HYDROLOGY OF THE CACHE PERCOTTE BASIN, ALBERTA, CANADA

by: D.R. Stevenson

1969

Alberta Research Council
Open File Report 1969-10

HYDROGEOLOGY OF THE CACHE PERCOTTE BASIN, ALBERTA, CANADA

by

Douglas Roy Stevenson

1969

Alberta
RESEARCH COUNCIL

CONTENTS

	Page
Abstract	1
Introduction	3
General statement	3
Location	3
Objectives	6
Scope	6
Methods of investigation	7
Previous work	8
Present work	9
Acknowledgments	9
The hydrogeologic environment	10
General concepts	10
Climate	11
Topography and aspect	15
Drainage	16
Vegetation	17
Soils	18
Surficial materials	19
Bedrock	20
The groundwater regime	23
General concepts	23
Field reconnaissance	23
Model solutions	24
The field model	25
Analog model	32
Discussion of the analogs	32
Quantification of the analogs	35
Basin yield	37
Leakage out of the basins	37
Coefficient of recharge	37
Physical quality of waters	39
Chemical quality of waters	41

Page

The groundwater balance 44

General 44

Recharge 44

Groundwater discharge 45

Equivalent specific volume discharge 48

Discussion of the groundwater balance 48

The hydrologic balance 53

The general equation 53

Precipitation 54

Total drainage from the basins 54

Evapotranspiration 55

Change in basin storage (ΔS) 57

Discussion of the hydrologic balance 60

Summary of results 62

I. The hydrogeological environment 62

II. The analogs 63

III. Physical quality 64

IV. Chemical quality 64

V. Groundwater balance 65

VI. The hydrologic balance 65

References 67

Appendixes 69

Appendix A. Summary of surface features expressing hydrogeological conditions 70

Appendix B. Specific conductance and chemical analyses of groundwaters 71

ILLUSTRATIONS

Figure 1. Location of the Cache Percotte and Whiskeyjack basins 4

Figure 2. Instrumentation network in Cache Percotte and Whiskeyjack basins 5

Figure 3. Water level fluctuations in piezometers and water table observation well at site CP-1 in response to precipitation 30

Page

Figure 4.	Water level fluctuations in piezometers and water table observation well at site CP-2 in response to precipitation	31
Figure 5.	Analog of regional groundwater flow	in pocket
Figure 6.	Analog of local groundwater flow	33
Figure 7.	Stream discharge fluctuations in response to precipitation	38
Figure 8.	Specific conductance profiles	40
Figure 9.	Chemical quality of waters in Cache Percotte and Whiskeyjack basins	43

TABLES

Table 1.	Long-term climatic records from Jasper, Entrance and Edson	12
Table 2.	Basin yield and specific volume discharge	28
Table 3.	Underflow in Cache Percotte and Whiskeyjack basins	49
Table 4.	Equivalent specific volume discharge	50
Table 5.	Total drainage from Cache Percotte and Whiskeyjack basins	56
Table 6.	A comparison of methods of estimating evapotranspiration	58
Table 7.	Evaporation from Cache Percotte and Whiskeyjack basins	59
Table 8.	Precipitation and changes in moisture storage in Cache Percotte and Whiskeyjack basins	61

MAPS

Map 1.	Geological map of Cache Percotte and Whiskeyjack basins	in pocket
Map 2.	Groundwater map of Cache Percotte and Whiskeyjack basins	in pocket

no maps available

HYDROGEOLOGY OF THE CACHE PERCOTTE BASIN,

ALBERTA, CANADA

ABSTRACT

Hydrogeological reconnaissance in Cache Percotte forest, including Cache Percotte and Whiskeyjack basins, produced descriptions of hydrogeologic environments, of the nature of groundwater discharge features, and of the quality of waters. Recharge and groundwater discharge areas were recognized and outlined on aerial photographs, and a groundwater map of the area constructed. The lateral and upper boundaries of groundwater flow systems of the field model were generally defined from a synthesis of the groundwater map, the topographic map, and water quality data.

The drilling program produced examples of changes in hydraulic head with depth in recharge and discharge areas, and a *regional value of hydraulic conductivity* (0.20 igpd/ft^2, or 1.32 x 10^{-2} darcys).

Two-dimensional analogs of the groundwater flow systems were constructed and quantified to evaluate groundwater movement. The *average specific volume recharge* is 0.031 igpd/ft^2 in Cache Percotte basin, and 0.037 igpd/ft^2 in Whiskeyjack basin. Contribution to regional groundwater flow, or *leakage out of the basins*, is approximated as 75 percent under the floodplains of the main creeks, and 15 percent under remaining areas. These values were applied to the field model of Cache Percotte and Whiskeyjack basins and the following respective hydraulic properties calculated:

natural basin yields are 4.13×10^5 igpd (0.77 cfs) and 2.72×10^5 igpd (0.51 cfs); *basin leakage values* are 1.6×10^5 igpd (0.30 cfs) and 0.82×10^5 igpd (0.15 cfs); *specific volume discharges* are 0.019 igpd/ft^2 and 0.029 igpd/ft^2, and *coefficient of recharge* in both basins is approximately 55 percent of precipitation, assuming seven months of active groundwater recharge. The total volume of groundwater discharge, from groundwater balance analyses, per square foot of discharge area, or *equivalent specific volume discharge*, cannot be calculated unless all the components of the groundwater balance equation are evaluated independently or measured directly. Applying the values of *specific volume discharge* to the groundwater balance equation during dry periods produces the following interpretation of the distribution of groundwater discharge in Cache Percotte and Whiskeyjack basins, respectively: 25 and 23 percent forms *streamflow*, 2 percent forms *underflow*, and the remaining 73 and 75 percent forms *evapotranspiration*.

Annual *precipitation*, (averaged over 4 years), over Cache Percotte and Whiskeyjack basins is 23.1 inches and 24.3 inches, respectively. Precipitation received by Cache Percotte basin is distributed in the following manner:

1. 76.0 percent forms evapotranspiration;
2. 16.1 percent forms streamflow (11.9 percent surface water, 4.2 percent groundwater);
3. 7.4 percent forms basin leakage;
4. 0.5 percent forms underflow.

Precipitation received by Whiskeyjack basin is distributed in the following manner:

1. 66 percent forms evapotranspiration;
2. 24.8 percent forms streamflow (19.4 percent surface water, 5.4 percent groundwater);
3. 8.5 percent forms basin leakage;
4. 0.7 percent forms underflow.

Discharging groundwater is diluted with surface waters at the ground surface, in the shallow subsurface, and in streams. Total dissolved solids contained in groundwaters discharging at the ground surface vary directly with the lengths of underground flow.

Most of the groundwaters and surface waters in the basins were of the calcium bicarbonate type. Waters from the west subbasin of Whiskeyjack basin were of the sodium-calcium bicarbonate type.

INTRODUCTION

GENERAL STATEMENT

The Cache Percotte basin is the project title given to two small, adjacent drainage basins (Figs. 1 and 2) that cover some three and three-quarter square miles of the Cache Percotte Forest, an area of approximately 11 square miles. These basins are drained by Cache Percotte Creek, and Whiskeyjack Creek, a tributary of Hardisty Creek, and shall be referred to in this report as Cache Percotte basin and Whiskeyjack basin. Watershed research is being carried out in these basins by cooperating provincial and federal government agencies as part of the National Program for the International Hydrologic Decade (Cache Percotte Progress Report, 1967). Hydrogeologic investigations, carried out by the Groundwater Division of the Research Council of Alberta, form the content of this report.

LOCATION

The Cache Percotte basin research area is situated in west-central Alberta, Canada, immediately southeast of the small town

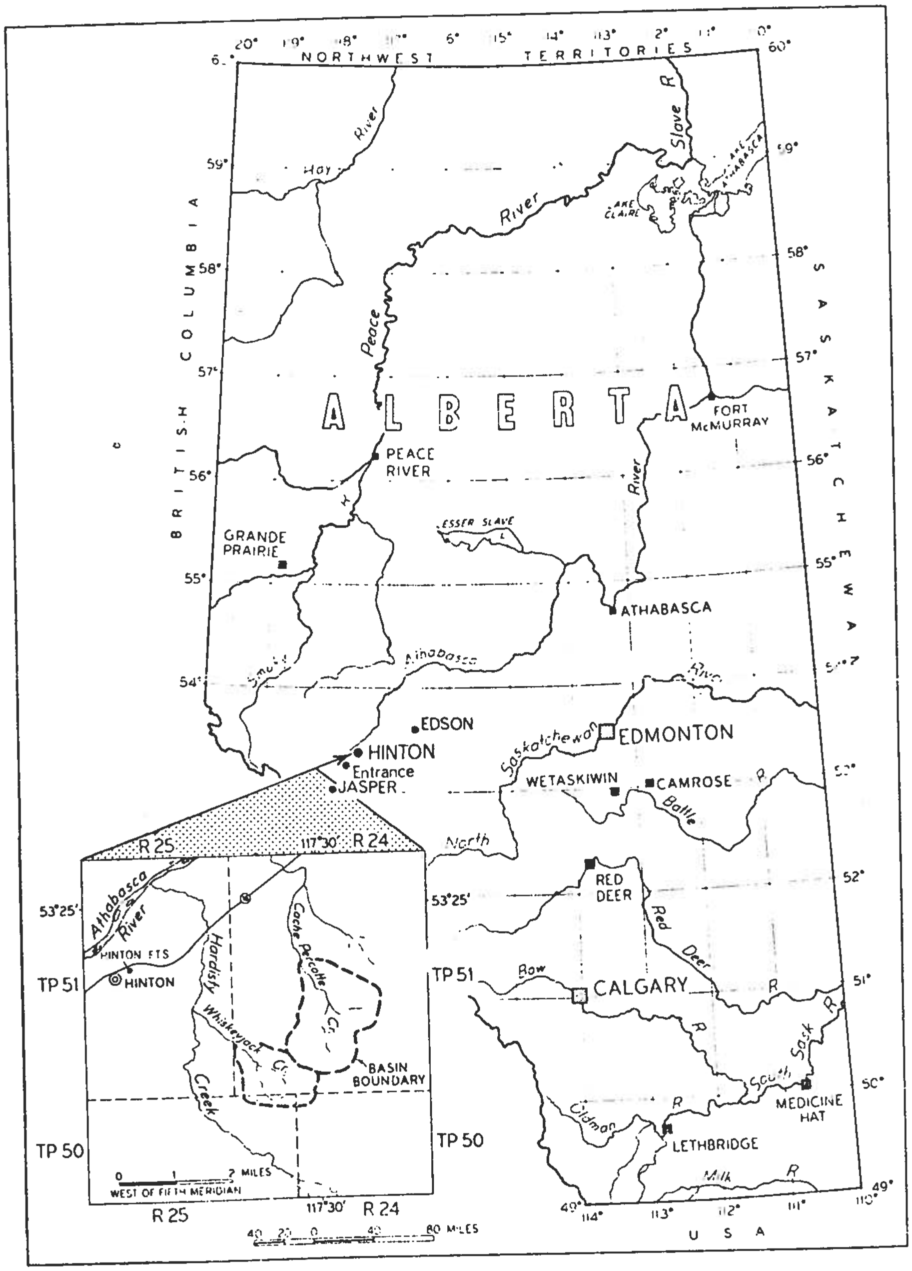

FIGURE 1. Location of the Cache Percotte and Whiskeyjack basins

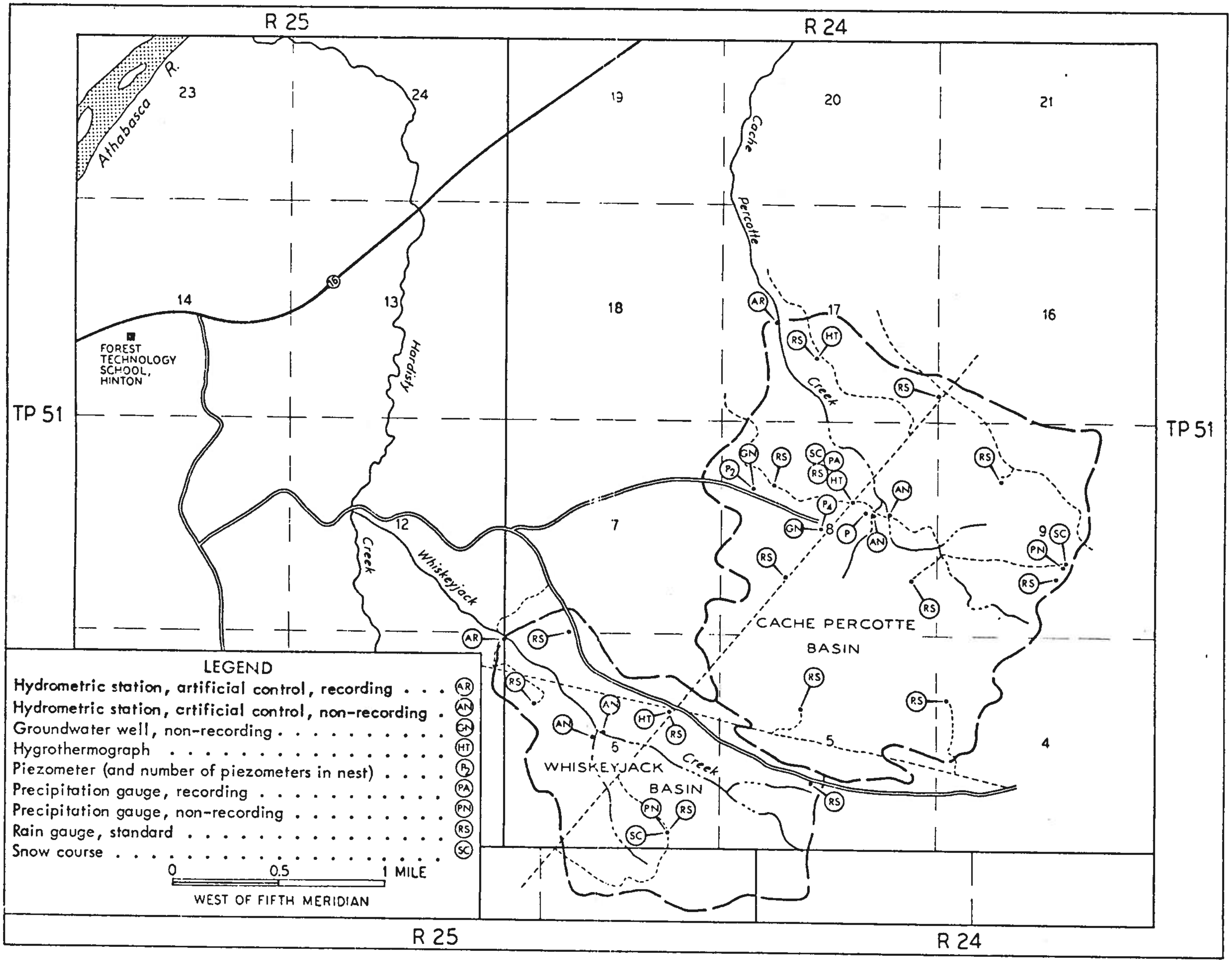

FIGURE 2. Instrumentation network in Cache Percotte and Whiskeyjack basins

of Hinton, approximately 180 miles west of Edmonton on the Edmonton-Jasper Highway (Fig. 1). This research area occupies most of the southwest part of township 51, range 24, west of the 5th meridian, in terms of the Alberta Land Survey System, immediately surrounding the intersections of latitude 53°23' north and longitude 117°30' west.

OBJECTIVES

The objectives were as follows:

1. To define a method of mapping groundwater discharge and recharge areas in forested watersheds by (i) the presence of groundwater discharge features in the field and (ii) their subsequent recognition on aerial photographs.
2. To determine the total volume of groundwater discharge (from balancing the groundwater discharge equation (defined in the section on "The Groundwater Balance")).
3. To determine the equivalent specific volume discharge (from dividing the volume of groundwater discharge by the mapped area of discharge).

