Alberta Research Council
Open File Report 1971-11

# COLLECTION AND COMPILATION OF GROUNDWATER DATA IN THE MARMOT CREEK EXPERIMENTAL BASIN

23 - 9 - W5

by

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June, 1971

THE GROUNDWATER PHASE OF THE MARMOT CREEK

EXPERIMENTAL BASIN

## General Statement

The primary groundwater study objective is to evaluate, by groundwater instrumentation, the amount and rate of water moving within the groundwater reservoir and its relation to the hydrologic balance of the basin.

The groundwater reservoir must be outlined in three dimensions, and its reservoir constants evaluated. Thus the geologic framework of the basin must be established and the hydraulic properties of the reservoir materials involved must be calculated by well-hydraulic methods.

Water-table observation wells set in the various reservoir materials within the basin will show the change of groundwater stage in relation to the hydrologic balance and outline the phreatic divides. Piezometer tubes will show the limits of the "effective" groundwater reservoir within any time period, the pressure gradients and direction of groundwater movement within the various components of the groundwater reservoir.

The parameters may be combined to provide a groundwater budget for any period limited by the assumptions involved.

## The Marmot Creek Basin

### Geology and hydrology

The accompanying maps generally outline the surficial and bedrock deposits underlying the area. The surficial deposits over most of the area consist dominantly of silty clay and boulders of limestone, sandstone, siltstone, and quartzite. These deposits are the result of the deposition and subsequent erosion of the medial moraines of the Kananaskis Valley glacier. These moraine-type deposits generally are poorly sorted and have low hydraulic conductivity values.

In the lower part of the confluence area the surficial deposits are glacio-fluvial in origin, thicker, and have higher hydraulic conductivity values.

The bedrock underlying the area ranges in age from Permian to Lower Cretaceous. The Rocky Mountain Formation underlying the mouth of the basin is a massive quartzite. The piezometers sat in this formation indicate no hydraulic connection with the active groundwater reservoir. Overlying the Rocky Mountain quartzite is the Spray River Formation, made up of thin bedded siltstones. Likewise, this formation does not appear to be involved in the groundwater reservoir.

The overlying Jurassic and Lower Cretaceous deposits are dominantly shales, sandstones with some coal and appear to be relatively impermeable.

Thus, the unconsolidated materials appear to be the major groundwater reservoir. The water-table observation wells developed in these materials shows the major recharge to be in spring in response to snowmelt, with a slow recession through the summer. Summer recharge periods vary with the duration and intensity of summer rainfall.

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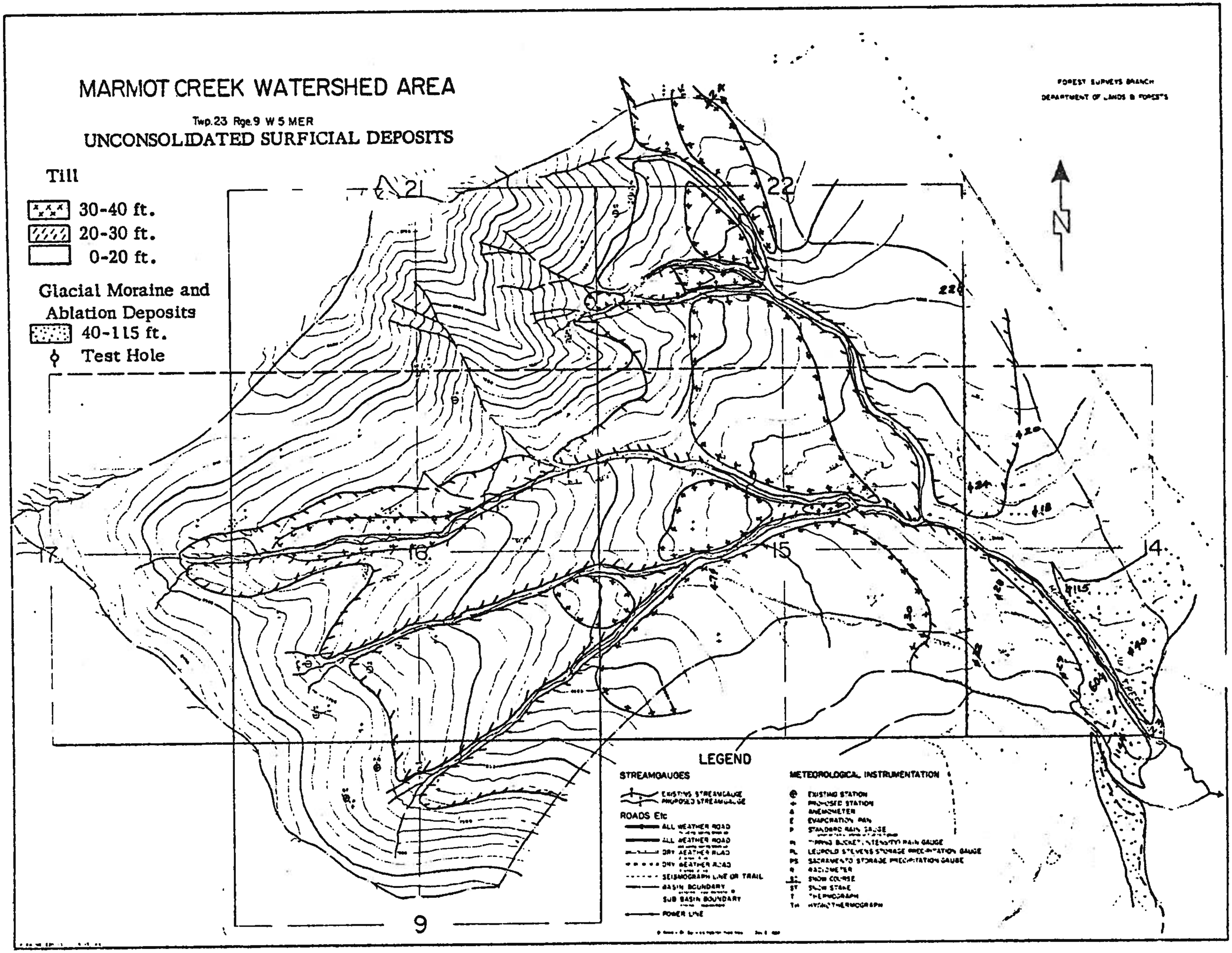
September 20, 1966.

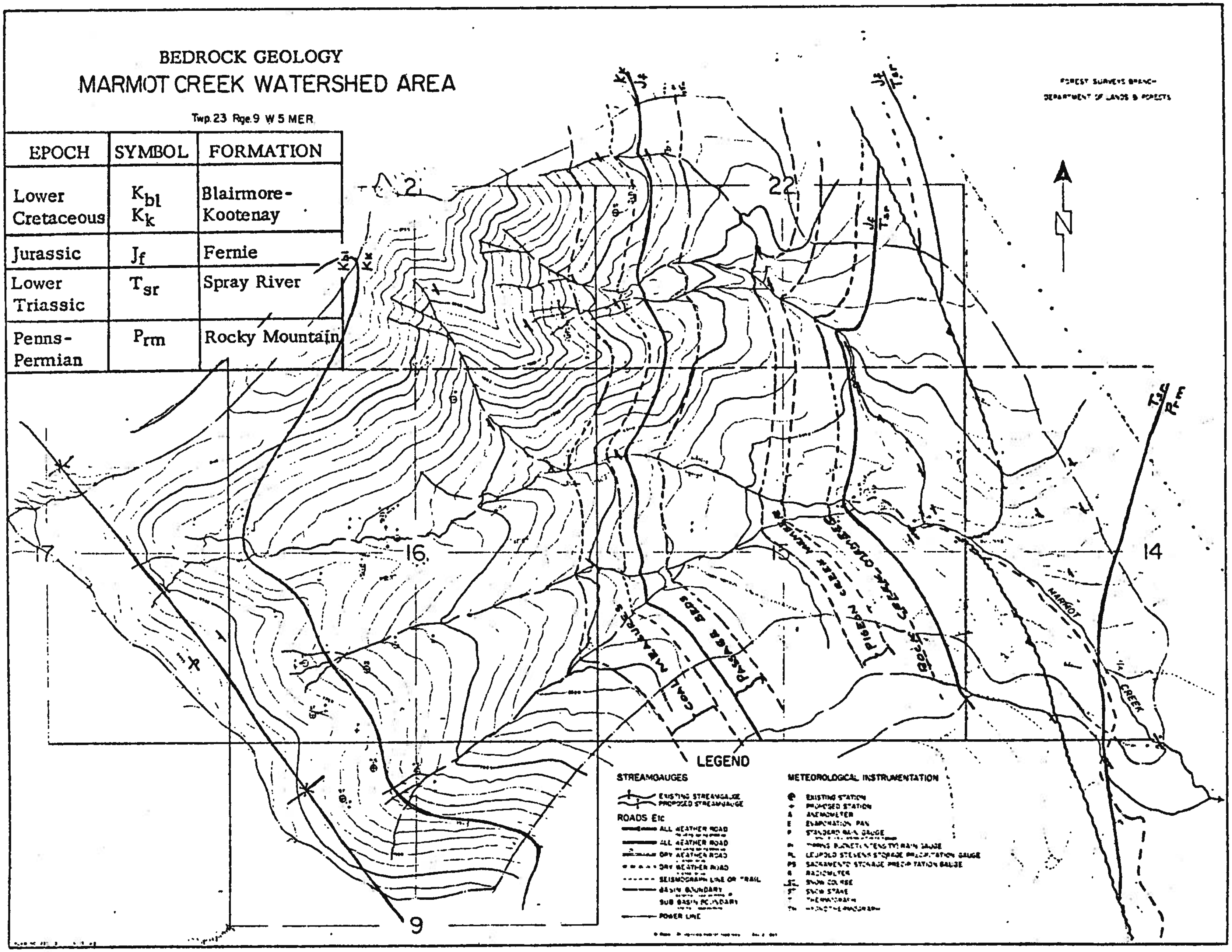

MARMOT CREEK WATERSHED AREA
Twp.23 Rge.9 W 5 MER
UNCONSOLIDATED SURFICIAL DEPOSITS
FOREST SURVEYS BRANCH
DEPARTMENT OF LANDS & FORESTS
Till
30-40 ft.
20-30 ft.
0-20 ft.
Glacial Moraine and
Ablation Deposits
40-115 ft.
Test Hole
N
21
22
17
16
15
14
9
LEGEND
STREAMGAUGES
EXISTING STREAMGAUGE
PROPOSED STREAMGAUGE
ROADS Etc
ALL WEATHER ROAD
DRY WEATHER ROAD
SEISMOGRAPH LINE OR TRAIL
BASIN BOUNDARY
SUB BASIN BOUNDARY
POWER LINE
METEOROLOGICAL INSTRUMENTATION
EXISTING STATION
PROPOSED STATION
ANEMOMETER
EVAPORATION PAN
STANDARD RAIN GAUGE
SACRAMENTO STORAGE PRECIPITATION GAUGE
SNOW COURSE
SNOW STAKE

## BEDROCK GEOLOGY

# MARMOT CREEK WATERSHED AREA

Twp. 23 Rge. 9 W 5 MER

| EPOCH | SYMBOL | FORMATION |
|---|---|---|
| Lower Cretaceous | $K_{bl}$<br>$K_k$ | Blairmore-<br>Kootenay |
| Jurassic | $J_f$ | Fernie |
| Lower Triassic | $T_{sr}$ | Spray River |
| Penns-Permian | $P_{rm}$ | Rocky Mountain |



# PROGRESS OF GROUNDWATER STUDY IN THE MARMOT CREEK BASIN

The purpose of this report is to briefly outline the activities of the Groundwater Division, Research Council of Alberta, in the Marmot Creek Basin in 1964, and to generally illustrate the future instrumentation required to enable basic groundwater data to be collected.

## Geology

The first part of the 1964 field season, July and August, was spent in the Marmot Creek area where the writer became familiar with the Mesozoic and Recent deposits. With the aid of aerial photographs a geologic map was constructed.

The general surficial and bedrock geology as shown on the overlays (in envelope) differs little from previous reports (R. Green & J. F. Jones, 1961) and (M. B. B. Crockford, 1949).

A joint analysis, being considered by the writer, may verify the rotational movement in the faulted Spray River Formation.

A more complete picture of the surficial geology is largely dependent upon drilling results as the large percentage of boulders in the glacial drift makes hand-augering futile.

## Groundwater Hydrology

The latter part of the 1964 field season was spent installing and instrumenting a number of water-table wells and piezometers. These locations are shown on part of a large scale (1 in. = 500 feet) topographic map included in the envelope. The 1964 drilling program was technically successful as well as supplying some of the information required to reasonably assess the cost of the necessary basic instrumentation.

Seven water-table wells and 4 piezometers were installed in the lower part of the Confluence Area'. Leopold-Stevens type FM recorders have been installed on on the seven water-table wells. The water levels in the piezometers are being measured twice weekly as were the water-table wells before the recorders were installed; a copy of these measurements is attached.

It is felt that this initial control supported by the future proposed instrumentation will supply the basic data required to assess the groundwater-flow systems in the lower part of the basin, and to ascertain whether or not the Main Weir is measuring the "total flow" of the Marmot Creek Basin.

A network of groundwater instrumentation should be located within the primary research areas of the sub-basins (see base map "A") to enable the primary objectives of the projects to be fulfilled. There is at present only minor access into these "sub-basin" areas. At present various drilling methods are being investigated that require varying amounts of site clearing, road construction, etc. Nevertheless it is felt that the access limitations pose a real threat to the emplacement of the necessary groundwater instrumentation as a part of the essential development of the Marmot Creek project. It is hoped that this problem may be sufficiently resolved to allow some groundwater instrumentation to be installed in the sub-basin areas in the 1965 field season.

## HYDROGEOLOGY OF MARMOT CREEK AND STREETER BASINS

Page

# HYDROGEOLOGY OF MARMOT CREEK AND STREETER BASINS, ALBERTA, CANADA

## Abstract

## Introduction

### General Statement

Watershed research in the Saskatchewan River headwaters began in 1960 under the East Slopes (Alberta) Watershed Research Program with the objectives of evaluating and improving land management for increased water yield (Jeffries, 1965). This program includes a study of the hydrology of different forest-cover types within small, gauged basins and the effects of their cover manipulation upon water yield, regime, and quality.

Marmot Creek basin (Fig. 1), established in 1962, is situated in a mountain environment under a forest cover of spruce and fir, and Streeter basin, established in 1963, is situated in foothills environment under a forest cover of Aspen. The third Experimental Basin of the East Slopes program, Deer Creek Basin, was established in 1966; however active research in this basin has been suspended. Topographic and geologic conditions in Deer Creek Basin are similar to those of Streeter Basin and concepts concerning the hydrodynamics of their groundwater flow systems are common. For these reasons the hydrogeology of Deer Creek Basin will not be considered separately in this report; however examples will be used and references made to the hydrogeology of Deer Creek Basin in the Introductory Section.

The inventory, instrumentation and calibration phases of each basin are being carried out with the cooperation of several provincial and federal government agencies. The Groundwater Division of the Research Council of Alberta has conducted hydrogeological investigations within these experimental basins from 1964 to 1969. These investigations form the body of this report.

## Objectives

The hydrogeological phase of the program includes three objectives:

1. To investigate the hydrogeology of each basin, including:
   i) investigation of flow-region geometries;
   ii) evaluation of hydraulic conductivity values by existing methods; and
   iii) definition of functional relations among groundwater-discharge phenomena and geologic and topographic conditions.
2. To prepare a groundwater balance and estimate its significance within the hydrologic balance of each basin. (This objective was not realized for reasons stated in the summary.)
3. To evaluate changes in groundwater regime resulting from forest-cover manipulation. (This objective is not considered in this report as no alterations of forest cover have been made.)

Secondary objectives of the Research Council include the definition of particular groundwater problems in high-relief areas, and a description of research needs to solve those problems.

## Methods of Investigation

Hydrogeological reconnaissance was carried out to observe and describe the nature of groundwater discharge and the associated hydrogeologic environment.*

*Conceptual treatments of the "hydrogeological environment" and the groundwater regime are given in the recent publication of J. Tóth (1970). The hydrogeological environment of an area is described by its topographical characteristics, by the nature of its geology, and by the local climatic conditions.

These observations include: spring-discharge rates; the visual nature of the permeabilities of exposed rocks; groundwater temperature and specific conductance; the local, physical characteristics of the land surface, such as slope, elevation and aspect; and nature of the associated vegetation. Aerial photographs were used to delimit areas of groundwater recharge and discharge, where possible. This was accomplished indirectly by outlining plant types associated with these phenomena. Water-table observation wells and piezometers were installed in different topographic settings to observe the elevations of their water levels, and the changes in those elevations with respect to climatic events and time. Hydraulic tests were conducted to evaluate relative hydraulic conductivities of the saturated media.

In summary, the field investigations were orientated to determine the geometry of the groundwater flow systems, the subsurface configuration of permeability and the physical relations between boundaries of the flow systems and the hydrogeologic environment. Two-dimensional electric analogs based on hypothetical concepts were constructed, to represent cross sections through the groundwater basins. These analogs are considered qualitatively correct where field observations and water-level measurements support their validity.

Basic hydrologic data provided by respective cooperating government agencies listed in the following paragraphs were used in considering the amount of water available for recharge.

Acknowledgments

Data on precipitation, evapotranspiration, snow accumulation and melt, were provided by The Meteorological Branch of the Canada Department of Transport. Data on stream discharge and discharge from gauged springs were provided by Water

Survey of Canada, Inland Waters Branch, Canada Department of Energy, Mines and Resources. Soil moisture and soil temperature data were supplied by the Canada Forest Service, Canadian Department of Fisheries and Forestry. Soil descriptions of the three basins were obtained from a Ph.D. thesis manuscript of Dr. J. Beke, Research Officer, Lands Classification and Soils, Canada Department of Fisheries and Forestry. Water-quality data were provided by the Water Quality Division, Inland Waters Branch, Canada Department of Energy, Mines and Resources. Forest cover types were mapped by the Forest Research Branch, Canada Department of Fisheries and Forestry. Several other provincial and federal government agencies have contributed in the fields of basin inventory or services to the development of the projects.

Water-table observation wells and piezometers were installed by Sedco Drilling, Edmonton; by the Water Resources Division, Alberta Department of Agriculture; by Forrester Water Well Drilling Ltd., Red Deer; and by Lousana Water Wells, Lousana.

Mr. D. Currie, Mr. D. Norton, Mr. D. Withers, and Mr. J. Beima assisted the writer during the drilling programs; Mr. N. Zacharko provided assistance during the hydrogeological reconnaissance. Mr. H. Weiss and ____________ drafted the figures and maps, and Miss D. Cunliffe typed the report.

Fifty per cent of salaries of watershed research staff was funded by the ARDA program of the Canada Department of Agriculture.

Acknowledgment is expressed to my associates in the Groundwater Division of the Research Council for their inspiring discussions which contributed to the development of this report.

## Basic Concepts

### Definitions

Definitions of the hydrogeological terms used in this paper may be found in Meinzer (1923), Hubbert (1940), Tóth (1962a, 1962b, and 1970), and in Freeze and Witherspoon (1966, 1967). Geological terms used are defined in standard geological texts.

### Hydraulic Potential, Hydraulic Head, and Maximum Hydraulic Gradient

Hubbert has shown (op.cit., p. 824) that "fluid potential" may be expressed in terms of its gravity and pressure components:

(1) $$\phi = gz + \int_{p_o}^{p} \frac{dp}{\rho} .$$

Where the fluid-potential field refers to a relatively shallow groundwater-flow region, the density "$\rho$" does not change with pressure, and equation (1) becomes:

(2) $$\phi = gz + \frac{p - p_o}{\rho}$$

where $\phi$ = hydraulic potential at any point "p" in the flow region;
$g$ = acceleration due to gravity;
$z$ = elevation of point "P" above a horizontal standard datum*;
$p$ = pressure at point P;
$p_o$ = prevailing atmospheric pressure;
$\rho$ = density of the groundwater.

On the upper boundary of the saturated flow region (water table), $p = p_o$ and equation (2) reduces to:

(3) $$\phi = gz.$$

The pressure at any point in the flow region, expressed in terms of its components, is:

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*In this paper the horizontal standard datum refers to mean sea level.

(4) $p = p_o + \rho g(h-z)$ where "h", known as the hydraulic head, is the elevation of the water level above a horizontal standard datum in a piezometer placed at that point.

Substituting for "p" (from equation (4) into equation (2))gives:

$\phi = (\rho gz + p_o + \rho gh - \rho gz - p_o)/\rho$ , or

(5) $\phi = gh$, which expresses the potential energy of a unit mass of groundwater in a conservative field of flow as a function of its elevation, or hydraulic head. Along the upper boundary of the flow region $h = z$.

Maximum Loss of Hydraulic Head Over the Length of the Flow Path

In a continuous region of groundwater flow, the loss of hydraulic head along a flow path from the upper boundary of the flow region (water table) to the point of measurement is the difference in elevation between the point on the water table where the flow originates and the water level in a piez meter placed at the point c. measurement. From figure 2, the maximum value of hydraulic head along flow path "n" is $h_n$, and occurs at the point on the water table where the flow path originates. At this point the hydraulic potential "$\phi_n$" = $gh_n$. At point "P", the value of hydraulic head is "$h_m$" and the value of hydraulic potential "$\phi_m$" = "$gh_m$". The loss of hydraulic head along flow path "n" from the water table to point P is "$(h_n - h_m)$". The distance along the flow path from the water table to point P is "l", and the average loss of hydraulic head with distance, or the average gradient of hydraulic head, along the flow path is equal to "$(h_n - h_m)/l$". This average gradient is a maximum where l is a minimum, which occurs where angle $\alpha = 0$, and $l = h_n - h_m$. Therefore, the maximum average gradient of hydraulic head between the water table and point P is $\frac{h_n - h_m}{h_n - h_m}$ = unity.

