AN INVESTIGATION INTO THE STREAMFLOW AND

GROUNDWATER HYDROLOGY OF WILSON CREEK

A SMALL MANITOBA WATERSHED

————————

A Thesis

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Master of Arts

————————

by

Rosemary Anne Cox

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ABSTRACT

A preliminary investigation was made into two aspects of the inter-relationships between groundwater discharge and streamflow in the Wilson Creek Watershed. The first aspect was to evaluate the relationships between the major dissolved ions in the stream (varying both with time and distance from the source) and the groundwater. The second was to attempt a baseflow separation of a peak-flow hydrograph using characterising groundwater ions.

Sulphate was used as the characterising ion because of the evidence of its being representative of the groundwater. The stream water was found to be from local and not deep groundwater reservoirs, because of the downward hydraulic gradient in the piezometers, and their chemical characteristics.

Consistent results utilising the relation-ships between the sulphate content and streamflow in calculating the groundwater discharge in a flood peak indicate that this method of baseflow separation is likely to be representative. This assumes a limited dilution of the groundwater component.

FORWARD

This thesis reports on the work done in 1968 on Agassiz Center Research Project S4, "Groundwater-Streamflow Systems in Small Watersheds – Wilson Creek" sponsored by the Department of Energy, Mines and Resources, the Agassiz Center for Water Studies, and the National Research Council; principal investigators: Dr. R. W. Newbury, Civil Engineering and Dr. J. A. Cherry, Geology.

The main Wilson Creek Experimental Watershed project, supported by the Governments of Canada and Manitoba, is denoted I.H.D. Experimental Basin Project IWB-EB-7, Man-1, supervised by the Wilson Creek Head-water Control Committee (Chairman, Mr. J. M. Parker, Secretary, Mr. G. H. MacKay).

Meteorological and hydrometric data for the 1968 field season were gathered and analyzed by the Wilson Creek Project staff under the supervision of Mr. J. E. Thomlinson, Project Manager. Water samples were collected by the Wilson Creek staff and analyzed by the author in June, July and August. Additional samples were analyzed by Mr. J. Thomlinson and the National Testing Laboratory, Winnipeg.

The analysis of the groundwater flow system and its implications in operational hydrology was under-

taken by the principal investigators; Mr. F. Schwartz,

graduate student, Geology, and the author.   The

analysis is summarized in: Agassiz Center Contribution

No.7, Groundwater-Streamflow Systems in Wilson Creek

Experimental Watershed, Manitoba (1968).

ACKNOWLEDGEMENTS

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1. INTRODUCTION

A. Problems investigated

This thesis is a report of the findings of a preliminary investigation into the inter-relationships between groundwater and surface water discharge in the Wilson Creek experimental watershed.

The investigation undertaken in the summer of 1968, considered the relationship between the groun- water discharge, the stream runoff, surface water dis- charge, and the concentrations of dissolved ions in the streamflow. The relationship was dealt with from two major view points. Firstly it was desired to determine whether the major dissolved ions in the stream discharge at a section and in the downstream direction can be related to the source water which accumulates in the stream to form the discharge, and secondly, whether the groundwater and interflow contribution during the rising and falling limb of a peak-flow hydrograph can be determined quantitatively using one or more of the major ion concentrations in the flow.

The first problem principally concerns relationships between spring water, stream water quality, and groundwater as obtained from piezometers and

observation wells.

During periods when there is no precipitation, the flow of the streams must be due to the inflow of groundwater from the numerous springs and seeps along the creeks. This water can be from one of two sources, either a relatively stable flow from the groundwater zone proper, or a highly variable flow from the soil zone. It is possible that the groundwater proper is from one of two sources, from the "in-basin" reservoir, or the "out-of-basin" reservoir. The first of these is composed of groundwater with a divide coinciding with that of the surface water, the reservoir thus being localised. The second is composed of water from wider sources, the divide not coinciding with that of the surface water, as such, it may have different characteristics. In order to come to some conclusions as to the problem of local versus non-basin groundwater, it must be determined which of the possible sources the water in the Wilson Creek watershed is from, and which of the characteristics of water are most useful for identification.

The second problem concerns the use of methods in base-flow separation which are relatively unexplored. The conventional methods of separation of the hydro-

graph are somewhat arbitrary and artificial (Gray and Wigham, 1966, p7.24). Davis and De Wiest (1966 p29-33) summarise methods that range from drawing a straight horizontal line from a point on the hydrograph before the rise, to a similar point after the peak, to the more sophisticated calculations based on mathematical rather than physical analyses of recession curves. The latter method assumes that the groundwater flow varies only with the values of the recession constant (Barnes 1940). It is understood that variations in the recession constant are due to the variations in the areal distribution of rainfall within a basin. A further attempt to obtain the groundwater component was proposed by Langbein (1940) where the value of the recession constant is obtained by plotting the mean daily discharge of one day against that of the next. Even here, however, the time of the peak of the groundwater recession, and the shape of the rising limb are chosen arbitrarily.

All these methods are approximate, yet very little work has been done in applying methods of chemical analysis. Kunkle (1965) is one of the few who has attempted to use the quality of the water in the determination of groundwater flow during flood

peaks.   It seems probable in many areas that the
groundwater has major or minor ionic concentrations
which are distinctive and which could be used as a
physical basis for hydrograph separation analysis.   An
example of the use of such geochemical methods in a
small well-instrumented, high relief watershed in
Southwestern Manitoba is presented herein.

B.   Location and Field Programme

     Studies were conducted in the Wilson Creek
watershed which is situated on the East facing Manitoba
escarpment, between the towns of Neepawa and Dauphin,
and just inside the Riding Mountain National Park.
The basin extends west in a pear-shaped formation from
$SE\frac{1}{4}$-24-20-16 (latitude 50°43'4" N, longitude
99°33'15" W) covering an area of 8.501 square miles
(fig.1).

     The principal chemical constituents of the
groundwater (both from the piezometers and springs) and
surface water in the Wilson Creek watershed were
determined during the period May - October 1968.   In
addition stream hydrographs, piezometers and observation
well data were used, particularly during low flow and
peak flow periods (Appendix A).
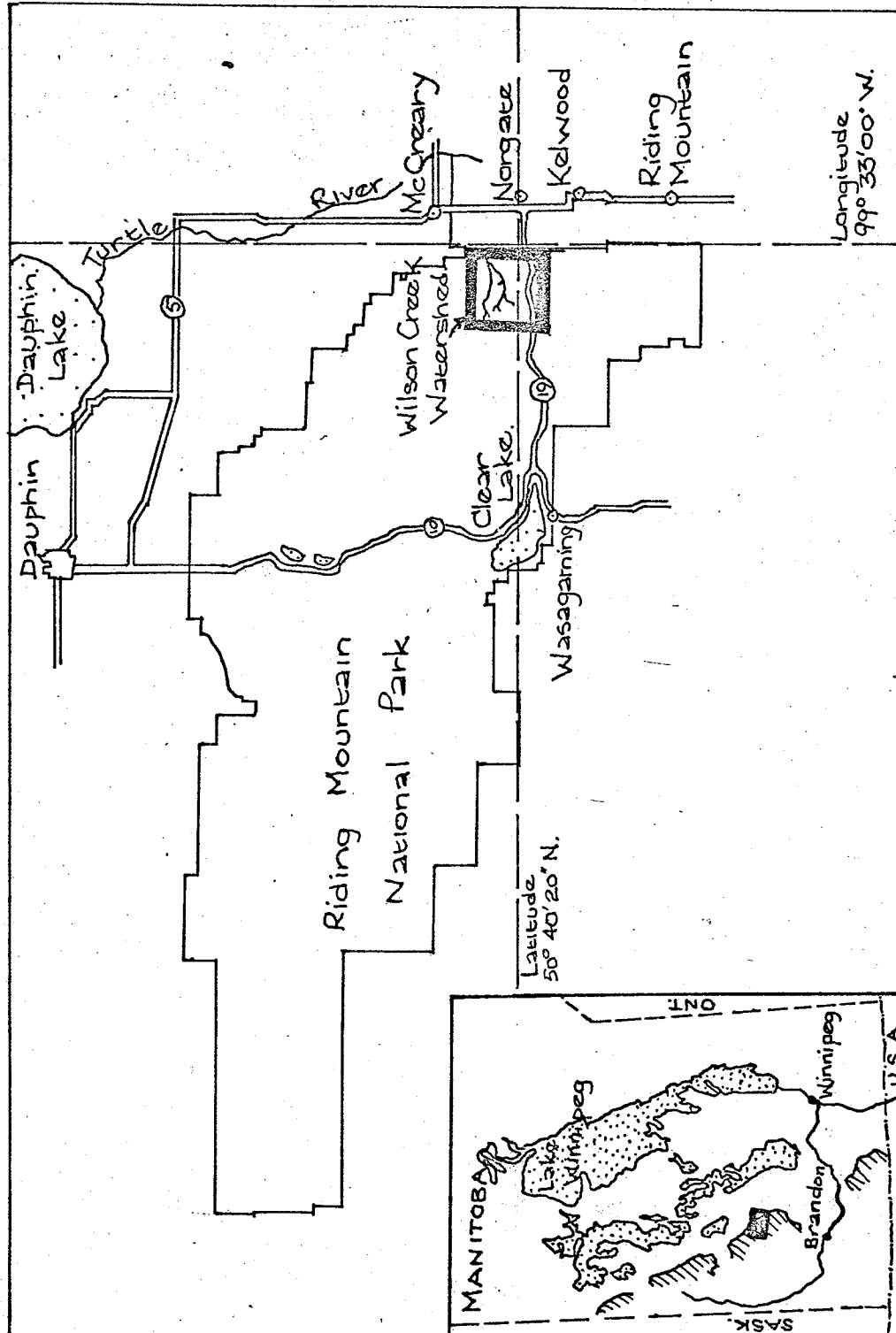
Fig. 1 - Location of the Wilson Creek Watershed