SCOPE

The scope of this report comprises:

1. a description of the parameters of hydrogeologic environments within the basins, including climate, topography, vegetation, soils and geologic materials;
2. the construction of a geological map outlining the location, approximate thickness, orientation and nature of geologic materials, and the location of sites where geologic materials were sampled;
3. the construction of a groundwater map outlining persistently dry areas (areas that usually indicate a relatively high rate of recharge), persistently wet areas (areas that usually

indicate a relatively high rate of groundwater discharge), and areas between the two extremes (hinge areas of dominantly lateral groundwater movement), and the location of sites where groundwater quality was measured or where samples were collected for chemical analysis;

4. an assessment of groundwater and hydrologic budgets based on existing data; and
5. a discussion of the results.

METHODS OF INVESTIGATION

Hydrogeologic reconnaissance was carried out to observe and describe the groundwater regime and the physical features of hydrogeologic environments. Included in the reconnaissance were observations or measurements of the following interrelations:

1. Forms of groundwater discharge and their location with respect to elevation, aspect, topography, and geology.
2. Temperature and specific conductance of spring waters, seepage waters, groundwater ponded at the ground surface, and adjacent stream waters.
3. Plant associations found in habitats having wet, damp, and dry soils, and their variations under different conditions of aspect, elevation, and slope.
4. Soil composition, thickness, and microtopography in groundwater discharge, hinge and recharge areas.
5. The composition, texture, and structure of geologic materials.

Plant habitats characteristic of concentrated groundwater discharge areas, sheltered and exposed hinge areas, and recharge areas were examined in the field and outlined on aerial photographs of the basins; these outlines were subsequently transferred to a topographic map at the same scale. In this manner an areal map of the basins was produced delimiting areas of concentrated groundwater discharge (persistently wet areas), areas of recharge (persistently dry areas), and hinge areas (lying between the two extremes).

Sections of surficial and bedrock materials exposed by road and stream cuts were examined during the reconnaissance. These deposits were outlined on aerial photographs and these outlines subsequently transferred to a topographic map at the same scale. Lithologic data obtained from the observation well drilling program, seismic shotholes, and geological reports were used to refine the geological map constructed from the interpretation of the aerial photographs.

Samples of geologic materials were selected for mechanical analysis. Selected samples of groundwater discharge and stream waters were collected for complete chemical analysis (Appendix B).

Hydraulic conductivity values of geologic materials were obtained from bail-test analyses, permeameter tests, and analog analyses.

Meteorological and hydrometeorological data from the basins, obtained from the Hinton School of Forest Technology and meteorological data from the Edson Weather Station, were analysed by existing methods and used in assessing the hydrologic budget.

PREVIOUS WORK

Bedrock geology of the general area, including Cache Percotte and Whiskeyjack basins, was mapped by A. H. Lang (1947) of the Geological Survey of Canada, at a scale of one inch to one mile. The surficial geology was described at a map scale of 1:50,000 by M. Roed in an unpublished report completed in 1964.

PRESENT WORK

The instrumentation phase of Cache Percotte basin (Fig. 2) that began in 1964 is now completed (Cache Percotte Progress Report, 1968). Data from instrumentation sites are being collected continuously by the technical staff of the Hinton School of Forest Technology. In 1966 the Technical Division of the Alberta Department of Lands and Forests prepared a topographic map at a 1:15,840 map scale contoured at 20-foot intervals; this map serves as the base map for the report. Aerial photographs of 1:7,920, 1:15,840, and 1:63,360 scales were used in the preparation of the report. In 1967 the Soil Survey Division of the Research Council of Alberta prepared an unpublished report (Lindsay, 1966), including a 1:15,840 scale map, outlining and describing the soils of the Cache Percotte basin.

During part of July, 1968, hydrogeologic reconnaissance, as previously outlined, was completed by the writer and a field assistant.

ACKNOWLEDGMENTS

The writer acknowledges the assistance of the technical and professional staff of the Hinton Forestry Training School for assistance in identifying plants in the area, and for providing hydrological data from meteorological, hydrometeorological, and groundwater sites.

Cooperation from the Meteorological Division, Canada Department of Transport, and from the Inland Waters Branch, Canada Department of Energy, Mines and Resources is appreciated.

Mr. R. Stein, Groundwater Division, constructed the analogs. Mr. N. E. Zacharko, Groundwater technician, assisted the author during the reconnaissance. Mr. H. F. Weiss of the Groundwater Division drafted the maps and figures. Mrs. D. C. Borneuf and Mrs. S. P. Cane typed the report.

THE HYDROGEOLOGIC ENVIRONMENT

GENERAL CONCEPTS

The parameters of the hydrogeologic environment (the climatic, topographic, and geologic conditions present) form the physical characteristics of an area. The interactions of these parameters and their influence on the properties of the groundwater regime change throughout the hydrogeologic domain. In recharge areas climate, topography, geology, and vegetation combine to determine the size of the area and the rate and frequency of recharge. These parameters also determine the proximity of the water table to the land surface and its interaction with the soil moisture and root zones.

Within the region of dynamic groundwater flow, existing geologic and topographic conditions control the shape and size of groundwater flow systems, as well as specific volume discharge and water quality.

In areas of groundwater discharge, climatic and biologic influences are significant where the groundwater flow system is hydraulically connected to the soil moisture or root zones. In such cases, groundwater discharge is consumed by evapotranspiration up to the maximum potential evaporation; excess groundwater discharge appears on the ground surface as seepage or spring-flow which is ponded at the surface or runs off to form the groundwater component of streamflow. In groundwater discharge areas where the groundwater flow system is not discharging to the soil moisture zone but, for example, into significantly more permeable subsurface or stream-bed materials, the major part of groundwater discharge may form interflow or underflow.

The following paragraphs describe the nature of the parameters of hydrogeologic environments present in Cache Percotte and Whiskeyjack basins.

CLIMATE

The general area surrounding Hinton has been classified as DFB to DFC, according to the Köppen classification of climates of the world (Canada, 1957). The letter "D" is defined as meaning "humid micro-thermal climates, rain or snow with cold winters." Mean temperature of the coldest month is below 26.6° F and mean temperature of the warmest month is above 50° F. The letter "F" is defined as meaning "precipitation throughout the year." The combination "DFB" is defined as meaning "humid, continental, cool summer, with no dry season," and "DFC" is defined as meaning "subarctic with a short, cool summer of one to three months, and having a mean temperature above 50°F."

Table 1 gives precipitation, temperature, and available wind data for Jasper, Entrance, and Edson; these towns are within a fifty mile radiua of Hinton and have 30 or more years of record. Temperature and precipitation records from Edson and Entrance are comparable and can be applied with reasonable confidence to conditions at Hinton which is located approximately five miles northeast of Entrance. Meteorological data from Edson were used in the calculation of the hydrologic budgets of Cache Percotte and Whiskeyjack basins.

Table 1. Long-Term Climatic Records from Jasper, Entrance and Edson

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	n
Jasper														
MEAN PRECIPITATION IN INCHES														
Rain	0.1	0.1	0.1	0.5	1.3	2.2	2.0	2.2	1.4	1.0	0.4	0.2	11.5	25
Snow (W.E.)	1.0	0.9	0.5	0.3	0.1	0.0	0.0	0.0	*	0.1	0.8	1.1	4.8	25
Heaviest 24-hr pptn (inches)	1.0	2.0	0.8	1.4	2.8	1.4	3.4	1.5	1.7	1.0	0.9	1.2	3.4	45
Year	55	48	30	55	44	35	35	57	38	21	55	38*	35	
MEAN TEMPERATURE IN DEGREES F														
Daily	13	19	26	38	48	54	59	57	50	41	26	18	37	25
Daily maximum	22	30	38	50	61	67	73	71	63	52	35	27	49	25
Daily minimum	2	8	15	26	34	41	45	44	37	29	17	10	26	25
Monthly maximum	44	48	55	68	77	81	89	87	77	70	52	44		25
Monthly minimum	-27	-24	-13	10	22	30	36	33	24	12	7	-21		25
WIND														
Percent frequency from noted directions														
North	5	8	8	6	6	7	4	6	5	4	5	3	6	26
Northeast	5	7	8	6	5	5	2	4	4	3	4	4	5	26
East	5	6	6	6	5	5	4	4	4	3	3	3	5	26
Southeast	3	2	4	5	5	5	5	4	4	4	4	3	4	26
South	15	14	15	14	15	15	18	17	20	20	19	15	16	26
Southwest	31	31	21	22	22	22	24	25	27	32	29	34	27	26
West	12	12	16	16	15	15	16	14	15	14	15	16	15	26
Northwest	3	4	5	7	7	6	5	4	5	4	4	3	5	26
Calm	21	18	15	18	19	17	22	21	16	16	16	19	18	26

.../continued

Table 1. Long-Term Climatic Records from Jasper, Entrance and Edson (continued)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	n
Entrance														
MEAN PRECIPITATION IN INCHES														
Rain	*	*	0.1	0.4	2.0	3.6	2.7	3.1	1.7	0.6	0.1	0.1	14.4	30
Snow	0.8	0.7	0.9	0.8	0.1	0.0	0.0	0.0	0.1	0.5	0.8	0.8	5.5	30
Heaviest 24-hr pptn (inches)	1.3	1.0	1.0	1.2	2.1	3.1	2.0	2.7	2.1	1.6	1.3	1.5	3.1	44
Year	59	57	20	35	35	35	44	53	38	32	32	33	35	
MEAN TEMPERATURE IN DEGREES F														
Daily	12	17	26	38	47	53	58	56	50	40	27	17	37	30
Daily maximum	23	30	39	52	62	68	74	71	64	53	38	28	50	30
Daily minimum	1	3	13	24	33	39	43	41	35	27	16	6	23	30
Monthly maximum	49	52	57	71	80	82	89	85	81	73	59	51		30
Monthly minimum	-34	-30	-20	4	20	29	32	31	20	7	-8	-25		30
Edson														
MEAN PRECIPITATION IN INCHES														
Rain	*	*	0.1	0.4	2.0	3.6	3.6	3.1	1.5	0.4	0.2	0.1	15.0	30
Snow	1.0	0.7	0.9	0.7	0.1	0.0	0.0	0.0	0.2	0.6	0.9	0.9	6.0	30
Heaviest 24-hr pptn (inches)	0.8	0.8	0.8	2.0	2.1	3.1	2.6	1.9	1.5	1.3	1.4	0.8	3.1	44
Year	43	36	20	40	46	44	55	31	38	39	42	33	44	
MEAN TEMPERATURE IN DEGREES F														
Daily	8	14	24	37	48	54	59	56	49	38	23	13	35	30
Daily maximum	19	27	36	50	62	68	73	71	63	51	34	24	48	30
Daily minimum	-2	1	11	24	34	40	44	42	35	25	14	2	23	30
Monthly maximum	45	51	57	71	81	82	87	85	81	72	55	47		30
Monthly minimum	-31	-29	-19	4	21	29	33	31	21	7	-8	-24		30

.../continued

Table 1. Long-Term Climatic Records from Jasper, Entrance and Edson (continued)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	n
Edson (continued)														
WIND														
Percent frequency from noted directions														
North	5	7	6	6	3	2	0	0	1	4	3	7	4	16
Northeast	11	14	10	11	7	2	4	1	5	3	14	10	8	16
East	6	11	12	11	16	11	4	8	6	2	5	9	8	16
Southeast	0	0	0	0	0	1	0	0	0	0	0	0	*	16
South	0	0	0	1	0	0	0	0	0	0	0	0	*	16
Southwest	1	6	6	1	1	1	2	0	1	0	5	3	2	16
West	41	50	42	48	44	51	68	61	47	57	42	49	50	16
Northwest	26	8	19	19	20	27	17	16	26	25	24	19	21	16
Calm	9	4	3	4	9	5	4	12	13	10	7	3	7	16

* Several occurrences of less than 0.05

n = No. of years of record

Figure 2 shows the hydrologic instrumentation network in Cache Percotte and Whiskeyjack basins. Data, collected from these instruments and from those at the Hinton Forest Technology School, were used in assessing the water budgets formulated in this report. Actual data are compiled in annual progress reports (op cit) or filed at the Hinton School of Forest Technology.

TOPOGRAPHY AND ASPECT

The Cache Percotte and Whiskeyjack headwaters are located on the northwest side of the divide separating the Athabasca River and McLeod River drainage systems. The highest elevation in the headwaters is 4,680 feet* which occurs on a ridge top on the southeast margin of the Whiskeyjack basin. The lowest elevation in the headwaters is 4,340 feet which occurs at the bottom of the southeast margin of Cache Percotte basin. Topography in the headwaters is characterized by parallel, northwest-trending ridges. These ridges are broken or terminated by transverse streams lower in the basins.

The Cache Percotte basin is somewhat asymmetrical in cross section; northeast-facing slopes dip about 7 to 8 degrees, whereas southwest-facing slopes dip about 12 to 14 degrees and cover smaller areas. This asymmetry is controlled by the structure and lithology of underlying bedrock. The wide valleys of the Cache Percotte basin indicate the presence of thick, more easily eroded underlying claystone and coal strata. Massive sandstone and conglomerate strata, more resistant to erosion, form the ridges. The Whiskeyjack basin is nearly symmetrical in cross section; V-shaped valley slopes dip 15 to 20 degrees.

---

* Elevations are in feet above mean sea level.

The confluence areas of Cache Percotte and Whiskeyjack basins are located just above a moraine bench approximately 500 feet above the bottom of the Athabasca River valley. The elevations of the outlets of Cache Percotte and Whiskeyjack basins are 3,760 feet and 3,900 feet, respectively. In the confluence areas, Whiskeyjack and Cache Percotte Creeks cut into thick moraine deposits; these deposits are curved, elongate ridges or circular, irregular-shaped hummocks that have as much as 60 feet of relief (Map 1).

DRAINAGE

The overall drainage pattern is sub-rectangular, which suggests that drainage is structurally controlled. The upper tributaries of Cache Percotte and Whiskeyjack Creeks begin as ephemeral streams conducting surface-runoff down-valley. Some distance from the top of the valley walls, streams become intermittent or permanent where springs emerge to provide an interrupted or continuous supply of groundwater to them. Drainage in Cache Percotte basin and in the upper parts of Whiskeyjack basin is not well integrated. Glacial erosion and deposition have created small, closed depressions where surface water or groundwater is ponded. On lower slopes where groundwater is discharging, tributary streams flow over and through thick organic soils in poorly-defined, shifting channels. Stream gradients vary from 500 feet per mile in the upper parts of the basins to 300 feet per mile in the lower parts of the basins.

Whiskeyjack Creek flows in a northwesterly direction to its confluence with the north-flowing Hardisty Creek (Fig. 1). Both Hardisty Creek and Cache Percotte Creek flow in northerly and northwesterly directions downward into the Athabasca River valley to their confluence with the Athabasca River.

VEGETATION

Plant types encountered during the hydrogeological reconnaissance under particular conditions of soil moisture, aspect and elevation are described in the following paragraphs.

Along creek banks and in drained areas of groundwater discharge, main trees are white spruce (*Picea glauca*), black spruce (*Picea mariana*), black poplar (*Populus balsamifera*), and mountain alder (*Alnus tenuifolia*); these trees are large and well developed. Main shrubs are bog willow (*Salix* sp.), water birch (*Betula occidentalis*), bearberry (*Arctostaphylos ava-ursi*), small clumps of buffalo berry (*Shepherdia canadensis*), mountain gooseberry (*Ribes irriguum*), wild rose (*Rosa* sp.), and shrubby cinquefoil (*Potentilla fruiticosa*); main herbs are heart-leafed arnica (*Arnica cordifolia*), labrador tea (*Ledum groenlandecum*), bunchberry (*Cornus canadensis*), mountain bluebell (*Campanula rotundifolia*), white geranium (*Geranium richardsonii*), and cow parsnip (*Heracleum lanaturn*). Common horsetail (*Equisetum arvense*), sedges and mosses are also present.

In boggy areas where groundwater discharge is ponded, main trees are stunted varieties of white and black spruce; main shrubs are bog willow, swamp birch (*Betula pumila* var. *glandulosa*), and shrubby cinquefoil; main herbs are bog orchids such as Solomon's seal (*Smilacina stellata*), white ladies slipper (*Cypripedium passerinum*), yellow ladies slipper (*Cypripedium calceolus*), fly-spotted orchid, ladies tresses (*Spiranthes romanzoffionat*), and wintergreen (*Pyrola* sp.). Rushes and sedges, and marsh grasses are present.