Thus, in a continuous region of groundwater flow, the maximum average gradient of hydraulic head along a flow path between the water table and any point "P" on the flow path is unity (i.e. one foot per foot). The corollary is that where the measured average gradient of hydraulic head between the water table and any point "P" on the flow path is greater than unity, the flow region is discontinuous, and the water table is perched with respect to point P.

In the recharge areas of a groundwater flow region where flow lines are vertically downward (Hubbert, op. cit., p. 930), the length of a flow path from the water table to the open lower end of a contained piezometer is approximately equal to the depth* of the piezometer below the water table. The loss of hydraulic head along the flow path is approximately equal to the difference in elevation between the water table and the water level in the piezometer. The average gradient of hydraulic head over the length of flow is approximately equal to the depth of water in the piezometer minus the depth of the water table divided by length of the piezometer below the water table.

Where two piezometers are completed at different depths in this environment (Fig. 2), the average gradient of hydraulic head along the flow path between the open lower ends of the piezometers is approximately equal to the difference in the depths to water in the piezometers, divided by the difference in piezometer depths. Where this average gradient approaches or is greater than unity, the flow region between the two piezometers may be discontinuous, or the flow region containing the upper piezometer may be perched with respect to the flow region containing the lower piezometer. A piezometer located in the unsaturated zone separating the perched water from the underlying groundwater would be dry.

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*Depths are measured from the land surface.

## Natural Gradients of Hydraulic Head in Recharge Areas, and Perched Regions of Groundwater Flow

Piezometer nest E4888 RCA and MR 5420 RCA are located on ridge tops in Streeter Basin and Deer Creek Basin, respectively. These piezometers are assumed to be located in the recharge areas of the underlying groundwater flow regions where the major component of direction of the groundwater-flow vector is vertically downward. Average hydraulic gradients were calculated for those parts of the flow region between the water table and the piezometers and used as indicators of their hydraulic condition (Table 1). Average hydraulic gradients were calculated from water level measurements taken on December 14, 1970, and June 1, 1968, during intervals when water levels were near the bottom of their annual recessions.

Piezometer $P_4$ of piezometer nest E4888 RCA and $P_3$ and $P_4$ of piezometer nest MR5420 RCA are dry throughout the year, whereas $P_6$ of piezometer nest E4888 RCA is dry for part of the year (Figs. 5 and 6). These piezometers have been filled with water which drains readily through their open lower ends, and are considered to be functioning properly. The saturated groundwater zones above them are considered to be perched. The average gradient of hydraulic head between piezometers WT and $P_2$ of MR5420 = .83 (Table 1). It is suggested that should $P_3$ and $P_4$ not be present this high value for the average hydraulic gradient between $P_2$ and $P_5$ could be interpreted as being indicative of perched groundwater conditions. Perched water conditions are also indicated by the high values of the average hydraulic gradients between WT and $P_6$, and $P_2$ and $P_1$, of E4888 RCA, and between $P_2$ and $P_1$ of MR5420 RCA. The negative average hydraulic gradient between piezometers $P_5$ and $P_3$ of E4888 RCA indicates that the zone containing $P_3$ is confined and is recharged outside of the flow system containing $P_5$. Hence, the suggestion is made that where the direction of groundwater flow can reasonably be assumed to be vertical, or nearly so, values of the average hydraulic gradients between piezometers completed at different depths can be used as indicators of the hydraulic conditions between them.

## Nature of Permeabilities and Hydraulic Tests

### Unconsolidated Deposits

Unconsolidated deposits in the Experimental Basins comprise mainly those materials deposited by mass movement, glaciers, and glacial meltwaters.

On ridge tops unconsolidated deposits consist, for the most part, of weathered bedrock covered in places by a thin mantle of till (see maps 1 and 2). These deposits are largely unsaturated most of the year, and generally have infiltration capacities exceeding precipitation rates (Beke, 1969).

A great variety of unconsolidated deposits are present on the valley sides. In Marmot Creek Basin these deposits include scree and talus, thick cumulative soils (Beke, op. cit.), thick lateral and recessional moraines and tills that thicken downvalley (Stevenson, 1967). Scree and talus are generally unsaturated but have very high infiltration capacities. The thick cumulative soils, moraines, and tills are generally saturated or partly so, and contain considerable volumes of water in storage. However, their hydraulic conductivities are generally low. Wells completed in these materials and pumped at 2 1/2 gallons per minute pumped dry in less than 15 minutes. In Streeter Basin, unconsolidated deposits on valley sides are relatively thin and unsaturated for much of the year, except for the small percentage of these materials that are located downslope from springs.

Along valley bottoms unconsolidated materials consist of rock fragments and lag boulders, buried in places by mud flows; alluvium, present beneath till deposits and lake clays, and at the surface; and moraine terraces that consist mainly of dirty gravels. Rock fragments and lag deposits have large, open pore spaces and the streams that flow over and through them disappear in places beneath their stream beds. These deposits as well as alluvium at the surface are confined within the stream channel and are not considered part of the groundwater reservoir. Alluvium buried beneath till or clay deposits in the valley bottoms have relatively high permeabilities (the hydraulic conductivity of similar materials, pump tested in Cache Percotte Basin, is 55 igpd/ft$^2$, calculated according to standard well-hydraulics methods (Jacob, 1950)). Buried alluvial deposits are present in Marmot Creek Basin but in relatively small amounts and not in the vicinity of the main stream discharge station, and therefore do not contribute to underflow, or unmeasured runoff from the basin. In Streeter Basin, the buried alluvial deposits are dry (see Streeter Basin section), and as a result act as a subsurface drain for the overlying perched stream-connected groundwater-flow system. Underflow through this buried alluvium is considered in the Streeter Basin section.

Moraine terraces are present only in the confluence area of Marmot Creek Basin. The hydraulic conductivity of this material (calculated from an analysis of pump-test data) is two igpd/ft$^2$. This material represents a very small percentage of the volume of unconsolidated material in Marmot Creek Basin and therefore is not considered as a significant part of the groundwater reservoir.

In summary, unconsolidated deposits are present on ridge tops, on valley sides, and along valley bottoms. Generally on ridge tops these deposits are unsaturated; along valley bottoms they are either unsaturated or, where saturated, they represent a small percentage of groundwater storage in the basins. On the valley sides of Marmot Creek Basin unconsolidated deposits are thick, saturated or partly so, and contain considerable volumes of groundwater in storage. Due to the very steep slopes a considerable portion of the total groundwater flow may take place within them. In Streeter Basin unconsolidated deposits on valley slopes are thin and unsaturated for much of the year.

Bedrock

All of the rocks observed in outcrop in the Experimental Basins contain two or three joint sets orientated approximately at right angles to bedding planes. Fractures in the plane of the bedding are generally present. The joints and fractures in shales appear in outcrop to be relatively dense (five to ten centimeters apart ) but continuous over only a few centimeters, whereas the joints in more resistant sandstones and siltstones are repeated over one half to one meter intervals, or greater, and are continuous over the depth of the rock unit. Openings along the joints in shales appear in outcrop to be very fine, and where groundwater discharge is present its seepy form indicates a low hydraulic conductivity. Openings up to several millometers were measured along the joints in outcrops of siltstones and sandstones. Almost all of the springs located above the valley bottoms discharge from the joints or bedding-plane fractures of siltstones and sandstones or coal seams (which are jointed similar to siltstones or sandstones).

Most of the siltstones and sandstones contain one set of near-vertical joints which are more consistent and much better developed than the other joint sets. The intersections of the well-developed joint set with bedding-plane fractures creates an anisotropic condition where the hydraulic conductivity parallel to the bedding planes in the direction of the primary joint set is potentially much greater than the hydraulic conductivity normal to the primary joint set. The associated permeability coefficient is a second order symmetric tensor, termed the "permeability tensor" (Irmay, 1951, p. 178), and has the shape of an ellipsoid. Snow (1969, p. 1288) states, on the basis of model studies of idealized systems of planar conduits, that the anisotropic permeability ellipsoid of two orthogonal sets of intersecting joints having equal properties has the shape of a prolate spheroid (assuming the fractures have uniform properties in space). Snow (op. cit.) also states, based on similar assumptions, that three orthogonal sets are statistically isotropic. This statement leads to the suggestion that the more intensely fractured shales might be considered isotropic, in which the coefficient of permeability would be a scalar.

Other types of fractures present in the Experimental Basins are "thrust" faults and "gravity" faults. Thrust faults are rock fractures which result from compression of the hanging walls of the faults against the footwalls of the faults causing the hanging walls to move up the footwalls. This compression and subsequent movement produces a "gouge" (Billings, 1954, p. 150), or fine, flow-like material having the hydraulic properties of clay. These types of faults are generally spatially large in contrast to joints, although relatively few in number, and have the hydraulic effects of barrier boundaries. Block faults are rock fractures produced by tension; subsequent movement along the fault produces open spaces along the fracture surfaces. These types of fractures are spatially large in contrast to joints, although relatively few in number, and have the hydraulic effects of line sinks or line sources depending on the potential gradient along their faces.

Most rock units in the Experimental Basins are cemented with argillaceous, carbonate, or siliceous materials or have high bentonitic contents, and as a result their intergranular permeabilities are low or nonexistent (Stevenson, op. cit.).

Intergranular permeability values were obtained from laboratory tests of the sandstones, siltstones, and shales of cores taken from Cache Percotte Basin, geologically representative of the foothills environment. These permeability values range from $.8 \times 10^{-14}$ $cm^2$ ($.8 \times 10^{-3}$ md) for shale, to $.17 \times 10^{-11}$ $cm^2$ (.17 md) for fine sandstone (Table 2), and approximate those values given by Davis and DeWiest (1966, p. 164) as representative of the intergranular permeabilities of tight sandstones and shales. Thus intergranular permeabilities of the rock units in the Experimental Basins are considered negligible with respect to their fracture permeabilities.

Analyses of bail tests and short pump tests carried out in the Experimental Basins yield values of hydraulic conductivities that range from $5.67 \times 10^{-6}$ cm/sec to $5.67 \times 10^{-4}$ cm/sec (.1 to 10 igpd/$ft^2$). These values are in close agreement with those derived from long-term pump tests in a foothills environment (D.V. Currie*, personal communication).

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## Groundwater Flow System Geometry and Hydraulics

Groundwater flow occurs in both the unconsolidated deposits and the bedrock underlying the Experimental Basins. In Streeter Basin groundwater movement within surficial materials is confined to the valley bottoms, whereas in Marmot Creek Basin considerable amounts of the annual groundwater turnover takes place within surficial materials. Because of these dissimiliar conditions the groundwater regimes of the surficial deposits of each basin will be considered separately in respective sections.

Rocks underlying the Experimental Basins comprise, for the most part, stratified, indurated, structurally disturbed siltstones, sandstones and shales, interbedded, in part, with coal seams. Hydraulic conductivity values, calculated for these strata, range over four orders of magnitude. Fractured siltstones and sandstones generally have the greatest hydraulic conductivities; from these more massive rock units most of the springs discharge. The more finely fractured shales have lower hydraulic conductivities; groundwater discharge from shales is generally in the form of seepage. Permeability distributions within these stratified rocks is therefore assumed to be stratified normal to the bedding planes; the lowermost boundaries of the contained groundwater-flow systems are assumed formed by the contacts between rock units having large permeability contrasts (Stevenson, in preparation).

In Streeter and Deer Creek Basins most of the groundwater occurs in bedrock units where shallow-dipping, highly permeable, fractured sandstones underlie saturated claystones and shales. Where the lower ends of these sandstone beds are open along the valley flanks they are rapidly dewatered (Stevenson, op. cit.). Springflows discharging from these beds vary over three orders of magnitude (Fig. 8) and frequently stop flowing during late summer. Piezometers installed in these permeable rock units are dry (Fig. 3), indicating that overlying saturated zones are perched. The relatively permeable zones are recharged mainly along valley sides on the updip side of the ridge, and to a lesser degree by leakage from overlying less permeable zones (see Streeter Basin section). The base of the overlying saturated zone is a plane of discharge. Where the lower ends of the permeable rock units are closed they may not become dewatered unless leakage across their discharge faces exceeds recharge to them.

In Marmot Creek Basin the lower ends of relatively permeable rock units are assumed closed as they dip back under the Basin where they turn upward to form the overturned syncline forming Mount Allan (see cross section in Marmot Creek section of this report). Discharge from these relatively permeable beds is in the form of contact springs along their upper edges at the valley sides, and to underlying rock units. These springs began many of the small tributary streams in the upper parts of the basin (Maps 1 and 2). Some leakage through the bedrock may occur down the plunge slope of the syncline into Ribbon Creek. It is hypothesized that where the lower ends of dipping permeable beds are closed, the closing mechanism forms a barrier boundary (it may have some permeability); this type of lateral boundary is stable. The lateral boundary of no-flow, formed by the flow line dividing groundwater moving in opposite directions within the permeable beds, may migrate up the dip slope and disappear as discharge ceases at the upper edges (springs dry up). This type of lateral boundary is very unstable, and its transient nature results in large changes in flow-system geometry. This type of flow system would be difficult to represent by a steady-state analog.

Upper boundaries of perched and underlying groundwater flow systems are formed by their water tables. Where flow systems are shallow and have shallow-dipping basal boundaries (see Streeter Basin cross section), water table fluctuation of a few feet may cause the lateral boundary, or the upper lateral edge of the saturated zone, to migrate many feet. This hypothesis is supported by the large fluctuation in spring discharge measured over the year. Phreatic divides on the upper boundaries of groundwater flow systems lying within permeable shallow-dipping rock units may be located very near the contact between the up-dip edges of these rock units and the valley side, and have no relationship to topographic divides. Where large increases in recharge (spring snowmelt) cause unsaturated zones to become saturated and perched flow systems to become temporarily hydraulically continuous with underlying regional flow systems, the upper boundary of the regional flow system may migrate several hundred feet in the vertical direction over the year. These large fluctuations of the upper boundaries of regional flow systems may contribute significantly to the large ranges in baseflows that occur in major streams.

In summary, groundwater flow systems in high-relief, structurally-disturbed areas tend to be perched part or all of the year. Basal boundaries are formed by surfaces of intersection between two rock units of different hydraulic characteristics. Lateral boundaries are transient in nature resulting in large changes in flow system geometries and associated groundwater discharges. Phreatic divides may be temporary and unrelated to topographic divides. Upper boundaries of regional flow systems may vary in elevation by amounts equal to the local relief, which condition may be the main cause of the high range of baseflows in major streams.

## Natural Groundwater Discharge

### Classification of Discharge

A Russian worker (Chernaya, 1964, p. 455) has identified two types of groundwater discharge within river basins (in reference to the underground feeding of rivers) that are relevant to groundwater discharge in the Experimental Basins. Descending groundwater-discharge (termed "descending type" by Chernaya) is defined as groundwater that reaches the stream after discharging at some higher elevation, whereas ascending groundwater-discharge (termed "backwater type" by Chernaya) discharges into the stream area below the water line of the stream from a flow system hydraulically connected with the stream. In the former case, discharge may result from induced flow into relatively permeable, interlensed strata which extend to the ground surface (Clissold, 1967, p. 7) or, be generated by a sudden decrease in the land slope (Stevenson, op. cit., p. 25). Neither of these conditions requires the flow system to be disconnected from the stream. Descending groundwater discharge may be from a perched groundwater system, where its basal boundary lies above the level of the stream area (see Streeter Basin cross section).

### Descending Groundwater-Discharge Phenomena

Generally, most natural groundwater discharge phenomena observed above valley bottoms of tributary basins in the Experimental Basins are of the descending type (Fig. 9).

1. Springs: Spring flows of the descending type originate from springs located above the valley floors. These springs are generally known as "Contact Springs"*, and appear to discharge laterally near the base of blocky to massive,

*A contact spring is a spring whose water flows to the surface from permeable material over the outcrop of less permeable material that retards or prevents the downward percolation of groundwater and thus deflects it to the surface (Meinzer, op. cit., p. 51).

vertically jointed sandstones, siltstones, and coal beds that crop out along the valley sides.

Discharge from these springs varies over three orders of magnitude during the year, ranging from less than a liter to nearly a kiloleter per minute. These springs are the starting points for tributary streams, which provide the major part of streamflow in small tributary basins for much of the year.

2. Seepage, mud flows, and earth flows: Descending groundwater discharge takes the form of seepage where lateral discharge occurs from minute pore spaces of argillaceous, silty tills which overlie bedrock or from minute fracture spaces of intensely fractured shale, exposed by road-cuts or earth flows, at rates in excess of evaporation. The increase in hydraulic gradients resulting from recharge during a period of steady rain causes an increase in pore pressure within the surficial materials overlying bedrock in groundwater-discharge areas. Where pore pressures increase until effective stresses (Rutledge, 1940, p. 180) are reduced to the point where the granular structure cannot resist the shearing forces set up by the weight of the material on the valley side, the material moves downvalley as mud flows or earth flows (Thornbury, 1956, p. 91), depending upon the slope of the valley side and the degree of water saturation. These processes of mass earth movement result in the formation of small amphitheatre-like bowls around springs or seepage areas on valley sides, which induces increased groundwater discharge. The bottoms of the bowls are formed from slowly moving, viscous mud flows, the surfaces of which are at a lower slope than surrounding valley flanks (Fig. 9). The steep arcuate-shaped sides of the bowls are developed as a result of the earth flows immediately above the points of concentrated groundwater discharge. Processes of mass erosion associ-

ated with groundwater discharge are accelerated where vegetation has been scarred or removed during road construction or logging.

3. Boggy areas, springy ground, and hummocky ground: Boggy areas, springy ground, and hummocky ground are all found within local depressions in descending groundwater discharge areas, and owe their presence to the relatively low permeability of underlying materials. In the Deer Creek Basin, for example, springflow enters one side of a depression, where it is partly evaporated and transpired; the remainder flows out on the other side of the depression as groundwater flow or streamflow. Much of the depression is infilled with peat and organic soils; some open water is present. Around the perimeter of the open water, peat moss and organic soil-cover is buoyant and springy to walking action; this feature appears similar to the "quick ground" phenomenon found in "ascending" groundwater-discharge areas, and described by Clissold (op. cit., p. 54). Hummocky ground is present around the perimeter of the boggy areas, and is attributed to the combination of the compaction of the soft, moist, organic peaty soils by animals, and the clump-like growth of mosses, sedges, and other vegetation. This condition is also present in the Cache Percotte Basin where partly closed depressions are common.

4. Groundwater quality and mineral deposits: Springflows in the Alberta foothills are generally low in total dissolved solids (from 100 to 400 gm/k liter), and have calcium carbonate-bicarbonate as the principal mineral constituents. However, where groundwaters have a particularly large quantity of a mineral in solution, this mineral will precipitate immediately upon discharge of the groundwater. Evidence of this phenomenon is present in Deer Creek Basin where cobbles and rock fragments in the stream bed adjacent to the spring are covered with lime, similar to

that formed on the inside of a tea kettle. Calcium carbonate precipitate from spring waters also takes the form of tufa, developed within the plant structure of club mosses, which grow in thick, velvet-green carpets around springs and seepage areas. The total dissolved solids in groundwater found in boggy areas maintained by groundwater discharge are generally between 200 and 400 gms/k liter.

5. Plant indicators: Trees are the most useful indicators of permanent, excessive soil moisture conditions, as they can be identified on aerial photographs. In areas of descending groundwater discharge, phreatophytic-plant types occur in strips along the valley sides and as "halos" around points of concentrated groundwater discharge. Plants described in the following paragraphs are generally found within evergreen-forest areas, such as Marmot Creek Basin, however some of them are also found in "Aspen-grassland" areas, such as Streeter Creek Basin.

Boundaries separating recharge areas and groundwater discharge areas on valley sides are sharply defined (their upper boundaries are subparallel to the contour line of the slope, or to contacts between rock units that have markedly different hydraulic properties). This condition results in abrupt changes in soil moisture and associated plant types.

Plant associations that characterize these areas of groundwater discharge are:

a) Tree types:
Black Poplar (Populus trichocarpa)
White spruce (Picea glauca)
Water birch (Betula occidentalis)
Willows (Salix spp.)

b) Shrubs:
Swamp birch (Betula pumila var. glandulifora)
Willows (Salix spp.)
Wild gooseberry (Ribes hirtellum)

c) Forbs:
Cow parsnip (Heracleum laratum)
Delphinium (tall larkspur) (Delphinium menziei spp.)
Baneberry (Actaea rubra)
Heart-leafed arnica (Arnica cordifolia)

d) Grasses and sedges, and mosses:

Timothy (Phleum spp.)
Sedge (Carex spp.)
Equisetum (Equisetum spp.)
Club moss (Lycopodium spp.)

