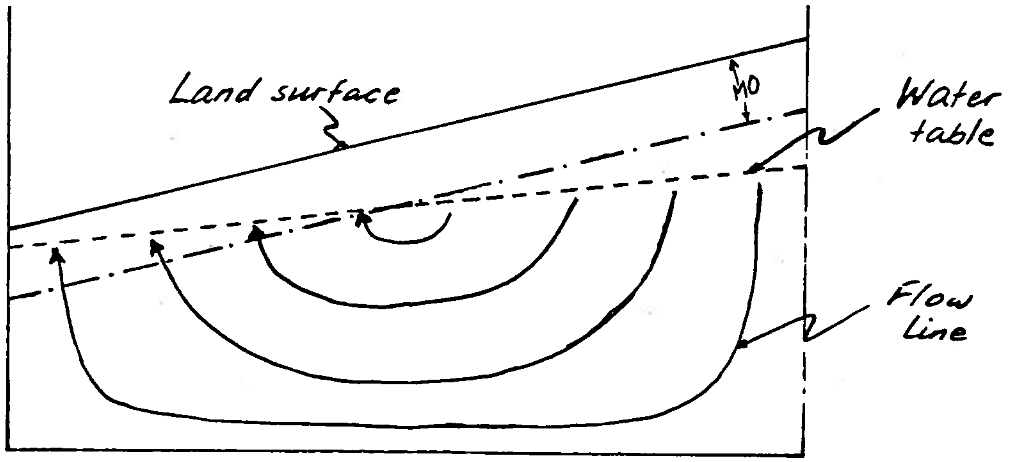

Figure 8b: Position of the water table in a hypothetical basin with an inclined Land surface.

only by the gains and losses through the land surface but will also be influenced by the flow of groundwater. The flow will result in the water table being farther from the land surface (than in the horizontal case) on the higher land, and closer to the land surface in the lower land (Fig. 8b).

The water table being farther from the land surface indicates that there is a deficiency of water relative to that which can be attributed to surface sources. In these areas, the water in the zone of saturation is moving away from the land surface. These areas are termed "hydraulic recharge" or "recharge" areas. Conversely, in the areas with the water table closer to the land surface, there will be a surplus of water relative to that which can be attributed to surface sources. In these areas water in the zone of saturation is moving toward the land surface. These areas are termed "hydraulic discharge" or "discharge" areas.

In recharge areas, the fluid potential of the groundwaters will decrease as the distance downward from the land surface increases. Discharge areas have an increase in fluid potential as the depth below the land surface increases along a line perpendicular to the plane of the land surface.

The distribution of fluid potential with depth is approximated by either a mathematical model or an analog-simulation system. These methods provide a solution for the potential distribution. From the solution, hydraulic cross sections are prepared along given planes. A good indication of natural groundwater movement in an area is obtained from the combination of the areal distribution of fluid potential provided by the water table map and fluid potential with depth, provided by the hydraulic cross sections.

Summary

From the natural movement of groundwater, areas of a relative deficiency of water are present upslope from the hingeline; downslope, a relative surplus of water exists. Relative surpluses of water are observable on the land surface in the form of discrete occurrences throughout the discharge area, as a result of small inhomogeneities in the flow medium. The chemical analysis of water samples collected from points in which groundwater outflows naturally onto the land surface or is available within three meters of the land surface provides the following: an areal distribution of groundwater chemistry; relative flow times for different groundwaters; and variations in the medium of groundwater flow.

Three phases of investigation are used to collect pertinent data. From the analysis of the data, the areal distribution of fluid potential is given by the water table map. Hydraulic cross sections are prepared from solutions of a mathematical model or an analog-simulation system.

Summary of Mapping Results

Preparatory Phase

Preparatory work was started on the 1:250,000 scale National Topographic System maps 83A and 83B with contour intervals of 60 meters (200 feet). Figure 9 shows the areal distribution of land for certain ranges of elevation. From this figure three major topographically high areas are obvious. Along the eastern edge of the area studied, the highland trends roughly north-south and intersects the Red Deer River near the northeastern boundary. The two regional highlands west of the river trend NNW-SSE and terminate within the area of study.

Figure 9: Distribution of major topographic land forms.

The deeply incised Red Deer River is a regional low. The present-day river follows a broad NNE-SSW trending linear depression. The Medicine River, which forms the western boundary, also occupies a broad linear depression. This depression is not a regional low; however, in terms of groundwater flow it serves as a major boundary.

The 1:50,000 scale National Topographic System maps with a contour interval of 15 meters (50 feet) were used to outline 12 settings (setting refers to an area in which the environments of groundwater flow is similar) (Fig. 10). The outlining of settings took into account only the distribution of topography. The climate and geology were reasoned not to be significantly variable over the area. The outline of each particular setting was made in an effort to delineate the extent of the flow systems circulating the greater percentage of the groundwater exchange.

<u>Reconnaissance Phase</u>

The first set of traverses in the Red Deer area was made in June 1966. During two days, 870 square kilometers (340 square miles) were covered by driving a along existing roads. From these traverses, one very important observation was made, namely, there were very few obvious occurrences of salt precipitates. This implied at the time that the quality of water in the general area must be low in total dissolved solids. This conclusion was later borne out by the chemical analysis of groundwater samples. Therefore, in a very short time, it was possible to obtain an impression of general groundwater quality over a very large area.

During the second set of traverses, each setting was traversed separately. In each setting one traverse was made from the topographically high area to the low area along a line as close to the major topographical gradient as possible. Features related to a relative surplus or deficiency were not numerous. Features related to a relative surplus were as follows: 1) three springs, 2) two soap-hole areas, and 3) a sparse scattering of salt precipitates. Definite features indicating a relative deficiency were not observed.

On the basis of the preliminary work, major groundwater flow systems were expected to start on the highlands, terminating on the lower part of adjacent slopes and lowlands. For the most part, very little of the water infiltrating on the highlands was thought to reach the Red Deer River. Small local flow systems were thought to be associated with the sand dune areas; the drumlinoid area and the steep bank of the Red Deer River valley were also expected to have local flow systems associated with them.

Detailed Mapping Phase

Procedure

Traverses for the detailed mapping phase were carried out on the ground over 460 square kilometers (180 square miles) and from the air over 410 square kilometers (160 square miles).

Traverses on the ground were made in a vehicle and on foot. In most cases, the road network was such that a traverse by vehicle could be made around the perimeter of an area 5.1 square kilometers (2 square miles). The intervening area was then traversed on foot. The routes of traverses made on foot were determined by two factors: 1) observations made while driving on the roads; and 2) points of interest determined from aerial photographs. Where no points of interest were detected either on the traverse or with the aerial photographs, two north-south traverses were made across the area approximately one-half kilometer (1/3 mile) apart.

27a

Table 1. Comparison of rates and costs of groundwater mapping between traverses by helicopter and traverses on foot and in a vehicle

	Traverses on foot and in vehicle	Traverses in helicopter
Average rates of mapping	$\frac{4.6\text{km}^2 (1.8\text{ mi}^2)}{\text{day}}$	$\frac{82\text{ km}^2 (32\text{mi}^2)}{\text{day}}$
Costs of mapping	$\frac{\$6.50}{\text{km}^2} \left(\frac{\$17.00}{\text{mi}^2}\right)$	$\frac{\$5.00^*}{\text{km}^2} \left(\frac{\$13.00^*}{\text{mi}^2}\right)$

*does not include ferry time/costs to and from the project area
~~hourly~~ charter rate for helicopter is $ per hour.

In the area two intermittent and 27 perennial springs (Fig. 11) were visited (a marked contrast to the two springs visited during a well survey in the area in 1965). Rates of discharge ranged from a minimum of a few millilitres per minute to a maximum of approximately 400 litres (100 gallons) per minute. Estimated discharge rates for 27 springs (Fig. 11) have been grouped according to Meinzer's (1923) classification of springs with respect to discharge based on the metric system. Table 3 summarizes the results.

Table 3. Grouping of Springs based on Discharge Rates

Magnitude*	Range of Discharge	Frequency
5	60 l/min–600 l/min	2
6	6 l/min– 60 l/min	15
7	600 ml/min–6 l/min	9
8	600 ml/min	1

*Meinzer (1923, p. 53)

Springs are associated with the steep slopes of the highlands and also the steep banks of linear depressions. Seventeen springs, which incudes springs with the largest discharge rates, are associated with the west ridge. Springs are absent from the highest land and on the low-gradient slopes.

At many locations the material from which springs are issuing is not obvious. However, locations at which the material could be readily identified served to indicate the variety of host material for springs. Along the Medicine River a spring is associated with sands (W-121), while along the Red Deer River two springs are discharging from gravels (E-210 and E-211). The largest discharge spring (W-12) is issuing from fractured sandstone. Along the Red Deer River valley and on the south ridge, springs were observed discharging from fractured shale.

Springs are the most obvious naturally occurring surficial phenomena indicative of groundwater moving toward the land surface. The surplus of water relative to that which can be attributed to surface waters is readily obvious. Apart from this obvious fact, a spring provides a basis for the interpretation of associated phenomena. From most springs it is also possible to obtain a groundwater sample for chemical analysis and also a temperature for the discharging groundwater. For these reasons, a spring is a cornerstone in this method of groundwater mapping.

b) seepage

A seepage is the naturally occurring diffuse discharge of groundwater in the liquid state from within the lithosphere, upon it, at an average rate which is not discernible but is equal to or exceeding that of local evapotranspiration. The difference between a seepage, as used herein, and a spring is only in the form of discharge. In some instances, discharge from a seepage area will exceed discharge from some springs.

Discharge at seepages, in some instances, is so diffuse that a positive identification is difficult. However, in the Red Deer area, 46 definite seepages were visited (Fig. 11). Seepages are for the most part located in the same general position within the basin as the springs. That is, they tend to be absent on the tops and upper slopes of the highlands and in the broad flat lowlands.

Discharge rates for groundwater in a liquid form are difficult to obtain except when water becomes concentrated in a linear depression downstream from a seepage area. Reasonable estimates of liquid groundwater discharge were made at

18 locations (Fig. 11). The largest of these rates was approximately 50 litres (13 gallons) per minute at observation point 184, also in the west highland. However, the majority of the seepages have discharge rates less than two or three litres per minute. Since the discharge rates only take into account liquid discharge, values for the rate of discharge are pessimistic. Because discharge is diffuse, a better estimate of total groundwater discharge would be obtained from multiplying the evapotranspiration rate per unit area by the area of the seepage and adding this value to the liquid discharge. However, evpotranspiration values for seepage areas are not readily available for the Red Deer area.

Various methods were used to positively identify seepages in the field. In some cases, discharge became concentrated in a linear depression leading from a seepage area. This was the case at E-1(d-3), W-1, W-49, W-102b and 184. At W-14 the presence of hydrophytic vegetation* over a change in elevation of approximately one meter, with no possible means of surface water being dammed up, was sufficient to identify the presence of a seepage. At location 387, temperature variation of puddled surface water helped to positively identify the seepage and also to locate the most actively discharging area.

A positively identified seepage is an important feature in groundwater mapping. Seepages, as in the case of springs, indicate surfaceward moving groundwater and also permit interpretation of associated features. The diffuse manner of discharge over a large area gives rise to the development of a larger array of associated features. From this point of view, a seepage is more useful than a spring. However, groundwater samples for chemical analysis and true groundwater temperatures are often much more difficult, if not impossible to obtain.

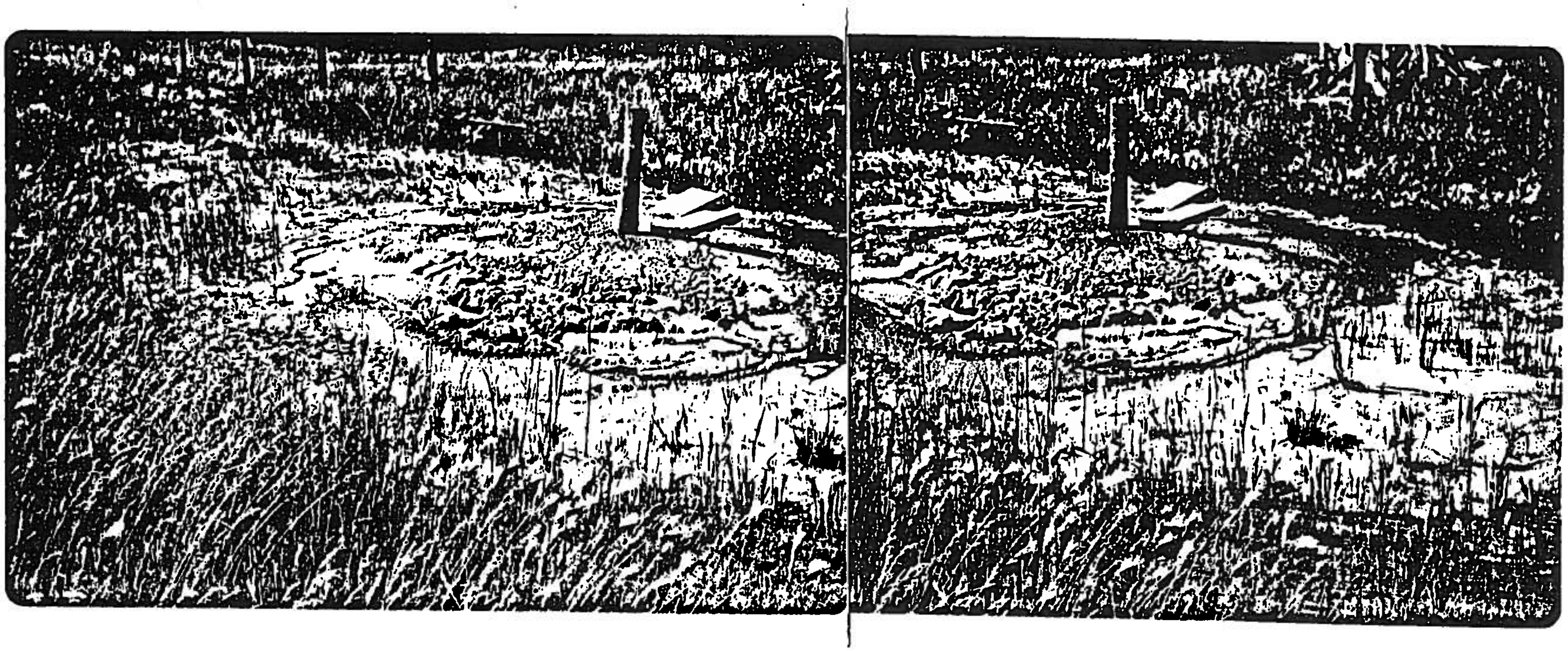

Figure 12. A stereo pair showing a large mound-type soap hole at E-1(c-10b) with a broad cone shape. Material being discharged is a viscous liquid (an admixture of sand, silt, clay and water).

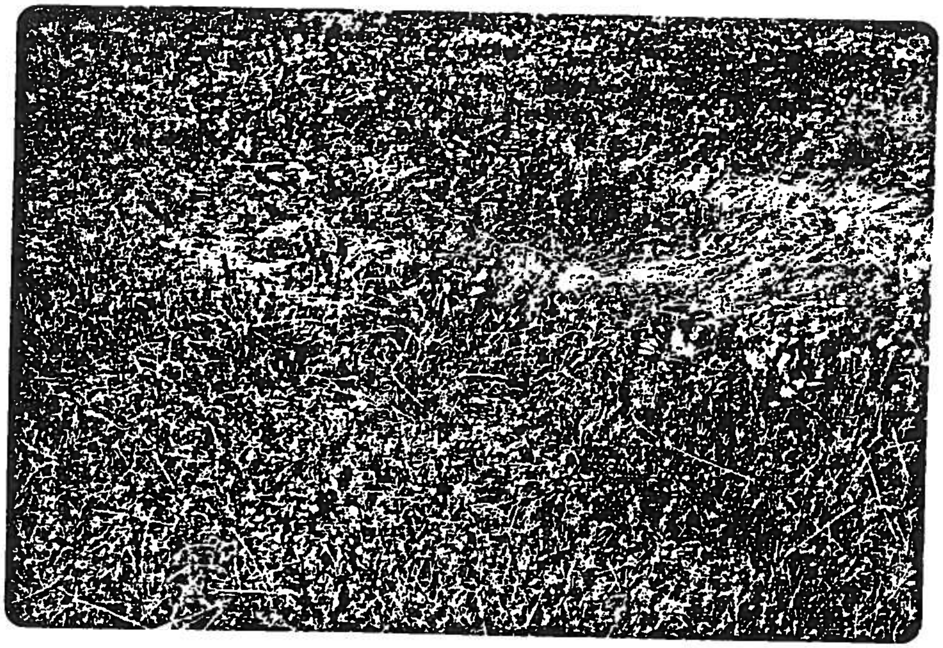

Figure 14. Flat-type, thick-crusted soap hole at E-1(c-8).

The division is arbitrary but corresponds closely with the thickness of crust required to withstand the weight of a man walking across the surface.

Flat-type soap-holes do not actively discharge mud or water. However, the surface of most of these features is usually either damp or wet. At E-1(c-8) water was observed standing on the surface of the feature on several occasions (one occasion was after 22 days without rain during the summer of 1966). Even though the surface remained wet, water was never seen flowing away from the feature. The only indication of discharge associated with some thick-crusted soap-holes was salt precipitates.

Core-type soap-holes resemble flat-type, thick crusted soap-holes with a mound of damp, medium brown silt to very fine sand present in the central region (Fig. 15). The areal extent of the cores observed varied from a few square centimeters to a few square meters. The height of the cores was never more than 15 centimeters above the surrounding land. As in the case of the flat-type soap-holes, the features do not actively discharge either mud or water. However, the cores were never observed dry, and an auger hole in one core had a water level eight centimeters below the top of the core. Around the periphery of the damp material of the core there was a slight accumulation of salt precipitates.

A detailed investigation of four different occurrences of soap-holes in the E-1 area was carried out by augering several small-diameter holes. The investigations indicated that similar arrangements of three types of material can be found associated with the soap-holes. Figure 16 shows a diagrammatic cross section of one investigation from E-1(c-10b) east through c-10a and c-10 to c-10c.

The characteristic material of soap-holes is the viscous liquid (type A

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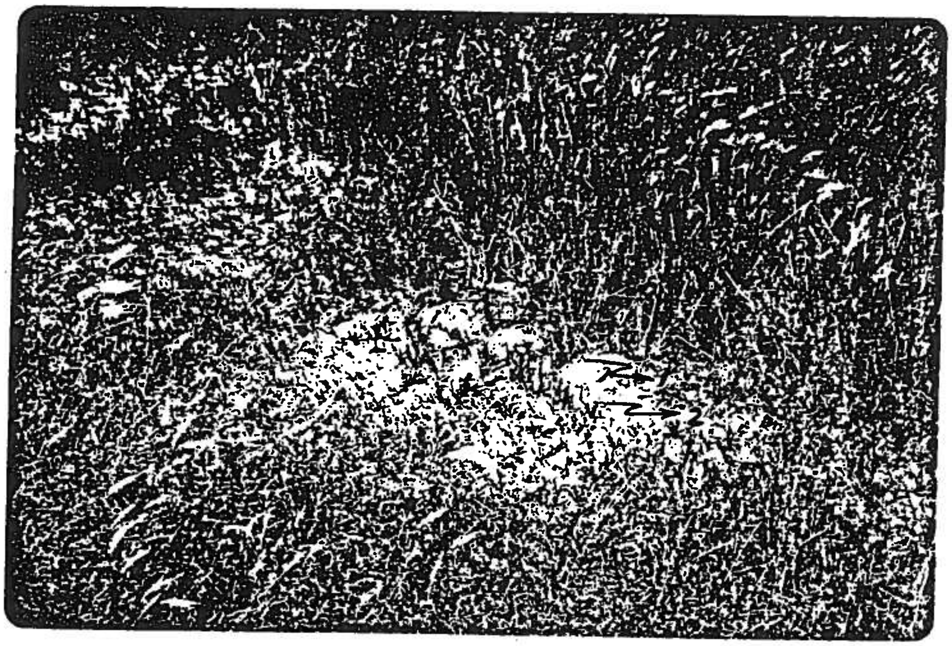

Figure 15. Core-type soap hole E-1(e-3). Arrow 1 points to damp material on core; arrow 2 points to salt precipitates.

material) being discharged at c-10b and d-5. A determination of the water content and particle size distribution of this material was provided by Dr. S. Thompson (written communication, 1966), Department of Civil Engineering, University of Alberta. The analysis was done on samples from c-10b and d-5. These analyses show that type A material has an average water content (weight of water/weight of solids) of 67.7 per cent and a particle size distribution (Fig. 17) with 21 per cent of total weight greater than 1/16 millimeter in diameter, 41 per cent between 1/16 millimeter and 1/256 millimeter and 38 per cent less than 1/256 of a millimeter.

The distribution of type A material in the vicinity of a soap-hole is shown in figure 16. From the diagram it can be seen that type A material is continuous between c-10b and a location immediately east of c-10. At locations c-10b, c-10a, and c-10, the viscous liquid is covered by little or no crust, while the intervening regions have a crust up to 25 centimeters thick. Dr. Thomson (personal communication) has suggested that this material represents a condition wherein neutral stresses caused by upward-flowing water are in excess of the total stress caused by the weight of the particles making up the solid material. When the stress on individual particles due to upward-moving water is in excess of the weight of the individual particles, there is no longer any stress transmitted from particle to particle and the admixture behaves like a liquid. When it is considered that groundwater issued from c-10a and c-10c, this interpretation is very plausible.