In the midslope or hinge areas, the trees are trembling aspen, lodgepole pine, black poplar, white spruce, and balsam fir

(*Abies balsamia*), and a few mountain ash (*Sorbus scopulina*); main shrubs are buffalo berry, bearberry, wild rose, and red honeysuckle (*Lonicera dioica*); main herbs are American vetch (*Vicia americana*), Indian potato (*Hedysarum* sp.), mountain bluebell, northern bedstraw (*Galicum boreole*), goldenrod (*solidago canadensis*), showy locoweed (*Oxytropis splendens*), groundsel (*Senecio* sp.), wild peavine (*Lathyrus venosus*), and buttercup (*Ranunculus* sp.).

On the ridges or recharge areas, the trees present are trembling aspen, lodgepole pine, white spruce, black poplar, and mountain alder; shrubs present are buffalo berry, bearberry, wild rose, and a few mountain juniper (*Juniperus scopulorum*); herbs present are locoweed, yarrow, white clover (*Trifolium repens*), cut-leaf anemone (*Anemone multifida*), low-everlasting (*Antennaria aprica*), devil's paintbrush (*Castillega* sp.), and northern bedstraw.

The northeast, shaded sides of ridges and mid-slope areas are characterized by a more dense, healthy tree cover; dominant tree types are white spruce and lodgepole pine, and very thick clumps of mountain alder.

On the exposed, southwest sides open patches are common and trees are more stunted. The dominant tree types are trembling aspen and lodgepole pine.

SOILS

A soil survey of the area was conducted by the Soils Division of the Research Council of Alberta in 1966. The area was mapped at a scale of one inch to 20 chains and the soils were described in an internal report by J. D. Lindsay (op cit). The following soil classifications and their descriptions were taken from this report. The "soil series" consists of soils developed on similar parent materials under similar environmental conditions. The soil series is the basic unit used for the field classification of soils based on the system established by the National Soil Survey Committee of Canada. In the Cache Percotte forest, six soil series were recognized and mapped. In many cases the soil series were not distinct, because one or more profiles occurred in the same area. Soil series "brunisolic grey wooded" comprises three distinct profiles; two, distinguished by soil depth, were developed over parent material of alluvium overlying till, and the third was developed directly over till. Brunisolic grey wooded soils are well drained and appear to coincide with areas of recharge. Soils in recharge areas are firm and dry with little micro-relief. The soil series classified as "western, brown-forest" was developed over parent material of recent, sandy alluvium overlying gravelly outwash, and is found along existing creek channels. The soil series classified as "orthic glysol", was developed over poorly drained, glacial till. The soil series, classified as "unique, mossy soil, or organic soil", is a thick organic peat overlying poorly drained till or alluvium. The orthic glysol and unique, mossy soil (peat) coincide with areas of groundwater discharge and areas where groundwater discharge is ponded, respectively. Soils in groundwater discharge areas are soft, moist, and have a hummocky micro-relief.

All soil series appear to have high calcium carbonate content, which is due to the presence of limestone in parent tills.

SURFICIAL MATERIALS

The entire area (Map 1) appears to be mantled by a thin layer of reddish-brown, very fine, silty sand; this layer is one to two feet thick where examined in the field. A sandy till underlies the thin, silty sand at the surface. This till is very thin or absent on the ridges but increases in thickness in the valley bottoms. In areas where surficial materials are shallow, the till matrix is a light grey medium- to fine-grain sand. In areas of thicker tills, the matrix shows a higher percentage of fine-grained material. Samples of the silty sand mantle and of the till matrix were collected for mechanical analysis.

The texture of the surface mantle of silty sand ranges from "fine sand to finer" on the Wentworth scale, whereas the texture of the matrix of the underlying till ranges from coarse sand to very fine sand.

The average hydraulic conductivity of the surficial materials is assumed to approximate 1.17×10^{-1} darcys or 1.77 igpd/ft^2 (Means and Parcher, 1963, p. 200), in the vertical direction.

BEDROCK

Bedrock underlying the area comprises indurated, sedimentary rocks of Late Cretaceous and Early Tertiary ages (Cross Sections, Map 1). The strata have been uplifted and at present strike about N70°W and dip to the northeast. The dip of the strata ranges from about 10° below horizontal underlying the eastern margin of the area to about 35° below horizontal underlying the western margin. Most of the ridges are formed from massive argillaceous sandstone, whereas the valleys are underlain by softer claystone or claystone interbedded with coal lenses.

In the western part of the area, underlying the Whiskeyjack basin, the bedrock consists of massive, cross-bedded, greenish-grey, fine-grain argillaceous sandstone interbedded with more thinly-bedded greenish-grey, silty claystone. It forms the divide between Whiskeyjack and Cache Percotte basins and is overlain by a series of claystones that underlie the western lobe of Cache Percotte basin; this claystone series is overlain by the massive conglomerate ("Entrance" conglomerate) that topographically divides the western subbasin of Cache Percotte basin proper. The conglomerate is overlain by claystones interbedded with siltstones, thin coal lenses and fine-grain argillaceous sandstones, which underlie most of Cache Percotte basin. The coal seams consist of low-grade bituminous coals that have been mined farther north along strike just south of the Edmonton-Jasper Highway. The eastern margin of Cache Percotte basin is formed from massive, cross-bedded, light brown, medium- to coarse-grain argillaceous sandstone; this massive sandstone is overlain by interbedded claystones and coal lenses. A definite correlation seems to exist between topography and bedrock lithology. This interrelation has been somewhat modified by glacial erosion and deposition.

One of the primary objectives of the drilling program was to measure the hydraulic conductivities of saturated geologic materials. This is normally done by carrying out bail tests or pump tests. It is necessary to have some idea of the amount of water a formation will produce to ensure that unconfined aquifers are not significantly dewatered during the test because of bailing or pumping at too high a rate. During the drilling program in Cache Percotte basin, bail tests were carried out at sites CP-1 and CP-2 (Map 1). Both test holes were bailed at excessive rates, resulting in significant dewatering of the aquifers. The plot of the drawdown versus the logarithm of time forms a recessional curve. Analyses of the bail tests show the value of hydraulic conductivity to range from 4.82 igpd/ft^2 to 0.19 igpd/ft^2 .

A hydraulic conductivity of 0.20 igpd/ft^2 (1.32×10^{-2} darcys) was chosen as being representative of the average regional value.

During the drilling program the upper 60 feet of the bedrock was cored. Core samples at 10-foot intervals were tested by laboratory methods for permeability to air. One of the samples was re-cut and tested for permeability to air and water at a different laboratory and a liquid/air permeability ratio calculated. The effect of cutting a small plug for the second test was to reduce its permeability to air by one order of magnitude. This reduction in permeability to air is attributed to the exclusion of small fractures in the core sample by cutting the smaller plug, which indicates a large contribution made by fractures to the total hydraulic conductivity. The extremely low liquid/air permeability ratio of 0.08 indicates the sensitivity of the sample to fresh water as the result of the high montmorillonite clay content of the sample. Hydraulic conductivities of the core samples tested in the laboratory ranged from 12.1×10^{-5} to 0.26×10^{-2} igpd/ft^2, or from one to four orders of magnitude lower than the field tests. This difference is interpreted as being representative of the difference between the hydraulic conductivity due to fracture porosity and to effective inter-granular porosity.

Examinations of outcrops and bedrock cores indicate that claystone and coal strata are more intensely fractured and jointed on a local scale than sandstone or siltstone strata: vertical joint-sets predominate. In this report, on a regional scale fractured and jointed rocks are assumed to be relatively homogeneous and isotropic with respect to water movement.

The somewhat lower values of hydraulic conductivity of bedrock materials compared with surficial materials indicates unconfined groundwater conditions in surficial deposits and ensures that bedrock aquifers are efficiently recharged and discharged.

THE GROUNDWATER REGIME

GENERAL CONCEPTS

The groundwater regime at any point within a groundwater flow system is defined by the distribution, movement, and physical and chemical nature of the groundwater at that point. These properties of the groundwater regime are controlled by the local conditions of parameters of the hydrogeologic environment. For example, the distribution of groundwater within any unit volume of the flow system is controlled by the volume of interconnected pore and fracture voids within that unit volume, or by the effective porosity. Where local changes in the effective porosity are related to the lithologic, structural, or diagenetic conditions present within the saturated geologic framework, and when geologic conditions are known, groundwater distribution, or storage, can be calculated. Likewise, the shape and size of a flow system and the internal distribution of fluid potentials and hydraulic conductivities are functions of climate, topography, and geology. Also, the chemical composition of groundwaters is controlled by the chemical nature of the soluble subsurface materials through which flow occurs. Thus, where functional relations among regime properties and environmental conditions are known, the knowledge of one allows a reasonable assessment of the other.

FIELD RECONNAISSANCE

Early in the groundwater program, field reconnaissance was conducted to describe and measure the characteristics of the hydrogeologic environment present within the study basin. Components of the groundwater regime associated with different environments were measured and assessments made of their interrelations.

MODEL SOLUTIONS

The most accurate model of the groundwater regime of a basin is generated by actual field measurements of parameters and is defined for this study as the field model. The first step in constructing the field model is to establish the boundaries of flow systems recharged or discharged, wholly or in part, through the basin surface. This is done by constructing a groundwater map of the area outlining areas of groundwater discharge and areas of recharge. A synthesis of the topographic map, groundwater map, and water quality data establishes the boundaries of groundwater flow systems in the basins, and divides their upper boundaries into areas of recharge and discharge. The next step is to carry out a subsurface exploration or drilling program to directly measure the distribution of fluid potential within the flow systems, locate basal boundaries of the flow systems, and to evaluate the hydraulic conductivities of the geologic framework. With these data a replica of the field model can be constructed and quantified within the limits of accuracy of the field data collected. In most cases, however, it is impractical or physically impossible to directly measure all of the subsurface components of the field model, such as distribution of fluid potential or the location of basal boundaries of flow systems. In such cases, an analog can be constructed based on conditions meausred directly or assumed from field evidence. The validity of the analog can be assessed by comparing the model solution with the actual field data.

The Field Model

The climate, vegetation, topography and aspect, and the geology of Cache Percotte and Whiskeyjack basins were examined in the field and their physical conditions described in the previous sections. Areas and types of groundwater discharge were located on the groundwater map (Map 2) and classified according to their appearance at the ground surface. Descriptions of the forms of groundwater discharge and associated environmental conditions are given in Appendix A.

The following observations are made regarding the field model by comparing the topographic, geologic, and groundwater maps:

1. Areas of recharge coincide with topographic highs and areas of groundwater discharge coincide with topographic lows. A transition or hinge area, separating recharge and discharge areas, coincides with mid-slopes.
2. Recharge areas are characterized by thin, hard, sandy soils and surficial materials. The infiltration capacity of soils and surficial materials appears high. Ground cover is sparse and their interception and storage capacity appear low. In recharge areas groundwater is present only in bedrock materials. The relatively high rates of spring discharge in the upper parts of the basins indicate that precipitation occurring in these areas during frost-free periods recharges the groundwater flow systems.
3. Discharge areas are characterized by thick, organic soils that have a pitted or hummocky micro-relief. Surficial materials are thick and of fine sand to silty texture. Ground cover consists largely of thick mosses that have high apparent interception and storage capacities. Groundwater

is present in closed depressions, soils, surficial materials, bedrock, and as the groundwater component of streamflow. A portion of precipitation is intercepted by ground cover or trapped by depression storage, the remainder forms surface runoff.

4. Groundwater discharge appears at the ground surface along the valley flanks between local mid-slopes and valley bottoms. The line of steady groundwater discharge appears at approximately the same elevation on both sides of the ridges which indicates that phreatic divides coincide approximately with topographic divides, and that groundwater discharge is relatively independent of lithology. The phreatic divides act as lateral boundaries across which no flow occurs.

5. Some form of groundwater discharge is usually present at or just below the sharp breaks in slope of valley flanks. Where breaks in slope are near valley bottoms, discharge is relatively steady, whereas breaks in slope that occur high on the valley flanks produce unsteady groundwater discharge, usually as a result of precipitation or snowmelt.

6. The major recharge areas are long and narrow and trend to the northwest paralleling the main creeks. Groundwater flows away from the phreatic divides in opposite directions toward adjacent valley bottoms. The relatively equal magnitudes of recharge areas and groundwater discharge areas (Table 2) indicate that the major portion of groundwater moves within locally small flow systems that are recharged and discharged within the basin.

7. The locally small systems flowing sub-normal to the creeks are superimposed over a larger regional system bounded laterally by the southeast margin of the basins and the

Athabasca River. The regional system is recharged on the upper portions of the basin phreatic divides and discharged into the lower parts of the Athabasca River valley. The effect of the regional system is considered as basin leakage. Regional flow is considered to be most active under the floodplains of the main channels where no counter-flows provided by local systems are present. Basin leakage is inherent in tributary basins that reach their confluence above the main valley bottoms unless the tributary basin is immediately underlain by a favourably located basal boundary.

8. Decreases in fluid potential with depth in recharge areas can be generally assessed by examining figure 3, which shows a loss of nine feet in piezometric head for the first 14 feet, or 0.64 feet per foot (assuming water movement is vertically downward). The loss in piezometric head then dropped to 0.18 feet per foot over the remaining 33 feet of piezometer depth.

9. Increases in fluid potential with depth in discharge areas can be generally assessed by examining figure 4, which shows an average increase in piezometric head of approximately 0.2 feet per foot over 90 feet, assuming water movement is vertically upward. Piezometers 3 and 4 may not represent true potentials at those depths as the well-points on the lower end of the pipes may be partially plugged.

To assess the fluid potential distribution and relative volume discharges of regional and local groundwater flow systems, analogs were constructed with boundary conditions and hydraulic conductivity configurations equivalent to the field model.