Analyses were carried out on water collected to determine the calcium, magnesium, bicarbonate, chloride, sulphate and iron content, and conductivity, and pH during the first two months of the field season. Later the determinations were restricted to conductivity and sulphate since these seemed to be of most value.

II. WILSON CREEK WATERSHED

A. Physiography

In the Wilson Creek watershed it is possible
to divide the escarpment into four distinct units (fig.
2).   At the summit, the Western Upland is encountered.
This forms an undulating plain containing numerous
beaver ponds (fig.3), muskeg (e.g. Pencil Lake), and
kettle holes (e.g. Lake Ritchie) (Plate I).   The Upper
Escarpment, extending down to the bedrock terrace at
1900 feet, is composed entirely of glacial deposits,
giving rise to innumerable mud flows, and slumps in the
narrow, though deeply incised valley (fig.4) and con-
stitutes the second unit.   The third unit is composed
of the Lower Escarpment, cut into the shale itself.   In
this section there are numerous cut-offs, abandoned
channels, terraces, and large scale landsliding (fig.5).
Finally, the Manitoba Lowlands (Ehrlich et al, 1958) at
the foot of the scarp is an area of deposition, in the
form of a great alluvial fan, or perhaps delta
associated with glacial Lake Agassiz.

So far the description of the Wilson Creek
watershed has been entirely qualitative.   It is
essential therefore, that some attempt at quantitative
analysis is made, in order to use the drainage network
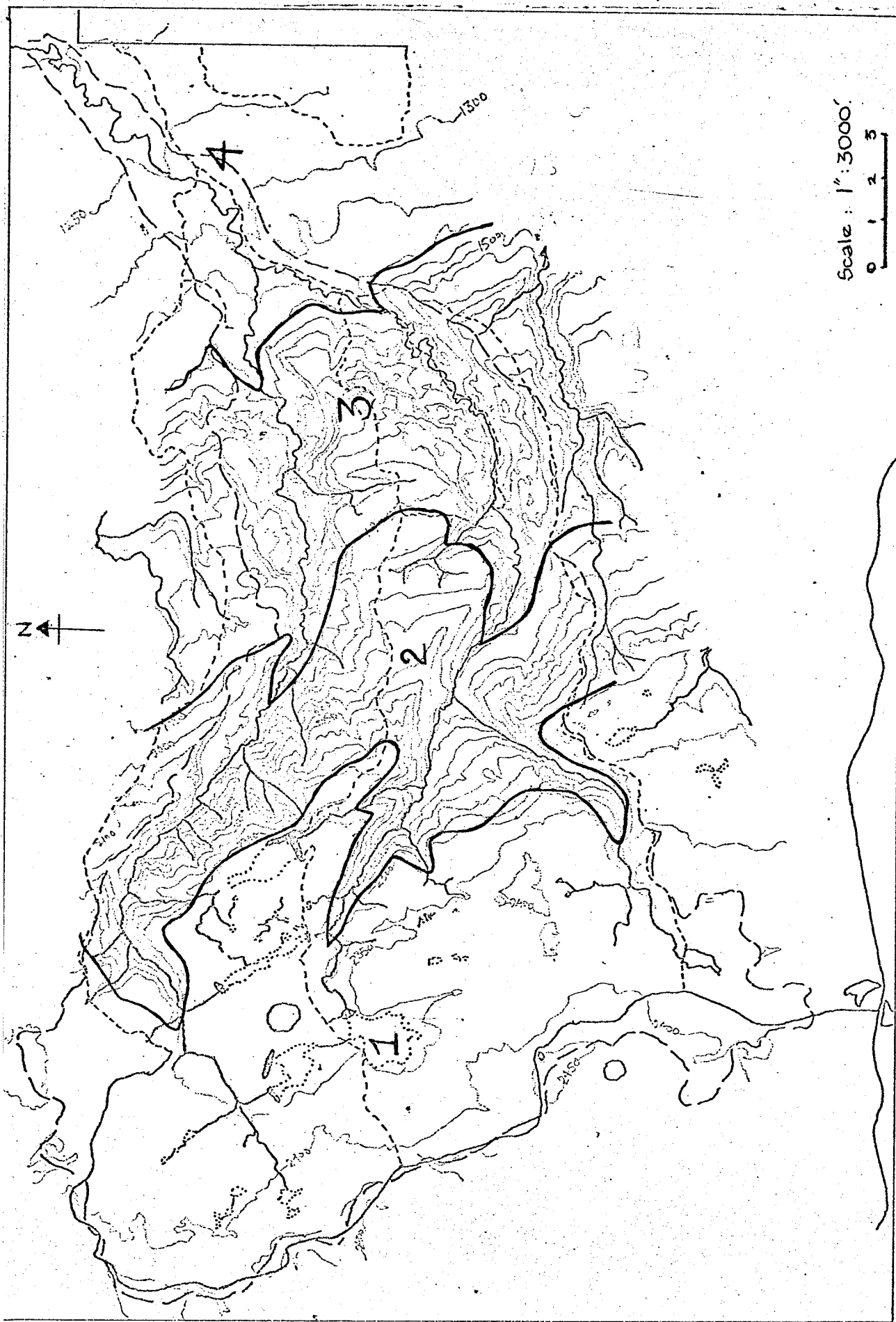
Fig. 2 - Physiographic Regions, 1. Western Uplands, 2. Upper Escarpment,