Dr. S. Polluck, Department of Soil Science, University of Alberta, has suggested that a high sodium ion content in the water would cause dispersion of particles in the medium, especially since there is a high montmorillonite content in the clay fraction of the type A material. Dispersion of the medium would cause

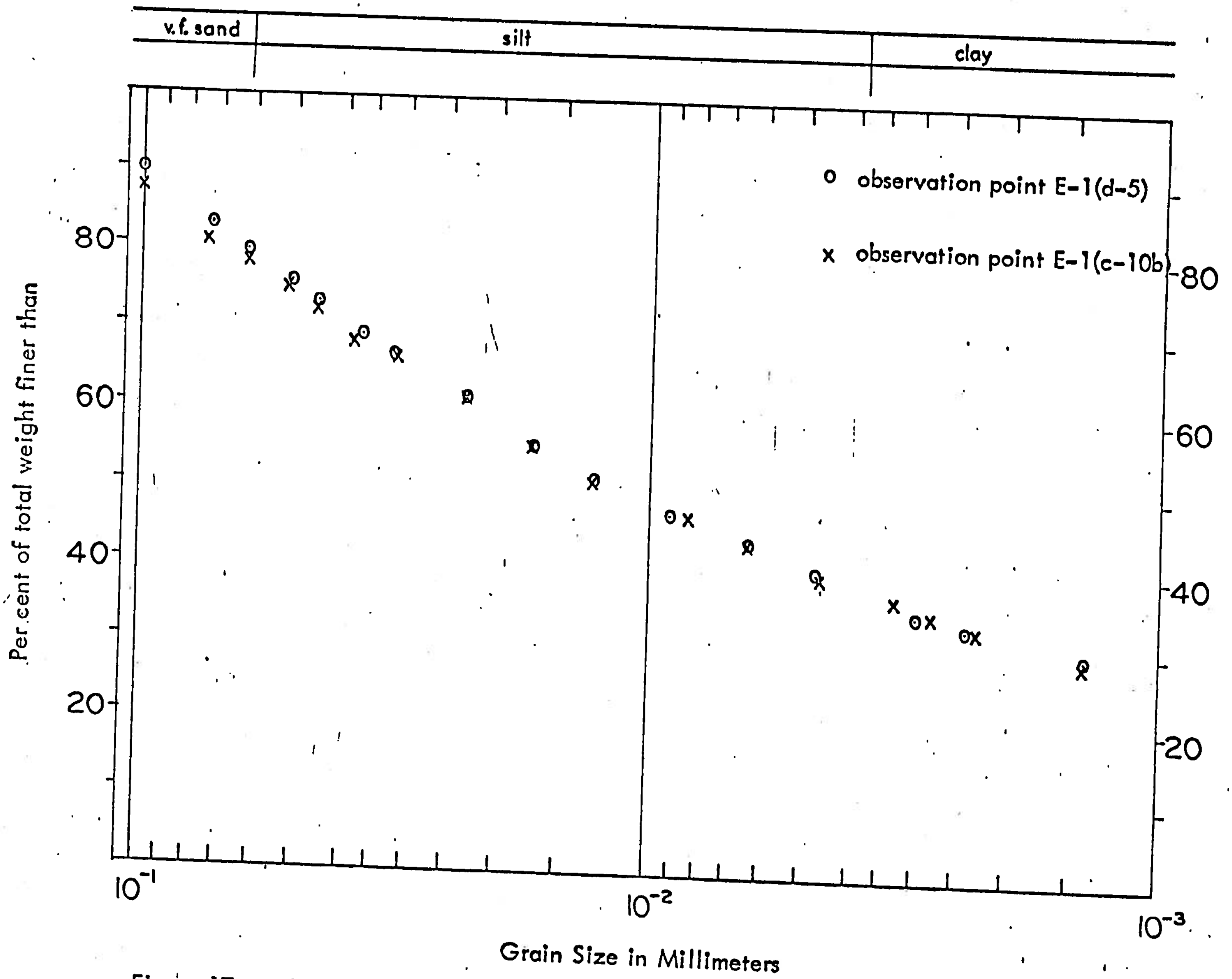

Figure 17. Relationship between percentages of total weight and corresponding grain size of two samples of viscous fluid discharging from soap holes E-1(c-10b and d-5).

surfaceward-moving water to exert a force on individual particles, giving the viscous liquid which exists in most cases. Absence of the sodium ion or montmorillonite might allow the medium to remain in colloids and water would have an open access to the land surface, forming a spring or a seepage. During the summer of 1966, this may have happened at soap-hole E-1(c-10a).

Associated with the soap-holes is a wet, sticky material which is pliable like modelling clay (type B material, Fig. 17). Type B material, while possessing more solidity than type A material, is still unable to resist deformation by small pressures. The lack of strength may be the result of either of the following: upward-moving water at rates less than those required to cause the material to become a liquid, as in the case of type A material; or the sliding effect resulting from failure of bends between individual particles, due to the combination of a high (70 per cent) montmorillonite content in the clay-size particles, and a high water content.

The third type of material associated with soap-holes is a dry, extremely hard infertile, light-colored material (type C material, Fig. 17). This material is believed to be the dehydrated counterpart of type A and type B materials. Type B and C materials were also encountered at locations other than soap-holes and will be duscussed under "less-fertile soils."

Soap-holes were only encountered at three locations in the 820 square kilometers (340 square miles) mapped (E-1 area, 109 and 436). Their scarcity suggests that a unique combination of geologic and hydrologic conditions are needed for their formation. Geologically, it is necessary to have fine-grained material with a high percentage of montmorillonite in the clay-size particles. Hydrologically, groundwater high in sodium ions with a resultant component of flow directed surfaceward is needed.

Therefore, soap-holes are a feature which is indicative of an extra surplus of water. This is indicated by the following: a spring at E-1(c-10b); a flowing auger hole 3 meters deep at E-1(c-10c); the quick condition; the high sodium content of discharging water which suggests groundwater discharge; and the presence of a spring at E-1(g-4).

ii) "swamps" -"Swamps" are the second quick ground feature. In this report, a "swamp" refers to that part of the land surface characterized by a local weakness of limited extent, covered by a vegetation mat. The surface of a swamp when walked across depresses and rebounds in much the same way as the mat of a trampoline when it is walked across. Underlying the vegetation mat at observation point E-61, there is a smelly blackish-colored, slightly viscous mud. (This material resembles what the soil scientists call "muck".)

Six swamps were visited on the slopes of highlands; four of them were on the west ridge (Fig. 11). In all cases, a relative surplus of water was readily determined. The four swamps on the west ridge all had excessively wet conditions over a change in elevation of at least one meter. The swamp on the east ridge had a seepage associated with it while the swamp on the south ridge occurred less than 50 meters (155 feet) from a spring and within 10 meters (35 feet) of a soap-hole.

In the area between the sand dunes by the Medicine River, slough bottoms were described by farmers as being flexible in various years. A farmer described the slough bottom at W-97 as a "floating" bottom. A second farmer told the story of how it had been necessary to use two pieces of window screen to cross the extremely flexible bottom of a slough in order that he could retrieve his fallen goose.

Though no definite evidence of seepages could be obtained from these sloughs, the association of salt precipitates, light grey soil, and the presence of a flowing shot hole at W-87 tends to indicate that these flexible-bottom sloughs have some relation to swamps.

q Detailed investigations of swamps were not carried out. The thickness of peat is not known, but swamps on slopes bear a strong resemblance to the feature known to soil scientists as a "hanging bog" ("bog" refers to peaty soil underlain by muck; "hanging" indicates a slope).

The area of local weakness in a swamp indicates a quick condition. The association of springs, seepages, and soap-holes indicates the presence of surfaceward-moving groundwater and therefore substantiates the interpretation of a quick condition.

The difference in surficial expression between soap-holes and swamps may result from either local inhomogeneities in the surface material or the amount of water which is discharged (being more for swamps in order that a vegetation mat can develop). However, the reason for differences is not a major point. The cause for the difference does not effect the conclusion that both features indicate surfaceward-moving groundwater.

Damp soil

Damp soil in this report refers to a soil which remains damp, while soil in adjacent areas under similar conditions is dried. Damp soil is found as a series of discrete patches, or as a continuous patch over an area of limited extent. It has been observed in closed depressions, on slopes, and on relatively flat ground (Fig. 18a).

Observations of damp soil were made in numerous cleared depressions over the area. This damp soil condition was usually detectable because of incomplete vegetation cover in the depression, a result of cultivation in drier years.

Damp soil patches were observed at several locations on relatively uniform slopes lacking any perceptible closed depressions. Four such locations are E-127, W-39, W-136, and 62. At these locations, the soil was more moist at the surface than in the surrounding area. Locations E-127 and W-39 were both observed at least two days after the last rain and both areas covered approximately 2×10^3 square meters ( ). W-136 is approximately 1.5×10^2 square meters ( ) in areal extent. The ground at this location (on a slope of approximately 1 in 50) was so damp that it "squished" like a wet sponge when walked across; this observation was made at least ten days after the last rain. Observation point number 81 (Fig. 19) is less than 250 meters (feet) from an intermittent spring at observation point number 62.

Damp patches are believed to indicate a saturated zone below the land surface. The movement of water from the saturated zone to the land surface occurs as capillary action through small openings in the ground. The height to which water will rise by capillary action is unversely proportional to the diameter of the capillary openings. However, as the eeight of rise increases (because of a decrease in the size of the openings) there is a decrease in the rate at which a given volume of water can rise in the column. Once the volume of water transmitted to the land surface becomes too small, evapotranspiration will be able to keep up with the supply of water. Hence, there will be no evidence of damp soil. Therefore, the depth to the saturated zone cannot be excessive at locations where damp soil is observed. The occurrence of damp soil in patches is thought to be the result of inhomogeneities

Figure 19. Damp soil on even slope at #82. In light grey areas the soil is dry on the surface and partially covered with funny salts (see Fig. 22).

in the surface or near-surface materials.

Damp soil observed in the ditch at observation point number 316 (Fig. 20) and on a slope at W-11 support the interpretation of a saturated zone close to the land surface. In both cases, an auger hole to a depth of less than 1.5 meters encountered a saturated zone. The water level in the holes rose to less than one meter below the land surface. The chemical analysis of each water encountered showed conclusively that these waters were continuous with groundwater system.

Damp soil is indicative of a saturated zone close to the land surface. When damp soil occurs on a slope, the associated saturated zone is continuous with the groundwater system. However, damp soil on flat ground or in a closed depression requires additional information such as water quality to conclude that the associated saturated zone is continuous with the groundwater system. Therefore, damp soil can be used to indicate a relative surplus of water.

Hummocky ground

Hummocky ground in this report refers to a location where small mounds of soil occur on the land surface. The mounds are 15-20 centimeters high and up to 25 centimeters in diameter. If the periphery of the mound is delineated by steep sides a vegetation mat is present only on top of the mound; a mound which graduates into the adjacent area has a complete vegetation cover (Fig. 21). The number of mounds at a location may be a few or many and they may be clustered together or spread out. The term "hummock" is used for the mound because of the similarity between this feature and what Washburn (1956) calls "earth hummocks." "Earth hummock" has not bee used since the term is in part genetic ("Although earth hummocks are almost certainly related to frost action,...", p. 831, Washburn (1956)), and the

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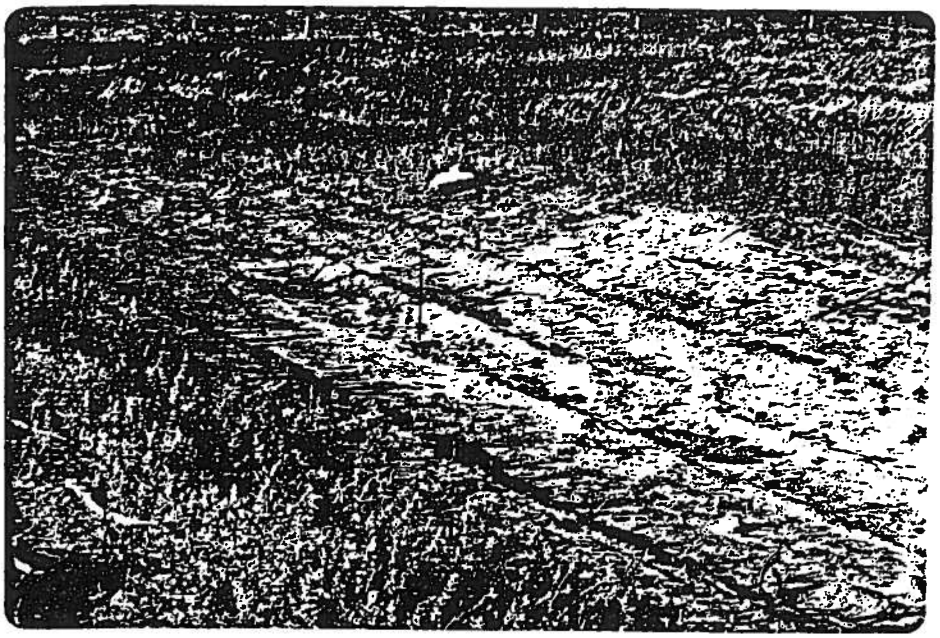

Figure 20. Damp soil in ditch at #316.

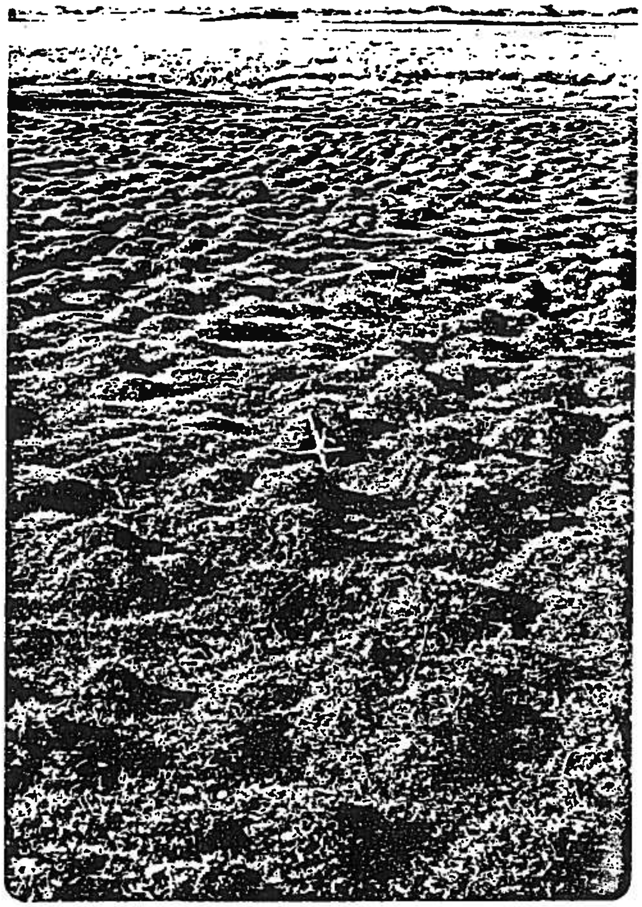

Figure 20a. Hummocky ground at #308a .

origin of hummocks was not sought. Instead, investigations near Red Deer attempted to establish any possible relationships between the presence of hummocks and the nature of moisture conditions on or near the land surface.

In an earlier report (Clissold, 1967), hummocky ground was reported to be associated with saturated zones within two meters of the land surface on slopes and at the base of steep slopes in linear depressions. The quasi-stable water levels in auger holes and the chemical analysis of waters from the holes showed conclusively that the saturated zones were continuous with the groundwater system. Because the hummocky ground investigated and reported in 1967 was on a slope, it appeared that hummocky ground was associated with seppages which did not have sufficient head to outflow on to the land surface. Therefore hummocky ground was grouped under the heading of "hidden seepages."

Field work in 1967 has shown that hummocky ground can occur in numerous topographic positions. The presence of hummocky ground in a closed depression or in a broad low area does not suggest a hidden seepage situation. Yet in cases where holes were augered in the vicinity of hummocks, a saturated zone was always encountered within three meters of the land surface. Therefore, hummocky ground has been set aside as an individual feature.

The distribution of hummocky ground occurrences is given on figure 18a. Of the 54 occurrences, a natural outflow of groundwater was present at seven locations and auger holes penetrating into the saturated zone occurred at 13 locations. In several instances, the saturated zone encountered in auger holes was in sand.

Hummocky ground has been definitely related to a saturated zone at a shallow depth; generally, the closer the saturated zone is to the land surface, the more pronounced and numerous are the hummocks. Investigations of this feature, and its association with definite points of groundwater discharge, indicate that hummocky ground is associated with a relative surplus of water.

Salt precipitates

The term "salt precipitates" refers to an accumulation of salt (compound formed from the cation of a base and the anion of an acid) on the land surface having precipitated from the evaporation of mineralized water. Toth (1966b) had eight samples chemically analyzed from the Trochu area. The main salt components of the samples were Na_2SO_4 (sodium sulphate), with varying amounts of $CaSO_4$ (calcium sulphate), $MgSO_4$ (magnesium sulphate) and $NaHCO_3$ (sodium bicarbonate).

When the main salt component is Na_2SO_4, the salt precipitate forms a white coating on the soil, for example, near Three Hills (Fig. 21). The presence of these salt precipitates is striking and definite. However, in the Red Deer area, the predominantly Na_2SO_4 deposits are not as extensive or as intense as illustrated in figure 21.

A second type of salt precipitate occurred at many locations in the Red Deer area. This salt accumulation from a distance has a light grey tinge (Fig. 19) rather than white as in the case of Na_2SO_4 precipitates; the form of precipitation is also different from Na_2SO_4. The accumulation of this salt is not in the form of a complete coating, but instead as a mottled accumulation (Fig. 22). These salt precipitates were not analyzed chemically but because they have no taste when licked and would not effervese in cold dilute hydrochloric acid, they were concluded to be either $CaSO_4$ or $MgSO_4$. However, the mineralized water from which

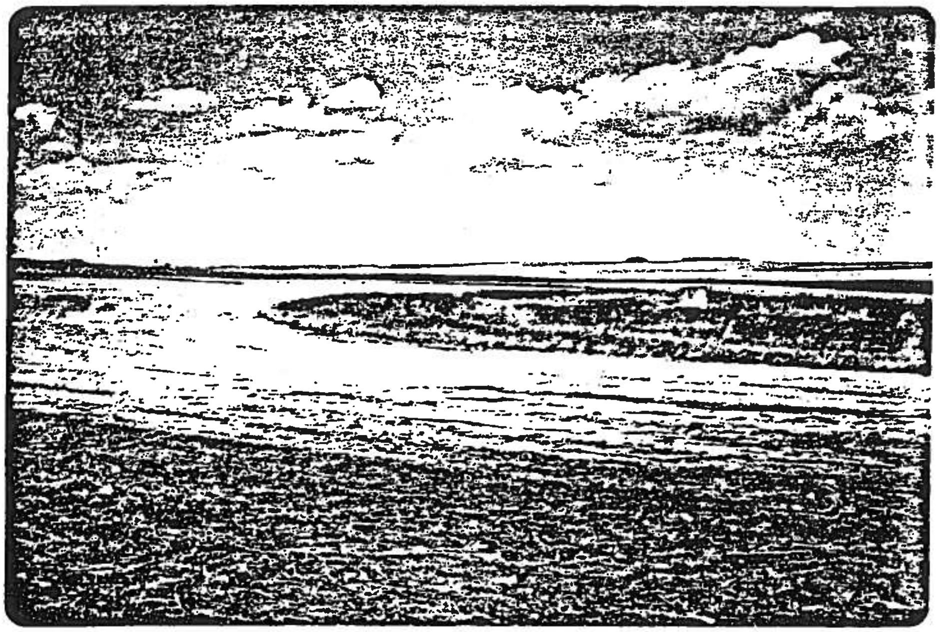

Figure 21. Salt precipitate deposit near Three Hills, Alberta.

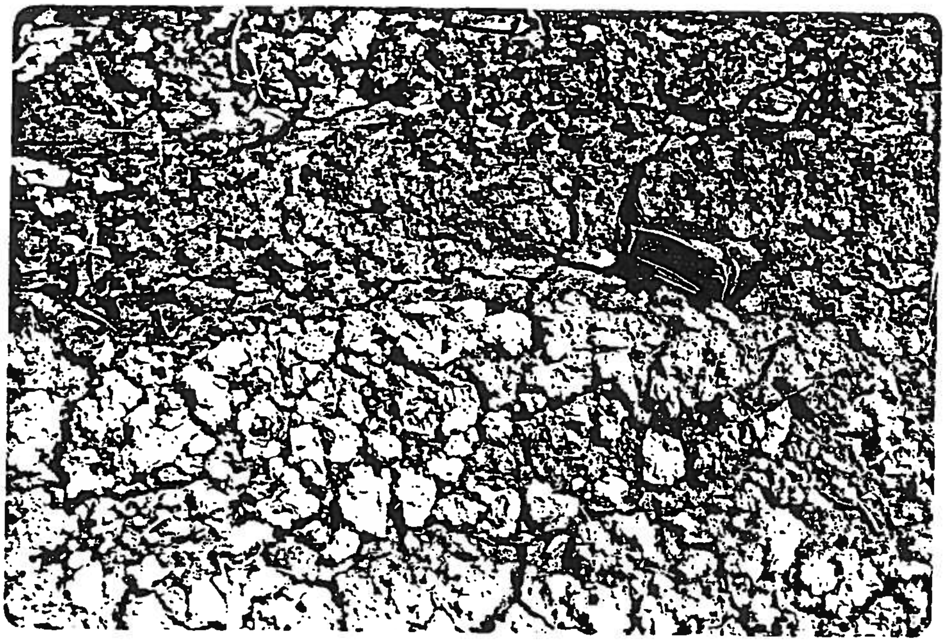

Figure 22. Mottled appearance of "funny salt" accumulation at #82.

these salts could be derived suggests that they are $NaHCO_3$. This second type of salt precipitate has been referred to as "funny salts" to differentiate it from the "normal" Na_2SO_4 precipitates.

The two types of salt precipitates have been differentiated on the map (Fig. 18b). The salt precipitates composed mainly of Na_2SO_4 are found predominantly in the extensive low areas, west of the Red Deer River and northeast of Penhold; these salts are also common on the slope of the southern highland and the adjacent lowland to the north. The funny salts are present on the slopes of the other highlands and the low area southeast of the city of Red Deer. They are most abundant in the low area and in the west-facing slope of the west highland near Evarts.