Table 2. Basin Yield and Specific Volume Discharge

	Unit	Cache Percotte basin	Whiskeyjack basin
Total basin area	miles^2	2.620	1.163
Area of recharge (dry)	miles^2	0.664 (25 percent)	0.397 (34 percent)
Area of discharge (wet)	miles^2	0.786 (30 percent)	0.338 (29 percent)
Hinge area	miles^2	1.170 (45 percent)	0.428 (37 percent)
Area in which 75% of recharge forms regional flow (from analog)	miles^2	0.144	0.055
Area in which 15% of recharge forms regional flow (from analog)	miles^2	0.520	0.342
Total area of recharge contributing to regional flow	miles^2	$0.144 \times \frac{75}{100} = 0.108$	$0.55 \times \frac{75}{100} = 0.41$
		$0.520 \times \frac{15}{100} = 0.078$	$0.342 \times \frac{15}{100} = 0.51$
		0.186	0.92
	feet^2	5.19×10^6	2.57×10^6
Total area of recharge contributing to intra-basin flow	miles^2	$0.664 - 0.186 = 0.478$	$0.397 - 0.092 = 0.305$
	feet^2	13.33×10^6	8.5×10^6

(continued)

Table 2. Basin Yield and Specific Volume Discharge (continued)

	Unit	Cache Percotte basin	Whiskeyjack basin
Average specific volume recharge	igpd/ft^2	0.031	0.037
	ins/day	0.060	0.062
	ins/mo	1.81	1.85
Subsurface runoff or basin leakage	igpd	1.61×10^5	0.82×10^5
	cfs	0.279	0.152
Percentage of total recharge	%	28	23
Total intra-basin groundwater discharge or basin yield	igpd	4.13×10^5	2.72×10^5
	cfs	0.767	0.505
Percentage of total recharge	%	72	77
Area of basin discharge	miles^2	0.786	0.338
	feet^2	21.9×10^6	9.42×10^6
Average specific volume discharge	igpd/ft^2	0.019	0.029
	ins/day	0.037	0.056
	ins/mo	1.10	1.67

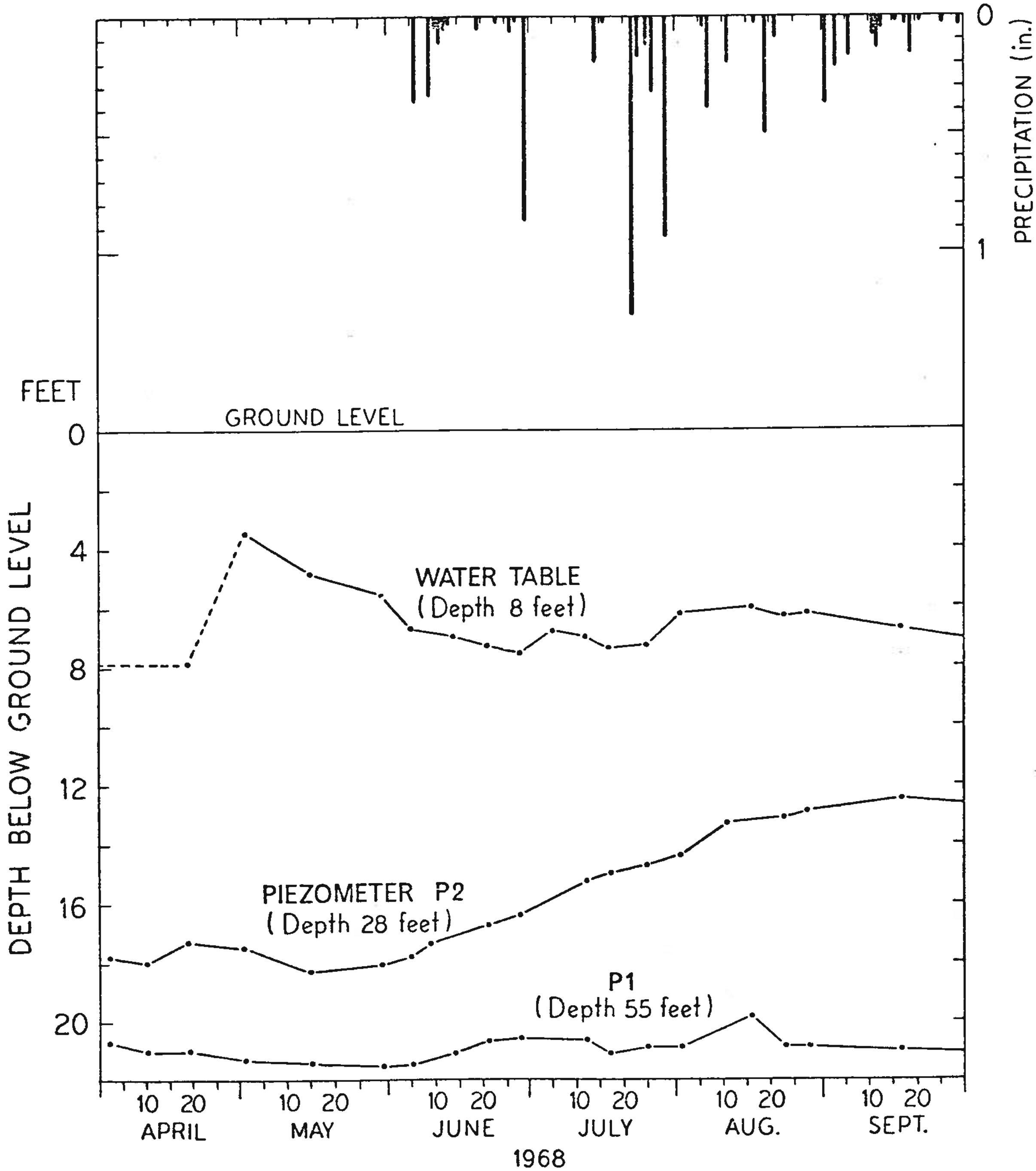

FIGURE 3. Water level fluctuations in piezometers and water table observation well at site CP-1 in response to precipitation

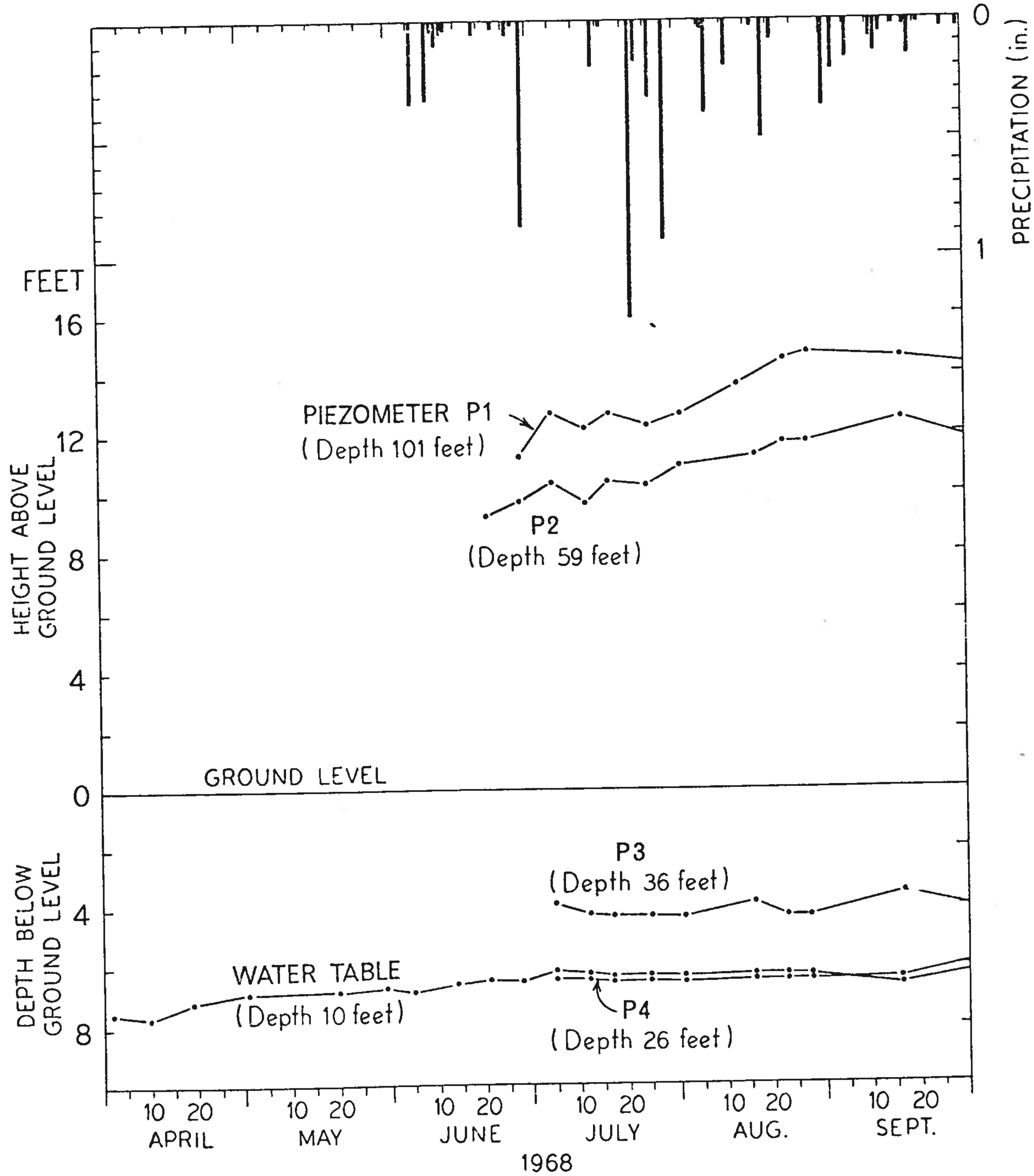

FIGURE 4. Water level fluctuations in piezometers and water table observation well at site CP-2 in response to precipitation

Analog Model

The type of analog used was the two-dimensional, conductive-solid, electric model developed and described by Tóth (1968, Appendix A). This model is adapted to the use of teledeltos paper, and has a multi-electrode arrangement along its upper boundary. These electrodes represent fluid potential values at discrete points along the section line of the water table. Two sections were selected (Map 2): one to represent groundwater movement from lateral divides to tributary valley bottoms (within local flow systems), and the other to represent the regional flow system from the regional high to the main valley bottom. The lateral boundary conditions of the analogs are assumed to represent the field model. Upper boundaries were constructed to coincide with the ground surface: this is the case in groundwater discharge areas, whereas no information is available in phreatic divide areas. A reduction in elevation of the upper boundary of the model of 100 feet at the phreatic divides resulted in a decrease in groundwater flow of 25 percent. Basal boundaries were chosen at the top of the Wapiabi for the local analog and at sea level for the regional analog. Lines of equal electrical potentials representing equal fluid potentials were drawn on the model and flow lines drawn normal to equipotential lines forming curvilinear squares (Figs. 5 and 6).

Discussion of the Analogs

1. Examination of the regional analog (Fig. 5) shows that flow systems of three orders are present: the first order flow systems are generated by local water table highs underlying small hills, ridges, etc. The second order systems underlie the first order systems and conduct the major portion of groundwater moving within the basins. The third order flow

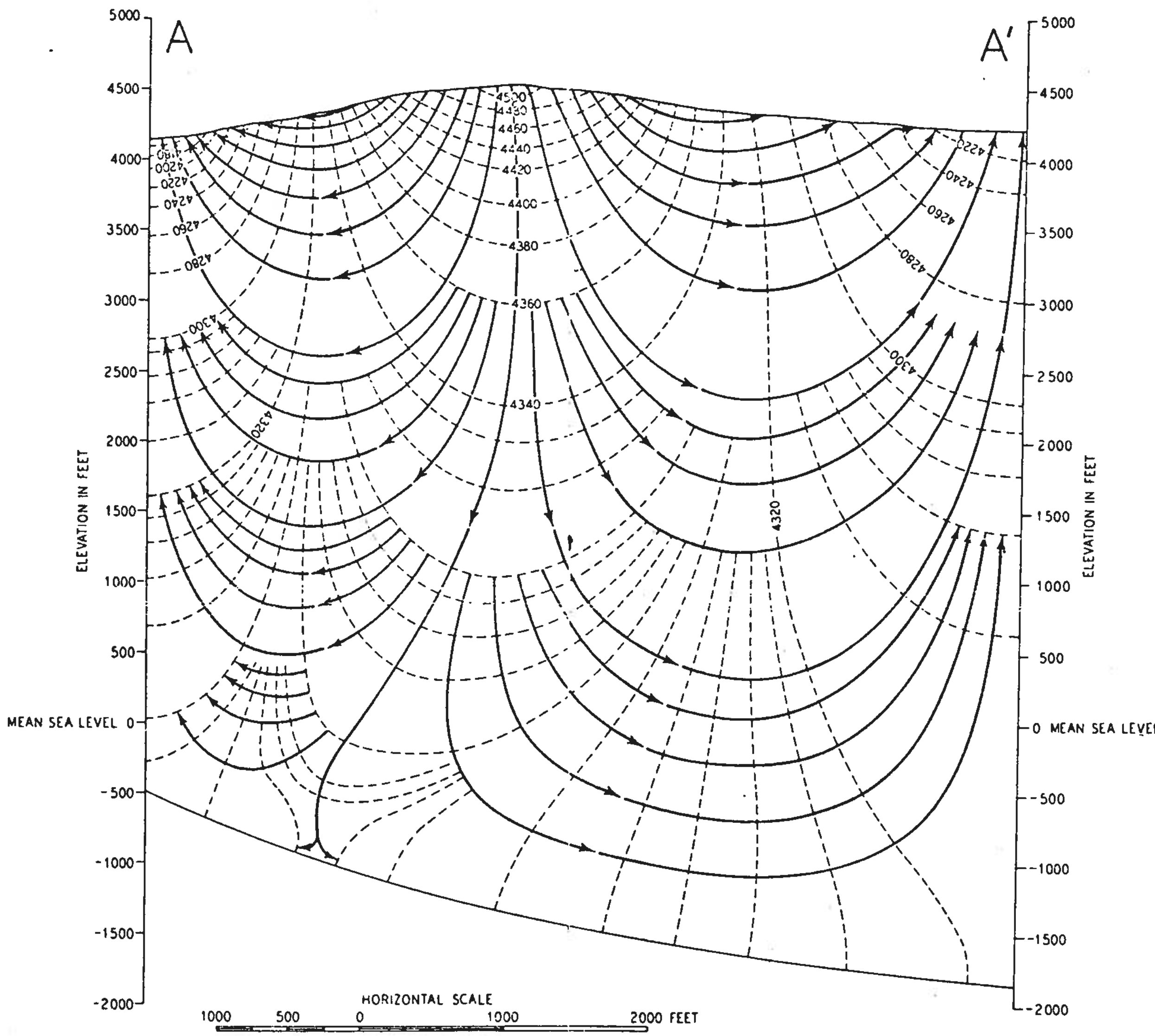

FIGURE 6. Analog of local groundwater flow

system underlies the second order system and conducts groundwaterfrom regional highs to the lower part of the Athabasca valley.

2. In the region underlying the floodplains of the main creeks (represented by the regional analog), 75 percent of recharge is discharged out of the basin (basin leakage). Groundwater moving within local flow systems (represented by the local analog) at depths below the 2,500 foot elevation levels is considered to contribute to regional flow: this is approximately 15 percent of groundwater flow. Planimetric measurements of floodplain areas were made on the topographic map and used in Table 2 to calculate areas of recharge contributing to regional and groundwater flow.

3. The following observations are made concerning observations of the local analog (Fig. 6):

   a. The total volume discharge in each system is directly proportional to existing gradients.

   b. Approximately 85 percent of the total flow is contained in the upper third of the cross-sectional area, regardless of the relatively homogeneous, isotropic nature of the flow medium. This phenomenon, present in nature as well as the analog, indicates the importance of model shape in concentrating groundwater flow near the surface. In some cases increased hydraulic conductivity near the water table may be the effect rather than the cause of similarly proportioned groundwater flow.

4. In comparing the analogs to the groundwater map, the following similarities were apparent:

a. Areas outlined as strongly recharging on the map closely coincided with the recharge areas on the analog.

b. Areas outlined as hinge areas on the map coincided with lateral flow regions on the upper basin portions of the analog, and as recharge areas on lower portions of the analog.

c. Mapped groundwater discharge areas coincided closely with the discharging portion of the analog.

d. Maximum changes in piezometric head with depth in recharge and discharge areas approximate 20 feet per 100 feet, or 0.2 feet per foot. These changes agree reasonably well with those measured in the piezometers at sites CP-1 and CP-2 (Figs. 3 and 4).

e. The coincidence of the upper boundaries of recharge and discharge on the analog with those on the line of section of the groundwater map, and the relatively close agreement of potential distribution, where measured, indicates that the analog is representative of the field model.

Quantification of the Analogs

After the flow nets were constructed (Figs. 5 and 6), flow through each stream tube was calculated from Darcy's law, where:

Q_1 = $K.\Delta h/\Delta l.\Delta m.w$

Q_1 = flow through each stream tube

K = average regional hydraulic conductivity of the flow media

Δh = drop in hydraulic head between adjacent equipotential lines

Δl = distance between adjacent equipotential lines

Δm = distance between adjacent flow lines

w = thickness of the flow systems normal to the plane of the section

For a one-foot thick section of the flow system within a homogeneous, isotropic medium, $\Delta m = \Delta l$, $w = 1$, and $Q_1 = K\Delta h$. In both the local and regional systems $\Delta h = 20$ feet, $K = 0.2$ igpd/ft^2 ($K = 1.32 \times 10^{-2}$ darcys), and $Q_1 = 4$ igpd. Total flow through a one-foot thick section of each flow system is $Q_n = nQ_1$, where n = number of stream tubes in the flow system. In the analog of the Whiskeyjack basin there are eight stream tubes. Total flow through a one-foot thick section of the Whiskeyjack flow system is $8 \times 4 = 32$ igpd. The area of recharge contributing to ground-water discharge within the permanently wet area is 870 square feet per foot of section width. This results in a value of specific volume recharge of

$$\frac{8 \times 4 \text{ igpd}}{870 \text{ ft}^2} = 0.037 \text{ igpd/ft}^2$$

Because the local analog of the Whiskeyjack flow system is considered representative of Whiskeyjack basin, 0.037 igpd/ft^2 was considered representative of specific volume recharge in Whiskey-jack basin and used in the subsequent calculation of natural basin yield, basin leakage, and specific volume discharge (Table 2).