Plant associations that characterize boggy areas are described as follows:

a) Tree types are small white spruce at high altitudes, and black spruce (Picea mariana), black poplar and willow at lower altitudes.

b) Shrubs are swamp birch and willows.

c) Forbs are mainly bog orchids, ele; hant head (Pedicularis groenlandica), and wintergreen (Pyrola spp.).

d) Marsh grasses, sedges and horsetail are present along with a very thick cover of club mosses.

## Ascending Groundwater Discharge Phenomena

In ascending groundwater discharge, groundwater is forced upward into the stream by the lower lateral boundary of the flow system, which extends from the basal boundary (at a lower elevation than the stream) to the stream surface. This lower lateral boundary may be a boundary of "no-flow" formed by another discharging flow system, as shown by Hubbert (op. cit., p. 930), or it may be a relatively impermeable rock unit, such as would result from fault displacement.

Where ascending groundwater reaches the surface through permeable conduits such as fractures or sand lenses, springs are developed. The spring flow discharges into the bottom of a pothole formed in the surficial materials and runs off over the land surface.

Where surficial materials overlying permeable conduits are silty in nature and have low hydraulic conductivities, the high specific volume discharge in the permeable conduits create high pore pressures in the surficial materials which may neutralize effective stresses (Rutledge, op. cit.) producing "quick ground" or "soap holes." This condition was described by Currie (1969, p. 68) to explain the formation of soap holes and quick ground in Tri Creek Basin, located in a similar environment. Similar conditions are present in Cache Percotte, Marmot Creek, and Deer Creek Basins (Fig. 10).

Where valley bottoms contain relatively permeable alluvial deposits or bedrock aquifers below the ground surface, ascending groundwater may not reach the land surface but may be drained away as underflow or in permeable subsurface aquifers.

In both ascending and descending groundwater discharge situations, the nature of the particular associated groundwater discharge phenomenon is a function of one or more of the following variables: volume-rate of groundwater discharge; nature of the permeability; groundwater quality; the texture, consolidation, and strength of lithologic materials; surface drainage; and slope, climate, and aspect.

Vegetation present in boggy areas resulting from ascending groundwater discharge are similar to those of the previously described boggy areas.

<u>Summary</u>

1. In a continuous groundwater flow region the maximum average gradient of hydraulic head along a flow path from the water table to any point on the flow path is unity.

2. Where two piezometers, located in a recharge area where flow paths are close to vertical, are completed at different depths, the average gradient of hydraulic head along the flow path between the open, lower ends of the piezometers is approximately equal to the difference in depths to water in the piezometers, divided by the

difference in piezometer depths. Where this average gradient approaches or is greater than one, the flow region between the two piezometers may be discontinuous, or the flow region containing the upper piezometer may be perched with respect to the flow region containing the lower piezometer.

3. Analyses of water-level data from recharge areas in the Alberta foothills indicate that perched regions of groundwater flow are present.

4. The permeabilities of rocks in the Alberta foothills are mainly due to the presence of fractures. Fracture intensity, continuity, and the size of fracture openings vary with the nature of the rock unit and depth of the rock unit below the ground surface.

5. Hydraulic conductivities vary indirectly with the type of rock unit, and directly with its position within the groundwater flow system. Hydraulic conductivities from bail test analyses ranged from $5.67 \times 10^{-6}$ to $8.5 \times 10^{-2}$ cm/sec (.1 to 1500 igpd/ft$^2$) according to standard methods of analyses. These values serve as indices of the relative permeability of the strata tested.

6. The geometry of groundwater-flow regions in the Experimental Basins is a function of the hydraulic properties of their underlying strata, their orientation in space, and the recharge to them. Perched groundwater-flow systems are present for all, or part of the year. These flow systems are shallow, and their transient boundaries result in large annual changes in flow-system geometries.

7. Groundwater discharge or springflow from perched groundwater-flow systems, ranges over three orders of magnitude, and streamflow, derived principally from groundwater discharge, likewise ranges over three orders of magnitude.

8. Groundwater discharge phenomena in areas of descending groundwater discharge (above valley bottoms) in the Alberta foothills include contact springs, seepages, mud flows, earth flows, slumps, boggy areas, hummocky ground, patches of phreatophytic plant types on valley sides, and mineral deposits around isolated springs.

9. Groundwater discharge phenomena in areas of ascending groundwater discharge (on valley bottoms) include pothole springs, soap holes, quick ground, hummocky ground; phreatophytic plant types are generally present over the entire area.

10. The nature of a particular groundwater discharge phenomenon is a function of one or more of the following variables: specific volume discharge; nature of the permeability; groundwater quality; the texture, consolidation, and strength of surficial materials; surface drainage; and slope, climate, and aspect.

11. Phreatophytic tree types and other groundwater discharge phenomena are recognizable on aerial photographs, and are useful in mapping areas of groundwater discharge.

12. To quantitatively assess the specific volume discharge from any groundwater-flow system the following physical conditions must be known:

(1) the shape and size of the flow-system geometry and its boundary values; the magnitude and rate of change of these boundaries in space,

(2) the nature, magnitude, and orientation of permeability tensors and their distribution within the flow system, and

(3) the magnitudes and directions of hydraulic gradient vectors.

In this report assumptions have been made regarding the nature of some of the listed flow-system parameters, and hypotheses given regarding their function;

however these relations are qualitative at best and values for water balance components based on the quantification of these relations would be misleading and serve no useful purpose. For these reasons no water balances were calculated for Streeter or Marmot Creek Basins.

## Recommendations

### Hydrogeological Problems and Research Needs in Areas of High Relief

The movement of groundwater within a continuous flow region is controlled by the geometry of the flow region, the boundary conditions, and the internal configuration of permeability. Hydrogeological problems, and research needs concerning these parameters are considered in the following paragraphs.

A. There is little quantitative information available concerning the geometry of groundwater flow systems in high relief areas. Analyses of water-level data from one piezometer nest in each of the Streeter and Deer Creek Basins indicate that perched groundwater-flow systems underlie ridge tops; however, to provide sufficient data to define the boundaries of these perched groundwater flow systems, and their transient nature, would require a network of piezometer nests extending to the base of the basin relief. The cost of such a network would be high and unjustified for every basin. For these reasons conceptual models, based on observations and data analyses, have been constructed for Marmot Creek and Streeter Basins, as representative of groundwater-flow systems in areas of high relief. However, the geometry of these flow regions, their boundary values and the changes in their position with time, and the relation between groundwater-flow system geometry and geologic conditions have been only assumed or inferred from field observations. Quantitative information is needed, concerning these geometric variables, so that their assumed characteristics can be verified and quantified.

B. Most areas of high relief in the Saskatchewan River headwaters lie within the structurally disturbed belt, in which the underlying strata have been uplifted, folded and faulted, and differentially fractured. The permeabilities of these strata are different in different directions and have the nature of second-order symmetric tensors. Overlying the weathered bedrock surface are unconsolidated glacial materials which consist of various mixtures of clay, silt, sand, and boulders, of medium to low intergranular permeability. Materials that underlie the floodplains of creeks and rivers consist of unconsolidated silt, sand and gravel. The unconsolidated materials are isotropic and homogeneous on a local scale; however, the entire unconsolidated unit may be considered anisotropic and inhomogeneous.

Homogeneous, isotropic medium have the following characteristics: the nature of the permeability is intergranular, the representative sample volume is relatively small, and the corresponding required time to measure permeability is relatively short. The isotropic permeability tensor is of zero order, requiring only a simple hydraulic test, modelled after homogeneous, isotropic conditions, to define its scalar value. However, stratified, fractured strata are anisotropic and inhomogeneous, the representative sample vaolumes are very large or nonexistent, and the corresponding time period needed to measure permeability is likely to be very long. In this case, the total permeability of the sample volume is the vector sum of the components of each permeability tensor resulting from each fracture system and from the intergranular permeability. The total permeability tensor may be ellipsoidal or irregular in shape. To obtain the shape and magnitude of the ellipsoid, the radius of the ellipsoid (scalar value of permeability) must be measured →

"in situ" along each principal axis. However, where the orientation of the ellipsoid is unknown, it is necessary to measure its radius in several directions. In this case true scalar values of permeability cannot be obtained by analyzing hydraulic test data by existing mathematical models based on assumptions of homogeneous, isotropic medium unless the size of the representative sample blocks are known and the time scale adjusted in proportion.

Future groundwater investigations must consider new methods of measuring fracture permeability "in situ" and of analyzing the results.

C. There is little quantitative information concerning the fluid potential or permeability distributions that result in discharge from springs. This information is essential to understand the water balance for such areas as Streeter Basin, where spring flow comprises the majority of streamflow.

# , HYDROGEOLOGY OF STREETER BASIN

# HYDROGEOLOGY OF STREETER BASIN

## Introduction

### General Statement

Streeter Basin was established to study the hydrology of montane-aspen forests and associated grasslands in the Southern Alberta foothills and to determine the hydrologic effects attendent upon converting the trees and shrubs to grassland.

### Location

Streeter Basin is located in the Porcupine Hills of southwestern Alberta at the latitude of 50°7' N and longitude of 114°3'W (Fig. 1). The research area covers an area of approximately 1.08 square miles in part of township 13, range 1, west of the 5th meridian, described according to the Alberta Land Survey System.

### Previous Work

The bedrock geology of the area including Streeter Basin was mapped in 1944 and 1945 at a map scale of one inch to one mile by the Geological Survey of Canada (Douglas, 1950).

### Present Work

The Groundwater Division, Research Council of Alberta, carried out a hydrogeological reconnaissance and groundwater-instrumentation program from 1965 through 1968. Since that time water-level data have been collected, analyzed, and evaluated. Piezometer levels in piezometers and water-table observation wells (installed in the autumn of 1968) have stabilized and are assumed to represent formation potentials. Short bail tests were conducted during drilling programs to obtain indices of hydraulic parameters of reservoir materials. Hydrogeological reconnaissance data and water-level data have been synthesized, and concepts and hypotheses formulated concerning the groundwater hydrology of Streeter Basin. These concepts and hypotheses are presented in following chapters.

## Physical Description

### Topography and Aspect

The area is relatively evenly divided into subparallel ridges and valleys. Trout Creek ridge, the highest topographic feature in the area (5,150 feet* on the east to 5,700 feet on the west side of the map area) strikes approximately east of north, parallel to and some 1,200 feet above the Willow Creek valley bottom, which is the lowest topographic feature in the area. Trout Creek ridge forms the headwaters and southern boundary of Streeter Basin. Smaller ridges extend northward from Trout Creek ridge toward Willow Creek, and form the lateral divides of the Streeter Basin and its sub-basins. The tops of these lateral ridges are 400 to 500 feet above the valley bottoms of the Streeter sub-basins. The average slope of valley walls is one in four, or approximately 15 degrees. Valley walls generally have a small-scale, step-like profile at their surfaces: scarp-faces of resistant sandstones form the risers of the steps, whereas less resistant shales form the tops or bottoms of the steps.

Generally, the north-trending ridges that form the lateral boundaries of the sub-basins of Streeter Basin have east and west aspects. However, these ridges are cut by a regular pattern of steep sub-parallel, erosional channels which results in approximately half of these valley sides having northerly or southerly aspects. The importance of aspect to groundwater recharge will be explained in a following section of the report.

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*All elevations in this report are above mean sea level.

## Vegetation

Eight vegetation communities have been recognized in Streeter Basin (A. Johnston, 1964). Generally the moist sites support stands of willow aspen or black poplar whereas the drier sites support grass cover. Douglas fir and limber pine occur on ridge tops. Small clumps of willows are present around springs, downslope from springs, and along the base of fractured blocky sandstones which crop out at the surface of the valley side. Better developed willow clumps are also present along the valley bottoms of the Streeter sub-basins where streams are permanent. Black poplar are restricted mainly to shallower slopes where there is a permanent supply of soil moisture, such as along the valley bottoms of permanent streams, and immediately downslope from permanent springs. Aspen is found in both dry and wet sites (well drained). These tree types can be distinguished on aerial photographs and are useful in delimiting areas of poss le groundwater discharge.

Generally fescue grasses are found over ridge tops and local topographic high areas, considered to be recharge areas, whereas timothy grasses, larkspur, cow parsnip and elephant head are found mainly over moist sites. Phreatophytic and mesophytic plant communities may also be used in delimiting areas where snow pack is retained in northern aspects until late spring.

## Soils

Soils of Streeter Basin have been mapped, described, and classified by J. Beke (op. cit.). The main soil types are Black and Dark Gray Chernozemic soils. Thin and eroded Chernozemic soils and Regosols (bedrock near surface) are present on ridge tops, whereas Deep and Cumulic Chernozemic soils are present over lower valley sides. Gleysolic soils have developed in permanently wet areas.

Mean infiltration rates are generally higher than maximum rainfall intensity (0.91 inches per hour, June 9, 1967).for all soils, whereas the Thick Cumulic Chernozems have the highest moisture capacities.

Geology

The bedrock underlying Streeter Basin comprise interbedded medium to very fine grained sandstones, siltstones, and shales with minor coal stringers (see lithologic log of Fig. 3). These rocks are part of the Porcupine Hills Formation of Tertiary age.

Only the more resistant siltstones and sandstones may be observed in outcrop along stream channels, on valley sides and ridge tops. Siltstones are regularly bedded, whereas sandstones range from thinly bedded strata to massive cross-bedded sandstone lenses. All strata appear in outcrop to be well jointed with one or two well-formed, near-vertical joint sets (Map 2), and prominent bedding plane partings. Reliable strike and dip measurement of these strata are made difficult because of the presence of the joints and cross beds, however a strike of N10°W and a dip of 2 1/2°NE were used as the average values across the area (the dip of the bedding planes shallow to the east).

Sandstone outcrops were located on the map and projections of their intersections with the ground surface were extended across the map surface. Comparisons of the locations of these projected sandstone-land surface contacts with the mapped locations of springs, phreatophytic and mesophytic vegetation types, etc., indicate that these sandstone beds, although cross bedded and lensey in nature, extend over considerable areas.

Sandstones and siltstones are generally cemented with argillaceous materials, slightly calcareous, and vary from being non-bentonitic to very bentonitic, and from soft to very hard.

Bedrock is generally covered by a thin mantle of sandy clay till, ranging in thickness from a few feet on the ridges to 30 to 40 feet in the valley bottoms — at the confluence of the sub-basins. From piezometer nests W4465 RCA on the west fork of Streeter Creek and M4495 RCA on the east fork of Streeter Creek, this sandy clay till is overlain by lacustrine clay (?) and clay till, which has a thickness of 45 feet at piezometer nest M4350 RCA.

## Surface Hydrology

### Precipitation

The average annual precipitation in Streeter Basin ranges from 20 inches along valley bottoms to greater than 24 inches over ridge tops (Singh, Storr, Davis and Stevenson, 1969, p. 6).

The isohyets parallel topographic contours, but are shifted eastward (Fig. 11), perhaps as a result of prevailing southwest winds. Approximately 65 per cent of the annual measured precipitation is rainfall; however these data corrected for undercatch of snowfall would change the measured snowfall-precipitation ratio to 50:50 (Singh, Storr, Davis, and Stevenson, op. cit., p. 6).

### Temperature and Humidity

Temperatures in Streeter Basin varied from two to four degrees fahrenheit between ridge tops and valley bottoms having east-west aspects; however temperature differences of 10°F have been measured between ridge tops and valley bottoms of adjacent basins where slopes have north and south aspects. Generally the maximum temperatures are lower and the minimum temperatures higher on ridge tops than in valley bottom.

Mean maximum relative humidity occurs in valley bottoms during early mornings during periods of minimum air temperature. However, there is little variation in humidity over the entire basin, and daily maximum and minimum relative humidities of 85 per cent and 40 per cent, respectively, are considered accurate anywhere in the basin, within the error of measurement.

Wind

The average wind speed over the basin is 12 mph with peak hourly values of 61 mph; higher wind speeds have been recorded during gusts. Generally wind speeds are considerably greater on ridge tops than in valley bottoms, and are greater during the winter months as a result of an increase in chinook winds.

Potential Evaporation and Transpiration

Evaporation from a class A pan was measured during the growing season at the confluence of East Streeter and Middle Streeter sub-basins. Analyses of four years of record show the average potential evaporation during the growing season is approximately 22.6 inches of water. This value serves as an index of evapotranspiration along stream channels and adjacent to springs where free water is at or near the ground surface over the growing season.

A considerable amount of water may be evaporated from the snow pack by chinook winds. This phenomenon is indicated by the absence or relatively small amounts of snow over bare ridges and valley slopes.

Willow and black poplar are present along the stream channel from the Streeter Creek Main Stem stream-discharge station upstream to East Streeter stream-discharge station. Davis (Singh, Storr, Davis, and Stevenson) obtained a value of .1 acre-feet per day for transpiration losses from Streeter Creek for a four-day period (July 22-26, 1967), calculated using Troxell's method (Troxell, 1936).

Upslope from the creek bottoms evapotranspiration is low because of the lack of available moisture; however where groundwater is discharged *

[illegible]

<u>Streamflow</u>

The streams of Streeter Basin have their beginning as a result of springs discharging into the upper reaches of their channels. These streams consist entirely of spring discharge throughout their length except for rainfall directly into their channels and runoff from spring snowmelt.

East Streeter Creek is an interrupted stream (Meinzer, op. cit., p. 58) in its upper reaches, and begins at springs "(4A)" and "(5A)" (see Map 1). Stream waters remain at the surface during periods of spring snowmelt and heavy rainfall; however as the discharge from springs (4A) and (5A) decrease, during summer dry periods, the streambed is dry a short distance downstream (Map 1). No underflow was observed through the shallow stream-bed materials (excavated by shovel), and hence it is assumed that this section of the stream is influent to underlying groundwater flow systems. For most of the year East Streeter Creek receives the major portion of its water from Spring "(3A)"; Springs "(1A)" and "(2A)" contribute lesser amounts. Spring (3A) is one of the larger, permanent springs observed in the area and its discharge results in the permanent condition of East Streeter Creek from spring (3A) downvalley.

Middle Streeter Creek is an interrupted stream throughout its length, particularly in the vicinity of its stream discharge station. Relatively small temporary springs discharge into the upper reaches of its channel; however this spring discharge does not remain at the surface for any distance downstream. Springs "(27A)" and an adjacent spring provide the major portion of the streamflow of Middle Streeter Creek. Discharge from these springs maintain streamflow during snowmelt and rainfall periods; however during dry periods of the year these stream waters likewise disappear into the fractured rocks over which they flow a short distance downstream. Likewise, spring "(30A)" maintains streamflow only a short distance downstream from its point of discharge.

Several major springs discharge near the valley bottom at the confluence of East Streeter and Middle Streeter Creeks and downstream to the confluence of West Streeter Creek. This part of the valley bottom is underlain by clay tills and clays (probably of glaciolacustrine origin). These clay materials have very low permeabilities (yielded $<1/2$ gpm during bail tests) and as a result the stream waters along their surface are maintained in a perched position (see Figs. 12 and 13).

West Streeter Creek, like Middle Streeter Creek, is interrupted and influent throughout its length. The major portion of streamflow is contributed by springs "(53A)", "(57A)" and "(58A)", although many smaller temporary springs are present on the upper slopes. Streamflow is measured throughout the year at the confluence of each sub-basin by means of an H-type flume with artificial controls adapted for winter operation.

Table 3 shows the average annual sub-basin streamflow yield, in inches, measured at the stream-discharge stations.

Table 3. Basin Annual Yield 1964-68

| Basin | Area ($m^2$) | Average Annual Streamflow | |
|---|---|---|---|
| | | inches | inches/sq mi |
| West Streeter Creek | 0.53 | 0.31 | .6 |
| Middle Streeter Creek | 0.35 | 2.11 | 6.0 |
| East Streeter Creek | 0.20 | 8.95 | 44.8 |
| Streeter Creek Main Stem | 2.30 | 3.00 | 1.3 |

The reason for the large disparity in streamflow per square mile of basin area is explained in the following section. Davis (Singh, Storr, Davis, and Stevenson, op. cit.) states that the average total runoff for the basin area is representative of the general area; however, it is below the long-term 1912-68 average of other streamflow stations in the area. The five-year average runoff is approximately 13 per cent of the average annual precipitation.

The clay till and clay which underlie Streeter Creek up to the East Streeter confluence area is present in the West Streeter Creek valley bottom up to and just past the upstream side of W4560 RCA. Most of the streamflow upstream from the clay till deposits is lost to influent seepage before it reaches the clay deposits. However, these clay tills hold perched water downstream near the confluence of Streeter Creek where spring (32A) drains downslope into them (Fig. 12).