3. Lower Escarpment, 4. Manitoba Lowlands.

Fig. 3 - Bald Hill Beaver Pond (released by the blast
August 16 1968).
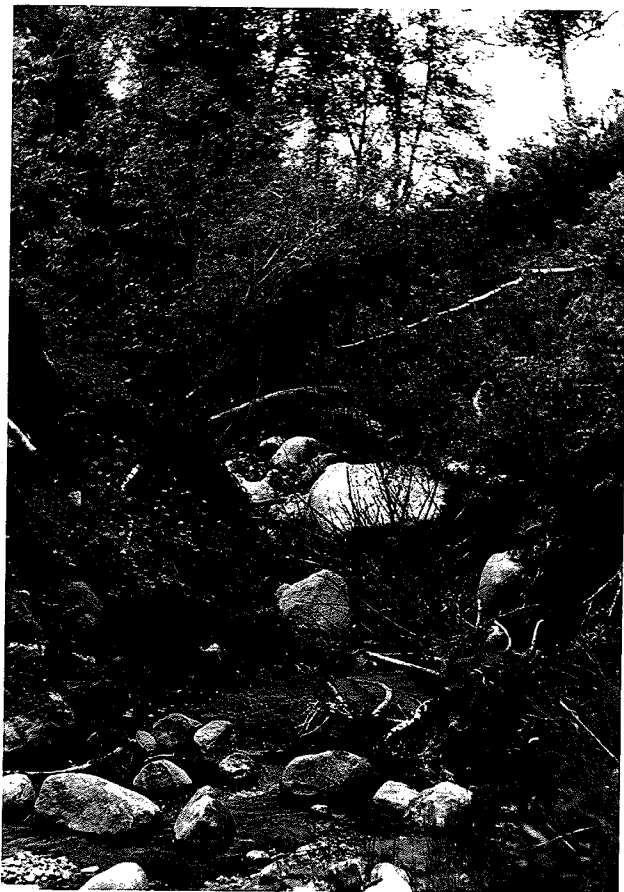
Fig. 4 - Deeply incised
South Branch
Bald Hill Creek,
in the Upper
Escarpment.

Fig. 5 - Below Bald Hill:
cut-off, abandoned
channel, terrace,
and large scale
landslide.

in further calculations.

The drainage density of the whole of the basin under study is 2.9. This figure was obtained using a total area of 8.501 square miles, and total stream length of 24.78 miles. The measurements were taken from a 1:12,000 map, and include streams plotted after field work in the area. Thus most streams of any consequence have been accounted for. Comparisons within the basin were obtained by breaking it down into its component parts. (Plate 1). The Bald Hill basin (including South Branch) has a drainage density of 2.451, while Packhorse has a drainage density of 3.26. Wilson Creek (excluding Packhorse above the weir, and the whole of the Bald Hill Creek system) has a drainage density of 5.15. A high surface runoff (i.e. as creeks) gives rise to high drainage density, yet the greatest density in the water-shed is the lowest part where there are no tributaries. However the valley area is very small, and the creek is widely meandering.

The drainage density, particularly on the smaller scale maps, may not be representative, since not all creeks are shown. In some valleys the water flows below the surface, entering the main stream either without actually visibly flowing, or appearing a few feet before the main stream (e.g. Ardee Creek).

In an attempt to overcome this, a texture ratio may be
utilised (Strahler 1957) to obtain a more representative
figure. In the Wilson Creek watershed, the 2000 foot
contour line appears to have the greatest number of
crenulations (using the 1:12,000 map). The length of
the basin perimeter is 18.09 miles, so giving a texture
ratio of 2.4.

B. Geology

In the upper portion of the escarpment thick
deposits of glacial till are to be found, while a thin
veneer overlies the units of Cretaceous shale into which
the river basin is incised in the lower sections. The
shale is generally fairly friable and weathered, forming
talus cones masking most of the larger outcrops.

Wickenden (1945) mapped the escarpment, and
Eastern Plains of Manitoba and Saskatchewan, and
indicates that the Wilson Creek basin is underlain by
Favel, Vermilion River, and Riding Mountain Formations
(fig.6). He showed no evidence of examination of out-
crops in this basin, and it is to be assumed that his
conclusions were drawn by correlation between outcrops
at Kelwood and Edward's Creek located 10 and more miles
south and north of the watershed.

The early reconnaissance of the area by Carr

GEOLOGIC CROSS-SECTION A-A'

GLACIAL DRIFT
PREDOMINANTLY TILL, CALCAREOUS WITH CLAY AND SILT AND OCCASIONAL LENSES OF GRAVEL AND SAND

RIDING MOUNTAIN FORMATION
SHALE NON-CALCAREOUS, NUMEROUS THIN INTERBEDS OF SILTSTONE, SOFT BENTONITIC SHALE AND OCCASIONAL BEDS OF SHALEY (LIMESTONE)

SHALE, INTERBEDDED NON-CALCAREOUS AND CALCAREOUS, OCCASIONAL BENTONITIC INTERBEDS

VERMILLION RIVER FORMATION

FAVEL FORMATION
SHALE WITH ABUNDANT CALCAREOUS FOSSIL FRAGMENTS AND CALCAREOUS SPECKS, OCCASIONAL THIN SHALEY LIMESTONE BEDS

ASHVILLE FORMATION
(SHALE, SHALEY LIMESTONE AND LIMESTONE)

DISCONTINUOUS VENEER OF DRIFT OVERLAIN IN PLACES BY ALLUVIUM AND COLLUVIUM

TEST HOLES

MODIFIED AFTER PARSONS, 1965 AND CARR 1965 UNPUBLISHED

1000 0 1000 2000 3000 4000
F E E T

FEET ABOVE SEA LEVEL
2400' 2200' 2000' 1800' 1600' 1400' 1200' 1000' 800'

Fig. 6 - Geological cross section of the Wilson Creek Watershed.

(1965) showed that only the Riding Mountain Formation
outcropped, often as slump blocks.   From this he drew
the conclusion that the underlying formations are
covered by these slump blocks.

Five nests of piezometers were installed in
1965 (Parsons, 1965, written communication), the test
holes of which give a good indication of the subsurface
geology of a cross section through the basin (fig.6).
At drilling site A (fig.17 p29) there was found to be
462 feet of glacial till, though this depth is thought
to vary across the top of the escarpment, indicating
pre, or may be even sub-glacial valleys etc.   Pockets,
too, are found down the escarpment (as at site C, where
it is 20 feet deep).   Below the till, the drillings
(at sites B, C, D) indicate a good depth of the Riding
Mountain Formation, of mainly non-calcareous shale,
right to the foot of the escarpment.   The Favel
Formation only occurs some 31 feet below the surface at
Wilson Creek weir (site E), as a more calcereous shale,
speckled with white deposits of calcium carbonate.

In an investigation into groundwater movement
it is necessary to study the detailed geology, because
the individual beds control the movement of water to a
great extent.

Although generally the structure is simple it

becomes apparent that in detail it is highly complex.

Investigation of shale outcrops along the valley walls

indicate that in some areas the shale is very highly

contorted and fractured (e.g. Bald Hill Creek). The

reason for this is not immediately obvious, but in

other areas faulting is indicated (e.g. shale bank 21

(station 64+40), and shale bank 15 (station 93+00 -

Plate 1) - both in Bald Hill Creek), so a certain amount

of instability at some stage in the geological history

is indicated. These fault lines seem to be important

in the groundwater movement, for springs were found to

discharge from many of the extremely jointed and

fractured zones (fig.7).