On the analog of Cache Percotte basin specific volume recharge is calculated to be 0.029 igpd/ft^2. Because some of the slopes in Cache Percotte basin are considered equivalent to the slope represented by the local analog of Whiskeyjack basin, an average value of 0.031 igpd/ft^2 was considered representative of Cache Percotte basin, and used in the calculations of Table 2.

BASIN YIELD

The total flow of groundwater through the basin, or natural basin yield (defined by Freeze, 1966, p. 185), was 4.13×10^5 imperial gallons per day (0.77 cfs) within Cache Percotte basin, and 3.15×10^5 imperial gallons per day (0.59 cfs) within the Whiskeyjack basin.

LEAKAGE OUT OF THE BASINS

Groundwater leakage during active groundwater flow is 1.6×10^5 imperial gallons per day (0.28 cfs), or 28 percent of total recharge, out of Cache Percotte basin, and 0.95×10^5 imperial gallons per day (0.18 cfs), or 23 percent of total recharge, out of Whiskeyjack basin.

COEFFICIENT OF RECHARGE

The average recharge required to maintain the shapes of the flow systems is 1.81 inches per month over the recharge area of Cache Percotte basin, and 1.85 inches per month over the recharge area of Whiskeyjack basin. This would be approximately 94 percent of the precipitation over the recharge areas, assuming steady groundwater flow throughout the year. The actual annual recharge required to maintain the shapes of the flow systems may be considerably less than 21.9 and 22.9 inches per year, respectively, due to the following reasons:

1. During the winter periods flow systems are at least partially confined by frozen ground, which would result in suspended or retarded flow.

2. The value of specific volume recharge assessed from the analogs will be greater than the actual specific volume recharge averaged over the basins as the actual water table,

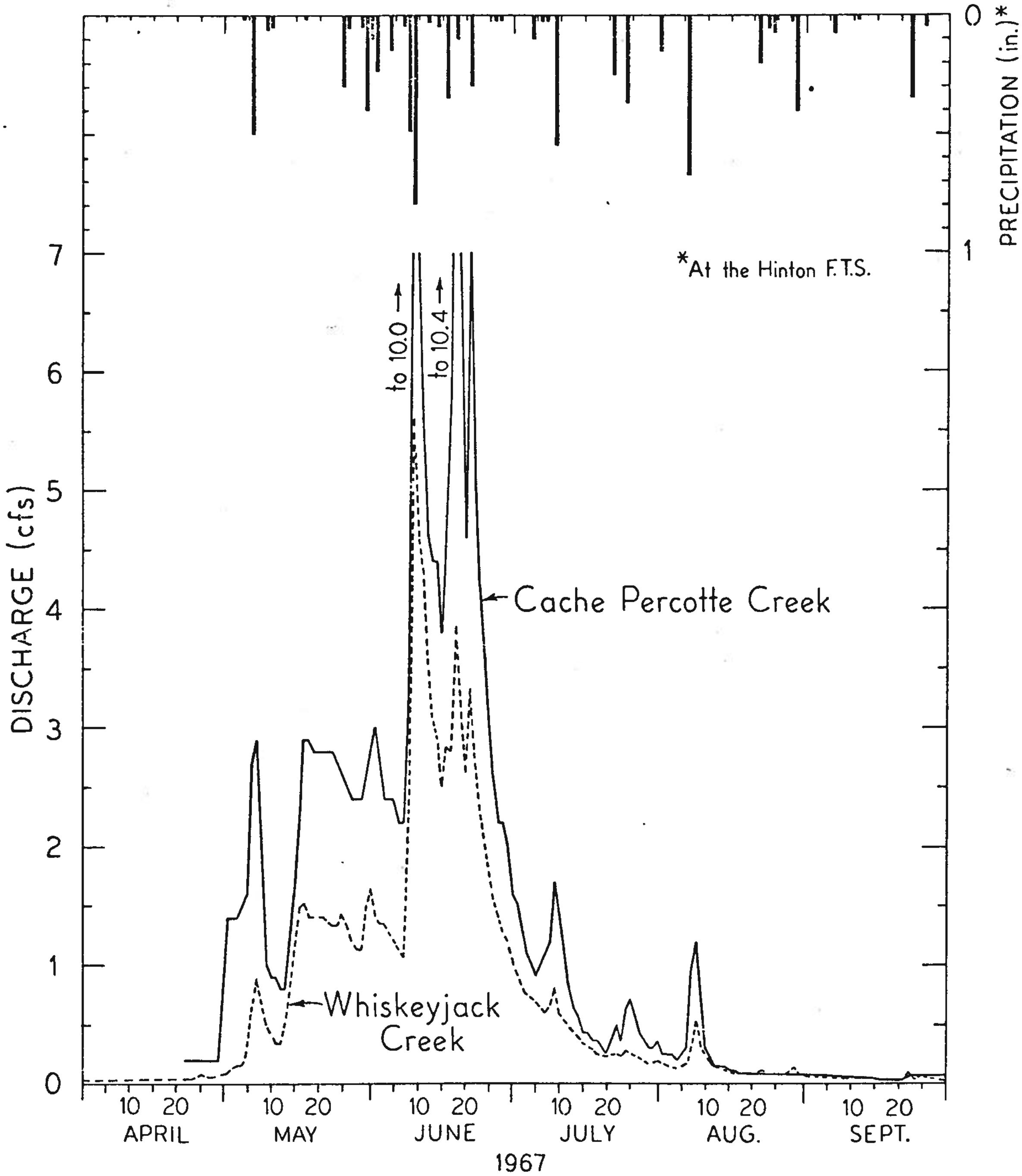

FIGURE 7. Stream discharge fluctuations in response to precipitation

or upper boundary of the analog, is below the ground surface in recharge areas. Assuming seven months of active groundwater flow per year, probable annual recharge is 7 (months) x 1.81 (inches/month), or 12.7 inches per year in Cache Percotte basin, and 7 (months) x 1.85 (inches/month), or 13.0 inches per year in Whiskeyjack basin. The coefficient of recharge, based on 7 months of active groundwater flow is

$$\frac{12.7}{23.2} \times 100$$

or 55 percent of precipitation (based on four-year average) in Cache Percotte basin, and

$$\frac{13.0}{24.3} \times 100$$

or 54 percent of precipitation in Whiskeyjack basin.

PHYSICAL QUALITY OF WATERS

Temperature, color, and turbidity were the physical qualities of groundwaters and surface waters measured during reconnaissance and subsequent laboratory analysis of selected water samples.

The color of stream waters varied from 5 to 30 Hazen units; however, the most common color was 20 Hazen units. The color of most of groundwaters was less than 10 Hazen units. The turbidity of spring waters and creek waters varied from 0.1 to 13 units. For the most part, groundwater had higher turbidity values than creek water. The temperatures of groundwaters varied from 35 to 38 degrees Fahrenheit, whereas the temperature of water ponded at the surface, flowing through the shallow subsoil, or in creeks varied from 42 to 51 degrees Fahrenheit. Water temperature was used during the reconnaissance to differentiate groundwater discharge from interflow.

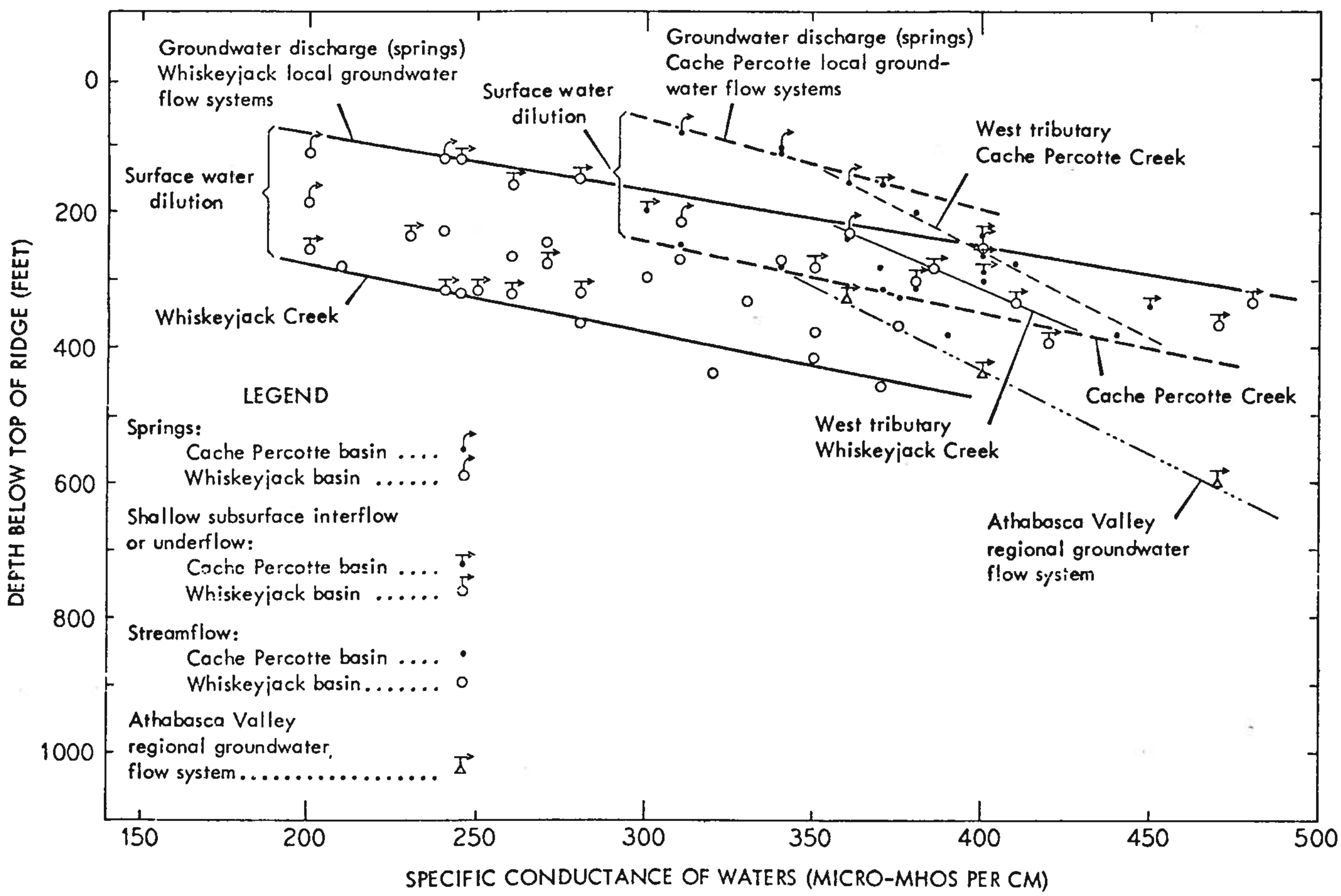

FIGURE 8. Specific conductance profiles

CHEMICAL QUALITY OF WATERS

During the hydrogeological reconnaissance measurements were taken of the specific conductance of groundwater discharging from springs, of surface water in creeks and surface depressions, and of shallow subsurface interflow. Water samples were collected from selected sites for complete chemical analysis (Appendix B): from these analyses the average ratio of "sum of constituents", or total dissolved solids (TDS), to specific conductance is 0.56. The relation between TDS and "length of underground flow", apparent during the reconnaissance, was examined graphically (Fig. 8) by plotting specific conductance of waters against corresponding elevation differences between sample points and the top of the ridges, in an upslope direction normal to the elevation contours (these elevation differences are considered directly proportional to the lengths of flow). Inspection of figure 8 indicates a linear relationship exists between TDS of groundwaters or creek waters and length of flow with respect to a particular slope, but not throughout the basins. The specific conductance profiles show that discharging groundwater in the west tributary of Cache Percotte basin has higher TDS and shorter "flow-paths" than discharging groundwater from the west tributary of Whiskeyjack basin. No relations between groundwater chemistry and rock chemistry or residence time were established due to insufficient basic data. The differences in TDS between waters occurring underground and on the land surface are due to the dilution of groundwater by water of surface origin. Most of the waters classified as shallow subsurface interflow have conductivity values between the specific conductance profiles of groundwaters and creek waters (Fig. 8), which indicates mixed water conditions. The specific conductance profile of groundwater dishcarge from the Athabasca Valley flow system (regional) parallels the profiles of local groundwater systems, which indicates similar "environment-regime" relations. The offset of the curves may be the result of surface water dilution at sample sites or deviations of actual lengths of flow from measured lengths of flow.

The percentage of equivalents per million of anions and cations obtained from the chemical analyses of groundwaters and surface waters of Cache Percotte and Whiskeyjack Creeks were plotted and classified on a trilinear diagram (Fig. 9) (Davis and DeWiest, 1966, p. 119). The central part of the diagram shows two types of water in the basins: a calcium bicarbonate type (Type I), which includes most of the waters in the basins, and a calcium-sodium bicarbonate type (Type II). A third type of water, sampled from the Athabasca River and shown on the diagram as Type III, is calcium bicarbonate changing to calcium-sulfate bicarbonate toward the end of the year. The increase in equivalent per million of sulfate is interpreted as increased groundwater component of total flow during periods of reduced river discharge.

Waters classified as Type II show an increase in the sodium-magnesium ratio from Type I waters. This condition is not the result of an increase in TDS, but is probably due to more active Na^{+} for Ca^{+} ionic exchange processes. The excess Na^{+} ions in the waters of the west subbasin of Whiskeyjack basin may reflect a higher percentage of montmorillonite clay or bentonite in the underlying bedrock.

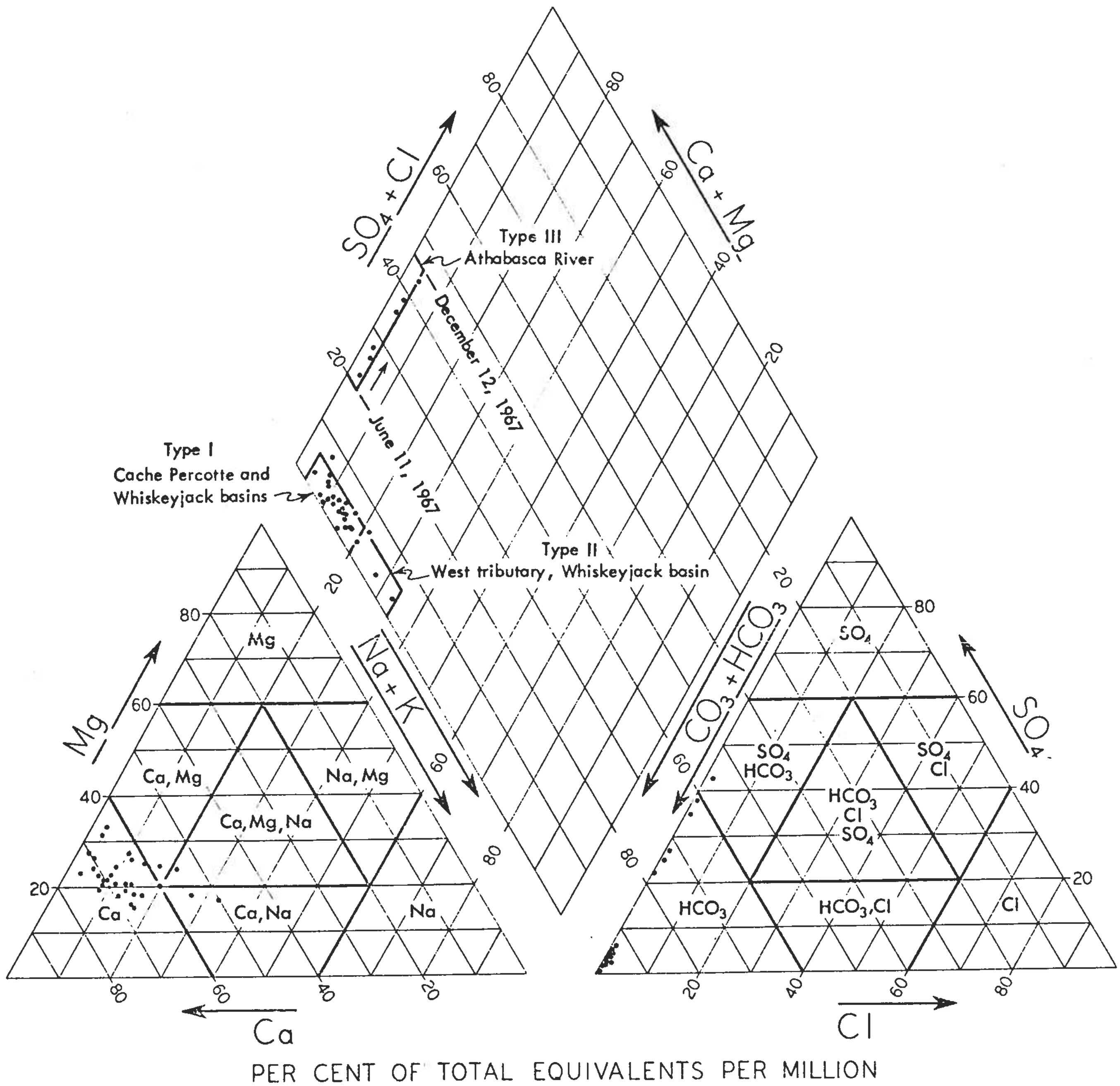

FIGURE 9. Chemical quality of waters in Cache Percotte and Whiskeyjack basins

THE GROUNDWATER BALANCE

GENERAL

In Cache Percotte and Whiskeyjack basins it is assumed that groundwater moves within hydraulically continuous flow systems. The flow systems are in a state of dynamic equilibrium, as the average volume of water charged to the systems is equal to the average volume of water discharged from them.