## Underflow

Underlow is movement of water in an underflow conduit (Meinzer, op.cit. p. 44), and is generally measured in the vicinity of the stream discharge station. This underflow conduit refers to channel alluvium or buried alluvium on the bottom of the bedrock channel. In Streeter Basin boreholes for piezometer nests W4560 RCA, W4465 RCA, M4495RCA and M4350 RCA were drilled along the thalwegs of respective streams into bedrock materials. No sharply defined zones of gravel or sand were found at the bottom of the bedrock channels (see Appendix B); however, the till from 5 to 15 feet above bedrock appeared sandy and to consist of a large percentage of weathered rock fragments. The piezometers of the above piezometer nests set into this zone are dry for all or part of the year; this zone was also noted to absorb drilling water. This zone is considered relatively permeable with respect to the overlying clay tills. However, it is dry except during periods of spring runoff and during heavy summer rainfall. During these periods a considerable percentage of streamflow forms underflow in West Streeter Basin. Some idea of the relative amount of this underflow may be gained by making a calculation of underflow for the following assumed conditions:

1) the permeability of the sandy till and weathered bedrock to be equivalent to that of fine sand, and to have the value of 13.2 darcys (equivalent to 200 igpd/ft$^2$), (Davis and DeWeist, op.cit., p. 375);

2) the active zone (normal to the stream channel) is 10 feet deep and 50 feet wide which equals an area of 500 square feet;

3) the hydraulic gradient in the vicinity of W4560 RCA is equal to the channel gradient, or 10 feet/145 feet = .069 ft/ft. According to Darcy's law (Q = KIA), underflow = 200 igpd/ft$^2$ x .069 ft/ft x 500 ft$^2$ = 6900 imperial gallons per day (data from W4560 RCA, water table well); the average annual underflow would be 60 days x 6900 imperial gals/day = 414,000 imperial gallons per annum. This is equivalent to .25 inches of water for the drainage area of West Streeter sub-basin or .25/.31 x 100 = 80% as much as the average annual streamflow measured at the stream discharge station. This is an optimistic estimate of the underflow from West Streeter sub-basin; however, it does not explain the large disparity with respect

to the other sub-basins.

## Groundwater Hydrology

### Geometry, Hydraulics and Types of Groundwater Flow Systems

Cross section A-A' (Fig. 14) was drawn across the upper reaches of the Streeter sub-basins and extended into adjoining basins (Map 1). This cross section was drawn to approximately bisect the angles of intersection of near-vertical joint sets and to pass through major springs where discharge measurements are taken. The direction of the cross section is assumed to approximate the direction of the major axis of the isotropic permeability tensor (see previous section "Nature of Permeabilities and Hydraulic Tests").

Groundwater flow-system geometry is based on observations of geologic conditions in outcrop and in boreholes, on measurements of hydraulic conditions in boreholes and in groundwater discharge at the ground surface, and from functional relations assumed to exist among these parameters (discussed in section "Groundwater Flow Systems Geometry and Hydraulics"). The rapid fluctuations of water level in wells and discharge from springs in response to rainfall (Fig. 15) indicate that groundwater flow-system geometries also change rapidly. Therefore, the cross section A-A' may be valid for only a small part of the year.

From the cross section it is apparent that the geometries of groundwater flow systems vary in shape and size and location. It is proposed that these flow systems be divided into three orders according to the criteria given in the following paragraphs.

First order systems are those that have their basal boundaries above two adjacent drainage channels and discharge into those channels; second order systems are those that have their basal boundaries below one or more drainage channels, and receive recharge from or discharge to these channels; and third order systems are those that have their basal boundaries below all local tributary channels, and are recharged locally by leakage through overlying beds or laterally from outside the area.

Flow systems of the first order receive recharge directly from infiltration or, where a perched overlying system is present, receives recharge in the form of leakage from the overlying system, and directly from infiltration at the valley sides. Flow systems of the second order are recharged from direct infiltration, from leakage from overlying flow systems and by leakage from influent streams.

Discharge from systems of the first order is generally in the form of seepage or is indiscernible. Discharge from systems of the second order ranges from seepage to permanent spring flow. This order of groundwater flow system transports the major portion of groundwater flow. Flow systems of the third order discharge into regional low areas; these flows are assumed to be relatively steady. Proceeding along the cross section in the direction of dip, flow systems of the second order become flow systems of the third order.

Factors Contributing to the Presence of Springs

To understand the hydrology of Streeter Basin and others similar, one must understand the hydrology of springs. Toward this end the following observations are made and a hypothesis put forth:

1) Springs discharge mainly from the bedding plane fractures and joints of floggy to massive, cross bedded sandstones; most of the major springs occur on the downdip side where these rock units intersect the valley sides. Springs lower in the valleys are more permanent, have higher rates of discharge, and fluctuate less

than springs located high on valley sides; and almost all springs are adjacent to a section of valley side that is tree-covered and has a northern component of aspect.

2) Tree patterns and spring locations indicate that a strong influence of stratification exists and that sandstone members extend across sub-basin boundaries.

3) Springs situated low in the basin respond to climatic events as rapidly as springs high in the basin, which indicates that the major portion of recharge to the lower springs comes directly from infiltration rather than by leakage from overlying flow systems.

The hypothesis proposed is that within the stratified sandstone units smaller zones of concentrated groundwater flow exist, as a result of the existence of fracture patterns, thick lenses of cross bedded sandstones, and so on. The zones of concentrated groundwater flow discharge as springs. The term "spring-recharge cell" is proposed to refer to the geometry of this zone of concentrated groundwater flow including the area of recharge. The type of spring present is governed by the magnitude and state of recharge. Areas were drawn on the map (Map 1) delimiting, in plan view, assumed areas of spring-recharge cells. Lateral boundaries of spring-recharge cells assumed to be controlled by the two sets of fractures within the most well-bedded sandstone units and deflected toward the spring (in drawing these boundaries water is not required to flow updip). The larger and more favorable the areas of recharge, the more permanent and steady is the spring discharge. The presence of springs discharging into the recharge area of a lower spring-recharge cell provides a more steady source of recharge for the lower spring.

## Improving Basin Yield

Most of the recharge to a spring-recharge cell occurs as a result of snowmelt. Therefore, to increase recharge one must collect and retain as much snow as possible in the recharge area. This is effected by managing the forest cover over the areas of recharge for increased snow catch.

R. Swanson (personal communication) reports that analyses of snow course surveys in Streeter Basin show that snow pack is increased in small open areas within the forest cover provided the widths of these areas are not more than twice tree height in diameter. Conversations with ranchers in the area also indicate that springs "dried up" after the tree cover was removed. This information indicates that some type of pattern cutting of tree cover might prove effective in increasing spring flows and, in so doing, test the validity of the spring-recharge cell concept and their locations as outlined on map 1.

## Chemistry and Temperature of Groundwaters

Generally spring waters, stream waters, and well waters from shallow water-table observation wells are of the same calcium-bicarbonate type (see figure 16): Specific conductance ranges from 400 to 600 micromhos per centimeter. Stream waters are from 75 to 80 per cent lower in total dissolved solids only a few yards downstream from its point of origin as springflow. Because the anion and cation ratios are the same, the decrease in total dissolved solids must be due to precipitation of calcium carbonate immediately upon discharging from the spring. This phenomenon occurs in other areas in which lime deposits are present (Marmot Creek and Deer Creek Basins).

Waters from piezometer nests vary considerably in type (Fig. 16). Generally, they are sodium bicarbonate or calcium-sodium bicarbonate waters; however, water from piezometer number 3 of M4350 RCA is a sulfate water. There is not enough data to draw any conclusions from the chemistry of waters from piezometer nests.

Almost all of the spring waters have similar amounts of total dissolved solids. This fact indicates that their time in transit through groundwater flow systems is approximately the same. This assumption is supported by a comparison of the hydrographs of springs located both high and low on valley sides (Fig. 17). The response times of these springs to summer rain are similar and of very short duration (a few days).

The temperature of groundwaters varied from 39°F to 62°F over the measurement period (late August, 1968). This large variation is attributed to two reasons: 1) the measurement was not taken at the immediate point of spring discharge which condition allows spring water temperature to increase toward the warmer existing air temperature, and

2) the location of the spring-recharge cell.

Where the spring-recharge cell is near the top of the valley, has less tree cover and has a southern aspect, spring waters are warmer than where the spring-recharge cell is tree-covered and has a northerly aspect. For example, spring (18A), of the first description, has a temperature of 47°F (see Appendix C), whereas spring (27A), of the second description, has a water temperature of 40°F. Permanent springs maintain temperatures of 35°F, or higher, and remain open all year.

## SUMMARY

1. The geology of Streeter Basin comprises interbedded, fractured and jointed sandstones, siltstones, and shales which dip at two to three degrees from west to east.
2. Streamflow for most of the year is made up of spring discharge. Streams are generally interrupted and intermittent, and influent to underlying groundwater flow systems. There is little correlation between streamflow measured at the confluences of the sub-basins and total basin area. The five-year average annual outflow from the Basin is 3 inches over the drainage area.
3. Average annual precipitation, measured over five years, ranges from 20 to 24 inches over the basin area. Potential evaporation during the growing season approximates 23 inches of water.
4. Water level measurements from a piezometer nest located on the top of the ridge show that perched groundwater flow systems exist above the floors of adjacent valleys.
5. A cross section of hypothesized groundwater flow system is presented showing relations among influent streams, piezometric levels, and spring locations.
6. The hypothesis is presented that springs are the result of concentrated zones of groundwater flow, or "spring-recharge cells," occur within interbedded sandstones. The concentration of flow is the result of the presence of fractures, thick lenses of cross bedded jointed sandstones, and the dip of the bedding planes. Generally, springflows increase almost simultaneously within a few days of a large rain.
7. Spring waters, stream waters and shallow groundwaters in the valley fill are a calcium bicarbonate type and range in specific conductance from 400 to 600

micromhos per cm. Water temperatures range from 39 degrees to 62 degrees fahrenheit in late summer; warmer springs waters are hypothesized as being the result of the spring-recharge cell having a southern component of aspect and lesser tree cover than those under northern aspects.

## RECOMMENDATIONS FOR FUTURE STUDY

The following recommendations for future work in Streeter Basin are:

1. Future work in Streeter Basin should be orientated toward measuring the geometries of perched groundwater flow systems and relations between their boundaries and the geologic conditions present in the Basin.
2. The geometries of zones of concentrated flow to major springs should be defined, and their areas of recharge delimited. Some insight into recharge area-springflow relations might be gained indirectly by clear-cutting or pattern cutting an area of tree cover and observing the effects of springflows in the adjacent areas. Those geometries shown on Map 1 provide a starting point for this reasearch.

# APPENDIX A. A CROSS SECTION AND INSTALLATION DESCRIPTION OF THE TYPE OF PIEZOMETER NEST INSTALLED BY THE RESEARCH COUNCIL OF ALBERTA IN THE RESEARCH BASINS

## Installation Procedure of Piezometer Nests and Water-Table Wells

After the drilling, sampling, and bail testing has been completed, piezometer "number one" is set into the hole. Before each piezometer is installed the casing retaining that part of the hole is pulled or loosened (where otherwise the hole would cave). A three-inch diameter disc cut from steel plate and welded on the bottom of each sand point keeps the points from penetrating the material on which they rest. Washed sand in calculated amounts is dumped down the hole to create a sand pack around the sand point at the lower end of the piezometer. The piezometer is then filled with water and an airtight cap screwed onto the top of the pipe (this water prevents sand or grout from entering the screen). Next, the proper amount of cement slurry (grout) is lowered to the bottom of the hole in a bailer, after which crushed or small-diameter (to prevent bridging) gravel is dumped in to bring the level of the concrete plug up to the level of the next piezometer. Where piezometers are several tens of feet apart in the hole, an additional batch of grout is required near the top of the concrete plug to create a tight seal. Once the top of the gravel (in the slurry matrix) is at the elevation of the next piezometer the hole is bailed dry or bailed until the water is clear. This bailing step is important to prevent the screen of the next piezometer from being grouted in. The casing retaining that part of the hole is pulled from the hole, before the concrete plug hardens. The above process is repeated until all piezometers are installed. The slotted water-well casing is installed in the top of the hole and the hole is backfilled with gravel to within six feet of the surface (Fig. 1). The piezometer number is welded on each pipe and cap and a 1/8 inch diameter hole drilled in each cap to allow the piezometer to breath. All piezometers are now filled with water to ascertain if they are functioning.

The outside walls of the upper four feet of each piezometer and the water-table well casing may be painted with undercoating to provide a surface of insulation between the concrete and the pipe. This insulation will prevent a frost build-up on the inside of the pipe or casing during sub-freezing temperatures. The diameter of the top 24 inches of the hole is now enlarged to approximately 4 feet in diameter and an open-bottomed barrel installed; the hole is filled level to the ground surface with concrete finished level inside and outside the barrel. The barrel should be fitted with a leak-proof cover.

To Accompany #6. Hydrology of Streeter Basin in

Collection and Compilation of Groundwater Data in the Marmot Creek Experimental Basin

by

D. R. Stevenson

CONTENTS

Page

# COLLECTION AND COMPILATION OF GROUNDWATER DATA IN THE MARMOT CREEK EXPERIMENTAL BASIN

## Introduction

The Research Council of Alberta is one of the cooperating government agencies engaged in watershed research in the Marmot Creek Experimental Basin.

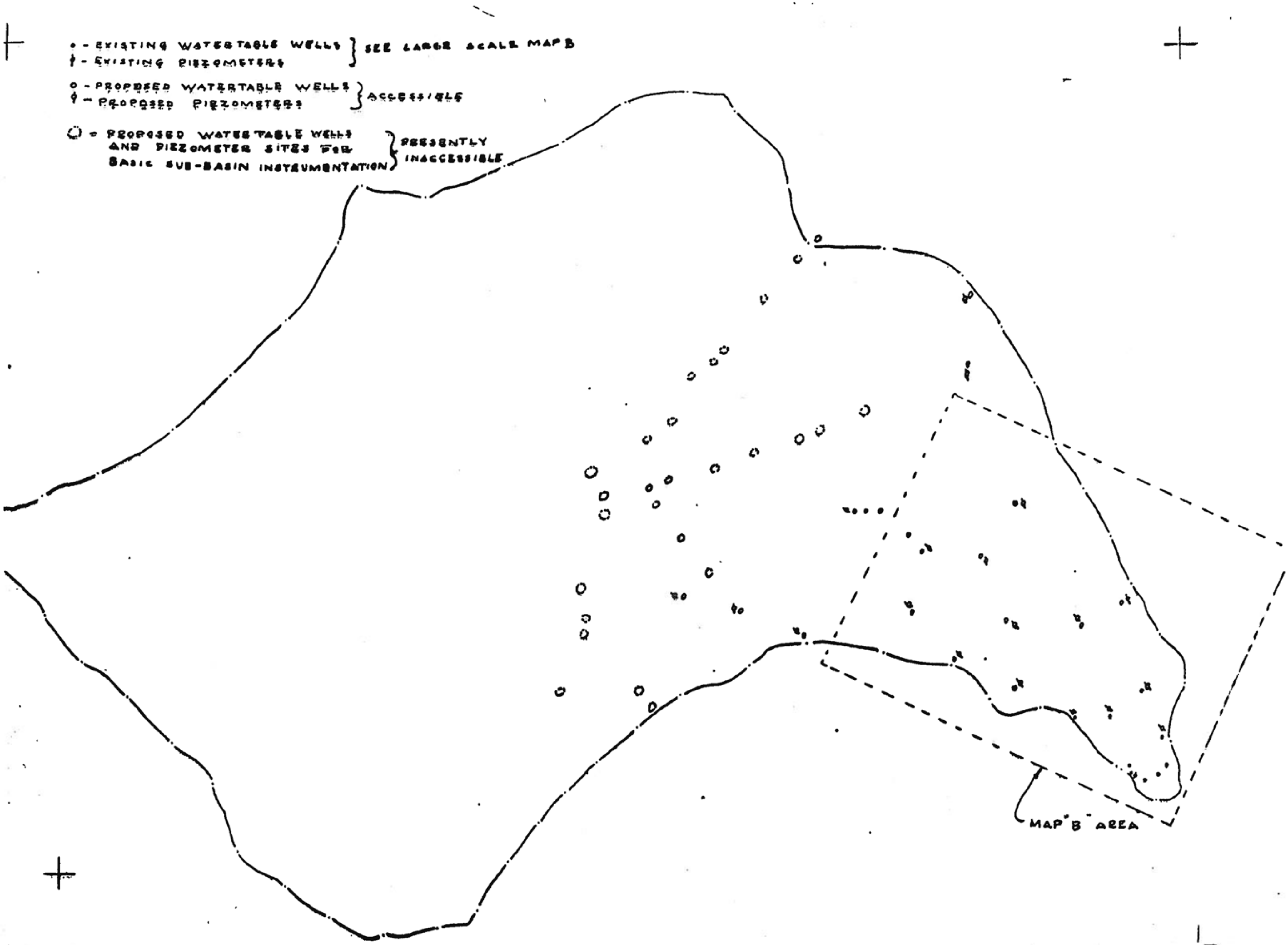
The Groundwater Division of the Research Council is responsible for the geological and groundwater phases of research including maps, groundwater instrumentation, compilation of groundwater data and their subsequent interpretation.

The Marmot Creek basin covers approximately 3.6 square miles and consists of the lower Confluence area drained by Marmot Creek and three sub-basins drained by the Twin Creek, Middle Creek, and Cabin Creek tributaries of Marmot Creek.

## Geology and Geomorphology

The Marmot Creek basin is generally covered by 20 to 30 feet of light brownish-grey, silty, calcareous till. A large percentage of the till consists of rock fragments of limestone, sandstone, dolomitic siltstone, and light grey quartzite. Continuing processes of slump, creep, rock slides, and sheet flow have resulted in thicker surficial deposits along the stream bottoms and in down-valley depressions. The surficial deposits generally "tend" to smooth out humps and hollows of the underlying bedrock, being thin over the highs and thick in the depressions.

The underlying bedrock dates from Late Paleozoic to Early Cretaceous age. The rock units generally strike N25°-35°W across the basin and dip at 15° to 20° west back into the basin.


• - EXISTING WATERTABLE WELLS
ϕ - EXISTING PIEZOMETERS
SEE LARGE SCALE MAP B
o - PROPOSED WATERTABLE WELLS
ϕ - PROPOSED PIEZOMETERS
ACCESSIBLE
○ = PROPOSED WATERTABLE WELLS AND PIEZOMETER SITES FOR BASIC SUB-BASIN INSTRUMENTATION
PRESENTLY INACCESSIBLE
MAP "B" AREA

The Kootenay Formation is capped by a headwall of Cadomin Conglomerate, of Lower Cretaceous age, that dips westward into the axis of an overturned syncline, the back limb of which forms Mount Allan.

## Geohydrology

The tributary streams of Marmot Creek originate in the headwalls of the sub-basins and drop downward in a generally perpendicular path across the strike of the steeply-dipping underlying Kootenay and Fernie Formations. In the lower part of the sub-basins where slopes flatten out, the streams are increasingly influenced by the structure of the underlying bedrock as in the lower part of the Cabin Creek sub-basin. This structural control of surface drainage suggests that the bedrock joints and fractures are taking an active part in groundwater movement and storage. Further evidence is the existence of calcite-filled bedrock fractures as found in the Pigeon Creek Member of the Fernie Group.

Groundwater exists in the Marmot Creek basin generally under water-table conditions, being recharged in the spring and early summer by infiltration from snowmelt and rainfall and gradually depleting during the late fall and winter to supply stream baseflow. Marmot Creek and its tributary streams are acting as V-shaped drains in the steeply-dipping water table that is a subdued replica of the basin surface. Where the slope of the water table decreases more rapidly than the overlying topographic surface, a contact spring or boggy area has usually developed. Significant loss of groundwater to bedrock fissures or faults would result in a local depression in the water table.

To establish the water-table surface, measure the change in groundwater storage, and generally assess the groundwater parameters involved in the groundwater balance of the basin, a groundwater instrumentation network was established.

Groundwater Instrumentation

During the 1964 and 65 field seasons, 17 water-table observation-well and piezometer sites were established in accessible parts of the Confluence area and adjacent sub-basins (shown in Fig. 1). A rotary rig with a 20-foot mast proved capable of drilling through the large, resistant boulders that make up a large percentage of the surficial materials, setting the well casing and/or piezometers and developing the wells.

Water-table observation wells were spaced over the basin and topographic divides to obtain the necessary control required to construct a water-table topographic map. Piezometers were set into underlying bedrock and in the more permeable zones within the surficial material to reveal any existing hydraulic variations within the groundwater reservoir. The more concentrated network of wells at the bottom of the Confluence area provides the closer control necessary to establish the phreatic divide and detect the presence of underflow southward down the plunge slope of the Rocky Mountain quartzite bench.

The water-level fluctuations in 13 water-table observation wells and one piezometer are recorded by Leopold-Stevens type FM weight driven recorders. These recorder charts will show water-level fluctuations of 0.01 feet at a gauge scale of 1:1 but due to lag introduced by the use of small-diameter floats the accuracy of the records varies from 0 to 0.1 foot. The remaining observation wells and piezometers are measured weekly with a "chalked" steel tape calibrated in hundreds-of-a-foot.