The shale itself tends to be predominantly

hard and light grey in colour, weathering to a rusty

brown (fig.8). It is generally non-calcareous, breaking

into angular fragments. Interbedded with the shale

are some siltstone layers (sideritic and dolomitic),

the occasional ironstone concretions (visible on Bald

Hill and Mount Dunning - fig.9), and bentonite bands

(fig.10). The bentonite was found, by X-ray

diffraction (P.A.Carr 1965) to be the non swelling

variety composed of calcium montmorillonite, with

traces of illite. The bentonite occurs in numerous

thin bands of widespread extent due to its origin as
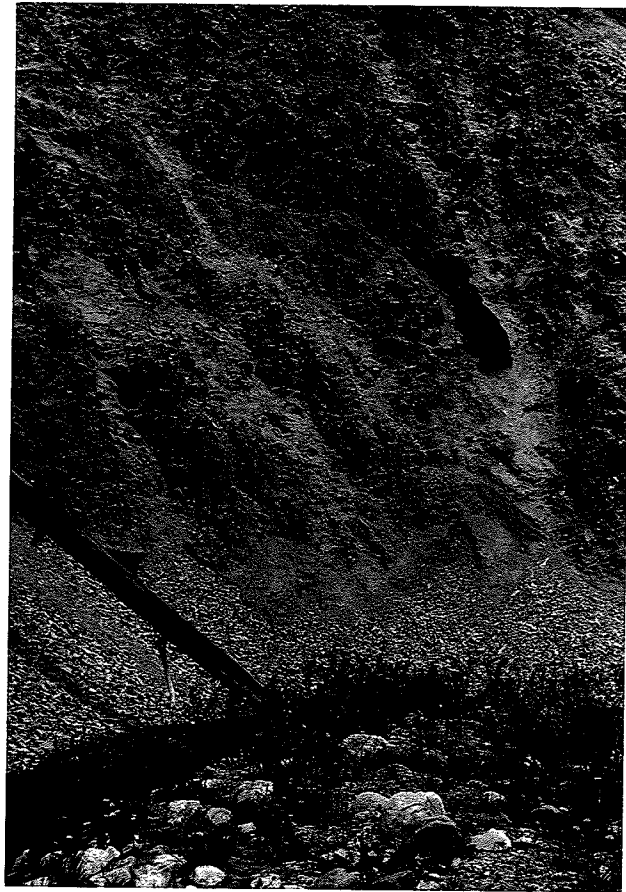
Fig. 7 - Seepage from a fault in shale bank 15,
Bald Hill Creek.

The annotations on the photograph read:
- till
- junction of till and shale.
- weathered shale — brown.
- fresh shale — blue/grey.

Fig. 8 - Shale bank 1, Bald Hill Creek.

N.B. junction of till and shale

weathered shale - brown

fresh shale - blue/grey

Fig. 9 - Iron concretions
on Mount Dunning

Fig. 10 - Bentonite band
on Mount Dunning.

volcanic ash, tuff, and related materials. It varies
in colour from greyish white and yellow, to orange, and
is usually plastic when wet. It is less permeable than
the shale, so during damp periods springs occur above
the bands of bentonite. Water seems to permeate,
however, for during dry spells, while the shale is dry,
the bentonite bands remain damp. This gives some
support to vegetative growth - small trees and grass -
which often appear on the shale slopes in long lines
(fig.11), giving good indication of the location of
such bands beneath a talus cover.

The Favel Formation is dark in colour,
characterised by white specks of calcium carbonate,
with interbeds of limestone, and a few thin bentonite
bands. It does not outcrop in the watershed however.

The till overlying the Riding Mountain
Formation is of two distinct varieties. Immediately
above the Riding Mountain Formation is a heavy blue-
grey clay containing shale fragments and igneous
pebbles, with the occasional limestone pebble. The
lighter, brown, upper till contains pebbles of igneous
and metamorphic rocks, and the occasional lens of
large boulders, but no shale fragments (Figs. 12 and
13). Although these two distinct types of till make
up most of the glacial deposits, there are lenses of
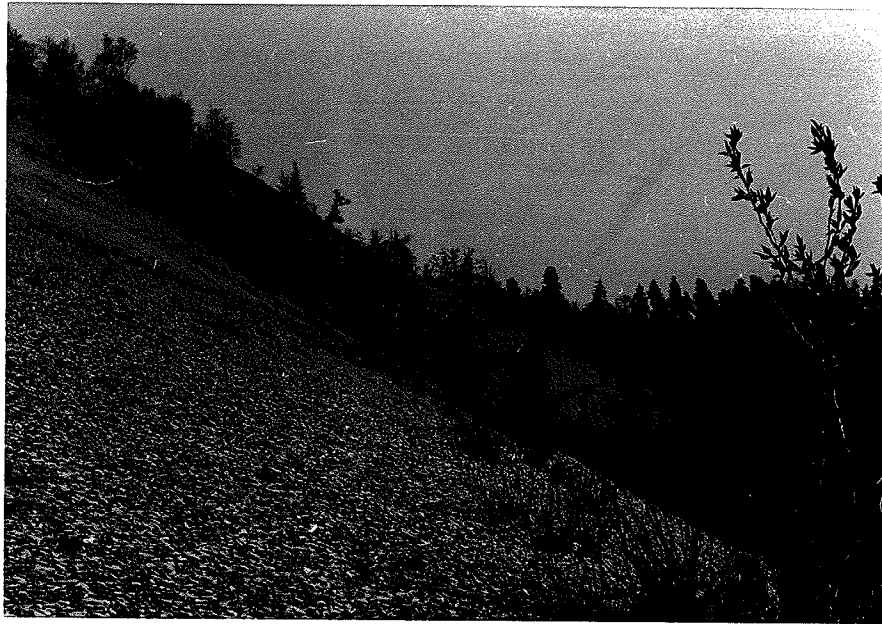
Fig. 11 - Vegetation in lines on bentonite bands
Mount Dunning.

Fig. 12 - Junction of
blue and brown
clay, South
Branch Bald
Hill Creek.

Fig. 13 - Downcutting
in blue, shale
filled clay,
South Branch
Bald Hill Creek.

sand and gravel to be found throughout the area, both in the horizontal and vertical plane. For example on South Branch Bald Hill Creek, in the area of station 22+30 (Plate I) where there is a large exposure of fine orange sand.

C. Climate

The watershed is dominated by a continental climate, with the usual extremes of absolute temperature ranging annually from -45°F to 110°F, and a low precipitation of approximately 19.5 inches each year (the winter precipitation being approximate due to the difficulty of measuring snowfall). A summary of the general climatic characteristics is shown in figure 14, a hytherograph (Morley K. Thomas, 1953) of Dauphin, some 50 miles to the North of the Wilson Creek watershed. Dauphin gives a fairly representative accurate general picture of the climate, though the micro-climate of the Wilson Creek watershed is often different from Dauphin, due to the effect of the forested escarpment.

D. Vegetation

The area is more than 90 per cent under forest cover, both hardwood and softwood, with the hard-
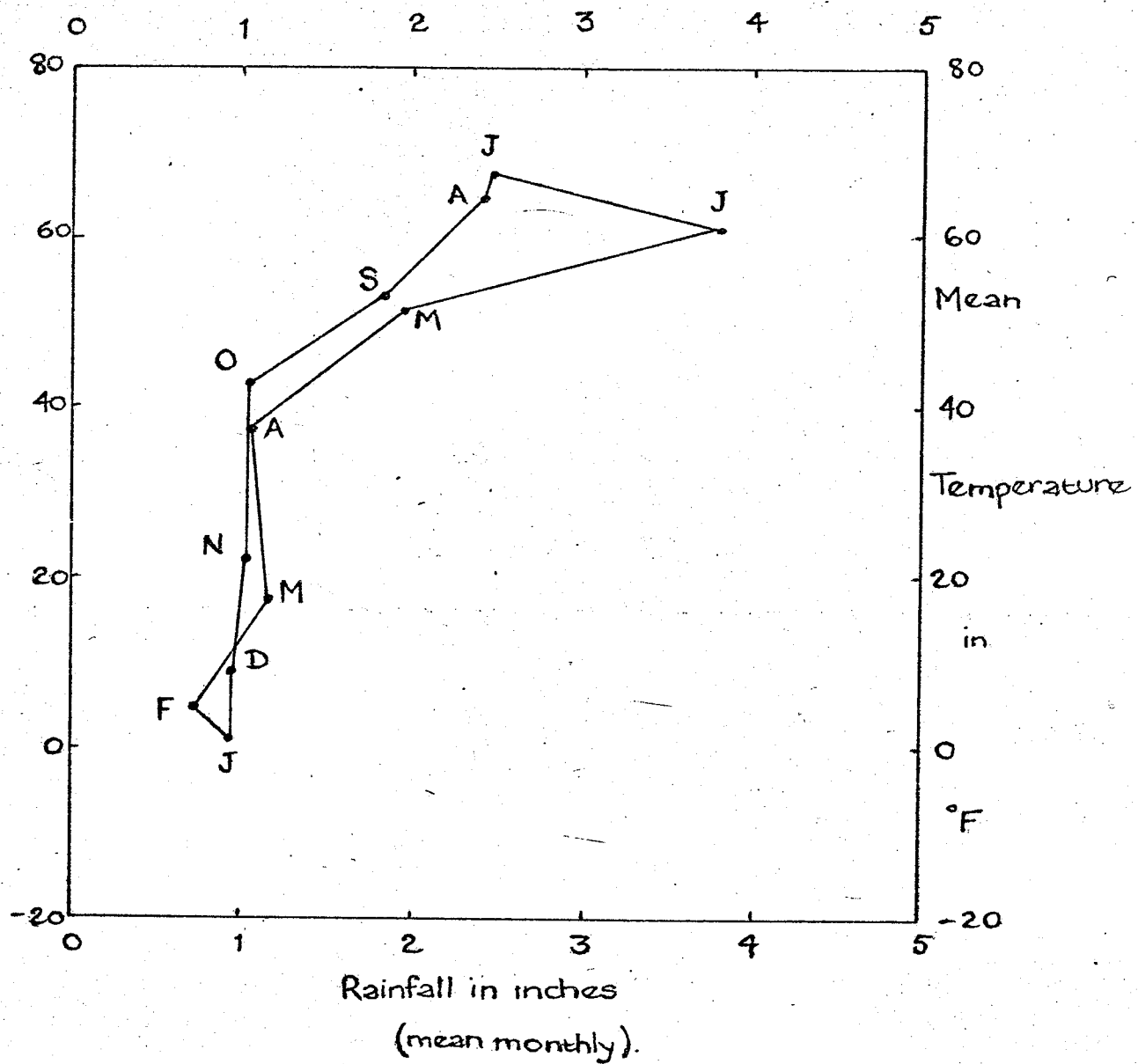
Fig. 14 – Hytherograph for Dauphin, Manitoba.