Salt precipitates are deposited from the evaporation of mineralized water. Theoretically, the intensity of a salt accumulation is a function of the amount of water being evaporated and the amount of dissolved mineral matter in the water. However, observations in the field indicate that the intensity of salt precipitates depends on the dissolved mineral matter in the water more than the amount of water evaporated. This is observable when salt precipitates form as a result of the direct evaporation of groundwater. If the total dissolved solids of the groundwater is high a very intense patch of salt precipitates will form (Fig. 21, total dissolved solids of groundwater in this area is). Conversely, when the total dissolved solids are low, a light grey tinge to the soil is all that is evident (Fig. 18b, total dissolved solids of groundwater in this area is approximately 800 ppm).

Dissolved mineral matter may be present in either groundwater or surface water, though amounts are generally larger in groundwater. Therefore, the presence of salt precipitates does not indicate necessarily that groundwater is being evaporated.

Yet a relationship between salt precipitates and groundwater discharge does exist.

In recharge areas the majority of salts dissolved by waters are moved downward away from the land surface. Therefore, the evaporation of surface water will not result in salt deposits. On the other hand, in the discharge area the surfaceward-moving groundwaters distribute salts to the land surface. Surfave water in the discharge area have a continuous supply of salts which can be dissolved. When these waters are evaporated from impounded areas salts will be precipitated.

Therefore, the presence of salt precipitates is indicative of surfaceward-moving groundwaters. The salt precipitates can be derived directly from the evaporation of groundwater or from the evaporation of surface water which has first dissolved and concentrated salts deposited by groundwaters.

"Less-fertile soil"

It is generally realized that groundwater conditions play an important role in soil development. Unfortunately, because of the lack of training in soil science, the author was unable to use the distribution of soil types to aid in the determination of the groundwater regime, except in very special cases. The special cases have been termed "less-fertile soil."

In this report "less-fertile soil" is defined as regolith in which the growth of natural or cultivated vegetation cover is impeded relative to that found on the adjacent friable soil. The areal extent of any one patch of less-fertile soil or adjacent group of patches may range from a few square meters (a few square yards) to a few square kilometers (few square miles).

Three soils of differing appearance satisfy the above conditions. The first type of material is locally referred to as "gumbo." This soil, where wet, is similar to type B material associated with soap holes and, where dry, is similar to type C material. The "gumbo" from E-112c has high pH (9.4), a high free lime and sodium content, and an electric conductivity of 0.9 millimhos per centimeter.* Water samples were obtained from auger holes less than two meters deep in gumbo patches W-60 and W-67. The analyses (Appendix A) show that the waters have high total dissolved solids, sodium plus potassium greater than 80 per cent of the total cations, and sulphates between 50 per cent and 80 per cent of total anions.

The second type of less-fertile soil is characterized by surface soils in which the structure is that of hard, dense lumps a few centimeters in cross section. A hole augered in a patch of this type of soil at W-67a passed through type B material from four to 46 centimeters below the surface. A water sample was obtained from the auger hole at a depth of 140 centimeters. Analysis of the water (Appendix A) shows the water to have a high total dissolved solids content, sodium plus potassium equal to 90 per cent, and sulphate content equal to 72 per cent. The presence of type B material, the similarity of water quality, and the geographic proximity of this point to the gumbo soils at W-60 suggests that these two soils are different expressions of the same phenomenon.

To determine the distribution of gumbo, some individual occurrences were noted, but not every one specifically. Instead, a map outlining the several areas in which gumbo was observed was made. This is because gumbo patches

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*Analyzed by Agricultural Soil and Feed Testing Laboratory, University of Alberta.

usually occur indiscriminantly over small areas. The map showing the distribution is given on figure 18c.

Gumbo is to some degree associated with all the broad low areas. The most common occurrence is in the lower slope of the higher land and toward the perimeter of the lowland. Determination of the presence or absence of gumbo in the central regions of the lowlands was not possible because of the accumulation of non-cultivated vegetation. Apart from the broad lowlands, gumbo is also present in the area of NNE-SSW trending lineations west of the Red Deer River.

There is a noticeable absence of gumbo on top of the highlands, the upper slopes of the highlands, and the sand dune areas. Gumbo is also noticeably absent in the northern part of the area west of the Red Deer River.

The presence of water levels close to the land surface at E-58, E-125b, W-54, W-60, W-67, W-67a, and W-68, and the relative stability of the water level at W-67a, measured from September 13, 1966 to October 6, 1966 and implied by the presence of the hand-dug wells at E-125b, W-54, and W-68, suggests that these forms of occurrence of less-fertile soils are related to water levels close to the land surface. The high total dissolved solids content of the water at W-60, W-67, and W-67a implies that the water has been in contact with the ground for a relatively long time interval. The presence of salt precipitates on the land surface at several locations indicates that water is moving toward the land surface. An additional fact worth considering is that according to local reports, it is possible to temporarily increase the fertility of these less-fertile soils by the addition of excessive amounts of barnyard manure. However, fertility decreases with time and after one or two years of increased fertility, the soil again becomes as unproductive as before the addition of the manure. This had been recognized by

Mitchell, Moss and Clayton in 1944. This suggests that the physical and chemical properties of these less-fertile soils are in equilibrium with a dynamic process. Because of the associated phenomena mentioned above, the dynamic process is interpreted as the continual addition of salts to the soil by discharging groundwater.

The third type of less-fertile soil is restricted to the local topographic lows in the dune area by the Medicine River. Neither trees nor cultivated vegetation will grow in these lows; however, a lush growth of hydrophytic vegetation can be found in uncultivated lows. Where cultivated, the dry soils have a definite light-grey appearance. At W-82, the light grey color was observed associated with an eight-millimeter thick crust. A water sample analyzed from an auger hole less than two meters deep in the cultivated low of W-80 indicated that, on the basis of water chemistry, these less-fertile soils are different from the ones previously mentioned. The variation in the fertility of the low areas indicated by the variation in vegetation strongly suggests a set of conditions similar to those existing at W-140. At W-140 the variation in vegetation is governed by the amount of water present, which in turn is regulated by the natural outflow of groundwater and by the slope of the land. However, at any given point within the area of W-140, the amount of water present will remain essentially constant with time. If the same conditions prevail in lows between the dunes, then the amount of water present must be relatively constant. A relatively constant water level indicates that the water in these depressions is for the most part of groundwater origin.

Both kinds of less-fertile soil indicate a relative surplus of water. Therefore, they can be used to indicate surfaceward-moving groundwater.

Vegetation

The distribution of vegetation in a basin is largely determined by the quality and quantity of water available. If a hydrogeologist is familiar with plant ecology, it is possible to determine the direction of groundwater movement with respect to the land surface and the chemical quality of surfaceward-moving groundwater. Meyboom (1966) has used this approach to study groundwater movement on the lower part of the flank of Arm River valley, Saskatchewan.

Without some training in plant science, a distribution of plant communities within a basin and their interpretation is not possible. However, it is possible to distinguish anomalous water conditions within a basin with a knowledge of a few species of plants and an awareness of changes in plant communities, identifying a few, or in some cases none, of the plants in the community.

The individual species of Baltic rush (Juncus balticus) and spruce trees (Picea glauca or mariana) were common and useful. Wild barley or foxtail (Hordeum jubatum) and red samphire (Salicornia rubrum) are of limited use in the Red Deer area since foxtail tends to be ubiquitous and red samphire is scarce. With the exception of the spruce trees, all the mentioned plant species are highly salt tolerant (Meyboom, 1966, after Bud, 1957; Dodd, 1960). In addition to being salt tolerant, Juncus and Salicornia are phreatophytes.*

Spruce trees are not classified as phreatophytes. However, when spruce trees have not been cultivated, there is a close correlation between more moist soil

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*Phreatophyte – "A plant that habitually obtains its water supply from the zone of saturation either directly or through the capillary rise." (Meinzer, 1923, p. 55) conditions and the presence of these trees. Yet, when the soil is too moist the trees will not grow. (This is well illustrated by the swamp at observation point 110. Spruce trees are all around the wet area; at the actual points of discharge no trees are growing (Fig. 23)). Because spruce trees prefer moist conditions but do not like excessive moisture, they are frequently associated with water in areas in which a large fluctuation in the water table does not occur. Therefore, the presence of spruce trees, especially in large numbers, is a good indication of the need for a closer investigation.

The map distribution of both Baltic rush and spruce trees is given on figure 18d. From the map it can be seen that neither species is common on top of the highlands. Occurrences of Baltic rush are far more numerous than spruce trees. This is even more emphasized by the fact that a complete distribution for spruce trees is not available because their usefulness was not realized until late in the field season of 1966.

The transition from one plant community to another usually manifests itself in an observed change in growing conditions. For example, rather than being aware of changes in a plant community, observed changes will be in terms of "more-favorable" or "less-favorable" growing conditions with respect to the surrounding area. Figure 23 illustrates this principle. An absence of trees is evident in part of the brush patch. A closer investigation will, without question, indicate a surplus of water where trees are absent without being aware of all the plant species present.

Except for one or two plants, vegetation in the present study was used to draw attention to anomalous moisture conditions. Places in which changes in

Figure 23. Relationship of spruce trees distribution to concentrated groundwater discharge.

moisture conditions are slight can only be detected in the field. However, when major changes occur, such as at observation point number 110 (Fig. 23), the anomalies can be detected in aerial photographs and can then be used to plan field traverses.

i) closed depressions

A closed depression is one of the most commonly occurring physiographic features in the Red Deer area. Unfortunately, it is also one of the most difficult to interpret. Difficulty in the interpretation of these features results from either the masking effect caused by the accumulation of water on the surface or by a depression being a point of discharge during part of the year and a point of recharge during the remainder of the year.

Water in a closed depression may originate from the following: a) surface sources only; b) groundwater and surface sources; and c) from groundwater only. If the water is of surface origin, there are two possible reasons for the water not infiltrating: first, the bottom of the depression is impermeable; and second, the ground beneath the depression is already saturated with groundwater moving toward the land surface.

Interpretation of the prevailing water condition at a closed depression can be obtained if there are, associated with the depression, some additional phenomena related to a relative water condition. In the case of a relative surplus, associated phenomena may be salt precipitates or some features indicating a relatively stable water level. For example, a relative surplus of water was deduced for E-153d for the following reasons: the presence of salt precipitates at E-153c and E-151a; and the relatively stable water level in the depression at E-153 during the entire summer, despite the broad, shallow nature of the depression and the lush growth of hydrophytes over the entire depression. The use of associated phenomena to deduce a surplus of water in closed depressions in local lows in the dune area adjacent to the Medicine River was outlined under less-fertile soils.

The interpretation of the chemical quality of surface water can be very complex. Some factors governing the amount of dissolved material in surface waters are as follows: 1) the source of the water, 2) if groundwater, the quality and quantity being discharged into impounded bodies of surface water; 3) amount of soluble salts in the soil; 4) amount of local relief in the catchment area; f 5) size of catchment area; 6) amounts and rates of evaporation; and 7) amounts and rates of precipitation.

Conductivities of surface waters were taken during parts of the summer of 1966 and throughout the summer of 1967. Despite the large number of factors affecting the total dissolved solids in surface waters, a relatively systematic distribution of dissolved material in surface waters does occur (Fig. 24). Generally, waters low in total dissolved solids occur on either regional or local highlands, while waters high in total dissolved solids occur in regional or local lows.

As was noted under the discussion of salt precipitates, waters low in dissolved minerals are expected in recharge areas. In discharge areas the total dissolved solids are expected to be higher. However, in the general discharge area it would still be possible to have surface waters with low total dissolved solids. For example, if an area was truly impermeable, groundwater would not actively discharge, yet wsurface water could be impounded. In this case, surface waters might be expected to be low in total dissolved solids. However, the possibility of water being high in total dissolved solids in a recharge area is unlikely.

Meyboom (1966) investigated a depression in hummocky moraine in a regionally high area, Allen Hills, Saskatchewan. He found, using piezometers, that the local lows in the hummocky area serve as discharge areas for part of the year and as recharge areas for the remainder of the year. A physiographic similarity exists between the depressions described by Meyboom and those observed at observation points E-114d, W-20, and on traverses W-27 and W-43. This suggests that these depressions are of the type which are discharge locations for part of the year and recharge locations for the remainder of the year. This is suppoeted by the observation that no closed depressions were observed which definitely indicated a relative deficiency of water.

An assessment of a closed depression, based only on the feature itself, is difficult. The depressions are best interpreted in light of associated features or the prevailing conditions in the general area. If a definite answer is required for a specific closed depression, then a thorough investigation of that depression should be carried out by installing piezometers. However, for general mapping the interpretation, if not conclusive, should be suggested but detailed investigation should be carried out.

Geomorphic features

Two geomorphic features which can in some instances be related to groundwater movement are gullies and stream meanders. The term "gully" in this instance is used to refer to a linear depression formed from running water and having steep slopes sharply delineated at their upper limits, one to several meters in depth with a similar width between the upper slope limits (Fig. 25). Most gullies are

Figure 25. Gully at E-1(a-9) from the ground.

very pronounced in the headward region, becoming less pronounced downstream and finally ceasing to exist. The gullies observed are usually at the most a few hundred meters in length (Fig. 26). The term "stream meander" refers to a location where a stream deviates from a straight course.

Gullies and meanders are associated at several locations with natural outflows of groundwater. Of the 38 gullies observed, springs and seepages were associated with eight. Some meanders on both the Medicine and the Red Deer Rivers were associated with springs and seepages on the valley wall forming the outside of the stream meander.

The association of gullies and meanders with points of a relative surplus of water seems to agree with the idea put forth by Toth (1966b). He suggested that at locations with soft and permeable pockets of surface material, and at which a continuous outflow of groundwater occurs, the ground is more vulnerable to surface erosion than adjacent locations where the above conditions do not exist. At locations where a continuous outflow of groundwater occurs, the resulting increase in erodability of surface materials may be the result of neutral stresses caused by the surfaceward-moving groundwater.

At locations where only indications of groundwater discharge are associated with gullies and meanders, their relation to groundwater discharge could result from either one or both of two conditions.

The first condition would be if the outflow of groundwater is intermittent. The best example of this is a spring or a seepage which is present only in the springtime. The outlfow of groundwater could result from an excess of groundwater in the discharge area resulting from the ground being frozen through the winter. If,during

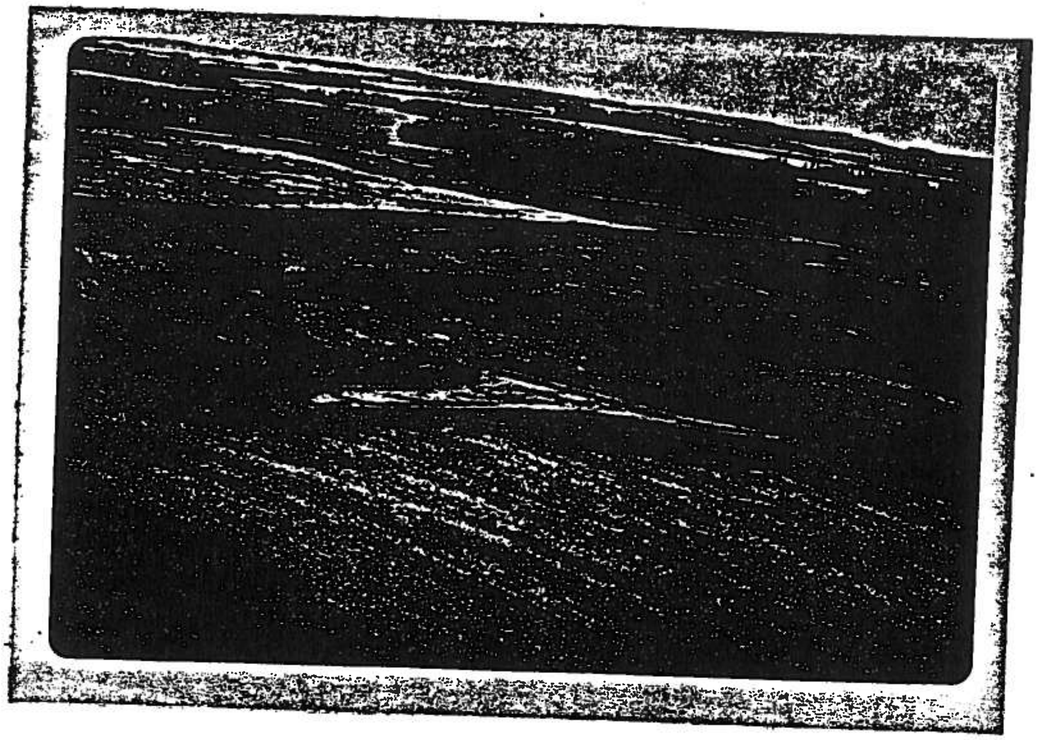

Figure 26. Gully at E-1(a-9) from the air.

the time of groundwater outflowing, any excessive overland flow occurs, a gully could start to form, being associated with the point of discharge. In the case of a stream meander, if the excess of groundwater occurs at the time of spring floods, erosion of the bank would occur in the areas weakened by groundwater discharge. If an indentation in the stream bank were to result from erosion, a small meander may develop if the indentation were to persist once the river level receded. In either of these cases, once the "summer equilibrium" is reached, presence of the spring or seepage would no longer be evident and the only indications of groundwater discharge might be some features associated with a relative surplus of water.

An example of gully formation under this condition was noted during the spring of 1967 at observation point number 62. The gully formed in a cultivated field. In this field there had been no indication of a gully when the field was seeded in late May. After an excessively wet June, an intermittent spring was associated with a gully less than a meter deep (Fig. 27). The spring had ceased to flow by late July but the soil in the general area was still damp and salt precipitates were present on the land surface over a large area.

The second condition whereby a gully or a stream meander could be related to groundwater discharge without an actual outflow of groundwater being observed would be if a feature associated with a relative surplus of water is related to an increase in permeability of surface material. Because of larger permeability, it is possible that the forces holding the soil particles together are less than in the adjacent lower permeability areas. Consequently, in times of excessive runoff, areas of higher permeabilities may be more easily eroded. This process could also be operative at points of groundwater outflow.

Figure 27. Association of a newly-formed gully with an intermittent spring at #61

In cases of excessively large discharge rates, it may be possible for gullies to form as a result of groundwater discharge alone. However, in the Red Deer area, rates of discharge are relatively small. Therefore, the association of gullies with evidence of groundwater discharge suggests that gully formation is caused by an interactionary relationship between surface waters and groundwaters.

The effects of an interactionary relationship are best shown at established stream meanders with established groundwater discharge. At such locations groundwater causes mass wasting of the slope (soil creep, slumping, etc.). The material which moves downslope is carried away by the stream. Hence, by the action of both agents, erosion of the stream bank is maintained at a rate greater than if only one were eroding by itself.

The association of gullies and stream meanders may also be related to points of groundwater discharge for another reason. Because both features result in a reduction of the elevation of the land surface, there may be a change in the configuration of the groundwater system. Any changes which would take place would be to introduce a low fluid potential area. This would result in the concentration of groundwater flow toward the feature and hence increase the possibilityfor a relative surplus of water to be detected.

Even though gullies and stream meanders do definitely form in the absence of groundwater discharge, they are still useful features in groundwater mapping for two reasons: a) the frequency of occurrence of gullies and stream meanders with a relative surplus of water is high enough to warrant a close investigation of each feature and b) both these features are easily detectable on aerial photographs and can therefore be used to plan field traverses.

Groundwater quality

The distribution of groundwater quality is based on the analysis of 125 water samples collected from locations in which groundwater outflowed naturally onto the land surface, or was available at shallow depths. This represents a density of one sample for every seven square kilometers (2.7 square miles). The distribution of the samples is shown in figure 11. There is a noticeable absence of water samples in the broad low areas and on top of the highlands.

The groundwater samples were collected from 26 springs, 38 seepages, seven swamps, 47 non-flowing and seven flowing auger holes or shallow hand-dug wells. Field methods were mainly used to analyze the water samples (Appendix A, Fig. 11). A few duplicate samples were collected and one of each set was analyzed by laboratory methods to check the correctness of the field analyses. A comparison of results is given in table 4; for the most part, the results are comparable.

Total dissolved solids have been determined mainly by a solubridge. The solubridge reading in micromhos per centimeter (mho/cm) at 25° centigrade is multiplied by 0.7 to determine the approximate total dissolved solids in parts per million.

Conductivity readings range from 310 to 14,050 mho/cm (Fig. 11). Significantly, 85 per cent of the values are between 350 and 1,350 mho/cm. West of the Red Deer River, the quality of groundwater is better on the average, with 85 per cent of the waters between 350 and 850 mho/cm, whereas east of the river 83 per cent of the waters are between 550 and 1350 mho/cm. However, in absolute terms, the groundwaters in both areas are very good by

Alberta standards.

The anion radicals carbonate ($CO_3^{=}$), bicarbonate (HCO_3^{-}) and sulphate ($SO_4^{=}$) were determined for most samples. The chloride ion (Cl^{-}) was not determined in many cases, since the amount of chloride in waters in the Red Deer area is very low.

Of the waters analyzed, 90 per cent have HCO_3^{-} plus $CO_3^{=}$ greater than or equal to 50 per cent of the total anions. The 10 per cent of the groundwaters with $SO_4^{=}$ plus Cl^{-} greater than 50 per cent of the total anions are found in the broad low area east of the Medicine River and the broad low areas north and east of Penhold.

The total calcium plus magnesium ($Ca^{++}+Mg^{++}$) was determined from analysis. The sodium plus potassium ($Na^{+}+K^{+}$) content was determined by difference. (The sum of the equivalents* per million of the anions minus the equivalents per million of calcium plus magnesium is equal to the equivalents per million of sodium plus potassium.)