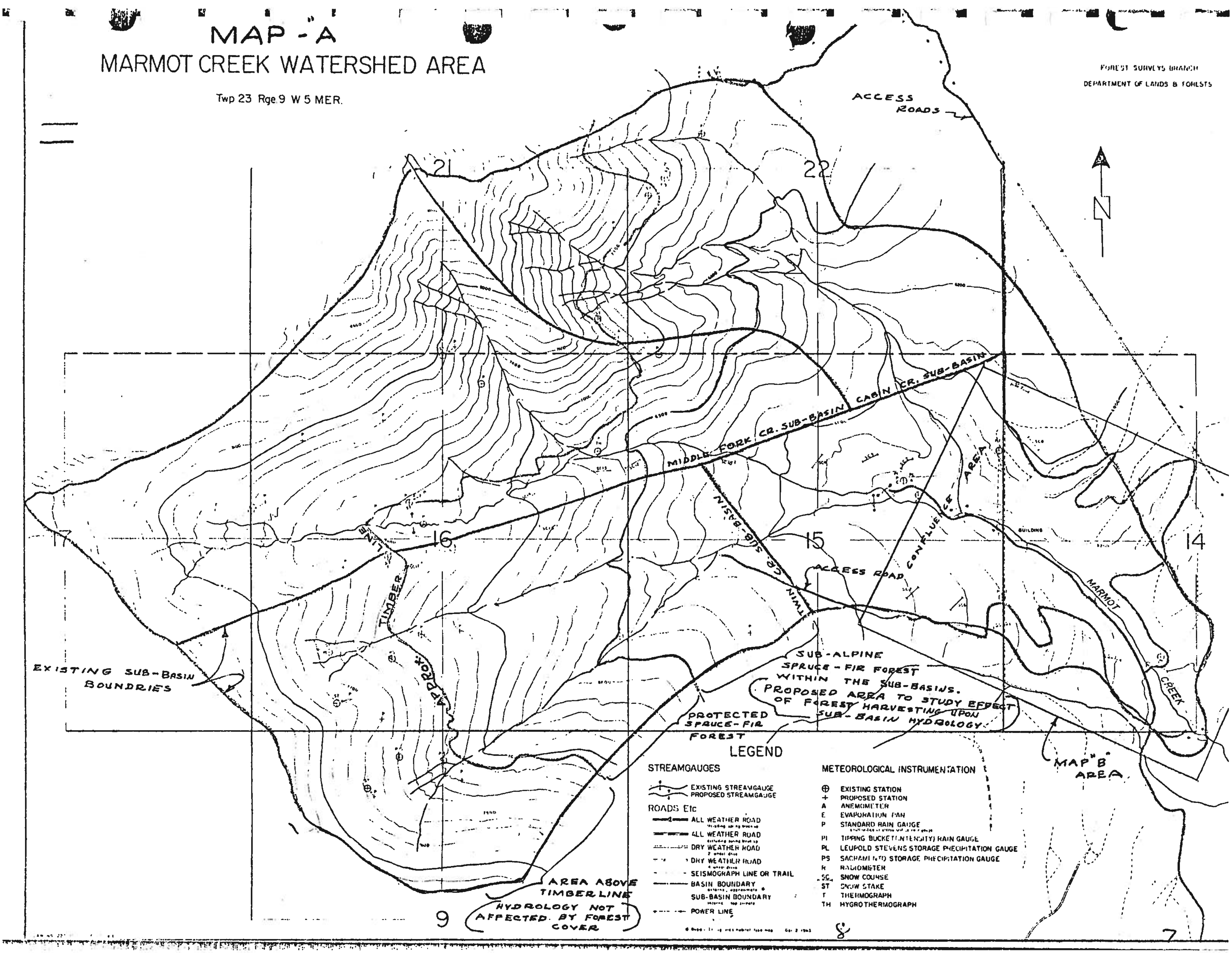
An explanation of symbols used in naming the observation well and piezometer sites will be simplified by the following example: N320 WT/RM38 is located on the north access road within the basin at an elevation of 320 feet above the 5,000-foot base level (arbitrarily chosen). This is a water-table observation well developed in surficial material above the Rocky Mountain Formation at a depth of 38 feet. S 400 P-SR32 is located on the south access road at an elevation of 400-feet above the 5,000-foot base level. The installation is a piezometer set into the Spray River Formation at a depth of 32 feet.

Preliminary Observations and Future Requirements

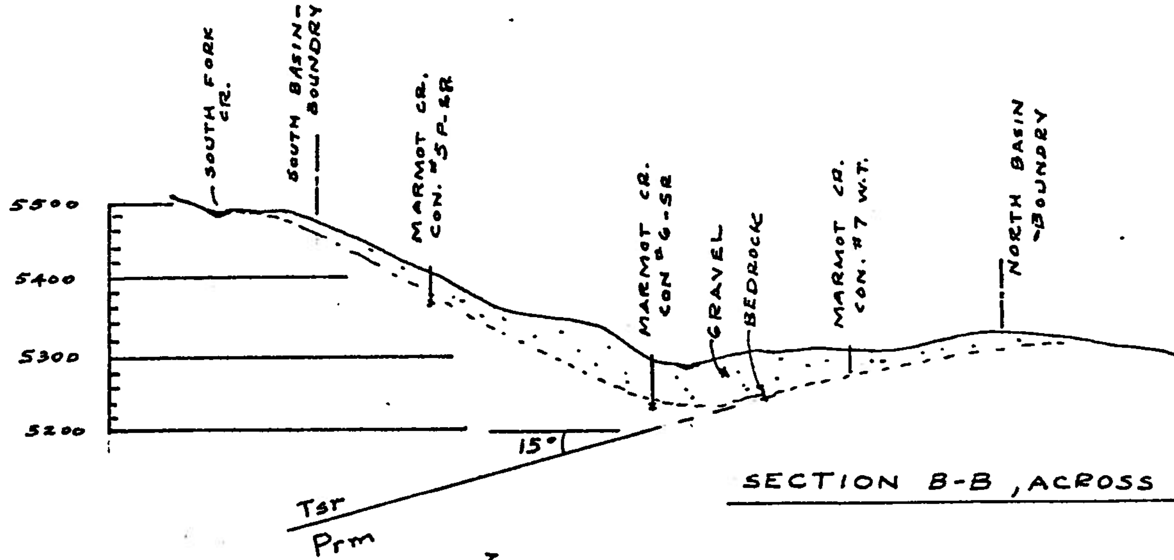
It was felt that the existing groundwater instrumentation network would allow a preliminary assessment of the groundwater balance within the basin and indicate where complimentary and supplementary instrumentation is required. This assessment is currently being prepared as a preliminary report and thesis and will be available later this year.

WELL AND PIEZOMETER WATER DEPTHS MEASURED FROM TOP OF CASING

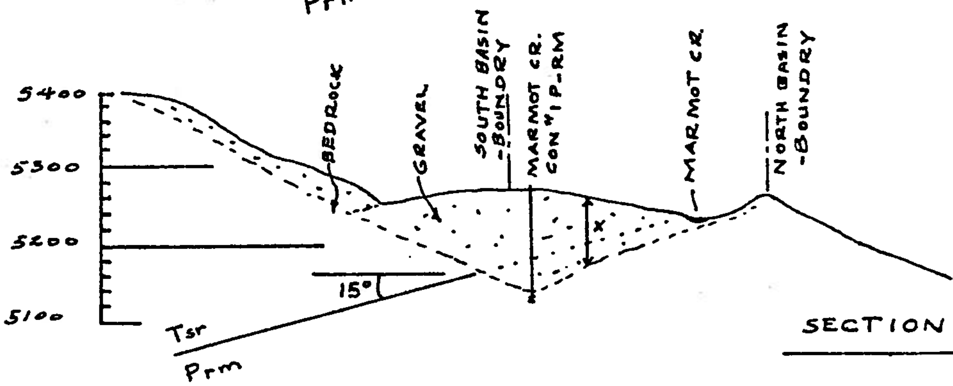
| | Marmot Cr. Con.#1-WT | Marmot Cr. Con.#1P-Gr/RM | Marmot Cr. Con.#1P-RM | Marmot Cr. Con.#2 | Marmot Cr. Con.#3 | Marmot Cr. Con.#4 | Marmot Cr. Con.#5 | Marmot Cr. Con.#5P-SR | Marmot Cr. Con.#6 | Marmot Cr. Con.#6P-SR | Marmot Cr. Con.#7 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pths of well asing and ezometers ow surface | 39.7' | 102.8' | 124.4' | 39.6' | 28.2' | 39.4' | 26.4' | 34.5' | 17.4' | 65.5' | 39.6 |
| evation at of casing | 5266' | 5263' | 5260' | 5254' | 5235' | 5278' | 5400' | 5400' | 5300' | 5300' | 5320 |
| Date | | | | | | | | | | | |
| Oct. 1/64 | 9.6 | | 42.8 | | | | | | | | |
| Oct. 2/64 | 13.8 | | 44.8 | 2.8 | | | | | | | |
| Oct.3 /64 | 16.5 | 39.7 | 45.9 | 2.3 | 2.8 | | | | | | |
| Oct. 4/64 | 16.9 | 41.6 | 44.4 | 3.0 | 3.3 | 23.1 | | | | | |
| Oct. 5/64 | 17.3 | 45.3 | 47.8 | 3.3 | 3.4 | 23.9 | 7.0 | | | | |
| Oct. 6/64 | 17.99 | 47.63 | 49.22 | 4.05 | 4.21 | 24.91 | 11.93 | | 5.26 | | |
| Oct. 7/64 | 18.01 | 48.47 | 49.56 | 4.35 | 4.64 | 25.49 | 16.08 | | 7.14 | | |
| Oct. 8/64 | 18.02 | 48.96 | 49.85 | 4.61 | 5.19 | 26.18 | 17.87 | | 7.41 | | 3. |
| Oct. 9/64 | 18.02 | 49.25 | 50.03 | 4.84 | 5.43 | 26.64 | 18.97 | 19.72 | 7.38 | 14.01 | 4. |
| Oct.10/64 | 18.03 | 49.27 | 50.05 | 5.16 | 5.59 | 27.37 | 19.89 | 19.86 | 7.47 | 13.63 | 5. |
| Oct.11/64 | 18.05 | 49.28 | 50.06 | 5.34 | 5.65 | 27.80 | 20.35 | 19.94 | 7.42 | 13.42 | 5. |
| Oct.12/64 | 18.06 | 49.28 | 50.07 | 5.48 | 5.68 | 28.11 | 20.53 | 19.99 | 7.32 | 13.23 | 5. |
| Oct.13/64 | 18.10 | 49.58 | 50.03 | 5.70 | 5.73 | 28.72 | 21.00 | 20.15 | 7.36 | 12.99 | 6. |
| Oct.14/64 | 18.15 | 49.50 | 50.25 | 5.84 | 5.75 | 28.94 | 21.11 | 20.18 | 7.37 | 12.83 | 6. |
| Oct.15/64 | 18.20 | 49.50 | 50.26 | 6.03 | 5.80 | 29.20 | 21.23 | 20.23 | 7.39 | 12.72 | 6. |
| Oct.16/64 | 18.19 | 49.50 | 50.26 | 6.18 | 5.81 | 29.39 | 21.38 | 20.28 | 7.40 | 12.72 | 6. |
| Oct.20/64 | 18.20 | 49.50 | 50.38 | 6.71 | 5.99 | 29.82 | 22.16 | 20.32 | 7.33 | 12.67 | 6. |
| Oct.23/64 | 18.22 | 49.50 | 50.26 | 6.97 | 6.05 | 30.98 | 22.48 | 20.32 | 7.34 | 12.51 | 6. |
| Oct.27/64 | 18.25 | 49.60 | 50.27 | 7.26 | 6.15 | 30.03 | 22.78 | 20.36 | 7.37 | 12.37 | 6. |
| Oct.30/64 | 18.26 | 49.48 | 50.27 | 7.44 | 6.15 | 30.04 | 23.02 | 20.38 | 7.37 | 12.36 | 6. |
| Nov. 3/64 | 18.32 | 49.49 | 50.26 | 7.58 | 7.09 | 30.07 | 23.26 | 20.40 | 7.38 | 12.22 | 6. |
| Nov. 6/64 | 18.33 | 49.43 | 50.16 | 7.68 | 6.17 | 30.07 | 23.47 | 20.38 | 7.39 | 12.13 | 6. |
| Nov.11/64 | 18.33 | 49.43 | 50.20 | 7.80 | 6.20 | 30.11 | 23.69 | 20.41 | 7.58 | 11.67 | 6. |
| Nov.13/64 | 18.38 | 49.47 | 50.24 | 7.83 | 6.23 | 30.13 | 23.93 | 20.42 | 7.37 | 11.93 | 6. |
| Nov.17/64 | 18.41 | 49.49 | 50.27 | 7.91 | 6.29 | 30.16 | 24.53 | 20.43 | 7.33 | 12.02 | 6. |


MAP "A"
MARMOT CREEK WATERSHED AREA
Twp 23 Rge 9 W 5 MER.
FOREST SURVEYS BRANCH
DEPARTMENT OF LANDS & FORESTS
ACCESS ROADS
N
21
22
17
16
15
14
9
8
7
MIDDLE FORK CR. SUB-BASIN
CABIN CR. SUB-BASIN
TWIN CR. SUB-BASIN
CONFLUENCE AREA
ACCESS ROAD
MARMOT CREEK
APPROX. TIMBER LINE
EXISTING SUB-BASIN BOUNDRIES
SUB-ALPINE SPRUCE-FIR FOREST WITHIN THE SUB-BASINS.
PROPOSED AREA TO STUDY EFFECT OF FOREST HARVESTING UPON SUB-BASIN HYDROLOGY.
PROTECTED SPRUCE-FIR FOREST
MAP "B" AREA
AREA ABOVE TIMBER LINE
HYDROLOGY NOT AFFECTED BY FOREST COVER
LEGEND
STREAMGAUGES
EXISTING STREAMGAUGE
PROPOSED STREAMGAUGE
ROADS Etc
ALL WEATHER ROAD
ALL WEATHER ROAD
DRY WEATHER ROAD
DRY WEATHER ROAD
SEISMOGRAPH LINE OR TRAIL
BASIN BOUNDARY
SUB-BASIN BOUNDARY
POWER LINE
METEOROLOGICAL INSTRUMENTATION
⊕ EXISTING STATION
+ PROPOSED STATION
A ANEMOMETER
E EVAPORATION PAN
P STANDARD RAIN GAUGE
PI TIPPING BUCKET (INTENSITY) RAIN GAUGE
PL LEUPOLD STEVENS STORAGE PRECIPITATION GAUGE
PS SACRAMENTO STORAGE PRECIPITATION GAUGE
R RADIOMETER
SC SNOW COURSE
ST SNOW STAKE
T THERMOGRAPH
TH HYGROTHERMOGRAPH

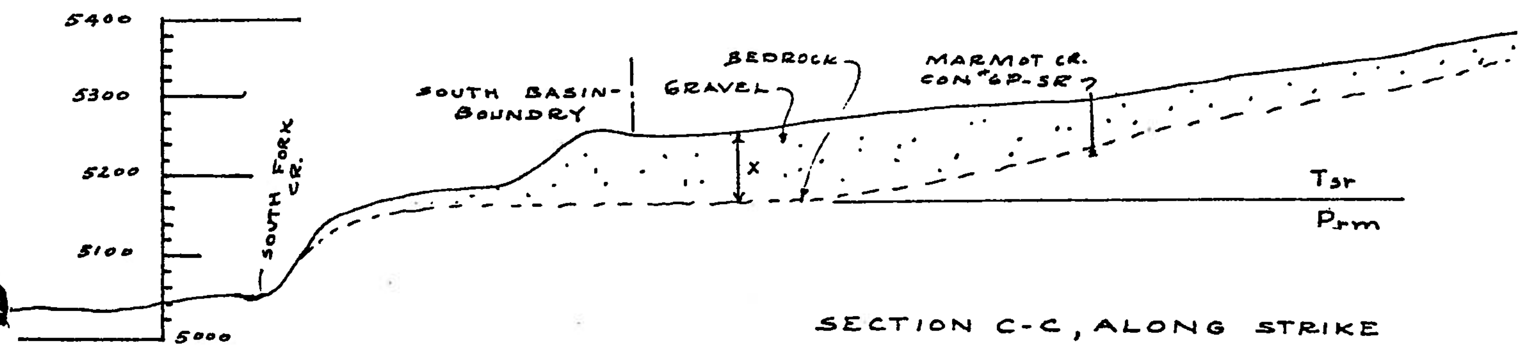
CROSS SECTIONS FROM MAP B




SECTION B-B, ACROSS STRIKE




SECTION A-A, ACROSS STRIKE




SECTION C-C, ALONG STRIKE

HORIZONTAL SCALE: 1 in. = 500 ft.

VERTICAL EXAGG. = 2:1.

## Some Points on the Evaluation of the Groundwater Budget of a Basin

The groundwater budget is basically:

Groundwater in = change in groundwater storage + groundwater out (Consumptive u
(Stream baseflo
(Groundwater ou
flow or underflc

1. To properly evaluate the above parameters a 3-dimensional picture of the geology of the basin must be framed. Surface geologic mapping supported by stratigraphic drilling will provide this information.

2. The position of the water table must be measured from water-table observation wells. The change in groundwater potential between bedrock and surficial materials must be measured by piezometers. The specific yields of the materials making up the groundwater reservoir must be calculated from pump-test data. These hydrologic data coupled with the geologic framework data and plugged into the appropriate equations will show:
   - the amount of groundwater in storage
   - the change in groundwater storage
   - the groundwater outflow
   - the interrelationships between precipitation, streamflow and groundwater recharge
   - the effects of changing surface conditions on the groundwater budget, and other basic information required to evaluate the groundwater budget.

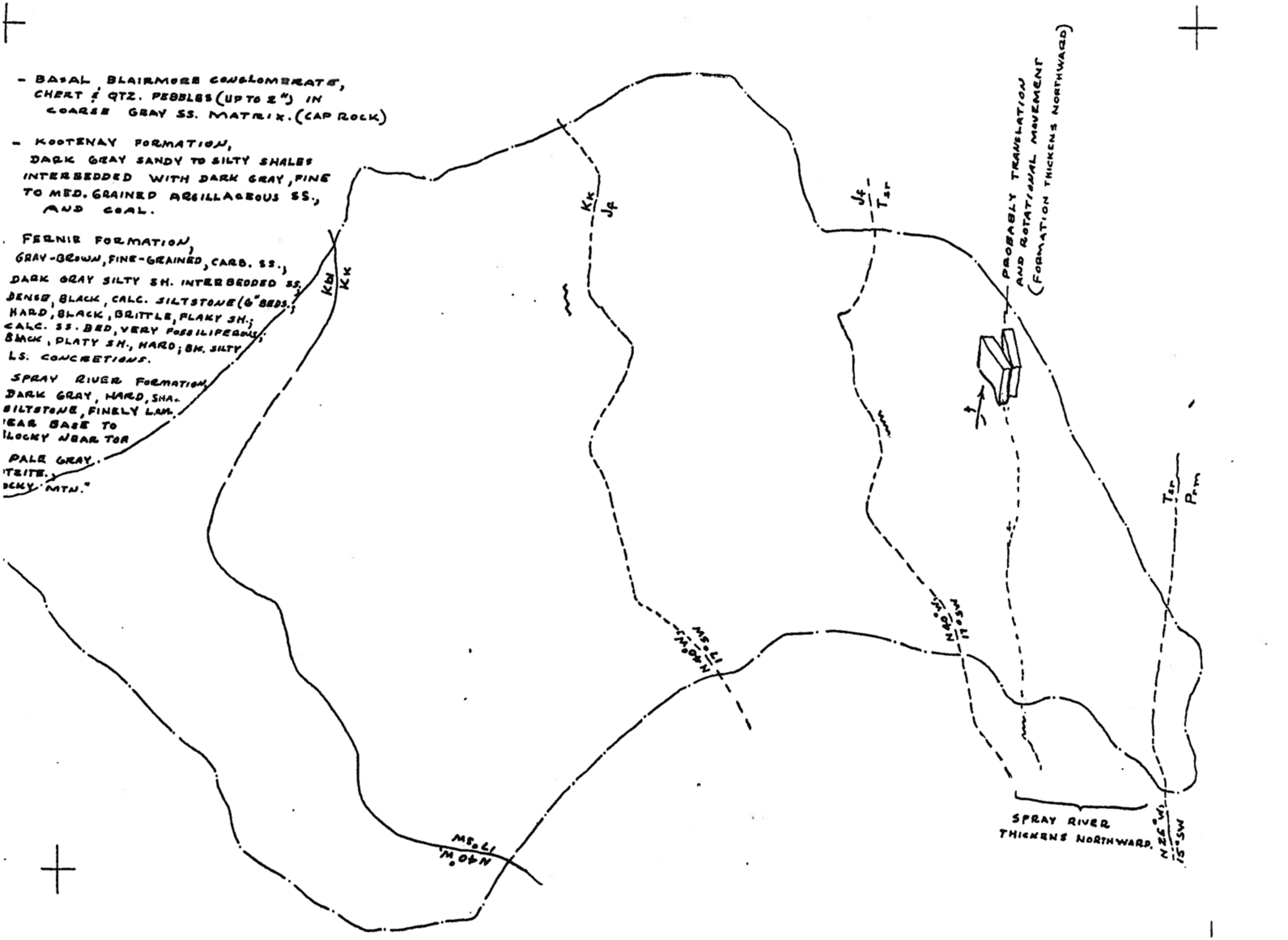
The preceding points on groundwater evaluation are being considered in both the Marmot Creek and Streeter basins of the South Saskatchewan River Headwaters.