RECHARGE

Recharge occurs under the following conditions:

1. The ground is unfrozen (May or June, depending on the elevation, until November, inclusive).
2. The mean daily temperature is above freezing (April until October, inclusive).
3. Water in excess of the soil-moisture deficit is present on the ground surface: (a) during late spring and early summer snowmelt and rainfall periods; (b) during sustained summer rains; (c) during autumn rains or snowmelt periods.

The major portion of recharge occurs during late spring and early summer. Between periods of recharge, the rate of water table decline is a maximum at the groundwater divide and zero at the hingeline. Figure 3 shows the record from observation well site CP-1, located between the phreatic divide and the hingeline: the water level of the water-table observation well fluctuates approximately four feet between spring recharge and subsequent recession. The water table rises in the summer in direct response to precipitation.

GROUNDWATER DISCHARGE

In groundwater discharge areas the water table is close to or at the land surface. The record (Fig. 4) from site CP-2, which is located in a groundwater discharge area, shows that water table fluctuations are small and relatively independent of rainfall. Between periods of rainfall groundwater discharge is distributed according to the following discharge equations:

1. Where groundwater discharge exceeds evapotranspiration:

$$Q_d = ET_d + \Delta S_d + R_g + U$$

where

Q_d = total volume discharge;

ET_d = actual evapotranspiration from the area of discharge;

ΔS_d = the change in water storage ponded at the ground surface;

R_g = the groundwater component of streamflow; and

U = underflow, or the water moving in the downstream direction through the materials underlying the stream bed.

2. Where groundwater discharge is equal to or less than evapotranspiration, the equation is the same as above except that ET_d is numerically less.

Components of the groundwater discharge equations are considered in the following paragraphs.

(ET_d) Actual evapotranspiration equals potential evapotranspiration where water is available to meet the demand, or where the soil is wet. Such areas occur where specific volume discharge is high, and are characterized by the presence of springs, seepages, and water ponded at the surface. These areas have been mapped as permanently wet. Potential evapotranspiration, governed by such climatic factors as temperature, net solar radiation, relative humidity, wind conditions, atmospheric pressure, etc., varies from nearly zero from October to March to a maximum in July or August. In hinge areas, where specific volume discharge is low, and equalled or exceeded by the maximum potential evapotranspiration, the ground may be wet or dry, depending on the actual evapotranspiration. Actual evapotranspiration from wet areas is assumed to equal potential evapotranspiration, which is generally considered to be approximately equivalent to evaporation from a Class "A" pan after the data have been corrected for advection and adjusted to equivalent shallow lake evaporation (Crieff and Thompson, 1967, p. M18). Data from the Class "A" pan located at the nearby Hinton School of Forest Technology were used in the calculations of evapotranspiration from the basins (Table 7).

(ΔS_d) Water is stored at the ground surface in soils, ground litter and in surface depressions. Surface depressions may receive groundwater discharge on one side and recharge a shallow groundwater flow system on the opposite side of the depression. Such is the case at sample-sites WJ-21A and WJ-20C (Map 2) located in the Whiskeyjack headwaters. Surface depressions appear to trap surface runoff, which must be considered in correlating rainfall over the area of groundwater discharge to streamflow. Considerable amounts of groundwater are stored in soils and shallow surficial materials while in transit to stream channels or while moving as interflow down valley slopes. Such is the case in the central part of the western subbasin of Cache Percotte basin where sample-sites CP-19A, CP-33A, and CP-18A are located. Sites, located where potholes in the soil have intercepted interflow and created water holes, have been classified as shallow subsurface interflow (Map 2). The change in depression storage was not measured so it is not included in the calculation of groundwater discharge from the permanently wet area.

(R_g) The groundwater component of streamflow makes up the major part of streamflow during periods of low stream stage. This groundwater reaches streams or their tributaries from springs, seepages, or as interflow through shallow, surficial materials and soils from groundwater discharge areas above the stream stage. During periods of maximum potential evapotranspiration, little excess groundwater discharge remains to contribute to streamflow, whereas during periods of low potential evapotranspiration (spring and autumn) a greater portion of streamflow consists of groundwater. During periods of frozen ground, groundwater discharge may be reduced by confining ground ice. In Cache Percotte and Whiskeyjack basins concentrated groundwater discharge, such as permanent springs, discharge the year round; during the winter this discharge is stored on slopes or in channels as ice.

The groundwater components of streamflow are measured by the flumes located at the main stream discharge stations on Whiskeyjack and Cache Percotte Creeks (Fig. 2). Stream discharge measurements during dry periods, when streamflow was judged to consist mainly of groundwater, were used in the calculation of groundwater discharge.

(U) Underflow is considered to be confined within the width of the floodplains of the stream and the depth of surficial materials. Where no control from stratigraphic drilling exists, estimates of depths of surficial materials were made from projection of the profiles of valley flanks located upslope from the main discharge stations. The widths of floodplains were measured on the topographic map or from the projected profiles. The stratigraphic log of drilling site CP-3 (Map 1), located in the floodplain of Cache Percotte Creek, was taken as being representative of the floodplain materials underlying the main discharge stations. Cut-off walls at the flumes were installed below the depth of the recent alluvium underlying the stream channels. The material below the cut-off walls, from the stratigraphic log of well CP-3, is a silty, argillaceous, stoney till, except for approximately 10 feet of sand and gravel just above bedrock. Hydraulic gradients were taken as equal to stream gradients and hydraulic conductivity values were taken from the coefficient of permeability table of materials in the "glacial till" to "sands and gravels" range (Means and Parcher, p. 200). Estimates of underflow from Cache Percotte and Whiskeyjack basins were made (Table 3) using Darcy's equation.

EQUIVALENT SPECIFIC VOLUME DISCHARGE

The groundwater budget estimates of total volume discharge (Q_d) from the permanently wet areas are calculated by summing the components of the groundwater discharge equation for each basin (Table 4). The components were summed for periods of no rainfall and the streams were assumed to consist entirely of groundwater. The value of total volume discharge was divided by the area of permanently wet ground in each basin to obtain values of *equivalent* specific volume discharge (discharge per square foot).

DISCUSSION OF THE GROUNDWATER BALANCE

The following comments are made with regard to Table 4:

1. Values of equivalent specific volume discharge (Column 12) varied from a minimum of 0.094 inches per day to a maximum of 0.245 inches per day in Whiskeyjack basin. Considering

Table 3. Underflow

Basin	A' Cross-sectional area of silty clay, stony till ft^2	A'' Cross-sectional area of sand and gravel ft^2	K' Hydraulic conductivity of till igpd/ft^2	K'' Hydraulic conductivity of sand and gravel igpd/ft^2	I Hydraulic gradient ft/ft	Q'=K'A'I Flow through till cross section igpd	Q''=K''A''I Flow through sand and gravel igpd	U=Q'+Q'' Total flow =underflow igpd	U cfs per day	cfs per year
Cache Percotte	9,000	600	1.77	177	0.06	960	6,370	7,330	0.014	5.11
Whiskeyjack	3,600	400	1.77	177	0.06	380	4,250	4,630	0.009	3.29

Table 4. Equivalent Specific Volume Discharge

1	2	3	4	5	6	7	8	9	10	11	12	13
Date	Basin	ET_d Evapotranspiration from wet areas			Groundwater component of streamflow R_g	Underflow U	R_g+U	(R_g+U) over the discharge area		$Q_d=R_g+U+ET_d$ (ΔS not included)	Equivalent specific volume discharge (q_d)	
		ins/day	multiplier	cfs	cfs	cfs	cfs	ins/day	igpd/ft^{2}x10^{-2}	cfs	ins/day	igpd/ft^2
une 8-21, 968	Cache Percotte	0.181	21.13	3.81	0.140	0.014	0.154	0.007	0.36	3.96	0.187	0.097
	Whiskeyjack	0.181	9.07	1.643	0.163	0.009	0.172	0.019	0.90	1.81	0.200	0.097
uly -12, 968	Cache Percotte	0.179	21.13	3.783	0.130	0.014	0.144	0.007	0.36	3.93	0.186	0.097
	Whiskeyjack	0.179	9.07	1.623	0.117	0.009	0.126	0.014	0.66	1.75	0.193	0.100
uly 5-20, 967	Cache Percotte	0.213		4.48	0.360	0.014	0.374	0.018	0.85	4.85	0.230	0.119
	Whiskeyjack	0.213		1.932	0.290	0.009	0.299	0.033	1.71	2.23	0.245	0.127
ugust -4, 967	Cache Percotte	0.149		3.145	0.238	0.014	0.252	0.012	0.57	3.4	0.161	0.076
	Whiskeyjack	0.149		1.351	0.153	0.009	0.162	0.018	0.85	1.51	0.166	0.079
ugust 5-18, 967	Cache Percotte	0.198		4.18	0.105	0.014	0.119	0.006	0.31	4.3	0.220	0.114
	Whiskeyjack	0.198		1.796	0.100	0.009	0.109	0.012	0.57	1.91	0.209	0.108
ugust 7-30, 968	Cache Percotte	0.126		2.663	0.280	0.014	0.294	0.014	0.66	2.96	0.140	0.066
	Whiskeyjack	0.126		1.143	0.125	0.009	0.134	0.015	0.71	1.28	0.141	0.067

(continued)

Table 4. Equivalent Specific Volume Discharge (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13
Date	Basin	ET_d Evapotranspiration from wet areas			Groundwater component of streamflow R_g	Underflow U	R_g+U	(R_g+U) over the discharge area		$Q_d=R_g+U+ET_d$ (ΔS not included)	Equivalent specific volume discharge (q_d)	
		ins/day	multiplier	cfs	cfs	cfs	cfs	ins/day	igpd/ft^{2}x10^{-2}	cfs	ins/day	igpd/ft^2
September 12-15, 1968	Cache Percotte	0.104		2.2	0.070	0.014	0.084	0.004	0.21	2.28	0.108	0.051
	Whiskeyjack	0.104		0.943	0.055	0.009	0.064	0.007	0.36	1.01	0.111	0.053
September 23-26, 1968	Cache Percotte	0.100		2.11	0.250	0.014	0.264	0.013	0.62	2.37	0.112	0.057
	Whiskeyjack	0.100		0.907	0.083	0.009	0.092	0.010	0.47	1.00	0.110	0.052
October 17-20, 1968	Cache Percotte	0.083		1.755	0.250	0.014	0.264	0.012	0.57	2.02	0.096	0.050
	Whiskeyjack	0.083		0.755	0.090	0.009	0.099	0.011	0.52	0.85	0.094	0.049
Cache Percotte Averages		0.148			0.203	0.014	0.217	0.010			0.161	0.071
Whiskeyjack Averages		0.148			0.131		0.140	0.014			0.163	0.071

the lowest value (0.094 inches per day), the specific volume recharge necessary to maintain hydraulic continuity would be

$$0.094 \times \frac{0.338}{0.305} \text{ (recharge/discharge area ratio)}$$

or 0.104 inches per day. This recharge is equivalent to 38 inches of recharge per year, whereas the basin only receives an average of 24.3 inches of precipitation a year (four-year average). The high values of equivalent specific volume discharge result from the assumption that all of the moisture used by evapotranspiration from wet areas is supplied from groundwater discharge. Subtracting the values of specific volume discharge (Table 2) from respective values of average *equivalent* specific volume discharge (Table 4) leaves a difference of (0.161 - 0.037 = 0.124 ins/day) 0.124 inches per day of evapotranspiration to be provided from the surface water component of storage in Cache Percotte basin, and (0.163 - 0.063 = 0.100 ins/day) 0.100 inches per day, in Whiskeyjack basin.

2. Using the values of specific volume discharge from Table 2 for the dry periods considered in Table 4, mean groundwater discharge provided 23 percent of the total moisture discharged from the wet areas of Cache Percotte basin and 39 percent of the total moisture discharged from the wet areas of Whiskeyjack basin. The remaining 77 percent and 61 percent, respectively, was provided by surface water storage and formed evapotranspiration.

3. Of the 23 percent of total moisture discharged from the wet areas of Cache Percotte basin, 25 percent formed the groundwater component of streamflow, 2 percent formed underflow, and 73 percent contributed to evapotranspiration. Of the 39 percent of total moisture discharged from the wet areas of Whiskeyjack basin, 23 percent formed the groundwater

component of streamflow, 2 percent formed underflow, and 75 percent contributed to evapotranspiration.

4. The total volume of groundwater discharged in poorly-drained discharge areas cannot be calculated during short periods from water budget methods unless changes in moisture storage in the discharge areas are measured directly and the groundwater portions of storage known.

THE HYDROLOGIC BALANCE

THE GENERAL EQUATION

Discontinuous meteorological and hydrometeorological records are available for Cache Percotte and Whiskeyjack basins from 1964 to 1968, inclusive. These records, as well as meteorological data from the Hinton School of Forest Technology, and the Edson Weather Station were used to evaluate the components of the hydrologic balance.

The general equation for the hydrologic balance of the basins is:

$$P = R + ET + \Delta S$$

where

P = precipitation to the basin surfaces;

R = total drainage from the basins;

ET = evapotranspiration from the basins;

ΔS = change in moisture-storage in the basins.

The components of the general equation may be subdivided according to the distribution and movement of water on either side and across the air-land interface.

PRECIPITATION

Rainfall in Cache Percotte and Whiskeyjack basins is measured by the network of standard rain gauges shown in figure 2, whereas total precipitation is measured by one Sacramento storage gauge in each basin and an automatic precipitation recorder in Cache Percotte basin. The mouths of the Sacramento gauges and the automatic recorder are located some seven to eight feet above ground level which results in some undercatch, compared with the average of the standard gauges (P. Murphy, personal communication); however, for purposes of assessing the water budgets, data from the Sacramento gauges were accepted as being representative of precipitation to the basins. Total annual precipitation from October 1964 to October 1968 is shown in Table 8.

Average precipitation at Edson for the same period was 19.6 inches, which was 1.4 inches lower than the 30-year average (Table 1).

TOTAL DRAINAGE FROM THE BASINS

Drainage from the basins is distributed according to the following equation:

$$R = R_s + R_g + U + L$$

where

R_s = the surface water component of streamflow;

R_g = the groundwater component of streamflow;

U = underflow; and

L = groundwater leakage out of the basin.

Streamflow ($R_s + R_g$) is measured directly at the stream discharge stations; R_g is estimated from average stream discharges during low-flow periods (Table 4). U and L are calculated. These components are summed in Table 5 from October 1965 to October 1968. Where streamflow records are incomplete stream discharges are estimated from projections of their hydrographs.

From figure 5, there is a direct increase in stream discharge from Cache Percotte and Whiskeyjack basins as a result of rainfall. Rainfall occurring during late August and September produced little increase in stream discharge; most of the rainfall probably was used to replenish soil-moisture deficits and depression storage.