woods generally predominating.   There are two main
divisions of forest cover - the degenerate forest of the
top of the escarpment (Western Uplands), which is no
longer actively regenerating due to the feeding of elk,
and is therefore composed of ancient trees;   and the
mixed woodland of the scarp slopes and the foot of the
escarpment.   The lower areas are very dense, with good
stands of timber, and heavy underbrush.

E.   Hydrologic Characteristics

The basin is very small and steep, therefore
the hydrograph indicates even small weather changes.
Although in previous years there has been a definite
diminishing runoff during the summer, in this wet year
(1968) it has not been obvious, in anything, there has
been a slight recharge in the system (see the low flows
in figure 15).   The characteristics of the hydrograph
and its relation to rainfall during the summer, is
obvious in figure 15, so that more detailed
description is unnecessary.

Average figures indicate the general trend
of the hydrograph over a summer (fig.16).   Although
the average total monthly rainfall is similar in each
month, the average discharge decreases during the
warmest months.   Examination of the yearly charts
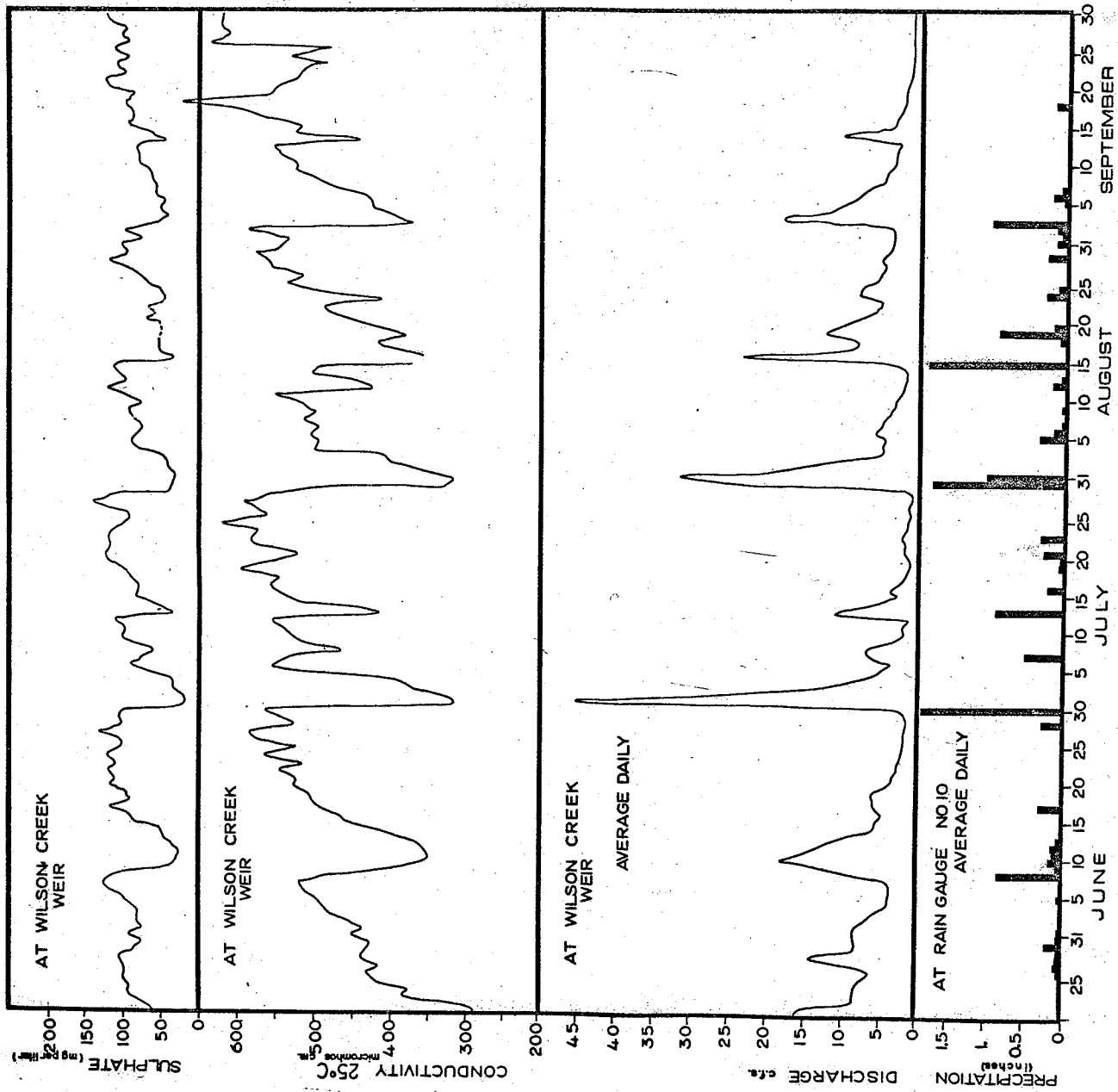
Fig. 15 (a) – Hydrograph at Wilson Creek weir, rainfall,
conductivity, and sulphate graphs.
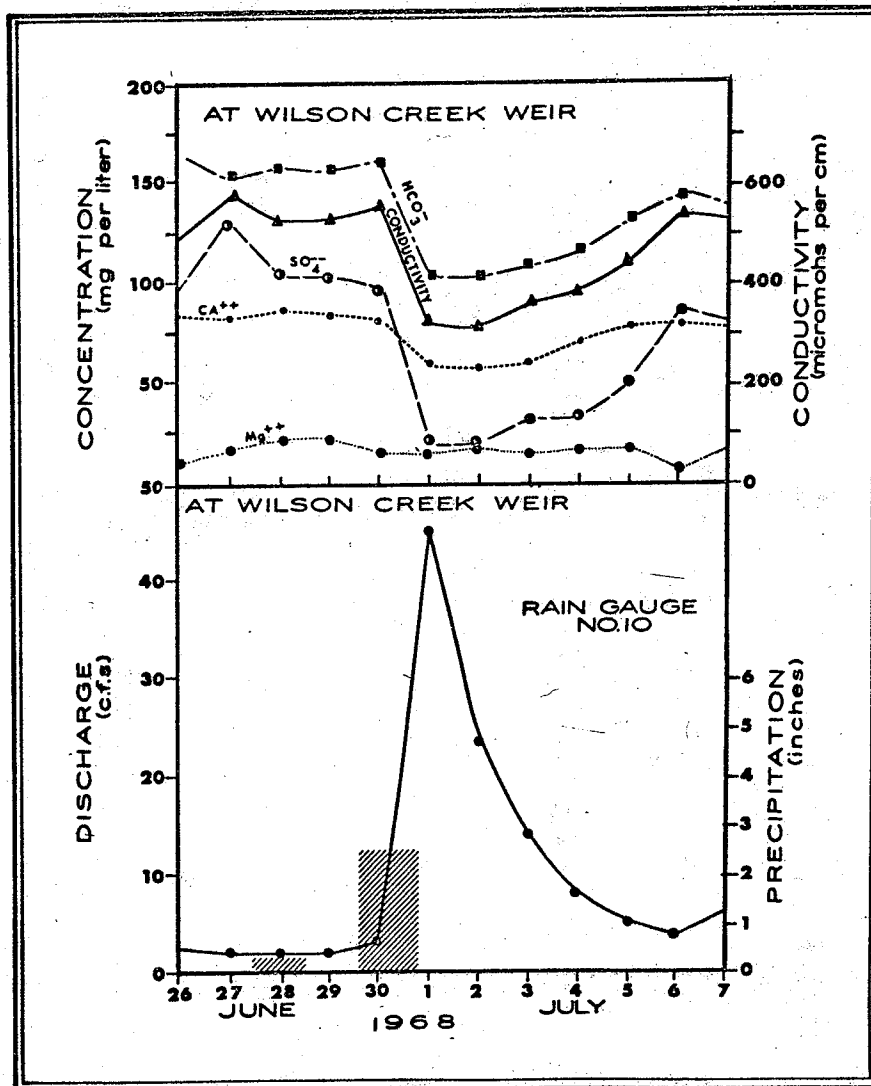
Fig. 15 (b) - Storm of 26 June to 7 July 1968
to illustrate the relationships