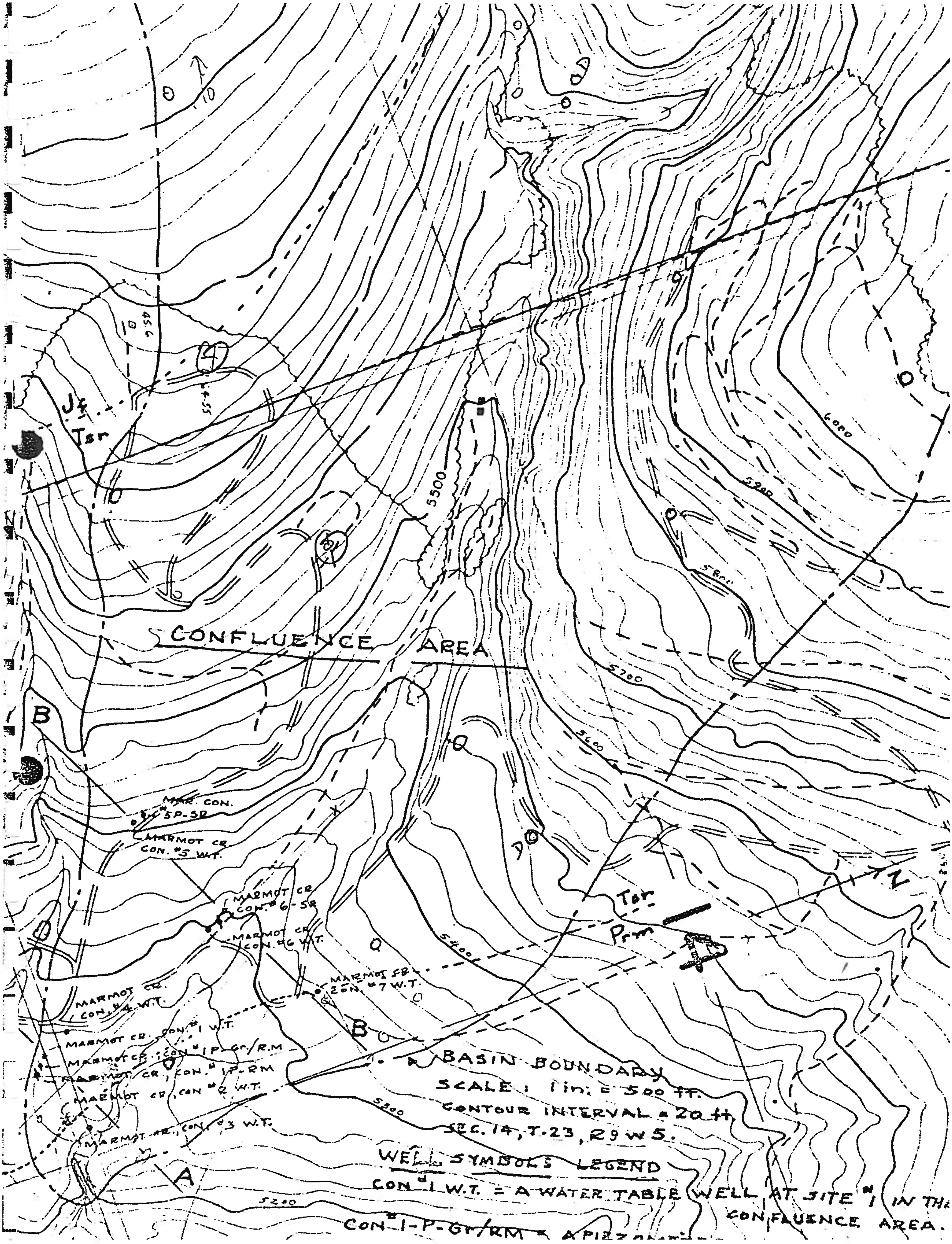
In the Marmot Creek basin the necessary groundwater control points, limited by the available access, have been installed. Further installation required to complement the existing control or required by improved access will take place after a preliminary budget evaluation has been made.

The necessary pump tests required to evaluate the aquifer specific yields will be made in 1966. Water-table and piezometer fluctuations should be measured over a sufficient period of time in order that changes in groundwater storage in response to yearly extremes in precipitation may be properly interpreted.

In Streeter Basin the necessary stratigraphic drilling and water-table observation well program is just underway.

# THE MAR IOT CREEK WATERS .D AREA




CONFLUENCE AREA
Jf
Tsr
B
5500
6000
5900
5800
5700
5600
5400
5300
5200
MAR. CON. #5P-SR
MARMOT CR. CON. #5 W.T.
MARMOT CR. CON. #6-SR
MARMOT CR. CON. #6 W.T.
MARMOT CR. CON. #7 W.T.
MARMOT CR. CON. #4 W.T.
MARMOT CR. CON. #1 W.T.
MARMOT CR. CON. #1P-Gr/R.M
MARMOT CR. CON. #1P-RM
MARMOT CR. CON. #2 W.T.
MARMOT CR. CON. #3 W.T.
Tsr
Prm
N
A
BASIN BOUNDARY
SCALE: 1 in. = 500 ft.
CONTOUR INTERVAL = 20 ft.
SEC. 14, T. 23, R 9 W 5.
WELL SYMBOLS LEGEND
CON#1 W.T. = A WATER TABLE WELL AT SITE #1 IN THE CONFLUENCE AREA.

Doug Strieser to Zacharias Tech.

Streeter Basin Reconnaissance Survey.

Tape #1.

The time is now 2:30 p.m., we have arrived in Streeter Basin and we are just setting up to begin our field reconnaissance. It is our intention to traverse up east Streeter Creek stopping to sample the springs and measure the temperature and conductivity and to describe the plant and vegetation present. Our general observation as we leave the Streeter Cabin is a very lush vegetation ~~and pleative~~ indicative of the amount of percipitation that has fallen here this summer. Some of the vegetation types along the creek bank are very large cow parsnip reaching heights of between 3 and 4 feet and water hemlock. Along the creek are very dense rows of water willows with trembling aspen occupying the highlands just back from the creek bottoms. Other weed types are buttercup, yarrow, timothy and broad leaf grasses, wild strawberry, a blue daisy yet unidentified, wild pea vine, plantain, bedstraw, wild raspberry which hada very lush red fruit, other weed types are golden larkspur, american vetch, a blue flower, somewhat similar to a zenia with the leaf resembling that of a mountain bluebell to be identified later, canadian thistle, dominant type being a blue daisy, yarrow, mountain goldenrod, timothy grasses, other shrub types noted are honeysuckle, wild gooseberry, larkspur is also present. Along the creek bottom, there appears to be a tremendous loss of water to the type vegetation. We will take our first reading of middle Streeter Creek just below the stream discharge station. Two other prelific weeds in the area are stinkweed and fireweed. (Correction, the first stream site samples was just below the confluence of the middle and east Streeter Creeks.) Water tempe ature is 53°F, specific conductance is 495 micromos per centimeter. Calcium hardness was between 5 and 6 grains per gallon, total hardness was slightly over 15 grains per gallon.

../2

There is an abundance of a silvery green type of weed with a leaf somewhat like a wolf willow and seams resembling those of lamb's quarters.

Our second reading is immediately at the stream discharge station at East Streeter Creek. The latteral cross section of the stream here is quite V-shaped in profile , and trembling aspen are growing on the stream bank. Dense growth of the phreatophytic water wollow and a type of tree not yet identified with the appearance similar to that of the mountain alder with plush growth of cow parsnip and water hemlock, broad leafed grasses and previously described weed types are also present. A picture was taken at this site. The first picture taken at this site showed the same discharge station, cottonwood grows on the left and phreatophytic willows and birch or alder along the creek bottom. Photo #2 showed the tremendous size of the cow parsnip in the area. Water temperature at the discharge station of East Streeter Creek is 48°F , specific conductance was 450 micromos per centimeter. The calcium hardness of east Streeter Creek was 8 grains per gallon, total hardness was 15 grains per gallon. There was no water flowing in the middle Streeter stream discharge station. Aphotograph was taken at this site. We will continue the traverse up East Streeter Creek to the first spring. We just passed a delphinium type plant that branches towards the top, with a 5-petaled white flower, with a pinkish bud, with approximately 1 - 1 1/2" across. A small white spruce was passed growing on the north side of the bank of East Cache-Percotte Creek.

A brown odulatious medium grained sandstone bedrock that is quite flimsy and cross bedded crops out along the north side of lower parts of East Streeter Creek.

The creek profile and cross section in this area has become very steep sided and v-shaped. Small saskatoon bushes are growing on the bank, in the steep banks just at this part. The saskatoons here are approximately 3 wks. to a month behind those in Edmonton, as the fruit is just ripening now. The lambs' quarters weed is also growing in this vacinity. Wild rose is also present, buffalo berry is also growing here in the odd scattered bunch. Small blueberry bushes are also noted along the steep side of the banks of the creek. Surprisingly enough, these small blueberry bushes have a white berry.

We have been in this basin approximately an hour, and it is our genearl conclusion that the from the pilrific berries in the area will be severely depleated upon our departure. Yellow daisy and coculbur also grow along this area, a xxxx tall plant resembling a false dandelion, this plant is probably a thistle. Purple larkspur that is very poisonous to cattle is quite common here. The local ranchers believe thatthis plant contains arsnic which is deadly poisonous to cattle. The dock weed is also present, wild gooseberry and swamp willow are very common along the creek bottom. Twisted stock is also noted along the creek bottoms. Water hemlock plant has a bunch of bright red fruit on the end of a stock similar to a red current. This fruit is mealy in appearance with a very sour odor. It was not sampled. Crsifer or mustard is quite common along the creek. We have reached the first small spring on the north side of the creek bank and we are stopping to sample xx it. The phreatic willow, buttercup, canddian thistle, blue daisy, wild aster, honeysuckle, wild gooseberry and wild raspberry, yarrow are very common, as well as stinkweed, and browneyed season are present here. The groundwater discharge at this site appears

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to be entierely absorbed by evpa-transpiration. One of the previously unidentified plants noted here is rag weed, a bright pink Indian paint brush was noted on the side of the creek bank. Shrubby cinquafoil was also noted. Another type of cinquefoil is also present just west of the previously mentioned spring area equisitum was noted along the creek bottoms. We have come to another small spring on the east side of the creek which we are about to sample, a very lush growth of water willow, cow parsnip, wild gooseberry, water hemlock, a type of water birch, delphinium, buffalo berry, thin mosses cover the flaggy sandstone type gravel over which the spring water is flowing. A picture was taken at this site. The spring shall be located on aerial photogrpph YC 1090 as site #1. Previously mentioned bright red fruit of the water hemlock is discovered at this site as being white. Water temperature at this spring was 48°F, specific conductance was 510 micromos per centimeter. Some of the great variety of plants species located here are honeysuckle, water birch, saskatoon busbes, wild raspberries, swampy willow, buffalo berry, cow parsnip, water hemlock, white and purple delphinium, wild gooesberry, wild raspberries, timothy grasses, yarrow, blue dasies, wild blue aster or zinia, pea vine, american vetch, Canadian thistle, wild strawberry, yellow daisy, golden rod, timethy and other broad leafed grasses, fruit from the wild raspberry and saskatoon bushes are extremely delightful to the . The calcium hardness of the previously mentioned spring is 5 grains per gallon, total hardness is 17 grains per gallon, correction as to spring for site #, we will renumber this site #1A and the adjacent stream just below the spring will be called Streeter No. 1.

Shrubby cinquefoil is another type of shrub noted here. Equisitum, and American vetch are quite common. The ground here is soft and somewhat rough but does not exhibit the hummocky type terraine, previously seen in other watersheds, such as Cache Percotte and Tri-creek. At site #1, the creek water has a hardness of 7 grains per gallon, this is the calcium hardness, the total hardness was 13 grains per gallon. Water temperature is 48°F at this site, specific conductance of site #1 was 460 micromos per centimeter. We shall continue up stream until the next spring. We continued a little further westward up east Cache-Percotte creek to the second larger

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spring cropping out on the east side of the creek bank, somewhat 20 to 30' above the creek bottom. This spring appeared as a contact spring flowing from thin bedded flaggy type sandstone. A picture was taken at this site. A new film was started at the beginning of this project, I believe this recent photograph is approximately photograph #5. Water temperature at spring 2a is 46°F, specific conductance is 490 micromos per centimeter. The calcium hardness at site 2a is 9 grains per gallong, the total hardness is 16 grains per gallon calcium carbonate. The creek water just below site 2a is estimated to be flowing at approximately 50 gallons per minute at site number two. Water temperature and conductivity was taken at this site. Right at the creek side the orchid, ladies tresses, or long orchid was present. It is estimated between 5 and 10 gallons a minute flowing from the spring ~~xx~~ from site 2a. W-ter temperature at site 2 was 47°F, specific conductance was 450 micromos per centimeter.

Local week was observed growing on the steep side of the V-shaped channel just above site #2. A very beautiful and delicate previously noted but not described mountain bluebell was present at this site. Previously noted but not mentioned more red berries of the twisted stock are growing along the creek bottoms. Continuing up stream we have come to a large spring from the west side of east Streeter Creek. This spring was flowing at a rate of approximately 50 test gallons per minute. Photograph #6 was taken at this site. This site shall be called Streeter 3a. Two photographs were taken at this site. Water temperature at this site was 43°F, specific conductance was 465 micromos per centimeter. A foggy to blackie sandstone is present around site #3a. This again appears to be a contact type spring with a small horseshoe shaped topography or bowl surrounding the site. This is probably caused by periodic slumping. The ground here is quite moist, soft and hummocky. Vegetation is as previously described. Cblcium hardness is 8 grains per gallon, total hardness is 15 grains per gallon.

Leaving site 3a and proceeding up stream, the creek bottom is dry, as all the water flowing in east Cache Percotte Creek below site 3a comes from spring 3a and 2a, 1a, etc. We are continuing upstream to try and locate a higher spring previously noted along this creek bottom. A yellow flower resembling strongly the sow

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thistle is quite common. It is probably a false dandeloin, correction on the yellow flower. It has a blade type leaf similar to the camas. This will be identified later. It is a composite yellow flower similar to the sow thistle type flower previously mentioned. Speratic pieces of foggy type sandstone have been noted up to this point where the bedrock is becoming much more massive and cross bedded. A cross section of the stream profile at this point is becoming more V-shaped. We have crossed several yards of the stream bottom where the stream is dry and has been walked over has become quite hard and a recharge type of bottom.

We are now coming to an area where the bottom is quite hummocky, equisitum, cow parsnip, water hemlock, and other phreatiphytic type vegetation is quite profuse. Plain cinquefoil, dockweed are also noted here. We are picking up an increasing amount of groundwater discharge and now water appears in the stream' bottom. From field observation and from observing the aerial photographs, it would appear as though the basin can be divided into discharge and recharge areas on vegetation type as the aerial photograph appears to have a much darker tone with dense growth of poplar, trembling aspen, in recharge areas giving way to dry timothy type grasses or vice versa, giving way to dry grasses in recharge areas with the dark tone and the dense aspen in discharge areas. An example of this is shown to be marked off on photo YC 1090-88. There is a type of cocklebur in this area that has a very pungent smell upon being crushed. Approximately 50 - 100 yards above the start of the groundwater discharge area in the stream bottom, the stream flow is estimated to be approximately 20 - 30 gallons per minute. We have encountered a clum of saskatoons growing on the east side of the creek bank which have fruit that are approximately the size of your finger to thumb nail. We have spent the last 5 min. having supper (dessert); and are now continuing upstream where we have encountered a small spring emerging from the southwest bank of the creek. A picture was taken at this site. Springwater is flowing from this site at approximately the rate of approximately 25 gals. per minute, the bedrock here is blocky to massive sandstone being very cross bedded. The spring flows from the base of a cliff approximately 20' in height. This again appears ~~as~~ as a contact spring, the areas are bowl shaped,

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plantane and equisitum are very thick on the floor of the creek bottom which is quite lumpy. Other plants growing here are the shrubby swamp willow, yarrow, pea vine, timothy grasses, abundant cow parsnip, water hemlock and delphinium as well as buttercup, Canadian thistle and previously mentioned blue flowers. Water temperature here is 43°F, specific conductance is 500 micromos per centimeter. There is also a spring issuing from the southeast bank a little farther downstream. Upstream from this area the creek bottom is dry. Very poisonous larkspur is also present here. Around the top of the bowl shaped basin surrounding the spring, there are groves of twisted dwarfish ~~pipex~~ types of trembling aspen. ~~Six~~ Stinkweed, mustard or crusivera, mountain goldenrod, yellow daisy, water hemlock, yarrow, wild goosebery, wild strawberry, pea vine, American vetch and water birch are also present at this site. The smaller spring issuing from the south east bank has a flow approximating 10 gals. per minute. Water temperature at this site was 44°F, specific conductance was 520 micromos per centimeter. This site shall be called 5a, the last site as shown on the map is 4a. The calcium hardness of site 5a is 11 grains per gallon, the total hardness is 18 grains per gallon. We will now return to 4a for a chemical analyses here. The calcium hardness at site 4a was 9 grains per gallon, while the total hardness was 16 grains per gallon.

We will now follow along the contour line to the top of the east ridge where we will visit the drilling sites. A star flowered solomon seal was noted in the vicinity of springs 4a and 5a. Water samples were collected from sites 4a and 5a. We have come up on top of the ridge vegetation is stinkweed, yarrow, shrubby cinquefoil, sage, bedstraw, cutleaf, anenemie, blue bell, brome grass, wild oats, browneyed susan, solomon seal, American vetch is very common, local weed, mountain goldenrod, stubby variety of a larkspur, blue daisy, tree growth on the ridge tops is a very stunted variety of trembling aspen.

We will now have the story of the piezometer depths from John Beima. PI - 637, P2 - 555, P3 - 330, P4- 240, P5 - 140 and a water table at 65, slotted from 35 to 65. We have left the trailer site and are retracing our steps back down the west slope of the east ridge. We went back to spring 2a issuing from the southwest side of east Streeter Creek and took a water sample. We are now proceeding downstream to

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the confluence area where we will sample the large springs there. We stopped at the small V-notched weir measuring spring flow from the large spring issuing from the Westside of the east ridge near the confluence of east Streeter and Middle Streeter creeks to measure the temperature, hardness and conductivity. A water sample was also taken at this site. This site was called Streeter 6a. Calcium hardness at this site was 8 grains per gallon, total hardness was 15 grains per gallon. Water temperature was 44°F , specific conductance was 490 micromos per centimeter.

The time is 7:30 p.m. very large last quarter of the moon is sitting right on the peak of Streeter basin to the west. We are proceeding to the large spring issuing from the east side of middle Streeter just above the weather station to the west, correction the west side of middle Streeter Creek is a small 90° V-notched weir measuring the discharge from this spring. This site shall be called Steeter 7a. The discharge from spring 7a and 6a are between 50 and 100 gallons per minute. Hardness of site 7a was 6 grains per gallon, calcium hardness and 15 grains per gallon total hardness. Water temperature was 43°F, specific conductance was 450 micromos per centimeter. This will be our last reading for this day, Wednesday, August 28, 1968.

"Royal Canadian, this is August 29, 1968, it is presently 8:25 a.m." Our traverse for the day will extend down streeter creek from the confluence of east and middle Streeter Creeks to Willow Creek, we will then come back up Streeter Creek to the confluence of Streeter Creek and west Steeter Creek, go over the west ridge and sample and measure a temperature and conductivity of the spring waters in MacIntosh Creek. We will then follow McIntosh Creek up to the headwaters over the headwaters ridge, called Trout Creek ridge, measure some contact springs on the south side of Trout Creek ridge proceeding west to the south end of east Streeter Creeks, we will then find Trout creek ridge to the north and proceed down the north side of Trout creek ridge into east Streeter and meet the end of our west traverse of yesterday.

Along Streeter Creek bottom, immediately outside the cabin there is a stunted twisted variety of black poplar. This was not noticed higher in the basin.

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Our first stop is the small spring on the east side of Streeter Basin that supplies water to the Canada Department of Forestry Trailer. Vegetation surrounding this spring is black poplar, mountain alder and all the previous described types of yesterday. Water temperature of the spring was 42°F, specific conductance was 490 micromos per centimeter. This spring water was sampled somewhat downstream from ~~itx~~ where it was being emitted from the rocks. It is quite likely that the temperature would be lower at the source. Calcium hardness of this spring water called site 8a is 8 grains per gallon, calcium hardness and 14 grains per gallon total hardness.

We stopped at the next fairly large spring issuing from the creek bottom just east of Streeter Creek. This site is 9a on the aerial photograph. Water temperature at this site was 43°F, specific conductance was 520 mircromos per centimeter. A photograph was taken at this site. Calcium hardness at site 9a was 10 grains per gallon, total hardness was 16 grains per gallon calcium carbonate. This photograph will be taken later as the light is very bad at this time. The flow of this spring was estimated between 75 & 100 gallons per minute, or maybe as high as 200 gallons per minute. The sun is shining, the sky is very clear and looks like we are in for an ideal day for observation. We are walking northward down stream along the entrance road. The tree cover we are observing are bog willows, black poplar and trembling aspen that follow the creek bottom downstream. Small clumps of spruce are dotting the hillsides with limber pine being reserved to the upper portion of the ridges. Vegetation in Streeter Basin grows in bands along the valley sides being indicative of the groundwater discharge areas of the basin of the harder ground, grassy slopes indiciative of the recharge areas. In the discharge areas where springs emerge these places can be identified by the string of ~~[illegible]~~ phreatyphtic vegetation that follows the point where the spring emerges downstream. At mapsite 10a along the flood pine of Streeter Creek, one such place exists where no free water was observed at the surface, although the ground was quite soft and lumpy with course sedgetype grass present and very thick growth of bog willows.

We are following the very large stream that is flowing towards Streeter

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from the west side of East Streeter Creek ridge. We are proceeding upstream towards the large spring to measure this spring at its headwaters. The lower part of the basin in this area as we ascend appears to be a groundwater discharge area as the gcound appears fairly moist, quite hummocky with very lush growth of vegetation including honeysuckle, blueberry, and trembling aspen, a small tributary stream bottom has very thick growth of bog willow.