The range of sodium plus potassium in per cent of total cations ranges from 0 per cent to 100 per cent. The higher percentage values for $Na^{+}+K^{+}$ are associated with the slopes of the east and southeast highlands; occasional locations along the Red Deer River valley; along part of the gentle slope west of the Red Deer River north and south of Sylvan Creek; the low area west and south of the west ridge; and in the pronounced linear depression west of the south end of Sylvan Lake.

The analyzed groundwaters have been divided into different water types on a scatter diagram (Fig. 28). The division of analyses is based on the percentage

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*equivalents per million (epm) $= \frac{\text{ion content in ppm}}{\text{equivalent wt. of ion}}$

of sodium plus potassium of the total cations and the percentage of bicarbonate plus carbonate of the total anions. The scatter diagram has been divided into six areas, even though only five of the six areas are applicable. The types of waters are as follows:

Types 1 to 3 $HCO_3^- + CO_3^=$ - 50% of total anions

Type 1. 45 samples

0% - $Na^+ + K^+$ - 33% of total cations
Average conductivity 629 mho/cm

Type 2. 47 samples

34% - $Na^+ + K^+$ 67% of total cations
Average conductivity 677 mho/cm

Type 3. 28 samples

67% - $Na^+ + K^+$ - 100% of total cations
Average conductivity 1,064 mho/cm

Types 4 and 6.

$HCO_3^- + CO_3^=$ 50% of total anions

Type 4. 2 samples

0% - $Na^+ + K^+$ - 33% of total cations
Average conductivity 1,755 mho/cm

Type 6. 3 samples

67% - $Na^+ + K^+$ - 100% of total cations
Average conductivity 7,210 mho/cm

Figure 28 is a pattern diagram. It diagrammatically represents the chemical composition of each type of water. The representation is in the form of the range and average conductivities for all the waters in each type, and the range and average of equivalents per million values for each group of elements within

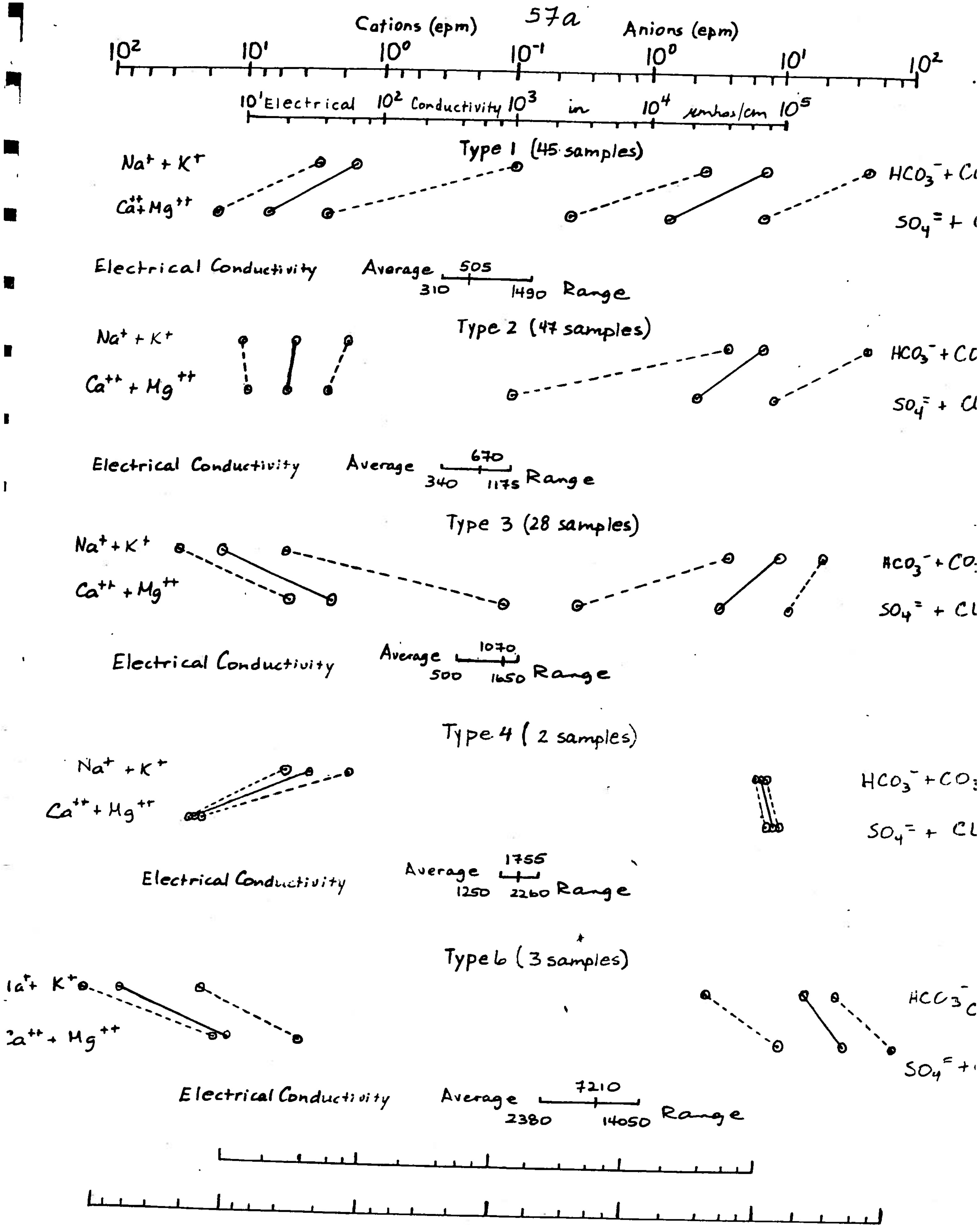

Figure 28b: Pattern diagram showing the five

each type of water.

One of the most important aspects of groundwater chemistry is its relation to groundwater movement. However, this aspect will be dealt with after the movement of groundwater has been interpreted. At this point, the chemistry can be used to detect relative water conditions.

When a water sample is obtained, it is necessary to establish its relationship with the groundwater system. If the water is associated with the groundwater system, then at the location of sampling there is a relative surplus of water. If the water sampled is not continuous with the groundwater, then a relative surplus does not exist. The best method to determine whether or not the water sample is from a groundwater source is to compare the chemistry of the water sampled with the chemistry of groundwater actively outflowing onto the land surface at some nearby location.

From the comparison of the chemical composition of waters sampled, the samples reported are believed to represent only those which are continuous with the groundwater system. Therefore, all therefore, all the points for which chemical analyses are available (Fig. 11) represent a relative surplus of water.

Groundwater temperatures

The temperature of groundwater was measured at locations with groundwater outflowing onto the land surface. At locations with low discharge rates, or diffuse discharge, temperatures were generally greater than 10° centigrade. These values were taken as unrepresentative of actual groundwater temperatures.

The temperatures believed to be indicative of groundwater temperatures range from 4°C to 9°C, inclusively. Of the 31 temperature readings, 6°C was recorded on eight occasions, 8°C on six occasions, and 9°C on five occasions. The remaining temperatures (4°C, 5°C, 7°C, and 9°C) were recorded at three locations each. The average value for the readings is 7°C.

Groundwater temperatures are also most useful for the interpretation of groundwater movement. However, in a few instances they can be used to establish a definite relative surplus. One example was mentioned under "seepages." At the location 387, the water in a puddle was interpreted as being of groundwater origin because of its low temperature compared to the relatively high temperatures of waters in similar puddles nearby.

Summary

From the office phase of the study, twelve settings were outlined on the basis of topography alone. Initial field traverses indicated that the groundwater quality of the general area was good; this was later confirmed by chemical analysis of groundwater samples.

Relative surpluses of groundwater are indicated by springs, seepages, and quick ground. Damp soil and hummocky ground on slopes are definite indications of relative surplus but in flat areas and closed depressions should be corroborated by water quality from an auger hole. Salt precipitates and less-fertile soils are directly or indirectly related to surfaceward-moving groundwater. Vegetation, by an inexperienced observer can be used to determine a relative surplus of water only at a few locations; most often, vegetation only indicates anomalous water conditions. Closed depressions by themselves are not too helpful, though usually with some associated phenomenon, an interpretation can be made. Gullies and stream meanders are worthwhile features to investigate since they can be related to groundwater discharge. Lastly, groundwater quality and groundwater temperature can be used indirectly to indicate a relative surplus of water.

Features indicative of, or suggesting, a relative surplus of water are common. The converse is not true. Features indicative of a relative deficiency are not common. The best indication of groundwater moving away from the land surface is the absence of discharge features. However, once the recharge-discharge map was prepared (to be discussed in the next section), the map was compared with the distribution of surface water conductivities. The comparison (Fig. 29) shows that the greater percentage of conductivity values less than 250 mho/cm are in the recharge area. The value of 250 mho/cm is only applicable to the Red Deer area, but undoubtedly from studying the distribution of surface water conductivity in other areas, a value for recharge areas could be obtained for each area.

In this section, the collection and interpretation of individual types of data have been considered. In the next section, an interpretation of the groundwater regime based on these results will be made.

Interpretation

Introduction

The "groundwater regime" refers to the combined processes of distribution, movement, and chemistry of groundwater. Interpretation of each parameter will be reported separately. The distribution is from field work alone; movement is from the combination of field work and laboratory work; and chemistry combines field work with the results of groundwater movement.

An interpretation of the availability of groundwater is based on field work and the interpretation of groundwater movement.

Distribution of groundwater

1) Water table - Groundwater is interstitial water in the zone of saturation. The upper limit of this zone in an unconfined system is the water table. Physically, the water table is the surface along which the absolute pressure is equal to atmospheric pressure. In areas of unconfined groundwater flow in which the water table is a subdued replica of the topography, the water table can be approximated by the land surface.

In the field, the water table is commonly determined from water levels in holes in the ground open to the atmosphere and penetrating only a short distance into the zone of saturation. In addition to holes in the ground, the water table can be inferred from the outflow of groundwater onto the land surface at points of natural discharge (for example, springs). In this case, the water table is an non-existent surface which, if present, would be above the land surface.

In the present study, since man-made features were not used, natural outflows of groundwater and shallow auger holes were the only locations at which a definite positioning of the water table was possible. Locations with features indicative of the nearness of groundwater to the land surface provided additional control points for the water table.

The number of control points and their distribution is not sufficient to draw a precise water table map. However, the distribution of points indicative of groundwater near the land surface is such that the water table can be assumed to be a subdued replica of the topography. Therefore, it is possible to prepare a water table map by a combination of topographic contours with locations in which the position of the water table can be observed or inferred. At locations with groundwater outflowing naturally, the water table contours will be downslope from the corresponding topographic contours; if the water table is near the land surface, the two contours will be more-or-less superimposed; and when the water table is below the land surface, the water table contour will be upslope from the corresponding topographic contour.

The water table map (Fig. 30) illustrates the nearness of the water table to the land surface throughout most of the Red Deer area. On the west highlands, the water table generally tends to be closer to the land surface than on the east or southeast ridges. This undoubtedly results from the differences in the steepness of the slopes bordering the highlands.

Aside from delineating the upper limit of the groundwater system, the water table map can be used to interpret the general direction of groundwater flow (Fig. 30). This can be determined directly since flow will be parallel to the maximum gradient of the water table. However, the actual path of groundwater cannot be determined directly from the water table map.

Distribution of recharge-discharge areas

As was noted earlier, areas characterized by the water table close to the land surface represent a surplus of water relative to that which can be attributed to surface sources. These areas are receiving water from groundwater sources. In other words, groundwater is moving toward the land surface in the zone of saturation, commonly referred to as the hydraulic discharge or discharge area. Conversely, areas with a relative deficiency of water correspond to areas with groundwater moving away from the water table in the zone of saturation, referred to as hydraulic recharge areas.

The map outlining recharge and discharge areas (Fig. 31) has been prepared from the information collected during the present study. The majority of the information collected was indicative of a relative surplus of water. This is because the existence of a relative deficiency of water in the Red Deer area will usually only be of short duration. Therefore, the detection of a deficiency would require detailed and frequent visits to locations at which a relative deficiency of water is suspected. Since this form of mapping is considered a reconnaissance tool, detailed and frequent visits to particular points are not justified.

After the completion of the recharge-discharge map, the result was compared with the map of the distribution of surface water conductivities. The comparison (as was noted earlier) (Fig. 29) shows that in the majority of cases, surface waters with an electric conductivity less than 250 mho/cm occur in the recharge area. While this situation is not infallible, because exceptions do occur, it adds support to the interpretation that non-discharging areas are recharge areas.

The determination of recharge and discharge areas was done by considering only the information collected in the field. The final boundaries between recharge and discharge areas were first drawn on aerial photographs. This was done for two reasons. First, tonal changes in the photograph often provide a means for interpolating between two points of control. The tonal changes by themselves, in most cases, are meaningless but when combined with information obtained in the field the tonal contrasts are very helpful. Second, the contour interval on the topographic map available is not fine enough to permit the consideration of all topographic features which are important in outlining the recharge-discharge areas. Once the final outline was completed on the photographs, it was transferred to the topographic map for illustration.

In general, the recharge areas occupy the regional and local highs, while discharge areas are found in regional and local lows. The existence of local discharge areas on the western highland helps to indicate how clearly the water table follows the land surface. In this area the local lows are not deep enough to be indicated by a contour interval of 15.3 meters (50 feet), yet the configuration of the water is such that a local discharge develops in those lows. The presence of this situation helps to justify the outlining of local highs as recharge areas in a broad discharge area, based solely on the absence of features related to groundwater discharge.

The distribution of the direction of groundwater movement in sand dune areas is difficult to outline on the map. The highs of dunes are recharge areas and the interdune lows are discharge areas. In the dune area southwest of the city of Red Deer the outlining of recharge and discharge areas has been completed but tneds to be somewhat generalized. The dune area by the Medicine River has been outlined as a particular area characterized by surfaceward-moving groundwater in the interdune areas and downward-moving groundwater on the dunes.

The recharge area adjacent to the steep banks of the Red Deer River valley is also based on the absence of features indicative of a relative surplus of water. However, the designation of this area as recharge is considered to be consistent with the solution given by Freeze and Witherspoon (1967, p. 625, Fig. 1A) for the flow distribution in a basin with a major valley present.

The distribution of groundwater indicates that the water table is a close replica of the land surface. A rough estimate of the distribution of recharge and discharge areas indicates that approximately 40 per cent of the Red Deer area is recharge and 60 per cent is discharge.

Groundwater movement

1) Boundary conditions – Groundwater moves from higher fluid potentials to lower fluid potentials along the line of maximum gradient in a homogeneous and isotropic medium. In the discharge area the groundwater moves toward the land surface; therefore, as the distance below the land surface increases, the fluid potential increases. Similarly, in the recharge area, an increase in the distance below the land surface corresponds with a decrease in the fluid potential.

The distribution of fluid potential in the groundwater region is described by the Laplace equation $= 0$. For a two-dimensional solution of a particular set of conditions, four boundary conditions are needed. The distribution of electrical potential in an electric field is also solvable by the Laplace equation with four boundary conditions given for the two-dimensional case. Therefore, an analogy exists between the solution of the potential distribution in the electric field and the groundwater region, providing both have the same boundary conditions.

The four boundary conditions for the solution of the potential distribution in the groundwater region consists of three impermeable boundaries and one boundary of variable potential. The variable potential boundary forms the upper limit of the region. Of the three impermeable boundaries, two are vertical and one is horizontal. The variable-potential boundary coincides with the water table. The two vertical impermeable boundaries are located along lines across which there is no horizontal component of flow. Because the water table has been shown to be a subdued replica of the land surface, these boundaries can be placed to coincide with the surface water divides (ridge tops and valley bottoms) of the basin. The placing of the horizontal boundary is more subjective. However, if the variable-potential boundary and the two vertically impermeable boundaries are fixed and the distribution of recharge and discharge areas is known, it should be possible to determine the position of the lower impermeable boundary. This would require the solution of several different situations corresponding to different positionings of the lower boundary. Although this approach would have been desirable for this study, it was not employed because it was not within the scope of the report. Therefore, the lower boundary has been placed at a depth closely corresponding to the Lea Park Formation. The Lea Park Formation, according to Toth (personal communication, 1968), is the first formation in the Red Deer area which has a formation permeability which is low enough to be considered impermeable in terms of active, near-surface flow systems.

The boundary conditions for the analysis of flow systems in the Red Deer area have now been defined. The water table is the upper boundary and values for it can be obtained from the water table map. The two vertical impermeable boundaries coincide with surface water divides and the lower boundary is the Lea Park Formation at an elevation of approximately minus 150 meters (500 feet).

2) Hydraulic cross sections - A solution of groundwater flow has been carried out along three hydraulic cross sections. Two of the cross sections extend out of the area of study. The water table in these areas has been approximated by the land surface.

Groundwater flow along the hydraulic cross sections has been determined with the aid of an electric analog. The conducting medium is Teledeltos paper. The water table configuration is painted on the paper with a conductive silver paint and the field is cut out to correspond to the shape of the groundwater system being investigated. The electrical potential distribution along the silver-painted surface is determined by inputting predetermined electric potentials at specific points along the surface. The electric potentials correspond directly to fluid potentials at equivalent points on the water table. Once the electrical distribution along the silver paint surface corresponds to the fluid potential distribution on the water table, equipotential lines can be traced on the Teledeltos paper. These electric equipotential lines correspond to the hydraulic equipotentiallines in the groundwater system.

The hydraulic cross sections show that local, intermediate, and regional flow systems are possible in the Red Deer area. The local systems are numerous and vary considerably in length, depth and intensity of flow. Intermediate flow systems are not important in terms of the amount of water which they circulate but are important in terms of explaining features related to the groundwater regime. (One exception is the intermediate system on the south flank of the Blindman River valley but this is outside the area of study.) Only one regional system is present and it is from the eastern ridge to the Red Deer River.

The most important local systems, in terms of the quantities of water circulated, are the ones originating on the highlands and discharging in the adjacent broad low area. These systems extend almost to, or reach, the horizontal boundaries. The systems on the west side of the west ridge (cross section 3), east side of the west ridge (cross section 1), and the west side of the east ridge (cross section 2) are 5.5 kilometers (3.8 miles), 5.5 kilometers, and 6.7 kilometers (4.8 miles) in length, respectively, and have a total change in elevation of the water table over these distances of 92 meters (300 feet), 61 meters (200 feet), and 110 meters (360 feet), respectively. Other local systems of importance tend to be shorter and not quite as intense. These systems still originate on the highlands with the exception of one. The exception originates on the NNE-SSW trending ridges west of the Red Deer River (cross section 1).

Smaller local systems are also present. In terms of quantities of water being circulated, most of the systems are unimportant; however, their effect on the over-all potential distribution can be quite significant. For example, on hydraulic cross section #2, a local system extending down to a depth of 215 meters (700 feet) results from a local relief only 4.6 meters (15 feet) in the water table.

Hydraulic cross section #1 illustrates three interesting characteristics of a flow system associated with a relatively steep sloping highland adjacent to a broad low sloping lowland. The first point is that the flow rates immediately downslope from the hingeline are large. These high rates of flow are conducive to the development of points of concentrated discharge (see discussion under "manner of groundwater discharge"). Therefore, the presence of springs along the steep slopes of the highlands just below the recharge-discharge boundary can be explained by a homogeneous situation. The fact that the springs in the Red Deer area commonly occur along the steep slopes of the highlands at approximately the same elevation does not necessarily imply that a particular geologic bed is responsible for their formation.

The second point deals with favorable locations for drilling flowing wells at depths less than 150 meters (490 feet) in a homogeneous environment. If point A (cross section #3) is considered, a piezometer installed at a depth of 155 meters would measure a fluid potential which is equivalent to a hydraulic head of 61 centimeters (2 feet) above the land surface. The piezometer at location B, at a depth of 155 meters, would measure a hydraulic head of 1.84 meters (6 feet) above the land surface. The piezometer, at 155 meters depth at location C, would indicate a fluid potential equivalent to that measured at point A. In other words, the increase in fluid potential with depth is three times as large at point B as at point A and C, even though the groundwater at point C is moving surfaceward almost vertically. A flowing well near the base of highland slopes is a common field phenomenon.

The third point brought out by the cross section is related to observations which would be made during the construction of the piezometer at point C. As the hole at point C is deepened during drilling, only slight increases in the fluid potential would be noticed. The most obvious interpretation of small increases in fluid potential with increased depth is that the hole is being drilled in a transition zone, that is at a location with groundwater flow essentially parallel to the land surface. This, of course, would be a complete erroneous interpretation. Therefore, the interpretation of groundwater movement from piezometers should take into consideration the configuration of flow tubes as well as changes in the fluid potential. In this particular example, the small increase in fluid potential result from divergence of flow lines and hence enlargement of flow tubes.

3) Summary of groundwater movement - From the configuration of the equipotential lines, recharge and discharge portions of the hydraulic cross sections can be outlined. Recharge areas correspond to the portions of the cross sections with an acute angle between the equipotential line and the line of the water table on the upslope side of the equipotential line. When this angle is obtuse, flow is surfaceward (discharge) and when the angle is a right angle, flow is parallel to the land surface.

A general comparison of the recharge and discharge areas outlined from field mapping with the areas outlined from the hydraulic cross sections shows that the three cross sections pass through a total of 21 field-mapped recharge areas. Along the hydraulic cross sections, 21 recharge areas are present. However, in detail the comparison is not as close but the results are comparable.

Before comparing the actual boundaries in detail, the two major shortcomings of the electrical cross section should be mentioned. First, the analog is solving a three-dimensional potential problem in only two dimensions. Therefore, the cross sections cannot take into account the effects of potential distributions, not present on the cross section. This problem becomes significant when the gradient of the water table is greater at some angle to the line of the cross section than along the line of the cross section. The problem is minimized by preparing cross sections parallel to the maximum water table gradients. However, in areas of low gradients, slight variations in the water table configuration can result in recharge or discharge areas developing along the line of the cross section which, if the three-dimensional picture were considered, would not develop at all.

Fortunately, when these problems develop, the effect on the interpretation of groundwater flow is usually insignificant.