between rainfall, runoff, and chemical
chemical content in the stream.
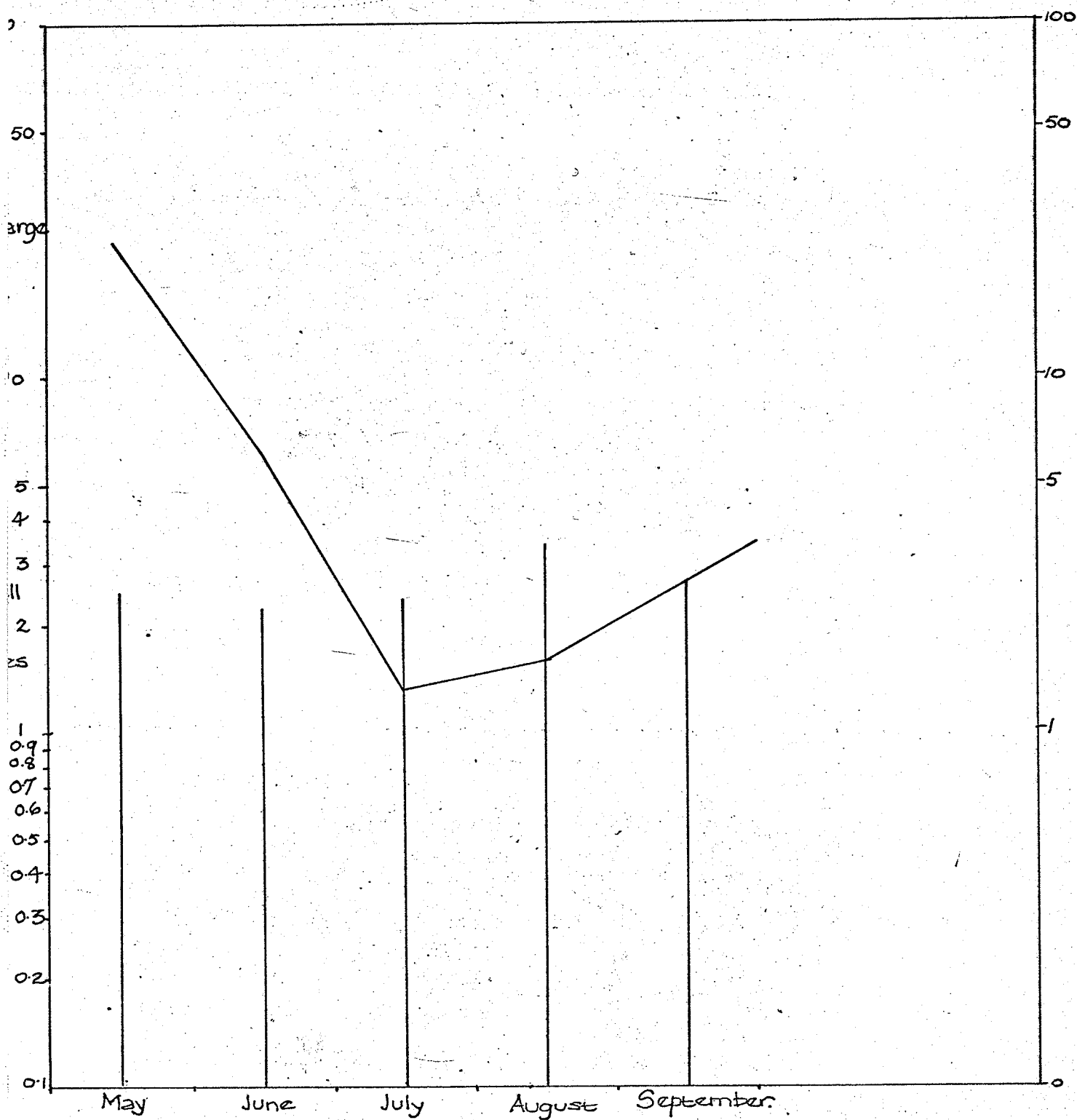
Fig. 16 - Graph showing mean monthly discharge, May through September.

indicates the importance of snow melt each year, whether there is any precipitation in April or May or not (e.g. 1967 - Wilson Creek Annual Report 1967-1968).

Apart from snowmelt, an average of 0.9 storms causing a runoff exceeding 20 cfs at Wilson Creek Weir occur each year, and 1.7 storms occur each year resulting in a discharge of more than 10 cfs. The snow-melt discharge ranges between 40 cfs and 140 cfs, as the discharge in Spring is the total result of the Winter's precipitation. Each storm has the characteristically sharply inclined rising limb, crest of very short duration, followed by a much more "gentle" recession as shown in figures 33 and 34 (page 56).

111. GEOCHEMISTRY OF SURFACE AND GROUNDWATER IN THE
WILSON CREEK BASIN.

A. Wells and Piezometers.

The piezometers are situated along the
central trail located on the ridge of land between
Packhorse, and Bald Hill Creeks (fig. 17). Except
for GS 2 and nests D and E, they do not indicate
conditions existing at the stream itself. They do,
however, give an indication of the direction of ground-
water movement, and a general idea of quality.

Water levels in the piezometers indicate that
a downward movement of groundwater predominates. This
is evidenced by the downward hydraulic gradient in all
the nests.