From Table 4, the average annual groundwater component of runoff (R_g) is 0.203 cfs per day, or 1.05 inches per year, from Cache Percotte basin and 0.131 cfs per day, or 1.53 inches per year from Whiskeyjack basin. From Table 5, the total average annual streamflow ($R_s + R_g$) equals 4.01 and 7.01 inches from Cache Percotte and Whiskeyjack basins, respectively. Runoff due to groundwater (R_g) makes up 26.2 percent and 21.8 percent of streamflow, respectively, or 16 percent of the total drainage from the basins.

EVAPOTRANSPIRATION

Evapotranspiration increases as moisture is available up to its maximum potential evapotranspiration. Potential evapotranspiration in the basins was assumed to equal actual evaporation from the Class A pan (corrected for advection and adjusted to shallow lake conditions) located at the Hinton Forestry School. Evporation pan data are available for the growing seasons of 1967 and 1968. The 1967 data, corrected for advection and adjusted to shallow lake conditions (Kohler *et al.*, 1955), were used as a standard for comparing evpotranspiration at Hinton and Edson computed by the Penman (Schulz, 1962) and Thornthwaite (1948)

Table 5. Total Drainage from Cache Percotte and Whiskeyjack Basins

		Streamflow (R_s+R_g)*	Percent R $\frac{R_s+R_g}{R} \times 100$	Leakage (L)	Percent R $\frac{L}{R} \times 100$	Underflow (U)	Percent R $\frac{U}{R} \times 100$	Total drainage from basins R
October 1964 to October 1965	Cache Percotte	5.6	78	1.55	21	0.07	1	7.2
	Whiskeyjack	10.41	85	1.77	14	0.10	1	12.3
October 1965 to October 1966	Cache Percotte	5.6	78	1.55	21	0.07	1	7.2
	Whiskeyjack	11.0	85	1.77	14	0.10	1	12.9
October 1966 to October 1967	Cache Percotte	3.49	68	1.55	30	0.07	2	5.1
	Whiskeyjack	4.82	72	1.77	26	0.10	2	6.7
October 1967 to October 1968	Cache Percotte	1.36	45	1.55	52	0.07	3	3.0
	Whiskeyjack	1.81	49	1.77	48	0.10	3	3.7
Cache Percotte Averages		4.01	67		31		2	
Whiskeyjack Averages		7.01	73		25		2	

* All values are in inches of water over the basin

methods (Table 6). Such data as "hours of sunshine", necessary in the Penman computation of evapotranspiration at Hinton, were estimated by projecting equivalent data from the Edson weather station. Evapotranspiration at the Edson weather station during the same period was computed by the Thornthwaite and Penman methods (Table 6). The Thornthwaite method consistently underestimated evapotranspiration at Hinton and Edson computed on a monthly basis; however, when averaged over the growing season, the values are within the range of reliability of evaporation-pan coefficients. The Penman method was the most accurate compared with adjusted evaporation pan data, and was used to estimate potential evapotranspiration from the wet areas of Cache Percotte and Whiskeyjack basins for periods from May 1 until November 1, 1965 to 1968 (Table 7), for which no evaporation pan data are available. The soil-moisture budget method of Holmes and Robertson (1963) was used to calculate actual evapotranspiration in the dry areas where potential evapotranspiration is reduced. The values of actual evapotranspiration from dry areas of Cache Percotte and Whiskeyjack basins during 1965 to 1968 are given in Table 7. Evapotranspiration from the hinge areas is assumed to approximate the average of the wet and dry areas during years when precipitation is heavy or when there is an increase in basin storage. During years when precipitation is light or when there is a decrease in basin storage, evapotranspiration from the hinge areas and the dry areas were considered equal. Evapotranspiration processes were considered active during annual periods from May until October, inclusive, for calculating the hydrologic balance.

CHANGE IN BASIN STORAGE (ΔS)

Moisture storage within the basins is distributed according to the following equation:

$$\Delta S = \Delta S_s + \Delta S_{sl} + \Delta S_g$$

Table 6. A Comparison of Methods of Estimating Evapotranspiration

Month	Hinton pan adjusted to shallow lake	ET, Hinton computed by Thornthwaite method	Percentage variation	ET, Hinton computed by Penman method	Percentage variation	ET, Edson computed by Penman method	Percentage variation	ET, Edson computed by Thornthwaite method	Percentag variatio
May 1967	3.87*	2.25	-42	3.41	-11.9	3.41	-11.9	2.62	-32.4
June 1967	4.95	4.17	-15.8	5.10	+3	4.80	-3	4.07	-17.8
July 1967	4.46	4.31	-3.4	5.12	+14.8	4.96	+11.2	4.32	-3.1
August 1967	4.65	4.30	-7.5	4.65	0	4.50	-3.2	4.48	-3.7
September 1967	3.63	3.17	-12.7	3.60	-0.8	2.40	-3.4	3.04	-16.2
Total	21.56	18.20	-15.6	21.88	+1.5	20.07	-6.9	18.53	-14

* All data are inches of water

Table 7. Evapotranspiration from Cache Percotte and Whiskeyjack Basins

Year	Basin	Annual potential ET*	Annual from ET in dry areas	Annual average ET from hinge areas	wet area / basin area	dry area / basin area	hinge area / basin area	Annual ET from wet areas	Annual ET from dry areas	Annual ET from hinge area	Annual total ET
October 1964 to	Cache Percotte	20.76	12.26	16.51	0.30	0.27	0.43	6.22	3.35	7.10	16.7
October 1965	Whiskeyjack	20.76	12.26	16.51	0.29	0.34	0.37	6.02	4.16	6.11	16.3
October 1965 to	Cache Percotte	18.59	11.20	14.90	0.30	0.27	0.43	5.57	3.12	6.40	15.1
October 1966	Whiskeyjack	18.59	11.20	14.90	0.29	0.34	0.37	5.39	3.81	5.51	13.9
October 1966 to	Cache Percotte	22.34	11.34	16.82	0.30	0.27	0.43	6.70	3.06	7.23	17.0
October 1967	Whiskeyjack	22.34	11.34	16.82	0.29	0.34	0.37	6.48	3.86	6.22	16.6
October 1967 to	Cache Percotte	24.75	10.72	17.73	0.30	0.27	0.43	7.42	2.90	7.62	17.9
October 1968	Whiskeyjack	24.75	10.72	17.73	0.29	0.34	0.37	7.17	7.62	0†	14.8
Cache Percotte Average											16.67
Whiskeyjack Average											15.40

* All values are in inches of water

† The rate of evapotranspiration from hinge areas is considered equal to the rate of evapotranspiration from dry areas when the accumulated basin storage shows a considerable deficit (see Table 8)

where

ΔS_s = change in moisture storage on the ground surface;

ΔS_{sl} = change in moisture storage in the shallow subsurface;

ΔS_g = change in moisture storage in the groundwater reservoir.

Moisture stored on the ground surface and in the shallow subsurface is replenished over the entire basin surface from precipitation, and in groundwater discharge areas from groundwater discharge. Surface and shallow subsurface moisture is depleted by evapotranspiration, by interflow, and by recharge to groundwater flow systems. Groundwater storage is replenished by recharge and depleted by groundwater discharge.

The change in moisture storage within the basins was not measured directly but is calculated from the hydrologic balance equation (Table 8).

DISCUSSION OF THE HYDROLOGIC BALANCE

Because the hydrologic balance is based on only four years of data, some of which are complemented by estimated or projected data, the following comments are speculative:

1. Precipitation in Whiskeyjack basin is consistently higher than precipitation in Cache Percotte basin. This condition may be due to higher elevation in the Whiskeyjack headwaters.

2. Streamflow per square mile is considerably greater from Whiskeyjack basin (25 percent) than from Cache Percotte basin (16 percent), assuming streamflow hydrographs represent actual stream discharges. This condition results from higher precipitation and lower evapotranspiration from Whiskeyjack basin.

Table 8. Precipitation and Changes in Moisture Storage in Cache Percotte and Whiskeyjack Basins

Year	Basin	Precipitation P	Drainage from basin R	R as percentage of P $\frac{R}{P} \times 100$	P-R	Evapotranspiration ET	ET as percentage of P $\frac{ET}{P} \times 100$	Change in basin storage ΔS (P-R-ET)	ΔS accumulated
October 1964 to	Cache Percotte	26.6*	7.2	27	19.4	16.7	63	+2.7	+2.7
October 1965	Whiskeyjack	28.2	12.3	44	15.9	16.3	58	-0.4	-0.4
October 1965 to	Cache Percotte	28.5	7.2	25	21.3	15.1	53	+6.2	+8.9
October 1966	Whiskeyjack	29.2	12.9	44	16.3	13.9	48	+2.4	+2.0
October 1966 to	Cache Percotte	17.6	5.1	29	12.5	17.0	96	-4.5	+4.4
October 1967	Whiskeyjack	18.9	6.7	35	12.2	16.6	88	-4.4	-2.4
October 1967 to	Cache Percotte	19.9	3.0	15	16.9	17.9	90	-1.0	+3.4
October 1968	Whiskeyjack	20.6	3.7	18	16.9	14.8	72	+2.1	-0.3
Cache Percotte Averages		23.1	5.6	24		16.7	76		
Whiskeyjack Averages		24.3	8.9	34		15.4	66		

* All values in Table 8 are in inches of water per year over the basin

3. Evapotranspiration is consistently greater from Cache Percotte basin (76 percent) than from Whiskeyjack basin (66 percent). This condition is the result of a larger area of depression storage present in Cache Percotte basin.

4. Basin storage acts as a buffer to smooth out large annual differences in precipitation.

5. Runoff per square mile is largely dependent upon antecedent conditions of basin storage, especially in such basins as Cache Percotte where significant depression storage is present.

6. The most apparent ways of increasing runoff from the basins are by reducing evapotranspiration, and the depletion of basin storage during years of low precipitation. This condition might be effected by clearing phreatophytic vegetation from the discharge areas of the basin and by draining closed depressions in discharge areas.

SUMMARY OF RESULTS

Results are summarized and discussed in the order of their consideration in the report:

I. THE HYDROGEOLOGICAL ENVIRONMENT

1. Recharge and groundwater discharge environments can be recognized in the field. These environments are mappable units on large-scale aerial photographs which can be used to produce a groundwater map. From the groundwater map the upper and lateral boundaries of the field model can be generally defined.

2. Average hydraulic conductivity on a regional scale approximates 0.20 igpd/ft^2, or 1.32 x 10^{-2} darcys. Permeability of the bedrock is primarily due to open joints and fractures.

II. THE ANALOGS

1. The analogs are considered to represent the field model as upper recharge and groundwater discharge boundaries coincide, and near-surface changes in piezometric head in the analogs and in the field models are comparable.

2. The analog of regional groundwater flow defined three types of flow systems: local and intermediate flow systems with their areas of recharge and discharge within the basins, and a regional flow system with its area of recharge at the phreatic divides of the basins and its area of discharge outside the basin boundaries. Regional discharge results in groundwater leakage out of the basins.

3. The analog of local groundwater flow indicates that the flow will be concentrated close to the upper surface as a result of the shape of the flow system; concentration of near-surface flow does not necessarily infer relatively higher near-surface permeabilities.

4. Groundwater leakage is inherent out of a tributary basin whose outlet is above the main valley bottom, unless it is immediately underlain by a relatively impermeable formation.

5. Recharge required to maintain the shape of the flow systems in Cache Percotte and Whiskeyjack basins is approximately 1.81 inches and 1.85 inches per month, respectively. Coefficient of recharge is approximately 55 percent of

precipitation to the areas of recharge, assuming seven months of active groundwater flow.

6. Basin yield is 4.13×10^5 igpd (0.77 cfs) from Cache Percotte basin and 3.15×10^5 igpd (0.59 cfs) from Whiskeyjack basin during periods of active recharge to groundwater flow.

7. Basin leakage is 1.6×10^5 igpd (0.28 cfs) from Cache Percotte basin, or 28 percent of total recharge, and 0.82×10^5 igpd (0.18 cfs) from Whiskeyjack basin, or 23 percent of total recharge during periods of active recharge to groundwater flow.

III. PHYSICAL QUALITY

1. Colder water temperatures distinguish groundwater discharge from shallow subsurface flow in Cache Percotte and Whiskeyjack basins.

IV. CHEMICAL QUALITY

1. Total dissolved solids contained in groundwaters increase directly as the lengths of flow paths, where measured along a particular slope. Comparisons of chemical quality of discharge from different flow systems require consideration of residence time and the chemical properties of the flow media.

2. Groundwater discharge is mixed with surface water at the ground surface and in the shallow subsurface. This results in lower ionic concentrations of dissolved chemicals in stream and shallow subsurface waters.

3. The main water type (groundwater, surface water, and shallow subsurface water) in Cache Percotte and Whiskeyjack basins is calcium bicarbonate. Waters from the west subbasin of Whiskeyjack basin were sodium-calcium bicarbonate: the increase in sodium ion concentration is interpreted as the result of increased sodium for calcium ionic exchange.

V. THE GROUNDWATER BALANCE

1. Calculated values of underflow are 5.11 cfs per year, or 0.073 inches over the drainage basin from Cache Percotte basin, and 3.29 cfs per year, or 0.105 inches over the drainage basin from Whiskeyjack basin.

2. During the dry periods considered in Table 4 for Cache Percotte and Whiskeyjack basins, respectively, 25 and 23 percent of groundwater dscharge formed streamflow, 2 percent of groundwater discharge formed underflow, and 73 and 75 percent of groundwater discharge formed evapotranspiration. The remaining 77 and 66 percent of total evapotranspiration from Cache Percotte and Whiskeyjack basins, respectively, was provided by the surface water component of moisture storage.

VI. THE HYDROLOGIC BALANCE

1. The annual average precipitation (over four years) received by Cache Percotte and Whiskeyjack basins is 23.1 inches and 24.3 inches, respectively.

2. Precipitation received by Cache Percotte basin is distributed in the following manner:

a. 16.1 percent forms streamflow (11.9 percent from surface water; 4.2 percent from groundwater)

b. 7.4 percent forms basin leakage

c. 0.5 percent forms underflow

d. 66.0 percent forms evapotranspiration

100.0 percent

3. Precipitation received by Whiskeyjack basin is distributed in the following manner:

a. 24.8 percent forms streamflow (19.4 percent from surface water; 5.4 percent from groundwater)

b. 8.5 percent forms basin leakage

c. 0.7 percent forms underflow

d. 66.0 percent forms evapotranspiration

100.0 percent

REFERENCES

Canada (1957): Atlas of Canada; Geographical Branch, Dept. of Mines and Technical Surveys.

Creif, R. W. and T. H. Thompson (1967): A comparison of methods of estimating potential evapotranspiration from climatological data in arid and subhumid environments; Geol. Surv. Water Supply Paper 1839-M, U.S. Gov't. Printing House, Washington.

Davis, S. and DeWiest, R. (1966): Hydrogeology; J. Wiley & Sons, 463 pages.

Freeze, R. A. and P. A. Witherspoon (1968): Theoretical analysis of regional groundwater flow: 1. Analytical and numerical solutions to the mathematical model; Water Resources Res., Vol. 2, No. 4, p. 641-656.

Holmes, R. M. and G. W. Robertson (1963): Application of the relationship between actual and potential evapotranspiration in dry land agriculture; Trans. Am. Soc. Ag. Engrs., p. 65-67.

Kohler, M. A., T. J. Nordenson, and W. E. Fox (1955): Evaporation from pans and lakes; U.S. Weather Bureau Res. Paper 38, Washington.

Lang, A. H. (1947): Brule and Entrance Map-Areas, Alberta, Canada; Geol. Surv. Memoir 244, Dept. Mines and Resources, 65 pages.

Lindsay, J. D. (1966): Soil survey Cache Percotte forest, Forest Technology School, Hinton, Alberta; Unpublished report, Alberta Soil Survey, Res. Coun. Alberta.

Means, R. E. and J. V. Parcher (1963): Physical Properties of Soils; Charles E. Merrill Books Inc., Columbus, Ohio, 464 pages.

Murphy, P. J. (1965): Cache Percotte Forest Watershed Study Project; Unpublished progress report to December 31, 1964, Training Branch; Forest Technology School, Alberta Forest Service.