The second problem in the construction of the cross sections is related to the contour interval of the water table. When the gradient is large, the contour interval need not be as small as in the case of low gradients with several minor fluctuations. The problem becomes most acute in areas of low gradient water tables. Therefore, problems can be expected in these areas.

A good correlation between field and cross sectional results is present in all cases except two general areas. One is the low slope adjacent to the Red Deer River valley on cross section #1; the second is cross section #2 through the area of aeolian deposits. In this area, it was difficult to outline recharge-discharge areas (see discussion under "Distribution of Recharge-Discharge Areas"), and for the model the control is difficult due to a low water table gradient, a large contour interval, and minor fluctuations in the water table.

In the other areas, horizontal differences between the boundaries from field work and from the cross sections vary between 75 and 300 meters (250 and 1,000 feet). The majority of the boundaries differ by 150 meters (feet) or less.

The good correlation between the recharge-discharge boundaries from the field mapping and from the hydraulic cross sections suggests two important conclusions which are interdependent. That is, if one is accepted as true, the second one must also be true. The conclusions are as follows:

1) The natural movement of groundwater in the Red Deer area is mainly as if the medium were homogeneous; and
2) The homogeneity extends to a depth of approximately 1,100 meters (3,600 feet) in the Red Deer area (top of the Lea Park Formation).

Groundwater chemistry

The quality of groundwater was discussed under "Summary of results." At that point, the main interest was to determine relative water conditions. Now, with a knowledge of groundwater movement in the Red Deer area, an interpretation of the distribution of the five different water types, as well as an explanation for their distribution, is possible.

Type 1 waters,with their low total dissolved solids, low sodium plus potassium percentage, and high carbonate plus bicarbonate, are indicative of "young waters." These waters have been in contact with the ground for only a short time and have had little opportunity to dissolve material matter. This seems to be a plausible interpretation since type 1 waters were sampled mainly close to the top of the west highland or at locations in which the waters sampled were associated with local systems.

The distribution of type 1 waters alone is restricted to the upper parts of the highlands, with only one exception (Fig. 33). The exception is associated with a short local system on the west-facing slope of the west highland.

Type 2 waters have, on the average, slightly higher total dissolved solids and higher sodium plus potassium per centages than type 1 waters. The main change from type 1 waters is only in the amount of sodium plus potassium. However, the fact that sodium plus potassium and total dissolved solids are higher suggests a larger flow time for type 2 than for type 1 waters. This becomes more evident when the position of type 2 waters on the highlands is considered.

These waters are common on the slopes of all the highlands. They have been outlined as occurring on the highlands and their association with type 1 waters has been suggested on the high area immediately east of the Red Deer River from the south border to township 38.

Type 3 waters have high sodium plus potassium percentages and noticeably higher average total dissolved solids than type 2 waters. This suggests longer flow paths for type 3 waters than for types 1 and 2 waters, and is substantiated by their distribution on the slopes.

At several locations where type 3 waters were sampled, the waters were discharging from shale. Therefore, the distribution of this type of water may be a reflection of shale layers at depth. This is further corroborated by the extent of the type 3 water on the south slope, since a road cut in this area exposed a section 17 meters high, of which only 50 cm was sandstone, the remainder being mainly shale.

Type 3 waters have been outlined at the base of most of the highlands, even though in some cases no occurrences of type 3 waters were recorded. The boundaries between type 3 waters and adjoining waters for the most part is only approximate.

Type 4 and 6 waters were observed at two and three locations, respectively, and all samples came from auger holes in broad low areas. These two types of waters have sulphate plus chloride greater than 50 per cent of total anions, which separates them from the type 1 to 3 waters. In addition to specific elements, the average total dissolved solids are also high and all have conductivity readings greater than 1,250 mho/cm. This all suggests that these waters have a longer flow time than the other waters. Their position in the basin also suggests this. The high sodium plus potassium percentage of type 6 waters also indicates that the flow path is long. However, the high percentage of calcium plus magnesium of the type 4 waters appears to be an exception. The reason for the high percentage of calcium plus magnesium may result from ion exchange which could have taken place in the belt of phreatic fluctuation. If it were not for the other points which suggest a long groundwater flow path, then type 4 waters would not be considered groundwaters.

Type 4 and 6 waters were sampled in the broad low areas southeast of the city of Red Deer and east of the Medicine River. All the other major low areas have been outlined as possible sources for either or both of type 4 and type 6 waters.

The water types associated with the highlands can be outlined by a few scattered points because the distribution is regular, being more or less consistent with the major topographic form. However, in four areas, the distribution of water types is difficult to delineate because of the interaction of two or three factors, and the low density of samples. Therefore, these areas (Fig. 33) will be dealt with separately and in a general manner.

Area 1. Aeolian deposits east of the Medicine River

The major feature in this area is the local topographic highs which result in local flow systems. For the most part, waters associated with these systems are of type 1. However, because of the presence of a flow system originating on the west ridge, waters in deep wells or in more pronounced topographic lows may intersect waters of type 3, 4, or 6.

Area 2. NNE-SSW trending ridges and aeolian deposits west of the Red Deer River

In this area the main flow systems are local. Consequently, most of the waters sampled are either type 1 or 2. Type 2 waters develop because the flow systems in the linear ridge area are not as short as those associated with the sand dunes. In some cases, even type 3 waters are present. Locations where these were encountered or can be expected have been outlined. Because of the absence of broad low areas and of flow systems originating on the highlands, type 4 and 6 waters are not expected to occur in this area.

Area 3. Steep valley walls of the Red Deer River valley and associated short linear depressions

The most important flow systems associated with the valley banks of the Red Deer River are local systems. These systems are of sufficient length for types 1, 2, and 3 waters to be present. The most common water type is 2. Any flow originating on the regional high would not be detected in the valley because of the small quantity of water being circulated by any regional systems which are present.

Area 4. Aeolian deposits east of Red Deer River

This area is very similar to area 1. The common flow systems are short and the associated waters would be expected to be mainly type 1. However, because of the presence of intermediate systems from the highlands to the east and southeast, deep wells and major lows can be expected to have type 4 or 6 waters present.

The distribution of water types based on the number and locations of the water samples available for this report is not as clear-cut as the boundaries dividing them may suggest. In some places, especially when boundaries are assumed or suggested, there may be considerable error. However, the distribution of different water types does give a good idea of the distribution of water quality in the whole area.

Availability of groundwater

1) Natural outflows of groundwater onto the land surface

The most obvious location for the availability of groundwater is one with groundwater outflowing naturally onto the land surface. In the Red Deer area, groundwater outflows naturally at 89 locations. In many instances only insignificant quantities of water are discharged. However, if the areas in the vicinity of the actual discharge points are cleaned up, rates of discharge at some locations can be increased significantly. An example of this possibility was demonstrated near Fox Creek, Alberta. The spring had a discharge rate of 240 liters per minute (60 gal./min.) before and 400 liters per minute (100 gal./min.) after the plant material and debris was removed from around the point of discharge. The discharge rate six months after cleaning up the area was still 400 liters per minute. Therefore, the increase in flow rate can be considered to be permanent.

Based on this experience, suggested possible yields for springs, seepages, and swamps in the Red Deer area have been divided into two groups. For the first group, discharge rates in the order of 4 liters per minute (1 gal./min.) should be possible after developing the area of discharge. The second group should be able to yield in the order of 40 liters per minute. The locations of the 35 possibilities in the first group and the 18 possibilities in the second group are shown on figure 33.

2) Artificial removal of groundwater

At locations in which the development of natural outflows of water is not possible, groundwater can be obtained from wells. In this section, an outline is to be provided giving estimated depths and magnitudes of yields for possible wells and test holes. The approach to be used will be to divide up the area mapped into eight separate areas based on field observations and interpretation of the analog results.

Type 1 area is on top of highland areas with relatively steep bordering slopes. Wells in this area can be expected to be deep generally and water levels can be expected to drop significantly with increased depth. However, because of the large flow rates in this area, there should tend to be higher permeability values in this area than in other parts of the basin, resulting from the flushing action of groundwater alone.

Wells in the type 1 area should be in the order of 60-100 meters ([illegible] feet) deep. This should ensure yields in the order of up to a few tens of liters per minute. Higher yields are not very likely because of anticipated low water levels resulting in low available drawdowns.

Type 2 areas occupy broad highlands with bordering slopes having a moderate topographic gradient. In these areas the decrease in fluid potential with increased well depth will be only one half to one fifth that of the type 1 areas. Therefore, in this area the groundwater flow rates will not be as high as the type 1 areas and rock permeability influenced by groundwater flow will be lower. However, yields of a few tens of liters per minute could be expected from wells 40 to 60 meters (130-200 feet) deep.

Type 3 areas are located on the steep slopes of the highlands. Conditions in these areas should be quite similar to the type 1 areas, except that yields of a few tens of liters per minute should be available at shallower depths, approximately 40 to 70 meters (130–230 feet).

Type 4 areas occupy the gentle slopes of the highlands. These areas are characterized by parallel or surfaceward-flowing groundwater. Groundwater flow rates are not as high as in area 1 and are higher than in area 2. Wells on test holes in this area should anticipate flowing conditions. Groundwater supplies of a few tens of liters per minute should be available within 25 to 50 meters (80–160 feet) of the land surface. Larger supplies would be possible with test hole depths as great as 300 meters (1,000 feet) in some cases. However, for large supplies of groundwater, test-drilling projects would be needed to determine optimum depths and potential yields.

Type 5 areas are the ones with low topographic gradients. These areas have a large component of surfaceward flow but stream tubes are strongly diverging. In these areas, permeability attributable to the flow of groundwater would be quite low. Toward the boundary of type 5 with type 4 areas, flowing conditions may develop from shallow wells but farther from the highland deep wells would be needed for flowing conditions.

Therefore, even though the fluid potential increases with depth in these areas (Type 5), deep wells will be needed for two reasons: first, glacial deposits tend to be thickest in the lowlands and, in the area mapped, these deposits are mostly fine-grained and thus do not provide even quantities of a few liters per minute in most areas; second, increases in fluid potential are small with depth and associated flow rates are low. Consequently, large thicknesses of water-producing zones would be needed for a few tens of liters per minute.

Type 6 areas are associated with aeolian deposits. In these areas permanent supplies of groundwater in rates of a few tens of liters per minute should be available in wells to depths of 10 to 30 meters (35–100 feet). Wells which are completed at too great a depth will encounter very slowly circulating groundwater with a result similar to that which exists in area 5. When possible, wells should be completed on the slopes of local highs. Development of large supplies is not thought to be possible.

The type 7 area is associated with the low NNE-SSW trending ridges. Local flow systems are associated with the highs but the position of these ridges is in a general recharge area. Therefore, well depths should probably be in the order of 30–60 meters (100–200 feet). Well yields will not be excessive but should be at least in the order of a few tens of liters per minute.

Type 8 areas correspond with the Red Deer River valley and the highlands adjacent to the river bank. Because of the draining effect caused by the steep banks, wells on the highland would need to be quite deep, probably 50 to 75 meters (160–250 feet). Yields of these wells could not be expected to be very large, probably not even a few tens of liters per minute. Wells on terraces or adjacent to the river may receive water from deposits saturated with water from the river.

Wells consturcted in the valley bottom to obtain circulating groundwater rather than infiltrated river water should probably be no deeper than about 150 meters (490 feet). Below this depth, the equipotential lines are spaced farther apart and flow rates will be lower. The depth of 150 meters refers to the optimum conditions. In these cases, yields may be several tens of liters per minute. On the whole, the possibilities in the river valley are not as favorable as some locations on the highland because of the small amount of circulating groundwater reaching the river valley.

In addition to drilled wells, it should be possible to develop "semi-permanent" groundwater supplies from dug wells associated with local lows in areas 2, 4, 5, 6, and 7. In areas 4, 7, and 8 it should be possible to develop flowing dug wells at depths of a few meters on some hills and bank slopes. However, in most cases, yields will not tend to exceed a few tens of liters per minute.

Summary

The groundwater regime has been interpreted from the mapping of naturally occurring surficial features. The water table is a subdued replica of the land surface but has been distinguished from it over the area studied. Recharge areas determined from field mapping occupy approximately 40 per cent of the area and discharge areas are present over the remainder of the area.

Hydraulic cross sections prepared with the assistance of an analog model show that the most active flow systems are the local systems originating on the highlands and terminating on the adjacent broad lowlands. Also shown by the cross sections is that in a homogeneous environment springs can be expected below the hingeline and shallow flowing wells can best develop near the base of the steep slopes. The good correlation between results from field mapping and hydraulic cross sections indicates that a direct relationship exists between the Lea Park Formation being the horizontal boundary for the more active flow systems in the area and the natural movement of groundwater being as if the medium were homogeneous.

From the groundwater movement, an interpretation of groundwater types has been made. The distribution on highlands, highland slopes and adjacent low areas is regular; in four special areas it is complex. Fifth-three springs, seepages and swamps were designated as possible natural sources of groundwater. Depths of wells range from 10 to 100 meters (35-350 feet) for supplies of a few tens of liters per minute and up to 300 meters for larger supplies.

In short, the groundwater distribution, movement and chemistry have been interpreted. Also, an interpretation of the availability of groundwater has been made. In the next section these results will be utilized for practical problems and an evaluation of the mapping method will be given.

Recommendations and Conclusions

Groundwater Supplies

1) Introduction

Groundwater information is most commonly used to obtain groundwater supplies. In Alberta, groundwater supplies for individual dwellings are very common (usually a few tens of liters per minute — approximately 5 gallons per minute will suffice). For these supplies, it is often sufficient to have an idea of the following: the depth to which a well will have to be drilled; the approximate amount of water available; and the general quality of the groundwater.

In the case of groundwater supplies for towns and industries which need supplies in the order of a few hundreds of liters per minute (approximately 50 gallons per minute), more favorable locations for a well completion are needed. Also, for these situations, a knowledge of possible well depths and groundwater quality is needed.

Towns, cities, and industries require water supplies in the order of a few thousands of liters per minute (approximately 500 gallons per minute) and therefore need to know areas which are more favorable for the development of large quantities of groundwater. In these areas, detailed test-drilling programs need to be carried out to establish actual groundwater qualities and quantities available. However, in outlining the areas to be tested, knowledge of possible well depths and groundwater quality are important considerations.

2) Individual groundwater supplies

Groundwater supplies for this purpose can be obtained throughout the entire area studied. At some locations, deep wells will be needed and, in some cases, only poor quality water will be available. Figure 35 is a map which has been prepared by the combination of the groundwater quality type map (Fig. 33) with the groundwater availability map (Fig. 34). From this map (Fig. 35) possible well depths and groundwater quality types can be determined. For example, point A (Fig. 35) on the west ridge is located in the zone designated as 4–1; this means that the expected depth of a well to produce a few tens of liters per minute would be 25 to 50 meters (80–160 feet) and the expected groundwater quality is type 1, which is characterized by low total dissolved solids and a predominantly calcium, magnesium, bicarbonate water.

Therefore, from figure 35 possible well depths and associated groundwater qualities can be determined for the area mapped. Also, the natural outflows of groundwater and their quality type are shown to indicate locations at which definite and readily available groundwater supplies exist.

3) Towns and industries with small groundwater requirements

The first consideration for a groundwater supply for a town or industry should be a natural outflow of groundwater. If a town or industry is in the planning stage, its location near a natural discharge could be a substantial asset. For example, if the need was 200 liters per minute, the spring at W-12 would be more than adequate. If, on the other hand, the town or industry is established, natural outflows of groundwater should be considered. In some cases, it might be more advantageous to develop a natural outflow two kilometers (one mile) from the need than to drill a well one kilometer (one half mile) away. For example, Benalto might find it an advantage to develop one of the swamps at either #204 or #206 rather than drill a well outside the town limits.

However, if there are no possibilities to use natural outflows of groundwater, the best locations to drill a well would be in the 4-1, 4-2, or 4-3 areas. These areas should be characterized by moderate well depths and good quality waters. If wells are completed in other areas, a well field may be necessary. In areas with the possibilities of type 4 and 6 waters, groundwater quality will be relatively poor.

4) Towns, cities and industries requiring large quantities of groundwater

For large quantities of groundwater, detailed test drilling projects are needed. These projects are carried out to establish specific information about the groundwater regime and the distribution in space of more permeable beds. In the development of large supplies of groundwater, geologic permeabilities are very significant. However, rather than test drilling over a large area, figure 35 can be used to restrict areas wherein test drilling conditions are more promising in terms of fluid potentials, quantities and qualities.

In terms of the natural groundwater movement, type 4 areas (Fig. 34) would be most suitable for the development of large quantities of groundwater. Only small portions of these areas are expected to have a poor groundwater quality. For the most part, the groundwater quality types occurring in the type 4 area are 1, 2, and 3, which are relatively good quality waters.

The other aspect in considering large groundwater supplies is the recharge area. Since all the groundwater enters the groundwater system through the recharge area, to have a high sustained yield the flow system being tapped should have a large recharge area. Apart from a large recharge area being present on the highlands (as in the case of the east flank of the Medicine River, hydraulic cross section #3, Fig. 32), it can be obtained by considering the concentration of groundwater because of the configuration of the water table. In the east and southeast part of the area, the recharge areas are small; therefore, the maximum use of the water-table configuration should be made to increase the effective size of the recharge area.

Figure 36 outlines the more favorable locations in which to carry out test-drilling programs for large supplies of groundwater. The most suitable locations are in association with the west ridge. In this area, groundwater quality is very good in the type 4 areas, the recharge areas are large, and the presence of large natural outflows of groundwater is indicative of high possible yields. The areas associated with the central ridge (Fig. 36) are not as promising as the west area. The central ridge flow system does not have large flow rates (hydraulic cross section #2, Fig. 32), the recharge area is small, and there is an absence of large discharging springs. However, the groundwater quality is almost as good generally as the west area.

The proposed test-drilling areas on the east and southeast ridges have the poorest general groundwater quality of the main ridges. Also, the recharge areas are the smallest; however, the large downward flow rates in the recharge area probably compensate for the small areal extent of the recharge area. Even though conditions are not as good on the east and southeast ridge, a systematic test-drilling project in the areas outlined should still provide a groundwater supply in the order of at least a few thousand liters per minute from a well field.

Uses of Mapping Method in Hydrogeology and Other Disciplines

Mapping results in hydrogeology

Hydrogeology can be considered as the science of the physical and chemical processes and the phenomena which result from the interaction between rocks and water during the water's entrance into, presence in, movement in, and exit from the formations. From the study of naturally occurring surficial phenomena, it is possible to study only the final condition, that which results once the water has gone through all the processes and has left the formations. Changes which take place before the groundwater discharges on to the land surface can only be inferred from variations in the groundwater recharge and discharge on the land surface. Nevertheless, hydrogeologic studies dealing with almost any aspect of the groundwater regime can be carried out, providing a differentiation can be made between features indicative of groundwater and those indicative of surface waters.

Mapping results in other disciplines

A knowledge of the groundwater regime can be used by many disciplines. In many cases though, a knowledge of only a particular part of the regime is needed. For example, a soil scientist classifying a soil needs only to know that an area is one of saline groundwater discharge, rather than being aware of the complete groundwater regime. If a forester needs to know the groundwater quality over a certain area, again it is not necessary to be aware of the complete groundwater regime. Therefore, in many disciplines, it would be sufficient to recognize naturally occurring surficial phenomena related to groundwater recharge and discharge. A recognition of pertinent features would give a quick interpretation of the role of groundwater in the field of study of an engineer or scientist.

If a knowledge of the groundwater regime is needed by another discipline, it is better to solicit the aid of a hydrogeologist to determine the groundwater regime, than for a person in another discipline to attempt to determine the regime. For example, in this study, vegetation was used to indicate anomalous water conditions. By the same token, a botanist studying the plant ecology of an area should use naturally occurring surficial phenomena to determine the direction of groundwater motion and, if surfaceward, the quality of the water, but should not become involved in determining the groundwater regime.

From this latter point of view, an awareness of naturally occurring surficial phenomena related to the groundwater regime would be helpful in many disciplines associated with the lithosphere, either on or near the surface

Evaluation of mapping method

The mapping of naturally occurring surficial phenomena has been used to determine the groundwater regime over an area of 820 square kilometers ([illegible] square miles). The following results were obtained either during, or interpreted from, the mapping.

1) A general knowledge of groundwater quality over a large area in a relatively short time interval (820 square kilometers in two days);
2) Distribution of groundwater quality over the whole area;
3) Distribution of particular features associated with the presence or absence of groundwater near the land surface. For example, springs, soap-holes, etc.;
4) Rates of discharge at features where groundwater outflows naturally onto the land surface;
5) Water-table map;
6) Relationship of the water table to the land surface;
7) Distribution of recharge and discharge areas;
8) An interpretation of groundwater movement.

The main shortcoming of the results is the lack of control with depth. Realizing this shortcoming and the basic requirements (there must be a detectable difference between phenomena resulting from groundwater flow and phenomena related to surface water; access to the majority of the area must be possible), this method of mapping satisfies the need for an interpretation of the groundwater regime. Mapping in this manner can be carried out by a hydrogeologist experienced in this facet of studying the groundwater regime in a helicopter at a cost of about $5.00 per square kilometer

($13.00 per square mile, Table 1).

In terms of what is known at the present time, this form of mapping appears to be most useful in groundwater hydrology studies for areas in which no hydrogeologic information is available. Presumably, in areas with some existing hydrogeologic information, this method of mapping could be used to supplement the available information. However, for areas with an abundance of information, a study such as the present one will not significantly add to the interpretation of the groundwater regime.

In other hydrogeologic studies, and in other disciplines, the present method of mapping may be of considerable use, whether hydrogeologic information is available or not. For example, in the Red Deer area the well survey in 1965 encountered two springs over 820 square kilometers; if a hydrogeologic study in the Red Deer area was concerned with springs, the two springs on file would not be representative of the 29 springs encountered during the present study.