It seems apparent that there are perched
water tables, possibly because of bentonite bands acting
as impermeable horizons. These occur principally at
nests B and C, though the best example is GS 13 (at
nest B). The water level in this piezometer indicated
its dryness for the first two months of sampling in
1968. Its working order was certified when water was
placed in it to a depth of 15.5 feet. This had emptied
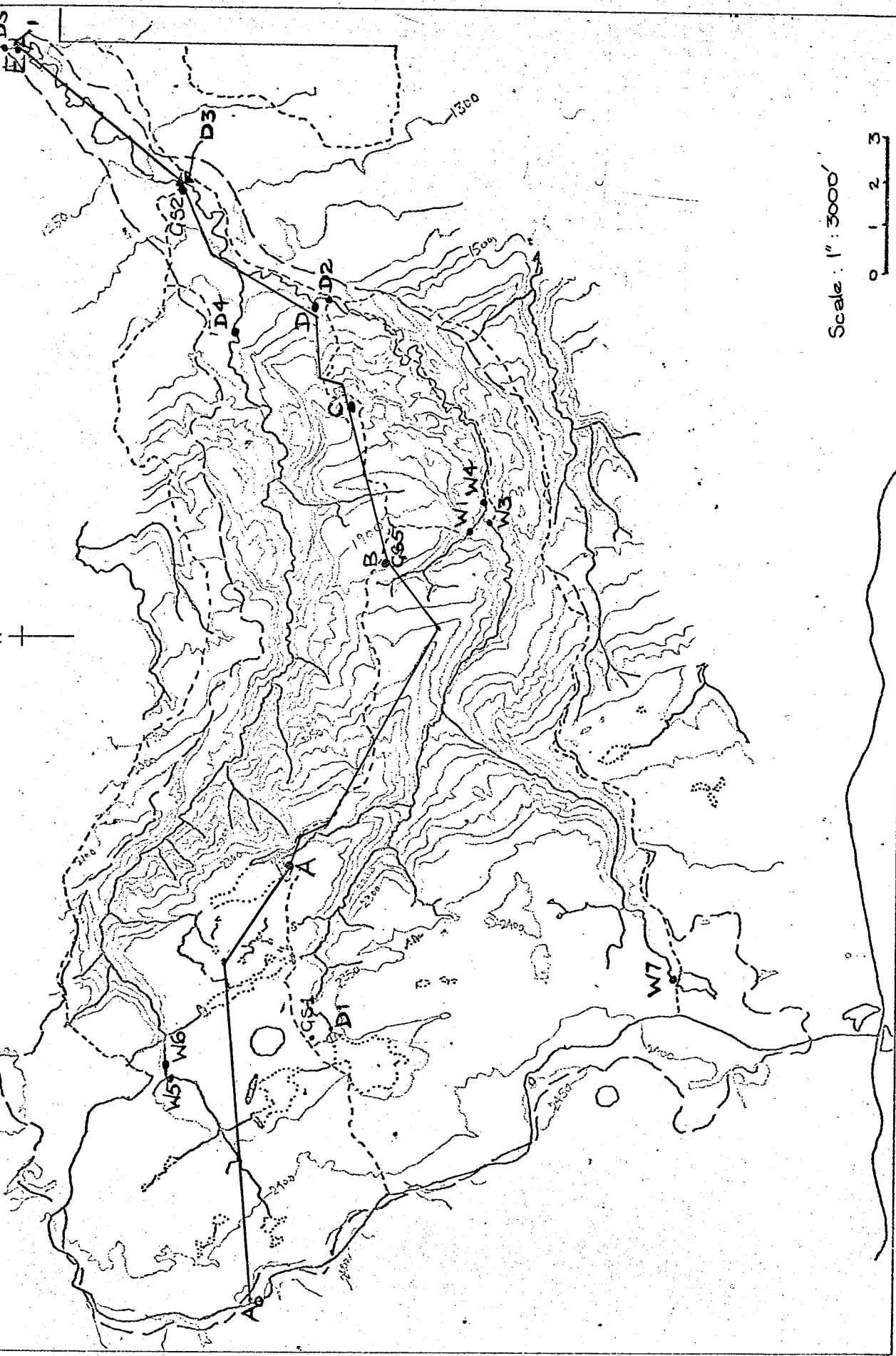
Fig. 17 — Location of stream sampling points (D1 - D5, W1 - W7), cross section (A_0 - A_1), and piezometer nests (A - E).

entirely by the second week after the test. At the end of June a substantial rain storm was experienced resulting in a rise of the water table, in this piezometer, from an elevation of 1863.00 feet to 1872.75 feet in one week. The water level has since dropped off at a rate of 1 - 2 feet each week, to remain between 1867.50 feet and 1868.5 feet in elevation.

A summary of the results of the chemical analysis of the water from the piezometers can be seen on the cross section (fig. 18), and in Appendix B.
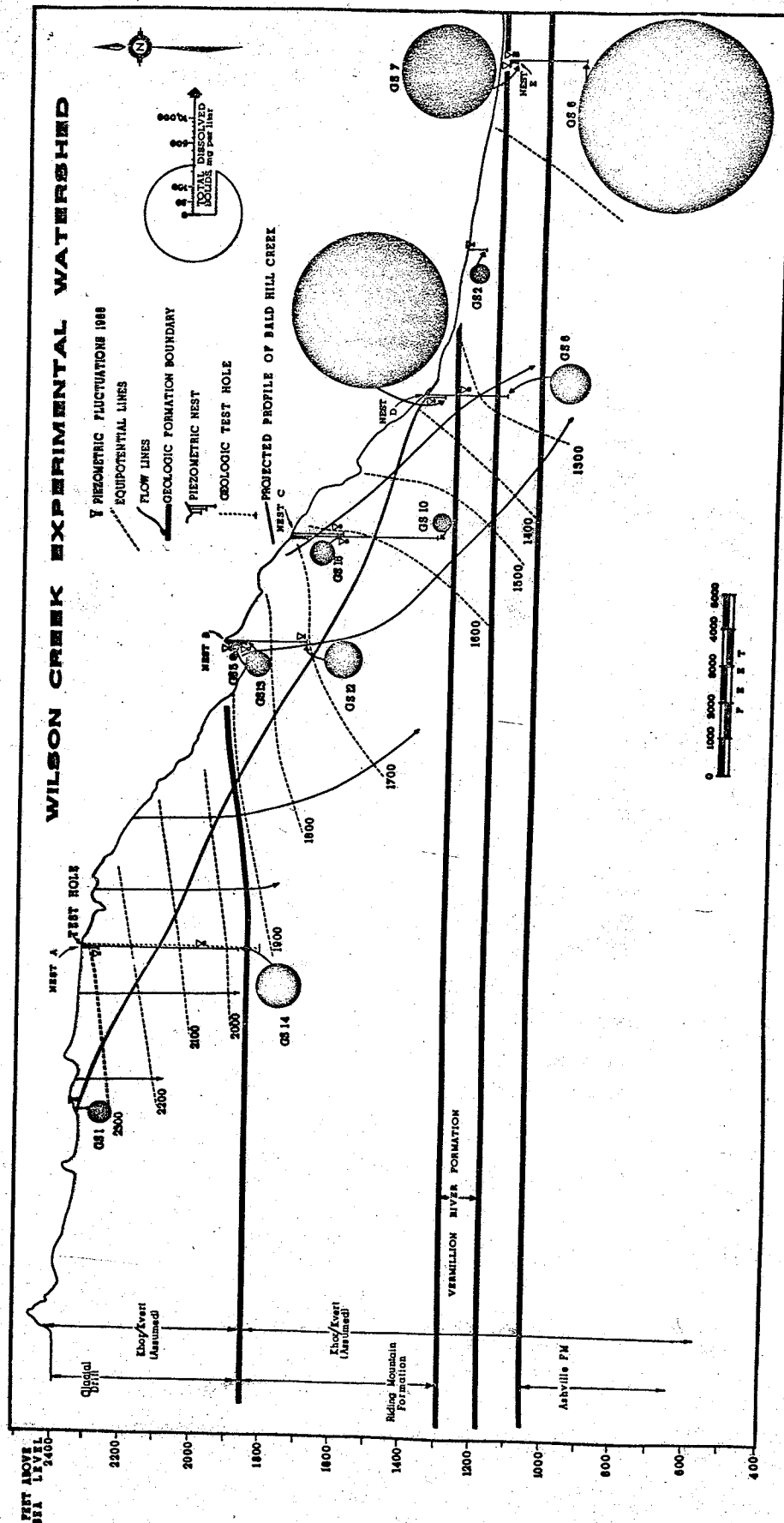
Fig. 18 (a) - Cross section showing the hydraulic gradient in the
plezometers, and the relative chemical content.
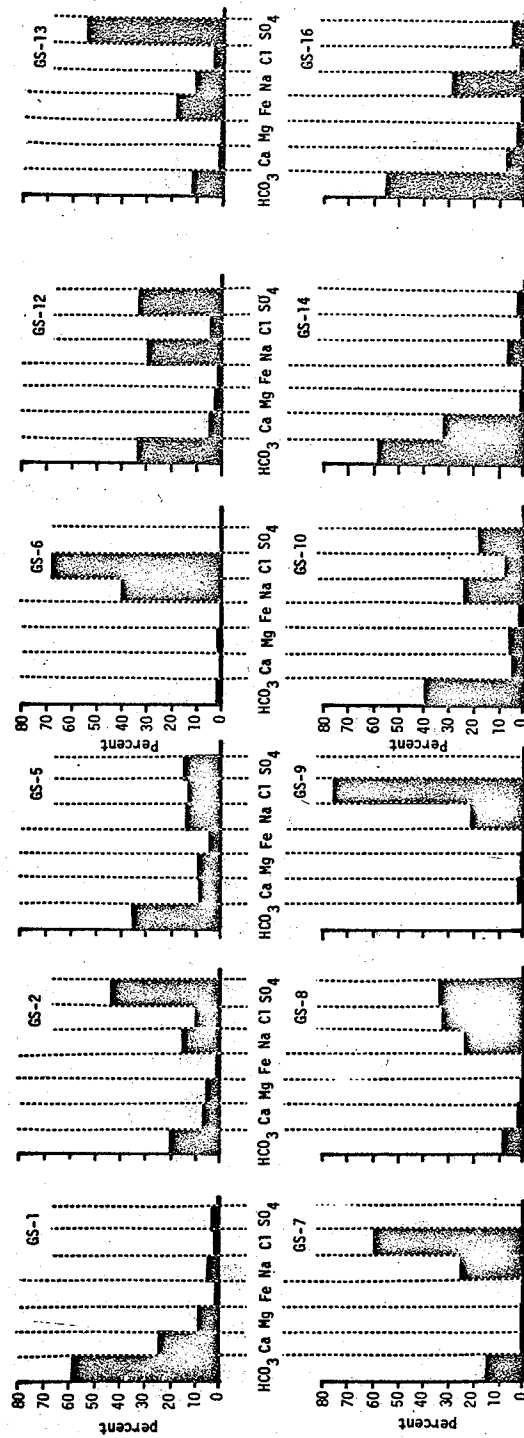
Fig. 18 (b) — Diagram to illustrate the relative importance of the individual chemicals in each of the piezometers.