As we follow the small tributary creek upstream, we note that the creek profile cross section is quite steepsided in its upper reaches, terminating in a spring at its upper end. The vegetation is fairly constant as we climb upward being dominantly trembling aspen, black poplar and bog willow. At the spring where the creek waters first discharge to the surface, there is a basin shaped topography. There is a clear area immediately above the spring. We will locate this on aerial photograph. This site shall be called 11a. Site 6a through 14 are located on photograph 131090-70, 1"=400 ft. A photograph was also taken at this site. A water sample was collected at this site. Temperature of the water at the spring was 41°, specific conductance was 470 micromos per centimeter. Calcium hardness was 8 grains per gallon, total hardness was 14 grains per gallon. This site is called 11a, estimated discharge of this spring is approximately 100 gallons a minute. This photograph was a time exposure with anet stop of 7, exposure time was 1 second. We will now follow the tributary spring downward and re-measure just before its confluence with Streeter Creek. (Cont. on Tape 2)

The water temperature of the small tributary creek from spring 11a has measured in the streeter Basin valley bottom as 48°F. Specific conductance is 475 micromos per centimeter. This is shown on the photograph as site 12a. We have ascended to the headwaters of the small tributary creek just opposite the tributary creek we just ascended. This is headed by a small spring issuing from the east side of the Middle Basin ridge. Th water temperature of this spring is 41°F, specific conductance was 520 micromos per centimeter. This is site 13a. The loose bedrock at this spring is quite flaggy sandstone. There is no large topographic bowl surrounding the spring only a small depression. Some 10 to 20 yards north of this spring, there is another smaller spring. This spring is discharging approximately between 25 and 50 gallons per minute. Calcium carbonate hardness is 10 grains per gallon, total hardness is 16 grains per gallon. We have descended to the creek bottom just before the small tributary streams issuing from the previously mentioned springs into the creek. We are taking measurement at this site called site 13. Water temperature at this site is 47°F, specific conductance is 480 micromos per centimeter. Calcium hardness is 9 grains per gallon, total hardness is 15 grains per gallon.

We will go downstream past the entrance of the side tributary streams to the beaver dam and take another measurement at that site which will be called 14. The spefic conductance reading was re-read 460 micromos per centimeter. The temperature scale was incorrectly set. Nestor will re-check this reading. The check is in the affirmative. A picture was taken of the lower Beaver Dam on Streeter Creek. Streeter Creek just before the tributary was west Streeter Creek appears to be flowing between 200 & 300 gallons per minute. We stopped at this site just before the road covered crossing measured the water quality. A sample was also taken at this site as well as the photograph. This site shall be known as site 14. Water temperature at this site was 54°, specific conductance was 450 micromos per centimeter. Calcium hardness was 8 grains per gallon, total hardness was 15 grains per gallon. A water sample and a photograph was taken at this site.

We are walking down the access road and down valley below the confluence of West Streeter and the Streeter Creek main. As we walk along, we note that along the road side on the upslope area, we are approximately close to the contact between re-charge and discharge. Beginning the discharge area, the ground becomes quite lumpy and moist with a growth of equisitum and coarse grasses including timothy grass and a type of crested weed grass. There are small bog willow and black poplar growing in this vicinity, in the vicinity of the discharge. The dominant weed types are American vetch, blue daisy, stinkweed, sow thistle, buttercup, yarrow, Canadian Thistle, mountain golden rod, bedstraw and a small white yellow centered daisy and two other plants which are quite prominant. There is also a very silvery-green plant that has the appearance of a cross between lamb's quarters and ragweed as yet unidentified. It is very common.

We have gone down to immediately east of the creek to check on a small area, a small thicket of bog willow to ascertain of whether or not spring water is discharging at the surface. There is no free water noted although many of the phreatyphtic type water indicators = water discharge indicators, such as wild gooseberry, honeysuckle, the thick bog willow, water hemlock, larkspur and a large buttercup type of leaf as well as wild rose and a coarse sedge type of grass.

We are continuing the traverse downstream to pick up another tributary stream fed from the spring. Just below the previously mentioned site shown on the photograph as site 15, there is bedrock outcropping along the east side of Streeter Creek This bedrock is flaggy to blocky, very crossbedded ardulatious brown sandstone. Walking along the steep flood plane deposit and the top of a flood plane deposit which is sharply insight by the creek, we have come across previously described recharge type plant as local weed and the small everlasting which forms a small white mat on the ground surface. Other shrubby varieties in plants and weeds in the creek bottom are cinquefoil, both types, and dockweed. One thing worthy of note as we proceed downstream, the number of springs decreases quite marketly. The springs that are present are coming from higher in the basin. This gives guidance to the thesis that the underlying sandstone is a higher permeability so that the groundwater in this area apart from the immediate vicinity of the creek is rather strongly recharging.

We have a small tributary eastward up the east slope to where the tributary Y's. A characteristic feature about this triubutary worthy of note is that in the upper reaches, where one would visulize groundwater discharge the stream cross-sectional profile was characterized by ~~sbuap~~ swamp, suggesting that swamp is another indicator of groundwater discharge. From the top of this Y, a photograph was taken westward towards the front range of the mountains. This range is called the Livingstone Range. We stopped on a small knoll along the east margin of the basin and took a photograph looking northward over the small lakes just above the Streeter Ranch house the northside of Willow Creek is marked by strings of outcropping sandstone bedrock. We stopped along Streeter Creek ~~xx~~ just south of the small lake and took a measurement of the Creek waters. This site is known as Streeter #16. Water temperature at this site is 61°F, specific conductance is 425 micromos per centimeter.

Site 16 is located on photograph YC 1090 33, scale 1" = 400'. Water Temperature is 61°F, specific conductance is 425 micromos per centimeter. Photograph was taken of the steep gorge cut by Streeter Creek flowing northwards into Willow Creek. WE have stopped at the southwest end of the mouth of the two small lakes, it is our plan to measure the water quality at this end which should be the recharge end and also at the northeast end which should be the discharge end. This area is called Streeter 16a. Water temperature is 69°F, specific conductance is 405 micromos per centimeter. A water sample was collected at this site. We took a measurement of water quality at the discharge end of the small lake. The temperature was 59°F and the specific conductance was 420 micromos per centimeter. This is shown on aerial photograph as location 16b.

We are now walking eastward along willow Creek above the Creek — ( cut on the upper level of a flood plane. From the top of the flood plane down to the Creek, some 50' below us are a very thick growth of bog willow, black poplar and trembling aspen. Other shrubs are honeysuckle, wild gooseberry, blueberry, weed types are yarrow, a daisy, goldenrod and buttercup.

We are walking eastward along Willow Creek in a southerly direction hoping to find some groundwater springs discharging from the southwest side of the upper slope. Hopefully, this would give us a measure of water quality of the regional groundwater flow system.

We proceded southeastward along the mid-slope of theffood plane, to the conjunction of Streeter Creek to Willow Creek without finding any actual free water discharging from springs, although seepage water was noted. We dropped down into willow creek and had our lunch. We took off our boots and waded in the cool waters of willow Creek and somewhat revived our flagging spirits. A photograph 2 was taken of the bedrock outcrop on the southface of the Creek. Note, the ~~xxx~~ eastward dip of the bedrock with groundwater seeping just above the flaggy to blocky sandstone bedded outcrop. This is photograph #18 or 19. Water quality ~~and~~ was sampled at the Willow Creek site which is known as Cache-Percotte #17. Temperature of the

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Willow Creek waters is 68°F. Specific conductance was 425 micromos per centimeter. Calcium hardness was 5 grains per gallon, total hardness was 13 grains per gallon. Immediately west of Willow Creek a small groundwater seepage was noted. This seepage was shown on the map as being 17a. Water temperature from this seepage was 56°F, specific conductance was 520 micromos per centimeter. Total hardness of the groundwater seepage immediately west of willow Creek was 15 grains per gallon. Proceeding along the flat of Willow Creek in the eastwardly direction into the MacIntire creek basin, we will proceed westward up the McIntire Creek basin, measuring groundwater discharge springs and the water quality of the McIntyre Creek

We have just stopped on the northside of Willow Creek and taken a
3 photograph of a large black poplar, approximately 3 ft. in diameter. There is a fairly thick growth of wolf willow lining the Willow Creek at this point. As we ascend the very steep slope from Willow Creek to the ridge, to the low ridge top in McIntyre Creek, we have passed previously described plant types plus shrubby cinque foil, low bush cranberry, and mountain juniper. This low bush cranberry is very like bear berry, with the exception that its leaf is more pointed at the tip.

We have climbed up on the west side of the Willow Creek Valley on to the lower east ridge of Cache-Percotte Creek. This topographic high is sort of a locally broad table lamp sloping off quite steeply into Streeter Creek. Photographs (panoramic, Photograph view) were taken looking west into east and into Middle Streeter Creek, sweeping around to the west, looking south into the middle Streeter Creek, sweeping around westward to the north looking over willow Creek and Allie Streeter's Ranch. We climbed to the top of the east ridge dividing Streeter Creek and McIntyre Creek. Looking southward to the west side of willow creek valley, two small lakes ponded in the flat on the west high terrace above the Willow Creek Valley. Immediately north of the lake there small molded hills resembling moraine. Similar features are noted immediately on the north east side of Streeter Lake. These moraine type hills may be due to a Valley glacier that went over the most part of the porcupine hills during pynoramic type of ice age. On the crests of the ridges there are carnitic, porcitic and limestone eradic deposited there. Many of the ridges are fairly flat on top due to the fact that the ridges are kept with thick lenses of massive sandstone. At the base of the sandstone ridges, there is a sharp break in slope and along this base that marks the contact betwen a steep sandstone cap and the underlying shales. These springs appear as contact springs, they may possibly be concentrated by the cross~~beeding~~-bedding of the sandstone.

We are following along the north-south road, on the east side of East Streeter Ridge looking into McIntyre Creek valley. We have crossed a small riveen with water discharging downhill from the road. Following this riveen up stream we have located free water at the surface at a small round bowl like seepage area, approximately 100 ~~yas~~ yards above the road. We are measuring the qualityof the water, and taking a sample at the road site. This is shown on photograph YC 1090-84 as site 18a. Water temperature at this site was 47°F, specifice conductance was 570 micromos per centimeter. The water at this site was found to contain 11 grains per gallon of calcium carbonate and 18 grains per gallon total hardness. I was presently collecting a water sample at this site.

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Continuing southward we have come into another small wooded ravine. There is no free water at the surface at the elevation that we have entered the ravine so we will drop down until we encounter groundwater discharge. Main vegetation types are a lush growth of cow parsnip, delphinium, trembling aspen, coarse bladed grasses, American vetch, blue daisy, black poplar and phreatyphytic clump willow. Cow parsnip being by far the most dominant plant type. Descending the ravine, we come to a small growth of black poplar marking the head of groundwaters spring. From the head of this spring downward, the tributary stream bottom is clogged with clumps of bog willow. This site is located on aerial photograph YC 1090 84, as 19a. The temperature at site 19a was 41°F, ~~spark~~ specific conductance was 520 micromos per centimeter, calcium hardness was 8 grains per gallon, total hardness was 18 grains per gallon.

We are continuing our traverse to the south where we will cut the next ravine, measure the physical properties of the next discharge spring. The western side and lower portions of McIntosh Creek where the brush has been cleared off, the second growth appears to be largely black poplar. The thesis suggesting that the largest amount of groundwater discharge occurred on the eastern sides of the ridges seems to be supported by the vegetation which is very, very lush on the eastern sides of the ridges.

We have come to the next small ravine and have stopped at its tributary which is a spring discharging from a blocky to massive medium grained argelatious sandstone. The sandstone appears very cross bedded. This site shall be called 20a. A photograph was taken at this site. Water temeperature at this spring is 41°F, specific conductance is 550 micromos per centimeter. Calcium hardness is 8 grains per gallon, total hardness is 18 grains per gallon.

We will now continue southward to cut the nexttributary and measure the next groundwater discharge spring. The discharge at this spring was estimated. Approximately 20 yards south of site 20a, another large spring is discharging from a flaggy to a blocky cross bedded sandstone. A picture was taken at this site. The estimated discharge of this spring is between 50 and 100 gallons a minute. The Previous

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spring was estimated to be discharging at approximately 25 gallons per minute.

We are now proceeding westward, southward, towards the next ravine in the next groundwater spring. The next ravine we came to that contained a very large spring with a flow between 100 and 200 gallons per minute. Approximately due east of the drilling site, in the McIntosh Creek Valley bottom. A water sample was taken here and water quality measurements. This site is called 21a. Water temperature at this site is 41°F, specific conductance is 480 micromos per centimeter. Calcium carbonate hardness here is 9 grains per gallon, total hardness is 14 grains per gallon.

Tape on Streeter #3.

The time is 8:00 p.m. It is our intention to continue a survey today. We will go up middle Streeter Creek and up over the top of the ridge. It is Friday morning, August 30, 1968. The time is 9:30 a.m. I have just left the drilling site where one piezometer has been installed and sand poured into the hole to bring the level of the top of the sand to bring the level above the screen, approximately 4 1/2 bags were poured in, to obtain 7 ft. of sand in the hole. A barrel of slurry was dumped on top of this to create a tight seal over the sand. This hole will be back filled with gravel, approximately 75 ft. Another batch of slurry dumped in, more gravel added to bring the level to the level of the next piezometer point. The remaining duluted slurry will be build off the top of the gravel plug. Another bag of sand added and the second point installed.

I have left the drilling site, proceeded eastward ~~wa~~ over the top of the east ridge and am walking along the east side of the east ridge which forms the west ridge of McIntosh Creek . My objective is to proceed to the headwaters of the west tributary of McIntosh Creek and measure the properties of the spring emitting thereof. The topographic profile of the west flank of McIntosh Creek is step-like with resistant sandstone members forming the steep risers and the underlying rust resistant shale forming the more gently sloping step. The movement of groundwater through this step like ~~a~~ configuration material is downward through the fractured sandstone step and being discharged at the base of the steep riser, which co-incides with the break in slope. Vegetation indicative of this groundwater discharge are

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the characteristic phreatyphytic clump willows. A photograph was taken to illustrate this looking westward. Three more photographs were taken in a panoramic fashion of the west sloping, east ridge of McIntosh creek. These photographs show the preferential growth of material along the discharge areas of the west facing slope. This vegetation is dominantly phreatyphytic type willows. This type of bog willow also follows the point where the spring emerges from the hillside downward into the valley side. Weed associations to the bog willow are stinkweed, water hemlock, blue daisy, a blue zenia, type weed, mountain goldenrod, as well as wild raspberry, delphinium, very lush growth of timothy grasses, buttercup, yarrow, Canadian thistle, etc. This vegetation grows over a relatively thick black, dark gray to black, organic type soil, ~~wik~~ while the slow and the steeper parts of the riser are a thin sandy brunasolic gray wooded type for spruce growths I have just taken off from a small clump very easily providing meat for the pot when the situation arises. A very well worn game trail follows the top of the step at the base of the steep riser along the contour line of the valley side.

TYpical game in the area are elk, white tailed deer, the odd black bear and a variety of marmoths, ground squirrels, etc. This is also the natural hypitat for coyotes. Dominant deer species in this area is white tailed deer, as a less prolific meal deer cannot compete with the white tail. Once the white tail move into an area, they more less take over from the meal deer.

We have come to the first of the small springs issuing from the west side of McIntosh Creek. We will stop and measure the quality of this water. This site shall be called ~~six~~ Streeter #22a. Water temperature at this site is 43 1/2°F specific conductance is 520 micromos p e r centimeter. The total hardness of this water was 16 grains per gallon. Check site number. This site number shall be known as Streeter 22a as marked on photograph YC 1090-90, 1" = 400'. The exposed bedrock at this site was a blocky to massive medium to fine grained argulatious cross-bedded sandstone. A photograph was taken at this site. A subsequent photograph was taken to show the approximate profile of the longitudal section of the spring with a very steep headwall, raughly bowl shpped topography.

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There is a very large number of ground squirrel houses in this vicinity exposing the rich looking black organic soil.

I am now proceeding southward to the next ravine and its enclosed spring. The next spring, called site, shown on the photograph as site Streeter 23a has a water temperature of 43 1/2° and a specific conductance of 490 micromos per centimeter. It is estimated that the total hardness will be approximately the same as the last site and so this property was not measured at this site.

I am continuing southward along the contour line measure the last major spring in the headwaters area of the west tributary to McIntosh Creek. I am now coming into a more heavily wooded section of the Water Shed. Main tree types being trembling aspen with small clumps of black poplar in the valley bottoms and scattered white spruce on the slope sides. Massive cross-bedded sandstone crops out along the contour line of progression. The estimated flow of the last two springs areas were somewhat less than 25 gpm. Perhaps quite close to that figure.

Now coming to the next ravine, on the north facing headwater slope of west tributary of McIntosh Creek, there is approximately 20 – 30 gallons per minute of water flowing in this small tributary. This water is discharging from a higher spring which I will measure. The spring disbharges from a small topographic bowl some 20 – 30 yds. up the slope. These characteristic topographic bowls could be formed by a prodess of slump around the sides and the top. This site shall be called Streeter 24a. Water temperature at this site 39°F. Specific conductance is 440 micromos per centimeter. The spring waters here have a hardness , total hardness of 15 grains per gallon, calcium carbonate.

The time is now 10:30 a.m. The plan is to proceed upward over the top of the ridge measuring any groundwater spring encountered, to go southward down the opposite side of the ridge and measure the quality of the first groundwater spring encountered there. The previously described fir trees were examined closely. Correction, spruce trees. The needles of these trees are square in cross-section appearing to grow regularly on all sides of the stem. The tree is shaped much like the characteristic white spruce tree. This tree appears to have flowered not long

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ago, as the flowers are approximately cone size in bunches of two at the tip of the stems. The bark of this tree is quite smooth in the upper portions being faintly rough on the lower parts of the trunk. Beside the spruce tree is a lodgepole pine having a characteristic two needle to the bunch grouping. On a spruce tree probably two flower per each stem is the male and the female flower together as one appears to be approximately twice the size of the other. The male flower being quite slender and curled, the female flower being quite thick. This appears to be analagis in humans. It is also possible that there is a variety of balsam fir growing here. A characteristic plant, probably an indicator of recharge conditions is a type of cutleaf anenemy growing on the top of the ridges. This plant along with loca! weed and heather and a very stunted variety trembling aspen appears to be indicative of groundwater recharge in this type of environment, correction plant classified as heather is probably sage. Other types of plants present are shrubby cinquefoil, yellow daisy, brown eyed susan, yarrow and blue zinia or aster previously mentioned, a blue daisy, a solomon seal type plant.

I am now standing on the south side of Trout creek ridge. I will measure water properties of the springs issuing there from. The profile of the south facing side is also somewhat steplike though much less pronounced than the east facing side of East Streeter Ridge. Descending the southside of Trout Creek ridge vegetation is very sparse, indicative of a much high evaporation rate. Other characteristic plants are the low bush cranberry and a consistant mat of small ever lastings. The plant classified as a low bush cranberry may possibly be bear berry, correction, I believe this plant to be the low bush cranberry. The plant classified as sage is approximately one foot high, grows in a collection of half a dozen stems shooting out from the base. Each stem has green sharp pointed leaves, sphere shaped approximately 2 - 3" in diameter in length rather and approximately 1/4 - 1/3 " across. This leaf is somewhat rough to the touch, being having stiff spines. The underside is lighter green than the upper side which is a very light apple green. There are no flowers on this plant although rather pink buds appear at the tip. The small wild roses are in bloom here, the flowers being white.

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Descending the riser to the base, the ground appears more lumpy and vegetation becomes denser and types such as buttercup, delphinium, mountain golden rod, sinquefoil and clump willow are present. This area is shown as the letter "X" on the aerial photograph.

A little lower in the valley, a strip of bedrock is exposed, this area of bedrock exposure is lined with bear berry and buffalo berry. In the vicinity of a small ravine, clumps of trembling aspen and honeysuckle is scattered. Almost to the stream bottom, the ravine floor is characterized by rather heavy growth of timothy grasses, Canadian thistle, dephinium, stinkweed, mountain golden rod, and groundsquirrel hummicks.

The floor of Trout Creek is lined with black poplar, spruce and pine. Black poplar being the dominant type. Descending to the creek, water properties were measured. This site is known as 25. The water temperature was 54°F, specific conductance was 425 micromos per centimeter. Total hardness at this site was 13 1/2 grains per gallon.

The weeds previously classified as blue daisy is probably a blue aster. The air temperature in Trout Creek bottom was approximately the same as the water temperature, around 54°. The air temperature on the southern exposure of Trout Creek ridge is approximately 64°F.

As I continue to traverse over the upper slopes, one thing becomes quite apparent, groundwater flow systems in this environment are extremely local. Immediately below a steepsided peak are relatively flat areas with a much more less growth of vegetation, characterized by thick timothy grasses, and other phreatyphitic plant types. The more southerly aspects are very dry with very thin brunosolic type soils. Stunted and dry type vegetations, all indicative of a very high rate of evaporation. Flat areas below breaks and slope specially in more northerly aspects exhibit much thicker black orgainic soils, lush vegetation, [illegible] and other ground water discharge indicators. It appears as though the particular biotic environment is very closely associated with topographyas controlled by underlying geology and aspect. There is a very small cactus type plant with needles resembling somewhat

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those of a spruce needle clump. There are a pale green in color and grow somewhere between one and two inches high.