Therefore, in summary, if an area is characterized by the basic conditions, the mapping of naturally occurring surficial phenomena to determine the groundwater regime has limited use in groundwater exploration projects and as a method in other aspects of science. In groundwater exploration projects, the limit is governed by the amount of existing information and the absence of a knowledge of permeability variations with depth. The limits in other aspects of science are governed mainly by the nature of the study rather than by shortcomings of the method or the amount of existing information.

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Comments on: "Groundwater Regime near Red Dee

1) No major shortcomings or omissions
2) General impressions obtained are:

a) that parts read like an elementary manual for students or "how to carry out a fieldsurvey of groundwater features"

b) that parts seem to go into unnecessary detail to explain concepts or details - points are belaboured too much

c) that some of the concepts are ~~either~~ expressed either too vaguely or imperfectly - there is a lack of clarity and incisiveness in the presentation

3. Although I don't question the basic control and concepts on which the philosophy of ~~discharge features is~~ distribution of discharge features is based, I do question the fact that little consideration is given to the possibility of major influence on the flow pattern induced by high-permeability "tubes" - eg buried gravel etc.
4. Is the need to obtain or tap an aquifer

APPENDIX A

LIST OF CHEMICAL ANALYSES OF WATER SAMPLES

Obs. pt. No.	TDS µmhos/cm @ 25°C	TDS (ppm)	Ca^{++} $+Mg^{++}$ (epm)	$Na^{+}+K^{+}$ (epm)	$Na^{+}+K^{+}$ % of total cations	HCO_3^{-} $+CO_3^{=}$ (epm)	Cl^{-} (epm)	$SO_4^{=}$ (epm)	HCO_3^{-} $+CC_3^{=}$ % of total anions	$SC_4^{=}$ % of total anions	pH	Type	Remarks
-1(a-1)	1650	1155	3	15.8	84	11	0.4	7.4	59	39	8.0	3	Flowing well
-1(c-10a)	1325	928	2	17.8	90	12	1.2	6.6	61	33	8.0	3	Spring (soap hole)
-1(c-10c)	1550	1085	1	19.9	96	14	0.8	6.1	67	29	8.0	3	Flowing auger hole
-1(d-3)	1150	805	2	12.7	86	10	0.4	4.3	68	29	8.5	3	Seepage
-1(e-6)	1650	1155	4	14.3	78	17	0.4	0.9	93	5	8.0	3	Seepage (soap hole)
-1(f-1)	750	525	8	5.4	40	10	1.2	2.2	75	16	8.0	2	Auger hole
-1(g-4)	1100	770	5								8.0		Spring
-47a	800	560	5	6.7	57	9	0.8	1.9	77	16	8.0	2	Auger hole
-61a	1200	840	1	15.2	94	12	0.4	3.8	74	24	8.7	3	Swamp
-97a	950	665	4.3	6.8	58	8.6	0.2	2.9	73	25	8.8	2	Auger hole
-104a	1100	770	1	13.8	93	12	0.4	2.4	82	16	8.4	3	Spring
-108e	675	473	9	1.3	13	8	0.8	1.5	78	15	8.4	1	Auger hole
-114d	470	329	7	0.4	5	5	0.8	1.6	68	22	8.0	1	Auger hole
-117c	800	560	6	5.2	46	9	0.8	1.4	80	13	8.0	2	Seepage
-118a	950		7	5.5	46	9	2	1.5	72	12	8.5	2	Seepage
-132a	850	595	8	4.8	37	10	0.8	2.0	78	16	8.1	2	Spring
-141c	580	406	7	2.4	26	6	1.2	2.2	64	23	8.4	1	Auger hole
-141e	950	665	9	5.3	37	10	0.8	3.5	70	25	8.0	2	Auger hole
-144b	360	252	5	0.4	7	4	0.8	0.6	70	11	8.0	1	Auger hole
-147c	1150	805	18	0	0	14	0.8	2.4	81	14	8.0	1	Auger hole
-147e	800	560	10	1.3	12	10	0.8	0.5	88	4	8.2	1	Seepage
-181d	1250	875	17	4	19	10	0.8	10	48	48	8.0	4	Auger hole
-196c	1050	735	16	1.1	6	15	0.8	1.3	88	8	8.0	1	Auger hole
-202	650	455	8	1.6	17	8	0.8	0.8	83	8	8.0	1	Seepage
-208	650	455	10	0.6	6	9	0.8	0.8	85	8	8.0	1	Seepage
-210	850	595	5	3.8	43	4.7	0.1	4.6	50	49	8.4	2	Spring
-211	1000	700									8.0		Spring

Obs. pt. No.	TDS mhos/cm @ 25°C	TDS (ppm)	Ca^{++} $+Mg^{++}$ (epm)	$Na^{+}+K^{+}$ (epm)	$Na^{+}+K^{+}$ % of total cations	HCO_3^- $+CO_3^=$ (epm)	Cl^- (epm)	$SO_4^=$ (epm)	HCO_3^- $+CO_3^=$ % of total anions	$SO_4^=$ % of total anions	pH	Type	Remarks
W-1	780	546	7.8	1.8	19	8.8	0.5	0.4	91	4	8.3	1	Seepage
W-3	670	468	7.4	1.6	18	8.4	0.2	0.3	94	3	7.9	1	Spring
W-11	510	354	3.4	2.6	43	5.3	0.1	0.8	86	13	8.7	2	Auger hole
W-12	530	370	3.2	2.8	47	5.9	0.1	0.0	98	0	8.4	2	Spring
W-19	440	308	2.8	1.2	30	2.6	0.1	1.4	63	34	8.1	1	Auger hole
W-32	510	354	6.0	1.2	17	6.2	0.3	0.6	88	8	7.7	1	Spring
W-33	370	260	4.3	0.3	7	4.2	0.1	0.4	89	9	8.6	1	Spring
W-44b	630	446	6.7	1.5	18	6.8	0.3	1.1	84	13	8.3	1	Spring
W-55	630	440	5.5	2.2	29	7.0	0.2	0.9	86	11	7.8	1	Auger hole
W-60	2380	1668	11.4	17.6	87	4.2	0.2	15.9	20	80	9.1	6	Auger hole
W-67	5200	3672	3.4	51.2	86	24.3	0.1	26.8	47	52	8.5	6	Auger hole
W-67a	14050	9838	13.8	136.6	90	42.0	0.1	110.0	28	72	9.0	6	Auger hole
W-80	590	410	4.8	1.3	21	4.6	0.2	1.3	75	21	8.9	1	Auger hole
W-100	1490	1040	12.6	2.1	14	8.2	0.1	7.5	52	48	7.9	1	Seepage
W-113	570	400	1.9	4.8	72	6.2	0.1	0.3	94	5	8.7	3	Spring
W-117 (west auger hole)	2260	1584	19.9	1.4	7	9.0	0.1	13.6	40	60	7.6	4	Auger hole to west
W-120	440	310	4.6	0.7	13	4.5	0.1	0.9	82	16	8.2	1	Seepage
W-121	460	320	4.3	1.9	31	5.4	0.1	0.9	85	14	8.3	1	Spring
W-122	560	390	4.4	1.5	25	4.6	0.1	1.5	74	24	8.2	1	Seepage
W-140	670	468	4.3	3.2	44	7.1	0.1	0.2	96	3	8.3	2	Spring
W-150	610	426	5.6	1.4	20	6.3	0.1	0.7	89	10	8.5	1	Spring
W-151	630	442	5.1	3.0	37	7.7	0.2	0.3	94	4	8.0	2	Spring
W-152	550	386	6.3	1.2	16	7.2	0.2	0.1	96	01	7.8	1	Spring

Obs. pt. No.	TDS mhos/cm @ 25°C	TDS (ppm)	Ca^{++} $+Mg^{++}$ (epm)	$Na^+ + K^+$ (epm)	$Na^+ + K^+$ % of total cations	HCO_3^- $+CO_3^=$ (epm)	Cl^- (epm)	$SO_4^=$ (epm)	HCO_3^- $+CO_3^=$ % of total anions	$SO_4^=$ % of total anions	pH	Type	Remarks
1a	310	217	3.9	1.1	24	3.4	.4	.8	76	17	.6	1	Auger hole
5	400	280	3.8	2.2	37	4.8	.4	.9	80	14.1	8.7	2	Auger hole
24	630	441	6.5	1.9	22	6.8	.4	1.2	82	14	8.0	1	Auger hole
29	675	472.5	8.2	1.3	14	9.2		.3	97	3	8.0	1	Seepage
50	1175	822.5	9.6	4.9	34	14.0		.5	96	3.5	8.0	2	Seepage
62	900	630	8.9	4.7	34	11.3	-	2.4	90	17.5	8.2	2	Spring
68	1100	770	6.5	10.2	61	15.0		1.7	89	10.0	8.1	2	Auger hole
86	700	490	6.8	3.6	34	8.2	.7	1.5	79	15	8.0	2	Auger hole
101	490	340	5.9	0.8	12	6.2	.1	.4	92	6	8.0	1	Spring
129	700	490	8.6	2.7	24	9.9	.7	.6	88	5	8.0	1	Swamp
138	750	525	8.9	2.2	19	10.6		.5	95	4.8	8.0	1	Seepage
139	650	455	7.5	2.0	21	9.2		.3	96	3.4	8.0	1	Seepage
140	510	357	6.2	1.5	19	6.8	.4	.3	89	4.2	8.0	1	Seepage
141	570	399	6.5	1.1	14	7.2		.5	94	6.7	8.0	1	Seepage
146	740	518	8.9	1.2	12	9.6	.4	.2	95	1.6	8.0	1	Seepage
153a	340	238	3.1	2.5	45	4.1	.4	1.1	73	20	8.0	2	Auger hole
184	520	364	5.1	2.7	34	6.8	.4	.6	88	8.0	8.0	2	Seepage
204a	590	378	7.9	2.3	27	7.2	.4	.6	85	7	8.0	1	Swamp
206	700	490	7.2	3.2	29	9.9	.4	.8	90	7	8.0	1	Swamp
246	530	371	5.5	2.5	31	7.2	.4	.4	90	5	8.0	1	Seepage
259	640	448	5.1	4.9	49	8.6	.7	.8	85	8	8.0	2	Swamp
276	600	420	6.5	2.2	25	6.8	.4	1.5	78	18	8.0	1	Auger hole
308a	525	367.5	5.1	4.2	45	6.5	.7	2.1	70	23	8.0	2	Auger hole
313	420	294	3.8	2.8	42	4.8	.7	1.1	73	16.7	8.6	2	Auger hole
315	420	294	3.8	2.0	35	4.1	.7	1.0	71	17.6	8.6	2	Auger hole
316			4.4	13.5	76	14.7	.4	2.9	82	16.1	8.6	3	Auger hole
321b	600	420	2.1	6.5	76	6.5	.4	1.6	76	19	8.8	3	Auger hole
335	500	350	3.8	3.6	48	5.1	.4	2.0	66	26.4	8.7	2	Auger hole
342	430	301	4.8	2.1	31	5.1	.7	1.1	74	16	8.7	1	Auger hole

Obs.pt. No.	TDS mhos/cm @ 25°C	TDS (ppm)	Ca^{++} $+Mg^{++}$ (epm)	$Na^{+}+K^{+}$ (epm)	$Na^{+}+K^{+}$ % of total cations	HCO_3^{-} $+CO_3^{=}$ (epm)	Cl (epm)	$SO_4^{=}$ (epm)	HCO_3^{-} $+CO_3^{=}$ % of total anions	$SO_4^{=}$ % of total anions	pH	Type	Remarks
62	800	560	6.2	3.2	24	10.2	0.4	2.9	76	21.3	8.0	1	Seepage
64	750	525	6.8	5.5	44	10.3	0.4	1.7	83	14	8.0	2	Spring
65	960	672	8.2	7.0	47	11.3	0.7	3.2	74	21.1	8.0	2	Spring
66	380	266	3.8	1.8	32	4.1	0.4	1.2	73	21.2	8.6	1	Seepage
78	1225	857.5	4.4	15.6	78	13.3	0.7	6.0	67	30	8.0	3	Seepage
80	800	560	7.2	4.9	40	9.6	0.7	1.8	79	15	8.0	2	Seepage
87	540	378	3.8	4.8	56	7.9	0.4	.4	91	49	8.8	2	Seepage
90	460	322	4.8	3.5	42	6.2	0.4	1.8	74	22	8.0	2	Spring
93c	360	252	3.8	11.8	33	4.4	0.4	.8	79	14.5	8.6	1	Auger hole
96	650	455	3.4	7.8	69	6.8	0.4	4.0	61	35.6	8.7	3	Auger hole
99	500	350	2.7	5.2	65	6.8	0.4	.7	87	9	8.8	2	Auger hole
02	675	472.5	6.8	3.7	35	9.6	0.4	.6	91	6.0	8.0	2	Seepage
03	670	469	6.5	4.3	40	9.2	0.7	.9	85	8.2	8.0	2	Seepage
04a	380	266	9.1	2.6	34	5.1	0.4	1.2	77	17.7	8.6	2	Flowing auger hole
12	875	612.5	8.6	5.2	38	11.3	0.4	2.1	82	15.4	8.0	2	Flowing auger hole
13	680	476	5.5	5.6	50	9.6	0.4	1.1	87	10	8.0	2	Seepage
16a	560	392	4.8	3.9	45	7.9	0.4	.4	91	4.6	8.0	2	Seepage
19	480	336	5.5	1.9	26	5.1	0.7	1.5	69	20.6	8.6	1	Auger hole
23a	750	525	.7	8.9	93	5.1	0.4	4.2	52	43.3	8.7	3	Seepage
27c	490	336	4.1	3.4	45	4.4	1.4	1.6	59	21.6	8.6	2	Auger hole
31	1100	770	3.1	13.2	81	12.3	.7	3.2	76	19.8	8.0	3	Seepage
33	800	560	.3	6.9	96	5.5	.4	1.3	76	18.0	9.0	3	Auger hole
34	850	595	4.8	8.9	65	10.3	.4	2.1	75	15.5	8.0	2	Spring
35	910	637	3.8	10.0	73	10.6	.7	2.5	77	17.9	8.0	3	Flowing auger hole
36	1050	735	.3	14.9	98	12.3	.4	2.6	79	16.7	8.0	3	Spring
37	1020	714	4.4	11.1	71	12.0	.4	3.2	77	20.7	8.0	3	Seepage
43	1500	1050	1.7	22.2	93	17.6	.7	5.6	74	23.4	9.0	3	Auger hole
44	1200	840	.3	16.8	98	13.7	.4	3.2	80	18.3	8.0	3	Seepage
46	1175	822.5	.3	17.6	98	15.0	.4	2.6	84	14.2	8.4	3	Flowing auger hole
5													

APPENDIX B

LEGAL DESCRIPTION OF OBSERVATION POINTS AND TRAVERSES

Obs. Pt. No.	Location W. 4th Mer. 1/4	Sec.	Tp.	R.
E-1	NE-19; NW-20; SW-29; SE-30		37	26
(a-1)				
(a-4)				
(a-7)				
(a-9)				
(c-1)				
(c-8)				
(c-10)				
(c-10a)				
(c-10b)				
(c-10c				
(d-1)				
(d-3)				
(d-4)				
(d-5)				
(d-6)				
(e-1)				
(e-3)				
(e-6)				
(e-8)				
(f-1)				
(g-4)				
E-2	NE	19	37	26
E-5	NE	19	37	26
E-6	NE	19	37	26
E-7	NE	19	37	26
E-8	NE	19	37	26
E-9	NE	19	37	26
E-10	NW	19	37	26
E-11	NW	19	37	26
E-12	NW	19	37	26
E-13	NW	19	37	26
E-14	NW	19	37	26
E-15	NW	20	37	26
E-17	SE	20	37	26
E-18	NE	20	37	26
E-19	NE	20	37	26
E-20	NW	20	37	26
E 22	NE	20	37	26
E-23	NE	20	37	26
E-24	NE	20	37	26
E-25	NE	20	37	26
E-26	NE	20	37	26
Trav.	NE	29	37	26
E-3	S1/4	32	37	26
E-27	SE	32	37	26
E-28	SE	29	37	26
E-29	SW	11	37	26
Trav.	NW	29	37	26
E-4				
E-31	SW	29	37	26
E-32	NW	29	37	26
E-33	NW	29	37	26
E-34	NE	29	37	26
E-35	NE	29	37	26
E-36	NE	29	37	26
E-37	NE	29	37	26
E-38	SE	29	37	26
E-39	SE	29	37	26
E-39a	SE	29	37	26
E-40	SE	29	37	26
E-41	SE	29	37	26
E-42	SE	29	37	26
E-43	SE	29	37	26
E-44	SE	29	37	26
E-45	NE	29	37	26
E-46	SE	31	37	26
E-47a	NE	31	37	26
E-47b	NE	31	37	26
E-47c	NE	31	37	26
E-47d	NE	31	37	26
E-48	NE	31	37	26
Trav.	NE	31	37	26
E-49	NW	32	37	26
E-50	NW	32	37	26
E-51	NW	32	37	26
E-52	NW	32	37	26
E-53	NW	32	37	26
E-54	NW	32	37	26
E-55	SW	31	37	26
E-56	SW	31	37	26
E-57	SW	31	37	26
E-58	SW	31	37	26
E-59	SW	31	37	26
E-60	NW	31	37	26

E-61	NE	31	37	26
E-61a	NE	31	37	26
E-62	NE	31	37	26
E-63	SE	31	37	26
E-64	SW	31	37	26
E-65	SW	30	37	26
E-66	SW	30	37	26
E-67	SW	30	37	26
E-68	SW	30	37	26
E-69	SE	31	37	26
E-70	SE	31	37	26
E-71	SE	31	37	26
E-73	SE	31	37	26
E-75	NE	31	37	26
E-76	NE	31	37	26
E-77	NE	31	37	26
E-78	NE	31	37	26
E-79	SE	31	37	26
E-80	NE	30	37	26
E-81	NE	30	37	26
E-82	NW	30	37	26
E-83	SW	30	37	26
E-84	SW	30	37	26
E-85	SW	30	37	26
E-86	SW	30	37	26
E-87	NE	36	37	26
Trav.	SE	25	37	27
E-88				
Trav.	NE	24	37	27
E-89				
E-90a	SW	24	37	27
E-90b	SW	24	37	27
E-91a	SW	24	37	27
E-91b	NW	24	37	27
E-91c	NW	24	37	27
E-91d	NW	24	37	27
E-91e	NW	24	37	27
E-91f	SW	25	37	27
E-91g	SW	25	37	27
E-91h	SW	25	37	27
E-91i	SW	25	37	27
E-92a	SE	25	37	27
E-92b	SE	25	37	27
E-92c	SE	25	37	27
E-92d	SE	25	37	27
E-92e	SW	25	37	27
E-92f	SW	25	37	27
E-92g	SW	25	37	27
E-92h	NW	25	37	27
E-93a	NE	36	37	27
E-93b	NE	36	37	27
E-93c	NE	36	37	27
E-93d	NE	36	37	27
E-93e	NE	36	37	27
E-93f	NE	36	37	27
E-93g	NE	36	37	27
E-94a	NW	36	37	27
E-95a	NW	36	37	27
E-95b	SE	36	37	27
E-95c	NE	36	37	27
E-95d	NW	36	37	27
E-95e	NW	36	37	27
E-95f	NW	25	37	27
Trav.	NE	36	37	27
E-95				
Trav.	NW	8	38	26
E-96				
E-97a	SW	8	38	26
E-98a	NW	5	38	26
E-99a	SE	5	38	26
E-99b	SW	8	38	26
E-99c	NW	5	38	26
E-99d	SW	5	38	26
Trav.	SE	5	38	26
E-100				
E-101	NE	5	38	26
Trav.	N1/2	8	38	26
E-102				
E-102a	NE	8	38	26
E-103a	NW	7	38	26
E-103b	NW	7	38	26
E-103c	NE	7	38	26
E-104a	SE	7	38	26
E-104b	SE	7	38	26
E-104c	SE	7	38	26
E-105	NE	30	37	26
E-106a	SE	6	38	26
E-106b	SW	6	38	26
E-106c	SW	6	38	26
E-106d	SW	6	38	26
E-106e	SW	6	38	26
E-106f	SW	6	38	26
E-106g	NW	6	38	26
Trav.	NW	7	38	26
E-107	SW	18	38	26
E-108a	NW	12	38	27
E-108c	NW	12	38	27
E-108d	NW	12	38	27
E-108e	SW	12	38	27
E-108f	NW	1	38	27
E-109	NW	12	38	27
E-110a	NE	12	38	27
E-110b	NE	12	38	27
Trav.	SE	12	38	2
E-111				
E-112a	NE	1	38	2
E-112b	NE	1	38	2
E-112c	NW	1	38	2
E-112d	SW	1	38	2
E-112e	SE	1	38	2
E-112f	SW	1	38	2
E-112g	SE	1	38	2
E-112h	NW	1	38	2
E-112i	SE	1	38	2
E-112j	SE	1	38	2
E-112k	SW	1	38	2
E-113a	SW	1	38	2
E-113b	SE	2	38	2
E-113c	SE	2	38	2
E-113d	SE	2	38	2
E-113e	SE	2	38	2
E-114a	SE	17	38	2
E-114b	SW	17	38	2
E-114c	SW	17	38	2
E-114d	SE	17	38	2
Trav.	NW	17	38	2
E-115				
Trav.	SW	17	38	2
E-116				
E-117a	SE	18	38	2
E-117b	NE	18	38	2
E-117c	NE	18	38	2
E-117d	NE	18	38	2
E-118a	NE	18	38	2
E-119a	SE	13	38	2
E-119b	SE	13	38	2
E-119c	SE	13	38	2
E-119d	SE	13	38	2
E-120a	NE	13	38	2
E-120b	NE	13	38	2
E-121a	NW	13	38	2
E-121b	SW	13	38	2
E-122	SW	20	38	2
Trav.	S1/2	19	38	2
E-123				
Trav.	W1/2	19	38	2
E-124				
E-125a	NE	24	38	2
E-125b	NE	24	38	2
E-126	SW	30	38	2