---------- (1967): Cache Percotte Forest Watershed Study Project; Unpublished progress report January 1, 1965 to September 30, 1966; Training Branch, Forest Technology School, Alberta Forest Service.

---------- (1968): Cache Percotte Forest Watershed Study Project; Unpublished progress report October 1, 1966 to September 30, 1967; Training Branch, Forest Technology School, Alberta Forest Service.

Roed, M. A. (1964): Bedrock and surficial deposits, Cache Percotte Creek area; Unpublished report, Res. Coun. Alberta.

Schulz, E. F. (1962): A graphical procedure to estimate potential evapotranspiration by the Penman method; Civil Eng. Dept., Colorado State Univ., Fort Colins, Colorado, 8 pages.

Thornthwaite, C. W. (1948): An approach toward a rational classification of climate; Geog. Review 38, p. 55-94.

Tóth, J. (1963): A hydrogeological study of the Three Hills area, Alberta; Res. Coun. Alberta, Bull. 24, 117 pages.

APPENDIXES

Appendix A. Summary of Surface Features Expressing Hydrogeological Conditions

Topographic setting	aspect & cover density	Characteristic vegetation: trees	Characteristic vegetation: shrubs	Characteristic vegetation: herbs	Characteristic vegetation: ground cover	Soil: type (after Lindsay)	Soil: thickness	Soil: density & firmness	Soil: micro-topography	Soil: moisture condition	Geology	Groundwater regime: flow direction	Groundwater regime: depth to water table	Groundwater regime: moisture presence
ridge tops	exposed, open	trembling aspen, lodgepole pine (retarded growth)	buffaloberry, bearberry, wild rose	white clover, loco weed, cut-leaf anenome, low everlasting	thinly grassed, red top, pine grass, moss & lichens over exposed bedrock	brunisolic grey-wooded (light sandy soils)	very thin	compact	flat, even surface	deficient	very thin till over sand-stone bedrock	down	over 30'	usually dry
upper midslopes (above break in slope)	southwest-facing, exposed, open	trembling aspen, lodgepole pine (open, hardy)	buffaloberry (thin clumps), mountain juniper, bearberry, blueberry	Loco weed, pussy toes, devil's paintbrush, yarrow, bluebell, mountain golden-rod	thinly grassed, broad-leaf grasses, woolly wild rye, blue grass	brunisolic grey-wooded (light sandy soils)	thin to thick	compact	flat, even surface	deficient	tills are sandy and stony, 5-15' thick over sandstone bedrock	down	approx. 10'	usually dry
	northeast-facing, sheltered	trembling aspen, white spruce, balsam fir, lodgepole pine, mountain alder (dense clumps)	dense clumps of buffaloberry, wolf willow, bearberry, wild rose, honey-suckle	hedysarum, peavine, mountain goldenrod, bluebell, bed-straw, red clover	thinly grassed, broad-leaf grasses, woolly wild rye, blue grass	brunisolic grey-wooded (light sandy soils)	thin to thick	compact	flat, even surface	damp	tills are sandy and stony, 5 to 15' thick over sandstone bedrock	down	approx. 10'	dry to moist
upland local depressions	shaded	white spruce, black poplar, mountain alder	shrub willow, buffalo berry	snow buttercup, mountain goldenrod	sedges, equisetum, thin mosses	orthic glysol	thick	hard, fairly dense	lumpy, uneven, cracked bottom if dry	moist to wet	thick till over interbedded claystone and sandstone	down	0-5' below surface	[illegible]
lower midslopes (below break in slope)	open to dense	white spruce, mountain alder, black poplar, black spruce	swamp willow, water birch, ground currents, shrubby cinquefoil	Labrador tea, bunchberry, coltsfoot, bedstraw, groundsel, delphinium	equisetum, slough grass, thick mosses, sedges	orthic glysol or organic soil	thick	soft, loose	irregular, lumpy ground	damp to moist	thick, sandy clay till over claystones; some slumps present	lateral	less than 2'	[illegible] and [illegible]
local saddles, the bottoms of small depressions or wind gaps	open to dense, shaded	black poplar, white spruce, mountain alder	shrub willow, wild goose-berry, ground current, honey-suckle	cow parsnip, bunchberry, coltsfoot, Labrador tea, delphinium	mosses, sedges, equisetum, ferns	orthic glysol or organic soil	thick	soft, loose	hummocky ground	moist to wet	thick, sandy clay till over interbedded claystone & sandstone bedrock	up	less than 2'	[illegible] and ponded ground-water

Appendix B

Specific Conductance and Chemical Analyses of Groundwater and Surface Water

Site†	Type** of water	Specific conductance (mmhos/cm)	Water temperature (°F)
Whiskeyjack basin			
WJ-1-1*	1	470	44
WJ-1-2*	1	340	49
WJ-2	1	370	43
WJ-3	1	320	42
WJ-4	1	350	41
WJ-5	1	330	42
WJ-5A*	2	340	45
WJ-5B	3	243	51
WJ-6-1	1	330	38
WJ-6-2	1	340	41
WJ-6-3	1	360	41
WJ-7	1	230	41
WJ-7A	2	350	45
WJ-7B	2	270	36
WJ-7C	2	310	35
WJ-7D	3	310	35
WJ-8	1	350	42
WJ-8A	3	310	38
WJ-8B	2	420	38
WJ-8C	2	320	47
WJ-9	1	375	41
WJ-9A	2	420	43
WJ-10A	3	480	41
WJ-11A*	2	380	38
WJ-11*	1	310	33

(continued)

Appendix B. Specific Conductance and Chemical Analyses of Groundwater and Surface Water (continued)

Site†	Type** of water	Specific conductance (mmhos/cm)	Water temperature (°F)
WJ-11B	2	380	46
WJ-12A*	3	360	37
WJ-13	ponded	380	68
WJ-14	1	280	47
WJ-14A	3	450	39
WJ-14B	2	385	43
WJ-14C	2	410	41
WJ-14D	2	530	49
WJ-15	1	300	43
WJ-16*	1	245	46
WJ-17	1	270	39
WJ-18	1	240	46
WJ-19A*	3	340	37
WJ-20*	ponded	450	74
WJ-21A	3	280	38
WJ-22A	3	200	39
WJ-23A	2	230	39
WJ-24	1	260	55
WJ-25A*	2	200	47
WJ-26	1	340	55
WJ-27	1	210	54
WJ-28	1	250	49
EWJ-1	1	400	50
EWJ-1A	2	240	48
EWJ-1B	2	320	52
EWJ-2	2	280	44
EWJ-2A	2	260	38

(continued)

Appendix B. Specific Conductance and Chemical Analyses of Groundwater and Surface Water (continued)

Site†	Type** of water	Specific conductance (mmhos/cm)	Water temperature (°F)
EWJ-3	1	240	48
EWJ-3A	2	250	42
EWJ-4A	3	200	35
EWJ-5A	3	260	49
EWJ-6	1	180	50
Hardisty Creek			
H-1A	3	650	56
H-2A	2	360	
H-3A	2	400	
H-4A	2	470	
H-5A	3	535	37.5
Cache Percotte basin			
CP-1	1	560	
CP-2	1	-	
CP-2A	2	-	
CP-3A	2	360	50
CP-4*	1	408	52
CP-4A	2		43
CP-4B*	2	239	47
CP-5*	1	390	44
CP-6	1	370	46
CP-7	1	340	47
CP-8*	ponded	270	49
CP-9A	2	440	44
CP-10A*	3	360	47
CP-11	1	340	43

(continued)

Appendix B. Specific Conductance and Chemical Analyses of Groundwater and Surface Water (continued)

Site†	Type** of water	Specific conductance (mmhos/cm)	Water temperature (°F)
CP-12	1	410	51
CP-13A	2	410	43
CP-14*	1	388	-
CP-15	1	444	-
CP-16A	2	450	42
CP-17	1	400	49
CP-18A	2	400	44
CP-19	1	400	49
CP-19A	2	400	39
CP-20*	1	310	46
CP-21	1	370	40
CP-22	1	380	46
CP-23*	1	375	46
CP-24	1	420	46
CP-25*	1	400	47
CP-26A	2	370	36
CP-27A	3	340	38
CP-28A	3	340	36
CP-29A	3	310	37
CP-30A	2	370	40
CP-31	1	380	41
CP-34A	2	300	49
CP-35	3	360	38
ECP-1*	ponded	240	62
ECP-2A	2	370	47
ECP-3†	ponded	220	66
ECP-4A	1	340	49

(continued)

Appendix B. Specific Conductance and Chemical Analyses of Groundwater and Surface Water (continued)

Site†	Type** of water	Specific conductance (mmhos/cm)	Water temperature (°F)
ECP-5A	2	270	46
NECP-1*	1	432	47
NECP-1A	3	-	-

† Site locations shown on the groundwater map

* Sites where water samples collected for complete analysis

** Type of water: 1 stream water
2 shallow subsurface water
3 spring water

Appendix B. Specific Conductance and Chemical Analyses of Groundwater and Surface Water (continued)

Sample site*	Type of water sample**	pH	Color (Hazen units)	Turbidity (units)	Total alkalinity (ppm)	Conductance @ 25 °C (mmhos/cm)	S.O.C.† - spec. cond. ratio	Na/K ratio (epm/epm)	Ca/mg ratio (epm/epm)	Cations (epm)				Anions (epm)				
										Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3
Whiskeyjack basin																		
WJ-1-1	1	8.5	20	1.3	248	510	0.54	35.8	2.3	2.994	1.300	1.109	0.031	0.236	4.719	0.308	0.020	-
WJ-1-2	1	8.6	20	0.6	200	396	0.54	22.4	2.5	2.595	1.053	0.583	0.026	0.236	3.760	0.121	0.020	-
WJ-5A	2	8.3	10	2.5	209	423	0.50	16.2	2.3	2.695	1.185	0.422	0.026	-	4.176	0.062	0.014	-
WJ-11	1	8.6	5	0.4	206	382	0.57	29.8	3.1	2.595	0.847	0.835	0.028	0.316	3.800	0.085	0.017	-
WJ-11A	2	8.3	20	0.6	204	388	0.56	35.5	3.1	2.395	0.765	1.101	0.031	-	4.076	0.077	0.017	0.002
WJ-12A	3	8.5	5	89	220	415	0.56	52.7	3.0	2.345	0.790	1.475	0.028	0.188	4.208	0.094	0.017	-
WJ-16	1	8.5	10	0.5	186	357	0.55	22.9	3.1	2.695	0.872	0.344	0.015	0.156	3.560	0.112	0.015	0.008
WJ-19A	3	8.4	5	13	189	379	0.52	22.0	2.4	2.445	1.020	0.439	0.020	0.396	3.380	0.069	0.017	0.019
WJ-20	ponded	8.5	30	0.6	217	379	0.60	30.7	3.2	2.944	0.913	0.552	0.018	0.188	4.148	-	0.023	0.029
WJ-24	1	8.5	20	1.7	186	363	0.55	26.5	3.3	2.794	0.856	0.344	0.013	0.188	3.528	0.139	0.014	-
WJ-25A	2	8.3	20	4.4	161	334	0.54	8.2	3.2	2.545	0.806	0.213	0.026	-	3.217	0.217	0.034	0.073
Cache Percotte basin																		
CP-4	1	8.4	20	0.1	219	408	0.58	31.1	3.2	3.094	0.971	0.622	0.020	0.205	4.171	0.146	0.014	-
CP-4B	2	8.2	10	0.7	256	465	0.56	26.3	2.7	3.493	1.291	0.474	0.018	-	4.115	0.044	0.014	-
CP-5	1	8.5	20	0.1	210	560	0.40	27.1	3.3	3.094	0.938	0.352	0.013	0.303	3.893	0.169	0.017	0.002
CP-8	ponded	7.7	20	4.6	129	244	0.56	-	3.7	1.996	0.535	0.222	-	-	2.577	0.012	0.011	-
CP-10A	3	8.0	10	1.1	179	345	0.54	15.4	3.5	2.695	0.765	0.278	0.018	-	3.576	0.110	0.014	0.021
CP-14	1	8.5	30	0.5	205	388	0.56	25.4	3.3	2.994	0.905	0.457	0.018	0.240	3.856	0.110	0.017	0.005
CP-15	1	8.5	20	0.4	242	444	0.57	54.2	4.3	3.443	0.806	0.813	0.015	-	4.835	0.060	0.014	-
CP-20	1	7.6	30	1.9	151	301	0.55	24.9	3.8	2.196	0.576	0.448	0.018	-	3.017	0.160	0.014	0.011
CP-23	1	8.3	30	0.3	194	366	0.57	38.2	3.5	2.645	0.749	0.687	0.018	-	3.876	0.096	0.014	-
CP-25	1	8.4	20	0.11	218	403	0.58	38.7	3.6	2.994	0.839	0.696	0.018	0.240	4.116	0.110	0.014	-
ECP-1	ponded	8.1	40	0.4	160	310	0.55	24.4	3.6	2.246	0.625	0.439	0.018	-	3.197	0.067	0.011	-
ECP-3	ponded	7.8	20	1.7	179	342	0.56	15.1	3.6	2.645	0.732	0.392	0.026	-	3.576	0.119	0.014	0.011
NECP-1	1	8.5	10	0.1	237	432	0.57	17.1	3.0	3.542	1.193	0.222	0.013	0.320	4.415	0.100	0.017	-
Athabasca River near Hinton																		
Date																		
11-06-67	1	7.7	5	14	76	204	0.51	3.4	3.2	1.412	0.440	0.044	0.013	-	1.518	0.437	0.006	-
09-08-67	1	8.2	5	7.8	72.1	205	0.53	3.3	2.5	1.387	0.547	0.026	0.008	-	1.441	0.543	0.006	0.002
13-09-67	1	8.1	20	54	68.6	193	0.51	2.7	3.2	1.322	0.416	0.035	0.013	-	1.371	0.460	0.006	0.002
19-10-67	1	8.0	10	39	84.6	254	0.58	4.7	1.9	1.761	0.916	0.061	0.013	-	1.690	0.924	0.017	0.005
15-11-67	1	8.3	5	25	106	332	0.53	5.8	2.1	2.315	1.102	0.087	0.015	-	2.118	1.307	0.017	0.006
20-12-67	1	8.2	5	0.7	107	375	0.58	7.3	2.6	2.675	1.021	0.109	0.015	-	2.138	1.622	0.017	0.006

* All samples from Whiskeyjack and Cache Percotte basins were collected between July 3 to 12, 1968
** Type of water sample: 1 - stream water; 2 - shallow subsurface water; 3 - spring water
† S.O.C./Cond. is the ratio of sum of constituents to specific conductance

Topographic setting	Aspect	Characteristic vegetation				Soil					Geology	Groundwater regime		
		trees	shrubs	herbs	ground cover	type (after Lindsay)	thickness	density & firmness	micro-topography	moisture condition		flow direction	depth to water table	moisture presence
along sloping creek banks	dense, shaded	white spruce, black poplar, black spruce, mountain alder, water birch	shrub willow, wild goose-berry, dogwood, shrubby cinque-foil	bunchberry, coltsfoot, cow parsnip, Labra-dor tea	equisetum, sedges, thick mosses, ferns	orthic glysol	thick	soft, loose	lumpy, irregular	wet	thick, sandy clay tills over clay-stones, and local coal lenses	up	less than 1'	seepage & springs present
in ponded groundwater areas, or bogs	open to dense	stunted white and black spruce	swamp willow, swamp birch, shrubby cinque-foil	white & yellow ladieslipper, elephant head, pyrola, Labrador tea	thick mosses, sedges, marsh-grasses, rushes, slough grass	organic soil or peat	very thick	soft, loose	hummocky ground	saturated	thick, sandy clay tills over clay-stones, and local coal lenses	up	water above ground	ground-water ponded at sur-face
along drained stream terraces	shaded	trembling aspen, lodge-pole pine, some white spruce	buffaloberry, shrub willow	goldenrod, fireweed, loco weed, hedy-sarum, blue-bell	broad-leaf grasses	western brown forest	thin to thick	hard, dense	flat, even ground	dry to damp	alluvium over till over claystone bedrock	down	5 to 10' below surface	dry to damp