I have just passed a very steep sided ravine headed by flaggy to massive cross-bedded sandstone out crop. This ravine appears to be a dry type wash with no spring water discharging, perhaps only immediately after rains.

I am proceeding westward along the southside of Trout Creek Ridge, hopefully to pick up a groundwater spring discharging down the south slope of Trout Creek ridge and measure its water properties. I have come to a fairly large spring discharging close to the top of the south slope of Trout Creek ridge. This is located on aerial photograph YC 1090-75 as site 26a. The properties of this water shall be measured. This spring discharges from a fairly well jointed flaggy to massive crossbedded medium grained brown argelatious sandstone. There appears to be some iron stained, or iron bacteria growing on the bedrock joints. Water temperature at this site is 48°F, specific conductance was 445 micromos per centimeter. Total hardness was 16 grains per gallon. Groundwater discharge at this site is estimated between 50 & 100 gpm. A photograph was taken of this site. A second photograph was taken here making a total of eight photographs taken today.

I am now proceeding eastward along the north side of Trout Creek Ridge along the road and are coming into the east tributary of the Middle Streeter Creek basin. Much of the bedrock on the upland appears exposed at the surface, though this is not a hard bedrock, but probably has a weathered zone some 10 - 15' below the surface. I have just passed the small evergreen having needles characteristic of balsom fir. It was hoped to find a cone to check the possibility of this being douglas fir, but no cone was apparent. A short way down the north slope, there is a change in slope , characteristic vegetation being a growth of black poplar and very dense cow parsnip with rather thick soft soils. Characteristic of this particular environment among the black poplar growth is a high percentage of tree deadfall making traverse extremely difficult. Pea vine, American vetch, honeysuckle, spria, and mountain blue bell are very common in this particular environment. Water hemlock is another characteristic plant type. Clumps of water birch and black poplar follow the ravines from the headwaters downwards into the valley.

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Water birch grow from a dozen or so clumps on a single stem. They are approximately 15' high, have horizontal markings on the smooth bark which is reddish in appearance. The leaves are round and sharply pointed often finly dotted on the underside. The fruit is a catkin approximately 1" long and 1/4" thick. The upper portions of these ravines have no water flowing in them. They are very steep V-shaped with large sandstone boulders and rocks along the bottom of the stream bed. The upper two steep ravines have their confluence immediately above the game trail crossing the stream valley. This was followed for a short distance westward towhere two large groundwater springs were discharging. Some 30 yds. to the west, we crossed a small shallow depression filled with lush vegetation. This was followed down slope to the area of the groundwater spring, correction, this line is immediately east of the area where the groundwater springs are discharging, shown on aerial photograph as line 1 Y. The first spring shown as site 27a was measured, the second spring taken as being similar to the first. The first spring has a groundwater discharge guage measuring the flow.a (Tape 4 next).

Readings from site 27a and 28a were not recorded on last tape so will be repeated here. There were two photographs taken at site 27a. Water temperature 40°F, specific conductance was 490 micromos per centimeter and total hardness was 17 grains per gallon, calcium carbonate. The discharge at site 27a was estimated to be approximately 50 gpm. The discharge from the spring immediately northwest of 27a was estimated to be between 10 & 20 gpm. The road following the contour line into the next basin was followed until the road crossed the next ravine. This ravine was followed upward to a major spring discharging into the ravine. This flow is estimated to be approximately 15 to 20 gpm. Water temperature was 40°F specific ~~xxx~~ conductance was 450 micromos per centimeter and total hardness was 16 grains per gallon calcium carbonate.

I will now follow the contour line northward to the next major spring on the east slope of mid-Streeter Creek Ridge. The time is approximately 2:20 p.m. Small dark clumps on the aerial photograph just below the tree cover are clumps of brush approximately shoulder high, waist to shoulder ~~xx~~ high dominantly,

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honeysuckle was scattered, wild raspberry, cow parsnip and delphinium and lush coarse grasses also grow along this area. The topographic slope here is shallower and this appears to be disseminated groundwater discharge. The bed straw and American vetch as well as a wild zenia type blue flower with delphinium are much in evidence.

Arriving at the large upper spring on the east facing slope of ridge called 29a, I stopped to measure the water quality. Watertemperature at this site was 40°F, specific conductance was 460 micromos per centimeter. Total hardness was not measured here as it was approximated to be the same as the last site. Bedrock cropping out in the area was similar to previously described being medium grained, flaggy cross bedded sandstone. Approximate discharge was between 50 and 100 gallons per minute.

We will now retrace our steps a short distance sourthward to the seismic cut line, ~~floax~~ follow the cutline lower into the valley and pick up some lower elevation springs. We are guessing somewhat to where the upper road crossed the ravine below site 28a.. The ravine or the stream tributary at this point, had no water in it. This exemplifies the type of recharge, discharge waters that alternate up and down the valley. Dropping into the valley at the confluence of the tributary creek, draining springs 27a and 28a, there was no water in their tributary from 28a. The 27a was containing water flow in the vicinity of 50gpm. Following this stream downstream, the creek cross sectional profile was V-shaped with flaggy cross bedded sandstones cropping out along each side of the stream there. The stream section was fairly straight, and dropped off the fairly rapid slope. Another spring along the left hand side proceeding downslope appeared to have a discharge of approximately 15 - 20 gallons ~~per~~ minute. This site is called 30a. Measurements ~~xxxx~~ were taken here. Site 30 just before the entrance of the discharge spring, site 30a into the stream was also measured, while site 31 downstream from the contribution of site 30 was also measured. Site 30 had a water temperature of 50°F, and a specific conductance of 440 micromos per centimeter. Site 30a had a water temperature of 45°F and a specific conductance of 470 micromos per centimeter. Site 31 had a water temperature of 52°F, a specific conductance of 450 micromos per centimeter and a total hardness of 15 grains per gallon, ~~sixx~~ This appears to be the last site and in middle Streeter Creek. I will

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now decsend to the cabin, pick up the wagon and go down to the northern most end of the west ridge of west Streeter Creek and measure the springs on the east flank of the west ridge at different elevati ons. A comment worthy of note is that in the vicinity of the confluence of Spring 30a with the creek, the creek water appears to have decreased from a discharge of some 50 gpm. to approximately 15 gpm. Immediately down stream from this confluence, the cross sectional profile of the xxx creek appears to flatten out and be much broader. This extends for a short distance downstream where the creek fence begins to meander and becomes incised in a v-shaped valley. This is characteristic of ground cutting through massive cross-bedded sandstones in this area, while the more flatter profile is characteristic of ground cutting through underlying claystone.

After flowing through the meandering reincised meander through sandstone, the stream dischage appears to decrease to approximately 5 to 10 gallons per minute. Soxxx Some 200-300 yds. farther downstream at the site of the main discharge station from Middle Streeter, there is no water flowing in the creek whatsoever.

I have climbed up to the first large spring at the northend of the west Streeter ridge. This site is located on photograph YC1090-36 as site 32a. A photograph was taken at this site.. Groundwater was discharging from walls jointed, flaggy to massive crossbedded sandstone. Iron staining appeared on the sandstone from where spring water was discharging. Water was dischargingat a rate of approximately 5-10 gpm. and appeared to savior the bedding plain. This water temperature was 46°F, specific conductance was 550 micromos per centimeter, total hardness was 19 grains per gallon.

Continuing northward, some 30 - 40 yxx yds, we come across another spring almost identical to the last site. This site shall be known as site 33a. The water temperature at this site was x33xF 43°F, specific conductance was 540 micromos per centimeter, total hardness was not taken at this site as it was xx assuming to be similar to the last site.

I have climbed arou nd the shaded northwest side of the point, at this particular aspect, there is quite a heavy growth of aspen, of local clumps of black poplar. In the small ravine, clump bog willow follow the ravine down valley.

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Climbing up through the forest cover to the top of the ridge to the exposed southeast side, there is a much sparser grass and weed cover over a thin sandy brunasolic type soil. The small ravines or areas of concentrated groundwater discharge are marked by lines of clump birch, or shrubby saskatoon bush leading down valley. Most of the groundwater in these ravines is either desseminated or evaporated and transpired faster than it moves to the surface and no free water is present. Looking across the valley, it appears that the more shaded northerly aspects have a much heavier growth of brush cover. Possibly the evaporation rate is considerably less over ~~thisx~~this aspect freeing more available water for transpiration.

I will now proceed down the east facingslope, back to the wagon and will then drive up to the end of the road of west Streeter Creek and measure some of the large springs in that vicinity. Although the hillside appears to be carpeted with low blueberry bushes or some type of , there are no berries present. We are on the northern end of the west ridge of west Streeter Creek, there appears to be a much more sparse thin type of vegetation than on the east facing ridge on the east side of east Streeter. This may be due to the ~~relax~~ relative upland area of groundwater recharge on the ridge top. This will be checked for confirmation.

I have arrived back at the wagon, and will terminate this survey for the day and ~~gox~~ go up on the east ridge and check the piezometer installations.

Good Morning sports fans, its Saturday Aug. 31, 1968. This morning we proceeded to load some pipe and take it up to rig site and then we planned to continue up in west streeter. We climbed the first marked groundwater discharge, but found a well defined groundwater route. We continued up the slope and found a groundwater seepage. We followed this route to the source and found a very slow trickle of groundwater, about 5 gpm. The temperature here was found to be 54°F, specific conductance was 410 micromos per centimeter. The calcium hardness was 7 grains per gallong, total hardness was 14 grains per gallon (51A). From here we traversed down the slope, back to west Streeter Creek, then ~~proceedi~~ proceeded up to the end of west Streeter Creek, up the trail to our next site which we shall call 52. Water temperature at site 52 was 50°F, specific conductance was 480 micromos per centimeter.

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Calcium carbonate was found to be 10 grains per gallon, total hardness 16 grains per gallon. " The raspberries are good at this site, Ellis just can't stop eating". We continued about 300' south of this site to site 53 and the water was discharging here about 20 gpm. Water temperature at site 53 was 44°F, specific conductance was 480 micromos per centimeter, calcium carbonate was ~~8 gpm~~. 9 gpg., total hardness was 14 gpg.

We will continue down this discharge route in an easterly direction and go up the other side to where we hope to find another spring discharge. As we proceeded down the east facing slope, a delphinium type of plant was noted as well as American vetch, golden rod , and plenty of raspberries. As we proceeded down the east facing slope and proceeded back up the west facing slope, we encountered small thick areas of trembling aspen. As we continued up the west facing slope, we encountered several areas heavily laiden with grasses, mountain bluebell, cowparsnip and areas where wild game apparently been bedded down for the night.

We continue farther up this slope and we found a game trail, measuring about 6' in width. We continued farther up this game trail until we came to an area where apparently spring groundwater had been discharging that was presently dry

We shall continue up to 100' directly north of this and have hopes of finding some groundwater discharge after which we will continue back down the slope and take another reading. This site is noted as site ~~#x~~ 54 on the aerial photograph. After we had traversed approximately 75' northward, we still had not found any groundwater seepage, therefore we continue to traverse back down the west facing slope near site 52. We crossed the main creek channel and I have prepared a solo crawl up the east facing slope or the west side of the main creek channel. I came to a point where the secondary channel split into two, however, no evidence of groundwater seepage is evident. I found the channels to be dry and therefore shall continue back down to the vehicle where Ellis hopefully has dinner.

We will now proceed southward up the creek from site 53 up across what we believe is a cutline and up the slope northward facing about 200'yards. We stopped where the creek crosses a cutline. We shall call this site #56.

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Measurements were taken here. The temperature was 53°F, specific conductance was 430 micromos per centimeter, calcium carbonate was 8 grains per gallon, total hardness was 14 grains per gallon.

We shall continue farther up this creek in a southwardly direction. We estimated this discharge to be about 15 gallons per minute at the seismic cutline crossing. As we proceeded farther and farther up from the cutline, the amount of flowing groundwater seemed to be increasing. Also, air temperature was taken and was found to be 81°F.

We have now arrived at site 57, where measurements will be carried out. The groundwater seepage here was estimated to be approximately 10 – 15 gpm. Water temperature at this site was 40°F, specific conductance was 470 micromos per centimeter, calcium carbonate, 5 gpg., total hardness 15 gpg. A picture was also taken this site. This picture taken was #14. We moved farther up, approximately 100' where another spring groundwater discharge was noted. The rate of flow here was approximately the same as number site 57, 10 – 15 gpm.

At site 58, marked on aerial photograph, the water temperature here was 44°F, and the specific conductivity was 480 micromos per centimeter. Total hardness tests were not taken here. The site marked 59 on aerial photograph proved to be dry, however, the area had clumps of some type of birch trees and the game are extremely puntful in this area as I just saw a whole herd of deer pass of in a southerly direction, those incidently were white tailed deer.

We proceeded up the slope to the site marked 60 and found that there had been evidence of groundwater discharge, but the area was presently dry. We proceeded farther up to the top to the basin's edge and now are over-looking the other side. We will proceed down and take measurements in the area. We proceeded down the slope about 700 yds. and found some groundwater discharge we took a reading on this and found it to be 40°F, specific conductance was 440 micromos per centimeter, total hardness was 15 grains per gallon, calcimum ~~ha~~ carbonate was 9 gpg. We estimated the discharge to be 30 and 35 gpm. A picture was also taken at this site. We next proceeded northward looking for more groundwater discharge, but none was evident, so we proceded down till we

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hit the creek which was marked site 62. The water temperature here was 62°F, 540 micromos per centimeter, total hardness was 17 grains per gallon, calcium carbonate was 9 gpg. We then proceeded farther northward and up the slope back to the basin edge where the vehicle is located. We next took the vehicle down the slope toward west Streeter road till we came to the first well site where we will take samples with the water sampler and take a specific conductivity reading.

After we had finished taking water samples from four different wells, some of which proved to be dry, after we had taken the samples, we headed up to the next site. After putting in the third piezometer, we headed back down to the cabin for supper. Tomorrow, we shall hoepfully collect a plant suite for Streeter Basin. This will be the completion of field reconnaissance Survey for Streeter Basin.

As previously mentioned, is the fact that the vegetation here appears to be very lush. It is my opinion that in this area much of the groundwater discharge is transpired by plants and very little appears as open water. This is characterizing this area by an apparent lack of groundwater springs at the base of slope.

We walked down the seismic line to where we intercepted the old trail coming down from the east ridge. From there we cut around the contour line to approximately the 3600' elevation and dropped straight down the steep cut to Cache-Percotte Creek. This cut had a slope of 40°. We continued on up the creek to the the Cache-Percotte main discharge station. We took a sample and a photograph here. This site was called Cache-Percotte #3. The Cache-Percotte main discharge station was a trapieoziodal weir. This type of discharge station appears to be the only reasonable type of station to use and a basin like Cache-Percotte that has such a coarse dead material. The stream discharge statio ns used higher in the basin on the tributaries were V-notched weirs, 90° type. These weirs caused a small dam of water to form behind them, some of which subsequently began leaking around the weir and within a space of two years, most of the water was by-passing the V-notch. The elevation of this site was 3760' above m in sea-level. The water temperature at Cache-Percotte #3 was 52°F.

As we traverse up the main Cache-Percotte Creek, the creek bottom appears to be quite V-shaped, filled with underbrush and dead ~~xxxx~~ fall. The banks along the creek are lined with fairly deep mosses, the ground is somewhat rough and lumpy. Such phreatyphytic plants as equisitum, labrador tea and shrubby swamp willow suggest that there is a fair amount of seepage continuously along the sides of the channel bottom. The main evergreen types are white spruce and balsom fir.

We proceeded up Cache-Percotte main creek to elevation 39-32. The time was 6:20 p.m. Air temperature was 75°F. At this point a considerable amount of groundwater seepage from discharge springs was entering the CachePercotte main stem from the southeast. We took a water sample here and also the water temperature, correction this elevation was 3892, water temperature of Cache-Percotte #4a, the groundwater discharge spring was 43°F. The water temperature of Cache-Percotte #4, the stream just above the discharge spring #4a was 52°F, hardness of the stream at this point was 11 gpg. calcium carbonate. The hardness of the groundwater discharge spring at Cache-Percotte #4a was 14 grains per gallon, calcium carbonate.

We followed tributary #4a upslope to the source. The valley slope for the lower part of the ascent was covered with thick hummocky mossy ground supporting the growth of sage and equisitum and labrador tea. Black poplar were also fairly abundant. As we ascended the slope broadened out into a flat boggy area with much open water. In this area was open water standing in a rather flow through type bog, xxx there are rather coarse sedge grasses , dwarfed white spruce, very hummocky lumpy moss, and bog flowers such as yellow lady slipper. White lady slipper and fly specked orchid also present is a three-leaf solomon seal.

We continued up the tributary stream to station, Cache-Percotte 4b, the elevation at this point was 3985' above main sea-level. We took a water sample here and a photograph. The air temperature was 75°F, the time was 6:50 p.m. Water temperature at this site was 47°F . This tributary is made up primarily of groundwater seepage. The groundwater appears to be seeping into the tributary which is no well-defined, channel, but, a rather broad boggy area as it ~~descends~~ Decsends downslope.

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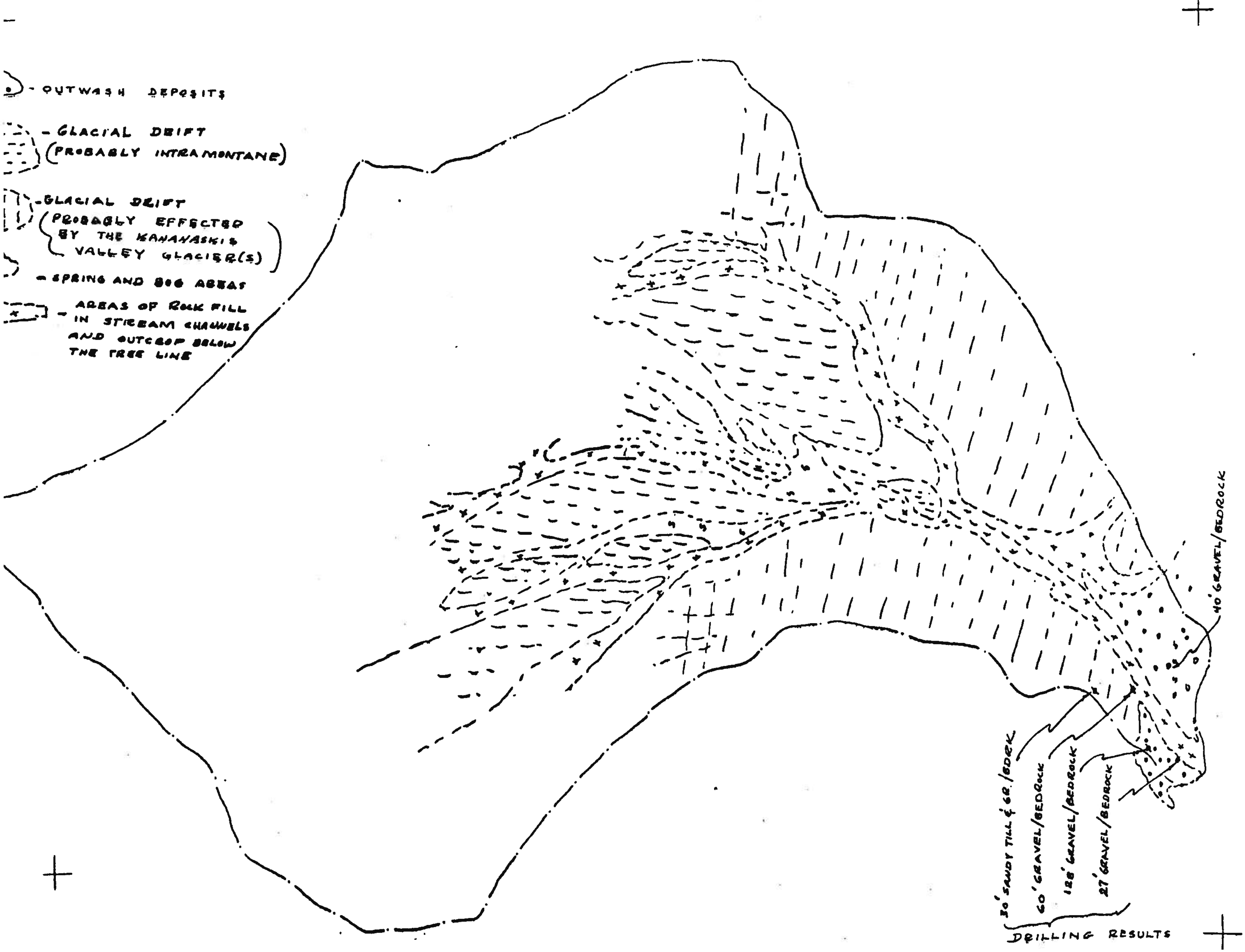
We continue to follow the ephemeral stream channel bed from 4b up slope through the two elevated mounds to ascertain whether or not the groundwater discharge is being fed by surface mounted water. As we follow up the emphemeral channel bed upwards, the channel bed was moss covered, lumpy and supported vegetation of equisitum, sedge grass, shrub willow, black poplar, etc. There proved to be no ponded water on the up sloped side of the elevated mounds.

We continued up slope and cut the road, we ended the day's traverse at 7:20 p.m. In closing the day was very hot, average approximately 80°F.

# THE MARM T CREEK WATERS D AREA

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