E-127a	NW	24	38	27
E-127b	SW	24	28	27
Trav. E-128	SW	30	38	26
Trav. E-129	NW	30	38	26
Trav. E-130	SE	30	38	26
Trav. E-131	E1/2	30	38	26
E-132a	NW	30	38	26
E-132b	NW	30	38	26
E-132c	NW	30	38	26
E-132d	NW	31	38	26
E-132e	NW	31	38	26
E-132f	NW	31	38	26
Trav. E-133	E1/2	31	38	26
Trav. E-134	NW	36	38	27
E-135	NW	36	38	27
E-136a	SW	36	38	27
E-136b	SW	36	38	27
E-137a	NE	36	38	27
E-137b	SE	36	38	27
E-137c	SE	36	38	27
E-137d	SE	36	38	27
E-137e	SE	36	38	27
E-137f	SE	36	38	27
E-138a	NW	25	38	27
E-138b	NW	25	38	27
E-139	SE	26	38	27
Trav. E-140	SW	25	38	27
E-140a	SW	25	38	27
E-140b	SE	25	38	27
E-140c	SE	25	38	27
E-140d	SE	25	38	27
E-140e	SE	36	38	27
E-141a	SW	26	38	27
E-141b	SW	26	38	27
E-141c	SE	26	38	27
E-141d	SE	26	38	27
E-141e	SE	26	38	27
E-142	NW	26	38	27
E-142e	NW	26	38	27
E-143	NE	26	38	27
E-144a	SW	35	38	27
E-144b	SW	35	38	27
E-144c	NE	34	38	27
E-145	SW	35	38	27
E-146	SE	34	38	27
E-147a	SE	27	38	27
E-147b	NE	27	38	27
E-147c	SE	27	38	27
E-147d	NE	22	38	27
E-147e	SE	27	38	27
E-148	NE	23	38	27
E-149a	NW	23	38	27
E-149b	NW	23	38	27
E-150	NW	23	38	27
E-151a	SW	23	38	27
E-151b	SW	23	38	27
E-151c	SW	23	38	27
E-152	SW	23	38	27
E-153a	NW	22	38	27
E-153b	NE	22	38	27
E-153c	SE	22	38	27
E-153d	SE	22	38	27
E-153e	SE	22	38	27
E-153f	SE	22	38	27
E-154	NE	22	38	27
E-155a	NE	15	38	27
E-155b	SE	15	38	27
E-155c	SE	15	38	27
E-155d	SE	15	38	27
E-156a	SW	14	38	27
E-156b	SW	14	38	27
E-157a	SE	14	38	27
E-157b	SE	14	38	27
E-157c	SE	14	38	27
E-158a	NE	11	38	27
E-158b	NE	11	38	27
E-158c	NE	11	38	27
Trav. E-159	NE	11	38	27
E-159k	NE	11	38	27
E-159l	NE	11	38	27
E-159q	SW	11	38	27
E-160a	NE	10	38	27
E-160b	NW	10	38	27
E-160c	NW	10	38	27
E-161a	SE	10	38	27
E-162a	SW	2	38	27
E-162b	SW	2	38	27
Trav. E-162	N1/2	2	38	
E-162e	SW	11	38	
E-162h&i	NE	2	38	
E-162k	SW	2	38	
E-162l	SW	2	38	
E-163a	SW	2	38	
E-163b	SW	2	38	
E-163c	SW	2	38	
E-163d	SE	2	38	
E-163e	SE	2	38	
E-163f	SE	2	38	
E-163g	SE	2	38	
E-163h	SW	2	38	
E-164a	NW	3	38	
E-164b	NW	10	38	
E-164c	SW	3	38	
E-164 d, e, f	SW	3	38	
E-164g	SW	3	38	
E-164h	SW	3	38	
E-164i	NW	3	38	
E-164j	NW	3	38	
E-164k	SW	10	38	
E-164l	SW	10	38	
E-164m, n, o, p, q & r	W1/2	10	38	
E-165a	SE	26	37	2
E-165b	SE	26	37	2
E-165c	SE	26	37	2
E-165 d & e	NE	26	37	2
E-165f, g & h	NE	26	37	2
E 165i	NE	26	37	2
E-165j, k & l	NE	26	37	2
E-165m	NE	26	37	2
E-165n	SE	26	37	2
E-166	SW	35	37	2

E-167a	SE	26	37	27
E-167b	SE	26	37	27
E-167c	SW	27	37	27
Trav. E-168	NW	26	37	27
E-169a	SE	26	37	27
E-169b	SE	26	37	27
E-169c	SE	26	37	27
E-169d	NE	23	37	27
E-170a	SW	26	37	27
E-170b	SE	26	37	27
E-170c				
E-171	NE	35	37	27
E-172a	SE	35	37	27
Trav. E-173	NW	34	37	27
E-174	SW	27	37	27
E 175	SW	27	37	27
E-176	SW	27	37	27
E-177	SW	27	37	27
E-178	SE	27	37	27
E-179	SE	27	37	27
E-180	NE	27	37	27
E-181a	NE	35	37	27
E-181b	SE	35	37	27
E-181c	NW	35	37	27
E-181d	NW	35	37	27
E-182a	NE	27	37	27
E-182b	SE	27	37	27
E-182c	SW	27	37	27
E-182d	NW	27	37	27
E-183a	NW	33	37	27
E-183b	NE	33	37	27
E-183c	NE	28	37	27
E-183d	NE	28	37	27
E-183e	SE	28	37	27
E-184	SE	28	37	27
E-185a	SW	28	37	27
E-185b	SW	28	37	27
E-185c	SW	28	37	27
E-186a	SW	28	37	27
E-186b	SW	28	37	27
E-186b	NW	28	37	27
E-187a	NW	28	37	27
E-187b	NW	28	37	27
E-188	NW	28	37	27
E-188Aa	NW	33	37	27
E-189a	NW	28	37	27
E-189b	NW	28	37	27
E-189c	SW	28	37	27
E-190a	NE	4	38	27
E-190b	SE	4	38	27
E-191a	SE	4	38	27
E-191b	SE	4	38	27
Trav. E-192	W1/2	4	38	27
E-193	SE	5	38	27
Trav. E-195	N1/2	5	38	27
E-196a	SW	7	38	27
E-196b	SW	6	38	27
E-196c	SW	6	38	27
E-197a	SE	12	38	28
E-197b	SE	12	38	28
E-198a	NW	1	38	28
E-198b	NW	1	38	28
E-199a	SE	12	38	28
E-199b	SE	12	38	28
E-199c	SE	12	38	28
Trav. E-200	SE	1	38	28
E-201	SW	1	38	28
E-202	SW	1	38	28
Trav. E-203	SE	26	37	28
E-204	SE	26	37	28
E-205a	SE	35	37	28
E-205b	NE	35	37	28
E-205c	NE	26	37	28
E-206	NE	36	37	28
E-207	NE	36	37	28
E-208	NW	9	38	27
E-209	NE	4	38	27
E-210	SW	17	38	27
E-211	SW	18	38	27

Obs. Pt.	Location W. 5th Mer.			
No.	1/4	Sec.	Tp.	R.
W-1	SW	25	37	2
W-2	NE	26	37	2
W-3	NE	26	37	2
W-4	NE	26	37	2
W-5	NE	26	37	2
W-6	NE	26	37	2
W-7	NW	35	37	2
W-8	NE	35	37	2
W-9	NE	35	37	2
W-10a	SW	26	37	2
W-10b	SW	26	37	2
W-11c	NW	26	37	2
W-12	SE	34	37	2
W-13	SE	34	37	2
W-14	NW	26	37	2
W-15	NE	36	37	2
W-16	SW	36	37	2
W-17	SW	36	37	2
W-18	SW	25	37	2
W-19	SW	30	37	1
W-20	SW	30	37	1
W-21	NW	30	37	1
W-22	NE	25	37	2
W-23	NE	25	37	2
W-24	NE	25	37	2
W-25	NE	25	37	2
W-26	NE	25	36	2
W-27	SE	36	37	2
W-28	NE	25	37	2
W-30	NW	36	37	2
W-31	NW	24	37	2
W-32	SW	24	37	2
W-33	SE	24	37	2
W-34	NE	14	37	2
W-35	SE	13	37	2
W-36	NE	13	37	2
Trav. W-37	W1/2	19	37	1
W-38	SW	18	37	1
W-39	SE	18	37	1
W-40	NE	18	37	1
W-41	SW	18	37	1
W-42	SW	18	37	1
Trav. W-43	E1/2	19	37	1
W-44a	NW	17	37	1

Obs. Pt.	Location W. 5th Mer.			
No.	1/4	Sec.	Tp.	R.
W-44b	NW	17	37	1
W-44c	NW	17	37	1
Trav.	SW	17	37	1
W-46				
W-47	SE	17	37	1
W-48	SE	17	37	1
W-49	SE	17	37	1
W-50	SW	16	37	1
W-51	SE	20	37	1
Trav. W-52	N1/2	20	37	1
W-52a	NW	20	37	1
W-52b	NE	20	37	1
W-53	SW	16	37	1
W-54	SE	16	37	1
W-55	NE	16	37	1
W-56	NE	21	37	1
W-57	NE	21	37	1
W-58	NE	21	37	1
W-59	NE	21	37	1
W-60	SW	9	37	1
W-61	NW	9	37	1
W-62	SW	4	37	1
Trav. W-63	NE	9	37	1
W-64	NE	9	37	1
W-65	NW	8	37	1
W-66a	SW	8	37	1
W-66b	SW	8	37	1
W-66c	SW	8	37	1
W-67	SE	7	37	1
W-67a	SE	7	37	1
W-68	SE	8	37	1
W-69a	SE	8	37	1
W-69b	NE	5	37	1
Trav.	NE	5	37	1
W-70	NE	6	37	1
	W1/2	6	37	1
W-71	NW	12	32	2
Trav. W-72	N1/2	1	32	2
W-72a	NW	1	32	2
W-72b	NW	1	32	2
W-73	NW	32	37	1

Trav. W-74	NW	1	37	2
W-74a	NW	1	37	2
W-75a	SW	29	36	1
W-75b	NW	29	36	1
W-76	SW	29	36	1
W-77	NE	32	36	1
W-78a	SW	30	36	1
W-78b	SW	25	36	1
W-78c	SW	25	36	1
W-78d	SE	24	36	2
W-79	NE	30	36	1
W-80	NE	35	36	2
W-81a	SW	36	36	2
W-81b	NW	36	36	2
W-82	SE	35	36	2
Trav. W-83	SE	2	36	2
W-83a	SE	2	36	2
W-84	SW	11	36	2
W-85	NW	11	36	2
W-86	NE	10	36	2
W-87	NE	10	36	2
W-88	NW	11	36	2
W-89	SW	11	36	2
W-90	SE	14	36	2
W-91	SE	23	36	2
W-92	NW	23	36	2
W-93	SE	14	36	2
Trav. W-94	SW	14	36	2
W-95	E1/2	15	36	2
W-96	SE	15	36	2
W-97	SE	21	36	2
W-97a	SW	22	32	2
W-98	NW	22	36	2
W-99	NE	22	36	2
W-100	SW	15	36	2
W-101	NW	23	36	2
W-102a	NW	23	36	2
W-102b	NE	23	36	2
Trav.	SW	23	36	2
W-103a	NW	14	36	2
Trav. W-103b	NW	14	36	2
W-104	NE	22	36	2
W-105	SE	34	36	2
W-106	NE	34	36	2
Trav.	SE	33	36	2
W-107	NE	28	36	2
W-107a	SE	33	36	2
W-108a, b, c, & d	E1/2	27	36	2
W-108e	NE	27	36	2
W-108f	SW	34	36	2
W-109a	NE	27	36	2
W-109b	NE	27	36	2
W 109c	NW	26	36	2
W-110a	NE	34	37	2
W-110b	NW	34	37	2
W-111	SE	3	38	2
W-112	NE	34	37	2
W-113	NE	34	37	2
W 114	SW	33	37	2
W-115	SW	33	37	2
W-116	SW	33	37	2
W-117	NW	32	37	2
Trav. W-118	S1/2	32	37	2
W-118a	SE	32	32	2
W-118b	SW	32	37	2
W-119	SE	10	37	2
W-120	NE	9	37	2
W-121	NE	9	37	2
W-122	SW	32	37	2
W-123	SW	32	37	2
W-124a	SE	29	37	2
W-124b	NW	29	37	2
W 124c	NW	29	37	2
W-125	NW	29	37	2
W-126	SW	29	37	2
Trav. W-127	N1/2	31	37	1
W-127a	NW	31	37	1
Trav. W-128	NW	30	37	1
W-129	NE	30	37	1
W-129a	NW	29	37	1
W-130	NW	29	37	1
W-131	SW	29	37	1
W-131a	NE	29	37	1
W-132	SW	29	37	1
W-133	SE	29	37	1
W-133a	SE	29	37	1
W-134	SE	32	37	1
W-135	SE	32	37	1
W-136	SE	32	37	1
W-137	SE	32	37	1
W-138	NE	32	37	1
W-139	NE	32	37	1
W-140	NE	32	37	
W-141	NW	28	37	
W-142a	NW	28	37	
W-142b	SE	33	37	
W-142c	NW	33	37	
W-142d	SW	33	37	
W-143	NE	33	37	
W-144	NW	34	37	
W-145	NW	34	37	
W-146	SE	28	37	
W-147	SE	28	37	
W-148	SE	28	37	
Trav. W-149	SE	28	37	
W-150	SE	4	38	
W-150a	SE	4	38	
W-151	SE	5	38	
W-152	SE	29	37	
W-153	SW	21	37	
W-154	NE	9	37	
W-155	SW	15	37	
W-156	SW	15	37	

OBS PT. No	Location				
	1/4	Sec	T.P.	R.	W.M.
1	SE	13	38	2	5
1 a	SE	13	38	2	5
2	NE	12	38	2	5
2 a	NE	12	38	2	5
2 b	NE	12	38	2	5
3	NE	12	38	2	5
3 a	NE	12	38	2	5
4	SE	12	38	2	5
5	NE	12	38	2	5
6	SE	13	38	2	5
7	NE	2	38	2	5
8	NE	2	38	2	5
9	SE	2	38	2	5
10	SW	2	38	2	5
10 a	NW	2	38	2	5
11	NW	2	38	2	5
12	NW	2	38	2	5
13	SW	11	38	2	5
14	SE	11	38	2	5
15	NE	11	38	2	5
16	NW	11	38	2	5
17	NW	11	38	2	5
18	SW	2	38	2	5
19	NE	1	38	2	5
20	NE	1	38	2	5
21	NE	1	38	2	5
22	SE	12	38	2	5
23	SE	12	38	2	5
24	SE	12	38	2	5
25	NE	12	38	2	5
26	NE	12	38	2	5
27	NE	10	38	2	5
28	NW	10	38	2	5
28 a	SW	15	38	2	5
28 b	NW	10	38	2	5
29	NW	10	38	2	5
30	SW	10	38	2	5
31	NW	3	38	2	5
32	NW	3	38	2	5
33	SW	3	38	2	5
34	SW	3	38	2	5
35	SW	3	38	2	5
36	SE	3	38	2	5
37	SE	3	38	2	5
38	SE	3	38	2	5
39	SE	3	38	2	5
40	NW	3	38	2	5
41	NW	3	38	2	5
42	SW	10	38	2	5

OBS PT. No	Location				
	1/4	Sec	T.R.	R.	W.M
43	NE	3	38	2	5
44	SE	10	38	2	5
45	SE	10	38	2	5
46	NE	10	38	2	5
46 a	NE	10	38	2	5
47	NE	10	38	2	5
48	NW	9	38	2	5
49	NE	8	38	2	5
50	NW	9	38	2	5
51	SW	4	38	2	5
52	SW	4	38	2	5
53	SW	4	38	2	5
54	NE	4	38	2	5
55	NE	4	38	2	5
56	NE	4	38	2	5
57	SW	9	38	2	5
58	NE	4	38	2	5
59	SE	9	38	2	5
60	SE	9	38	2	5
61	NE	9	38	2	5
62	SE	8	38	2	5
63	NW	8	38	2	5
64	NW	8	38	2	5
65	NW	8	38	2	5
66	NW	4	38	2	5
67	NW	8	38	2	5
68	NW	8	38	2	5
69	NW	5	38	2	5
70	SE	8	38	2	5
71	NW	5	38	2	5
72	NE	5	38	2	5
73	NW	5	38	2	5
74	NW	5	38	2	5
75	SW	5	38	2	5
75 a	SW	5	38	2	5
75 b	SW	5	38	2	5
75 c	SW	5	38	2	5
76	SW	5	38	2	5
77	SE	5	38	2	5
78	SE	5	38	2	5
79	NE	5	38	2	5
80	NE	5	38	2	5
81	SE	8	38	2	5
82	NW	8	38	2	5
83	SE	6	38	2	5
84	SE	6	38	2	5
85	NE	6	38	2	5
86	NE	6	38	2	5

OBS. PT. No	Location				
	1/4	Sec	T.R.	R	W.m.
88	SE	18	38	2	5
89	SE	18	38	2	5
90	NE	18	38	2	5
91	NE	18	38	2	5
92	NE	18	38	2	5
92 a	NE	18	38	2	5
93	NE	18	38	2	5
94	SE	19	38	2	5
95	NE	18	38	2	5
96	SE	19	38	2	5
97	NE	19	38	2	5
98	NE	19	38	2	5
99	NE	19	38	2	5
100	NW	19	38	2	5
101	NW	19	38	2	5
102	NE	24	38	3	5
103	NW	20	38	2	5
104	SW	20	38	2	5
105	SW	20	38	2	5
106	SW	20	38	2	5
107	SW	17	38	2	5
108	SE	17	38	2	5
109	SW	17	38	2	5
110	SE	17	38	2	5
111	NE	17	38	2	5
112	NE	17	38	2	5
113	NE	17	38	2	5
114	SE	20	38	2	5
115	SE	20	38	2	5
116	SW	20	38	2	5
117	NW	20	38	2	5
118	NE	20	38	2	5
119	NE	20	38	2	5
120	SE	20	38	2	5
121	NE	20	38	2	5
122	NE	20	38	2	5
123	NW	20	38	2	5
124	SW	29	38	2	5
125	NW	21	38	2	5
126	NW	21	38	2	5
127	NW	21	38	2	5
128	NW	21	38	2	5
129	SE	21	38	2	5
130	NW	16	38	2	5
131	NW	16	38	2	5
132	SW	16	38	2	5
133	SW	16	38	2	5
134	SW	16	38	2	5

OBS PT No	Location				
	1/4	Sec.	T.R.	R.	W.m
136	SE	16	38	2	5
136 a	SW	16	38	2	5
136 b	SE	16	38	2	5
137	SE	16	38	2	5
138	SE	16	38	2	5
139	NE	16	38	2	5
140	SE	21	38	2	5
140 a	SE	21	38	2	5
141	NE	21	38	2	5
142	NE	21	38	2	5
143	NW	22	38	2	5
144	NW	21	38	2	5
145	SW	22	38	2	5
146	NW	15	38	2	5
147	NW	15	38	2	5
148	NE	15	38	2	5
149	NW	15	38	2	5
150	SW	15	38	2	5
151	SW	15	38	2	5
153	SE	15	38	2	5
153 a	SE	15	38	2	5
154	SE	15	38	2	5
155	SE	15	38	2	5
156	SE	22	38	2	5
157	NW	22	38	2	5
158	NE	22	38	2	5
158 a	NW	22	38	2	5
159	NE	23	38	2	5
160	NW	23	38	2	5
160 a	NW	23	38	2	5
161	SE	26	38	2	5
162	NW	23	38	2	5
162 a	NW	23	38	2	5
163	SW	23	38	2	5
163 a	SE	23	38	2	5
164	SE	23	38	2	5
165	NE	14	38	2	5
165 a	NE	14	38	2	5
166	SE	14	38	2	5
166 a	SE	14	38	2	5
166 b	NE	14	38	2	5
167	SW	14	38	2	5
168	NW	14	38	2	5
169	SE	23	38	2	5
170	NW	14	38	2	5
171	NW	14	38	2	5
171 a	NW	14	38	2	5
171 b	NW	14	38	2	5

OBS. pt No.	Location				
	1/4	Sec	T.R.	R	W.m.
173	SE	28	38	2	5
174	SE	28	38	2	5
185	NE	27	38	2	5
176	NW	28	38	2	5
177	NE	27	38	2	5
178	SE	33	38	2	5
179	NE	33	38	2	5
180	NE	33	38	2	5
181	NW	33	38	2	5
182	SE	32	38	2	5
183	SW	32	38	2	5
184	SE	29	38	2	5
185	SW	29	38	2	5
186	SW	29	38	2	5
187	SE	29	38	2	5
188	NW	29	38	2	5
189	SE	29	38	2	5
190	SE	29	38	2	5
191	NW	28	38	2	5
192	NW	28	38	2	5
193	SE	28	38	2	5
194	NE	30	38	2	5
195	NW	30	38	2	5
196	NW	30	38	2	5
197	NW	30	38	2	5
198	NW	30	38	2	5
199	NE	25	38	3	5
200	SW	30	38	2	5
201	SW	30	38	2	5.
202	SW	30	38	2	5
203	SE	30	38	2	5
204	NW	31	38	2	5
204 a	SW	6	39	2	5
205	SE	35	38	3	5
206	NW	36	38	3	5
207	NE	36	38	3	5
208	NW	25	38	3	5
209	SE	25	38	3	5
210	SE	35	38	3	5
211	SE	35	38	3	5
212	SE	35	38	3	5
213	SW	5	39	2	5
214	NW	5	39	2	5
215	NW	5	39	2	5
216	SE	5	39	2	5
217	NE	5	39	2	5
218	SE	5	39	2	5
219	NW	7	38	1	5

OBS. Pt. No	Location				
	1/4.	Sec	T. P.	R	L
219 b	SW	5	38	1	5
220	SW	7	38	1	
221	SE	7	38	1	
222	SE	7	38	1	5
223	SE	7	38	1	5
224	SE	7	38	1	5
225	NW	5	38	1	5
226	NW	5	38	1	5
227	SW	5	38	1	5
228	NE	6	38	1	5
229	NE	6	38	1	5
229 a	NE	6	38	1	5
229 b	NE	6	38	1	5
229 c	NW	6	38	1	5
230	SW	7	38	1	5
231	SW	7	38	1	5
232	SW	7	38	1	5
233	NW	6	38	1	5
234	SE	6	38	1	5
235	SW	6	38	1	5
236	SW	6	38	1	5
237	NW	6	38	1	5
238	SW	6	38	1	5
239	SE	6	38	1	5
240	NE	6	38	1	5
240 a	NE	6	38	1	5
241	SE	8	38	1	5
242	NW	8	38	1	5
243	NW	8	38	1	5
244	NE	8	38	1	5
245	NE	7	38	1	5
245 a	NE	7	38	1	5
246	SW	9	38	1	5
247	SW	9	38	1	5
248	NE	9	38	1	5
248 a	NE	9	38	1	5
248 b	NW	10	38	1	5
249	NW	2	38	1	5
250	SW	2	38	1	5
251 a	NW	4	38	1	5
251 b	NW	4	38	1	5
251 c	NW	4	38	1	5
251 d	SW	4	38	1	5
251 e	SW	4	38	1	5
252	SE	4	38	1	5
253	SE	4	38	1	5
254	NW	4	38	1	5
255	NE	4	38	1	5

OBS. pt. No.	Location				
	1/4	Sec	Tp.	R.	W.m.
258	SW	3	38	1	5
259	NE	3	38	1	5
260	SW	10	38	1	5
261	SW	10	38	1	5
262	SW	2	38	1	5
263	NW	2	38	1	5
264	NE	2	38	1	5
265	SW	1	38	1	5
266	SW	1	38	1	5
267	SE	1	38	1	5
267 a	SE	1	38	1	5
267 b	SE	1	38	1	5
267 c	SE	1	38	1	5
268	SE	1	38	1	5
268 a	NE	1	38	1	5
269	NE	1	38	1	5
269 a	NW	1	38	1	5
269 b	NW	1	38	1	5
270	NE	6	38	28	4
271	NW	6	38	28	4
271 a	SW	6	38	28	4
272	SE	6	38	28	4
273	SE	6	38	28	4
274	SW	5	38	28	4
275	NW	32	37	28	4
276	SE	5	38	28	4
277	SE	5	38	28	4
278	SE	5	38	28	4
278 a	SE	5	38	28	4
279	SW	5	38	28	4
280	SE	5	38	28	4
281	NE	5	38	28	4
281 a	SE	8	38	28	4
282	NE	5	38	28	4
283	NW	5	38	28	4
284	NE	6	38	28	4
285	NW	6	38	28	4
286	NW	20	37	28	4
287	SE	19	37	28	4
288	NE	20	37	28	4
289	NE	20	37	28	4
290	SE	32	37	28	4
291	SW	32	38	28	4
292	SW	20	38	28	4
293	SW	20	38	28	4
294	NW	31	37	28	4
294 a	SW	19	37	28	4

OBS. pt. No.	Location				
	1/4	Sec	T.P.	R.	W
295	SW	19	37	28	
296	SE	19	37	28	
297	SE	19	37	28	
298	NW	19	37	28	
299	NE	19	37	28	
300	SE.	31	37	28	
300 a	SE	31	37	28	
301	SW	31	37	28	
302	SW	31	37	28	4
302 a	NW	19	37	28	4
303	SW	19	37	28	4
304	NW	36	37	1	5
305	NE	35	37	1	5
306	NW	25	37	1	5
307	NW	25	37	1	5
308	NW	25	37	1	5
308 a	SW	25	37	1	5
309	SW	25	37	1	5
310	NE	25	37	1	5
311	NE	25	37	1	5
312	NE	36	37	1	5
313	SE	36	37	1	5
314	NW	36	37	1	5
315	SE	36	37	1	5
316	NW	35	37	1	5
317	NW	35	37	1	5
318	SE	35	37	1	5
318 a	SE	35	37	1	5
318 b	SE	35	37	1	5
319	NE	26	37	1	5
319 a	SW	26	37	1	5
320	SW	26	37	1	5
320 a	SE	27	37	1	5
321	SE	26	37	1	5
322	NE	26	37	1	5
322 a	NE	26	37	1	5
322 b	NE	35	37	1	5
323	NW	34	37	1	5
323 a	NW	34	37	1	5
324	SW	27	37	1	5
324 a	SW	27	37	1	5
324 b	NW	22	37	1	5
325	SW	27	37	1	5
325 a	NE	27	37	1	5
326	NE	22	37	1	5
327	NW	22	37	1	5
328	SW	27	37	1	5

OBS. PT. No	Location				
	1/4	Sec	T.P.	R.	W.m
328 a	SW	15	37	1	5
329	SW	15	37	1	5
330	NW	15	37	1	5
331	SE	15	37	1	5
332	SW	14	37	1	5
333 a	SW	14	37	1	5
333 b	SE	14	37	1	5
333 c	SE	14	37	1	5
333 d	NW	14	37	1	5
333 e	NE	14	37	1	5
334	NE	14	37	1	5
335	SW	23	37	1	5
336 a	SW	13	37	1	5
336 b	SE	13	37	1	5
336 c	SE	13	37	1	5
336 d	SE	13	37	1	5
336 e	SW	13	37	1	5
336 f	SW	13	37	1	5
336 g	SW	24	37	1	5
336 h	NW	24	37	1	5
336 i	SE	23	37	1	5
336 j	NW	13	37	1	5
336 k	NW	13	37	1	5
336 l	SW	13	37	1	5
336 m	SW	13	37	1	5
336 n	SW	13	37	1	5
336 o	SW	13	37	1	5
336 p	NE	13	37	1	5
336 q	NE	13	37	1	5
337	NW	24	37	1	5
338 a	NW	24	37	1	5
338 b	SE	24	37	1	5
339 a	NW	19	38	28	4
339 b	NW	17	38	28	4
339 c	NE	18	38	28	4
339 d	SW	20	38	28	4
339 e	NE	19	38	28	4
339 f	NW	19	38	28	4
340	SW	18	38	28	4
341	NE	7	38	28	4
342	NE	19	38	28	4
343 a	SW	12	37	1	5
343 b	SW	12	37	1	5
343 c	SW	12	37	1	5
343 d	NW	1	37	1	5
343 e	NW	1	37	1	5
343 f	SW	1	37	1	5
343 g	SW	1	37	1	5

OBS. PT. No	Location				
	1/4	Sec	T.P.	R.	W.m.
343 h	SE	2	37	1	5
343 i	NE	2	37	1	5
343 j	NE	2	37	1	5
343 k	NE	2	37	1	5
343 l	SE	11	37	1	5
343 m	NE	11	37	1	5
343 n	NE	11	37	1	5
343 o	NE	11	37	1	5
344 a	NE	1	37	1	5
344 b	NE	1	37	1	5
344 c	NE	1	37	1	5
344 d	SE	12	37	1	5
344 e	SE	12	37	1	5
344 f	SE	12	37	1	5
344 g	SE	12	37	1	5
344 h	SE	12	37	1	5
345 a	NW	11	37	1	5
345 b	NE	10	37	1	5
346 a	SW	11	37	1	5
346 b	NE	2	37	1	5
346 c	SW	2	37	1	5
346 d	SW	11	37	1	5
346 e	SW	11	37	1	5
347 a	SW	2	37	1	5
347 b	SW	2	37	1	5
348 a	NE	3	37	1	5
348 b	SE	3	37	1	5
348 c	NE	3	37	1	5
348 d	SE	3	37	1	5
348 e	SE	3	37	1	5
348 f	SW	3	37	1	5
349	NW	10	37	1	5
349 a	NW	10	37	1	5
349 b	NW	10	37	1	5
350	NE	3	37	1	5
351	SE	3	37	1	5
352	NW	3	37	1	5
352 a	SW	10	37	1	5
353	SW	10	37	1	5
354 a	NW	10	37	1	5
354 b	NE	10	37	1	5
354 c	NE	10	37	1	5
354 d	NW	10	37	1	5
355	SW	4	37	1	5
356 a	SE	7	38	28	4
356 b	NW	7	38	28	4
356 c	SW	7	38	28	4
356 d	SW	7	38	28	4

Obs. pt. No.	Location				
	1/4	Sec	Tp	R	W.M.
356 f	NE	7	38	28	4
356 g	NE	7	38	28	4
356 h	NE	7	38	28	4
356 i	NE	7	38	28	4
357 a	SE	6	38	28	4
357 b	SE	6	38	28	4
358	NW	6	38	28	4
359	NW	6	38	28	4
360	NE	7	38	28	4
361 a	NE	8	38	28	4
361 b	NW	8	38	28	4
362	NW	9	38	28	4
363 a	NE	16	38	28	4
363 b	SE	21	38	28	4
363 c	SE	21	38	28	4
363 d	SE	21	38	28	4
363 f	NW	16	38	28	4
364	NE	34	37	28	4
365	NE	27	37	28	4
366	SE	28	37	28	4
367 a	SE	20	37	28	4
367 b	NW	20	38	28	4
367 c	SW	17	37	28	4
367 d	NE	17	38	28	4
367 e	SE	20	37	28	4
368	NW	20	37	28	4
369	NE	18	38	28	4
370	NE	20	38	28	4
371a	SW	33	37	28	4
371b	SW	33	37	28	4
371c	NE	33	37	28	4
371d	SE	33	37	28	4
371e	SE	33	37	28	4
371f	NE	28	37	28	4
371g	NW	28	37	28	4
371h	SW	28	37	28	4
371 i	SE	29	37	28	4
372 a	SW	27	38	28	4
372 b	SE	34	37	28	4
372 c	SE	34	38	28	4
372 d	NW	24	37	28	4
372 e	SW	34	38	28	4
372 f	NW	34	38	28	4
373a	SW	27	37	28	4
373b	SW	27	37	28	4
374	NE	34	37	28	4

OBS. pt. No.	Location				
	1/4	Sec	Tp.	R.	W.m.
376	NE	33	38	28	4
376 a	SE	4	38	28	4
377	NW	3	38	28	4
378	NW	3	38	28	4
378 a	SW	3	38	28	4
378 b	SW	3	38	28	4
379 a	NW	2	38	28	4
379 b	SW	2	38	28	4
379 c	SW	2	38	28	4
379 d	SW	2	38	28	4
379 e	SW	2	38	28	4
379 f	NE	3	38	28	4
379 g	NE	3	38	28	4
379 h	NW	2	38	28	4
379 i	SE	3	38	28	4
379 j	SW	18	38	28	4
380	NW	35	37	28	4
381	SE	2	38	28	4
381 a	SW	33	37	28	4
381 b	SE	33	37	28	4
381 c	NE	33	37	28	4
381 d	SE	33	37	28	4
381 e	SE	33	37	28	4
381 f	NE	28	37	28	4
381 g	SW	33	37	28	4
381 h	NW	28	38	28	4
381 i	SW	28	37	28	4
382	SE	11	38	28	4
383 a	NE	10	38	28	4
383 b	SW	10	38	28	4
384	SW	10	38	28	4
385	NW	9	38	28	4
386 a	SE	4	38	28	4
386 b	SE	4	38	28	4
386 c	NW	4	38	28	4
386 d	SE	9	38	28	4
386 e	NW	9	38	28	4
386 f	SW	9	38	28	4
386 g	NW	33	38	28	4
386 h	SW	34	38	28	4
386 i	SE	9	38	28	4
387	SE	29	38	28	4
387 a	SE	29	38	28	4
388	SW	29	38	28	4
389	SW	28	38	28	4
390	SW	28	38	28	4
391	NW	21	38	28	4
391 a	NW	21	[illegible]	[illegible]	[illegible]

OBS. PT. No.	Location				
	1/4	Sec	Tp.	R.	W.m.
392 b	SW	21	38	28	4
392 c	NW	17	38	28	4
392 d	NW	17	38	28	4
392 e	NW	17	38	28	4
392 f	SW	17	38	28	4
392 g	NW	17	38	28	4
392 h	SW	17	38	28	4
393 a	SE	21	38	28	4
393 b	NE	21	38	28	4
393 c	SE	21	38	28	4
394	SE	17	38	28	4
395 a	NW	22	38	28	4
395 b	NW	16	38	28	4
396	NE	16	38	28	4
396 a	NE	16	38	28	4
397	SE	22	38	28	4
398 a	NW	22	38	28	4
398 b	SE	22	38	28	4
398 c	NE	15	38	28	4
398 d	SE	22	38	28	4
398 e	NW	22	38	28	4
399	NW	23	38	28	4
399 a	NW	23	38	28	4
400	NW	23	38	28	4
401 a	NW	24	38	28	4
401 b	NE	24	38	28	4
401 c	NE	24	38	28	4
401 d	SW	23	38	28	4
401 e	NW	14	38	28	4
401 f	NW	14	38	28	4
402	SW	24	38	28	4
402 a	NE	24	38	28	4
403	NE	18	38	28	4
403 a	NE	11	38	28	4
404	SE	14	38	28	4
404 a	NW	13	38	28	4
405	SE	28	38	28	4
405 a	SE	28	38	28	4
405 b	NW	27	38	28	4
405 c	SE	27	38	28	4
406	NW	26	38	28	4
407 a	SE	26	38	28	4
407 b	NE	26	28	28	4
407 c	NW	25	38	28	4
408 a	NE	25	38	28	4
408 b	NE	25	38	28	4
408 c	SE	25	38	28	4

OBS. PT. No.	Location				
	1/4	Sec	T.P.	R.	W.m.
409 b	SW	31	38	27	4
410 a	NW	32	38	27	4
410 b	NW	32	38	27	4
410 c	NW	3	39	27	4
410 d	SE	4	39	27	4
411 a	SE	32	38	27	4
411 b	SE	32	38	27	4
412	NW	28	38	27	4
413	NW	33	38	27	4
414	NW	31	38	27	4
414 a	NE	35	38	28	4
414 b	NE	34	38	28	4
415	NE	35	38	28	4
416	NE	33	38	28	4
416 a	NE	33	38	28	4
417 a	NE	34	38	28	4
417 b	NW	34	38	28	4
418 a	SW	33	38	28	4
418 b	NE	33	38	28	4
418 c	SE	28	38	28	4
419 a	SE	1	39	28	4
420 a	NW	5	39	27	4
420 b	NW	5	39	27	4
420 c	NE	5	39	27	4
421	SE	3	39	27	4
422 a	NE	3	39	27	4
422 b	NE	3	39	27	4
423 a	SE	11	39	27	4
423 b	SE	13	39	27	4
423 c	NE	8	39	27	4
424 a	SE	14	39	27	4
424 b	NE	9	39	27	4
424 c	SW	9	39	27	4
424 d	SW	9	39	27	4
424 e	SE	8	39	27	4
424 f	SE	8	39	27	4
424 g	NE	5	39	27	4
425	SW	12	39	28	4
426	SE	11	39	28	4
427 a	SW	11	39	28	4
427 b	NW	2	39	28	4
427 c	SW	3	39	28	4
428	NE	22	37	27	4
429	NE	14	37	27	4
430	SW	14	37	27	4
431	SE	2	37	27	4

OBS. PT. No	Location				
	1/4	Sec	T.P.	R.	W.M.
433	SW	18	37	26	4
434	NW	7	37	26	4
435	SE	7	37	26	4
436	NE	7	37	26	4
437	SW	24	37	26	4
438	NW	17	37	26	4
438 a	SE	19	37	26	4
438 b	NE	19	37	26	4
439	NW	1	37	27	4
439 a	NE	2	37	27	4
439 b	SW	13	37	27	4
440	NW	35	36	27	4
441 a	NW	34	36	27	4
441 b	SW	34	36	27	4
441 c	NE	33	36	28	4
441 d	NW	33	36	27	4
442	SW	3	37	27	4
443	NE	5	37	27	4
443 a	NE	5	37	27	4
443 b	SW	5	37	27	4
443 c	NE	5	37	27	4
444	NE	3	37	27	4
445	SW	11	37	27	4
445 a	NW	11	37	27	4
446	SE	10	37	27	4
446 a	SE	10	37	27	4
446 b	SW	10	37	27	4
447	NE	9	37	27	4
448	SW	16	37	27	4
449	SW	19	37	28	4
449 a	NW	19	37	27	4
449 b	SW	19	37	27	4
449 c	NW	18	37	27	4
450	NW	29	37	27	4
451	SE	31	37	27	4
452	SW	1	37	28	4
452 a	SW	36	36	28	4
452 b	SE	1	37	28	4
452 c	NE	1	37	28	4
453 a	NW	15	37	27	4
453 b	NE	15	37	27	4
453 c	NE	15	37	27	4
453 d	SW	15	37	27	4
454 a	SW	22	37	27	4
454 b	SW	22	37	27	4
454 c	SW	22	37	27	4

OBS. PT. No.	LOCATION				
	1/4	Sec	Tp	R	W.M
455 a	NW	4	37	27	4
455 b	NE	4	37	27	4
456 a	SE	16	37	27	4
456 b	SW	16	37	27	4
456 c	NE	17	37	27	4
456 d	NW	16	37	27	4
457	NW	21	37	28	4
457 a	NEW	21	37	27	4
457 b	NE	21	37	27	4
458 a	SE	31	36	27	4
458 b	SW	32	36	27	4
458 c	SE	6	37	27	4
459 a	SE	8	37	27	4
459 b	SE	17	37	27	4
460	SE	17	37	27	4
461	NE	17	37	27	4
461 a	SW	20	37	27	4
462 a	SE	29	37	27	4
462 b	SE	29	37	27	4
462 c	NE	29	37	27	4
463 a	SE	18	37	27	4
463 b	NE	19	37	27	4
464 a	NE	7	37	27	4
464 b	SE	13	37	28	4
464 c	NW	18	37	27	4
464 d	NE	30	37	28	4
465	SE	36	37	28	4
466 a	NE	25	37	28	4
466 b	SE	25	37	28	4
466 c	SE	25	37	28	4
467	NE	14	37	28	4
467 a	SE	23	37	28	4
468	NW	12	37	28	4
468 a	SE	14	37	28	4
469	SW	11	37	28	4
469 a	SW	11	37	28	4
469 b	SW	11	37	28	4
470	SW	2	37	28	4
471	SW	35	36	28	4
472 a	NW	33	36	28	4
472 b	NE	34	36	28	4
472 c	SW	3	37	28	4
472 d	NW	3	37	28	4
472 E	NW	3	37	28	4
472 f	SE	15	37	28	4
472 g	SE	15	37	28	4

OBS pt. No		Location				
		1/4	Sec	Tp.	R.	W.m.
473		NE	32	36	28	4
474	a	SW	9	37	28	4
474	b	SW	15	37	38	4
474	c	NW	12	38	28	4
474	d	NE	12	38	28	4
475	a	SE	27	37	28	4
475	b	SE	22	37	28	4
476		NW	7	38	27	4
477		NE	27	37	28	4
478	a	NE	34	38	2	5
478	b	NE	35	38	2	5
478	c	NW	34	38	2	5
478	d	NW	36	38	2	5
478	E	SW	6	39	1	5
479		SE	35	38	2	5
✓ 479	a	SW	35	38	2	5
✓ 480	a	SE	26	38	2	5
480	b	SE	25	38	2	5
481		NW	30	38	1	5
482	a	SW	32	38	1	5
482	b	SW	32	38	1	5
483		SE	32	38	1	5
484	a	NW	29	38	1	5
484	b	SW	29	38	1	5
484	c	NW	28	38	1	5
485	a	NW	19	38	1	5
485	b	SW	19	38	1	5
486		NW	19	38	1	5
487		NE	24	38	2	5
488	[illegible]	NW	24	38	2	5
488	a	NW	24	38	2	5
489	a	NE	13	38	2	5
489	b	NW	18	38	1	5
490		NW	17	38	1	5
491	a	SW	20	38	1	5
491	b	NW	20	38	1	5
492	c	SW	28	38	1	5
492	a	NW	16	38	1	5
492	a	NE	17	38	1	5
493		NE	16	38	1	5
493	a	NE	16	38	1	5
494		NW	15	38	1	5
494	a	SW	15	38	1	5
495		SW	22	38	1	5
496		SE	22	38	1	5
496	a	NE	22	38	1	5

OBS pt. No.		Location				
		1/4	Sec	T.P.	R.	W.M.
497	b	NE	26	38	1	5
497	c	SW	26	38	1	5
497	d	NE	27	38	1	5
497	E	NE	27	38	1	5
497	F	SE	35	38	1	5
497	G	NW	26	38	1	5
497	H	SE	36	38	1	5
497	i	NW	25	38	1	5
498		NE	27	38	1	5
499		NE	34	38	1	5
500		SW	2	39	1	5
501		NE	3	39	1	5
502		SW	10	39	1	5
502	a	SW	10	39	1	5
502	b	NW	10	39	1	5
503		SE	11	39	1	5
504		SE	2	39	1	5
504	a	SE	2	39	1	6
505		SW	1	39	1	5
505a		SW	1	39	1	5
505b		SW	1	39	1	5
506		NE	1	39	1	5
507		SW	36	38	1	5
508		NW	31	38	28	4
508	a	SE	5	39	28	4
509		SE	31	38	28	4
510	a	SE	25	38	1	5
510	b	SW	30	38	28	4
511		SW	25	38	1	5
512a		SE	15	38	1	5
512	b	SW	11	38	1	5
513		NW	11	38	1	5
513	a	SE	15	38	1	5
514	b	NE	8	38	28	4
515	a	SE	17	38	28	4
515	b	NW	17	38	28	4
516	a	NW	29	38	28	4
516	b	NW	29	38	28	4
517	a	SE	32	38	28	4
517	b	SE	32	38	28	4
518		NW	4	37	27	4