B. Springs

1. Type and location.

The main creeks are fed continually by
innumerable small tributaries and springs. These can
be divided into five categories - bank seepage
(composed of the licks* and the concave bank type
developments), those directly out of the shale (both
from the shale and the fault zones), those out of
bentonite bands, those from the stream bed, and small
creeks.

Seepage from the banks occurs mainly in the
upper escarpment, from the till which is unsorted with
lenses and layers of sand and clay. The springs are
due to water discharging from the top of one of the
impermeable layers. The licks are obvious from the
numerous animal trails leading to them, and seem to
occur fairly randomly along the creeks in the middle
two sections. They vary in size from small (e.g.
Packhorse Creek at crest gauge 11 (fig. 19), and

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* "Lick is the colloquial word used to describe those
springs of high chemical content which are used by the
animals to augment their salt supply.

Fig. 19 - Small lick, Packhorse Creek, at Crest Gauge 11.
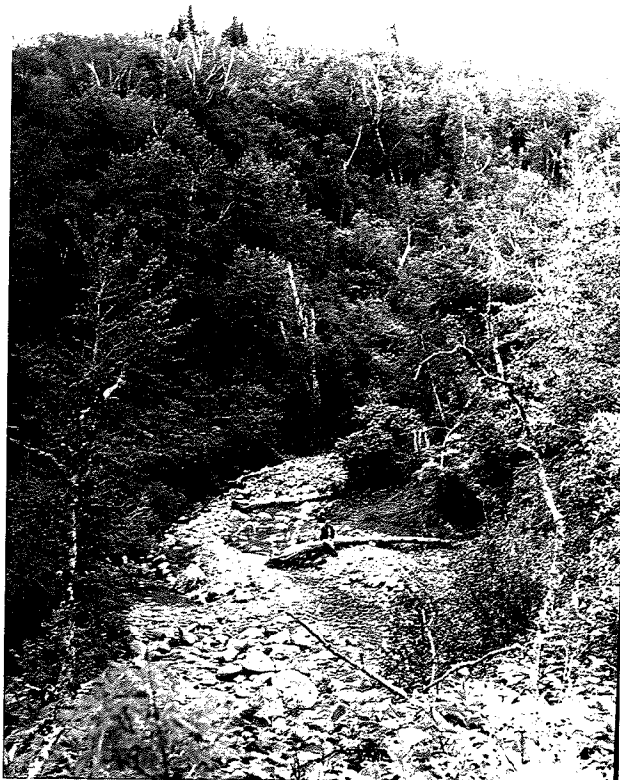
Fig. 20 - Large lick, South
Branch Bald Hill
Creek, at Crest
Gauge 8.

Conway Creek at the junction with Bald Hill Creek), to
very large (e.g. South Bald Hill Creek at crest gauge
8 (fig. 20). Other springs from the typical concave
development around them (e.g. Springs RR, SS, TT, and
I (fig. 21).

The springs from the shale can again be
divided into those directly from the shale (as Spring
X and Spring L - fig. 22), and those from the fault
zones (e.g. Spring R at shale bank 21,64+40 - and
Spring S at shale bank 15 at station 93+00, also
Packhorse Creek - fig. 7). These seem to occur at any
height in the shale cliff. The springs coming from the
bentonite bands are numerous. The poor drainage
properties of bentonite are the obvious reason for
these (e.g. Spring Z and J - fig. 23).

Several springs well up into the actual bed of
the stream. These are only noticeable when the level
of the stream is low enough to make them visible.
Examples can be found at Wilson Creek Weir - figure 24
- Spring V on Bald Hill Creek at Reference Point 9,
Spring W below Bald Hill, and Spring M on Packhorse
Creek - figure 25. It would seem likely that this is
a very prevalent form of groundwater addition to the
stream. Due to difficulty in finding such springs

Fig. 21 - Spring I, with concave bank development.

Fig. 22 - Spring L, issuing from the shale.
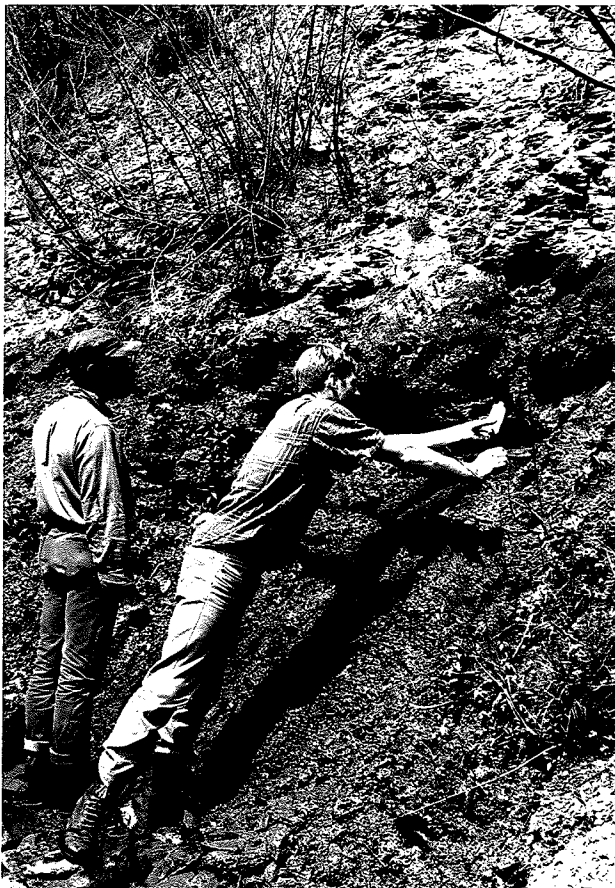
Fig. 23 - Spring J, coming
from a bentonite
band, Packhorse
Creek.
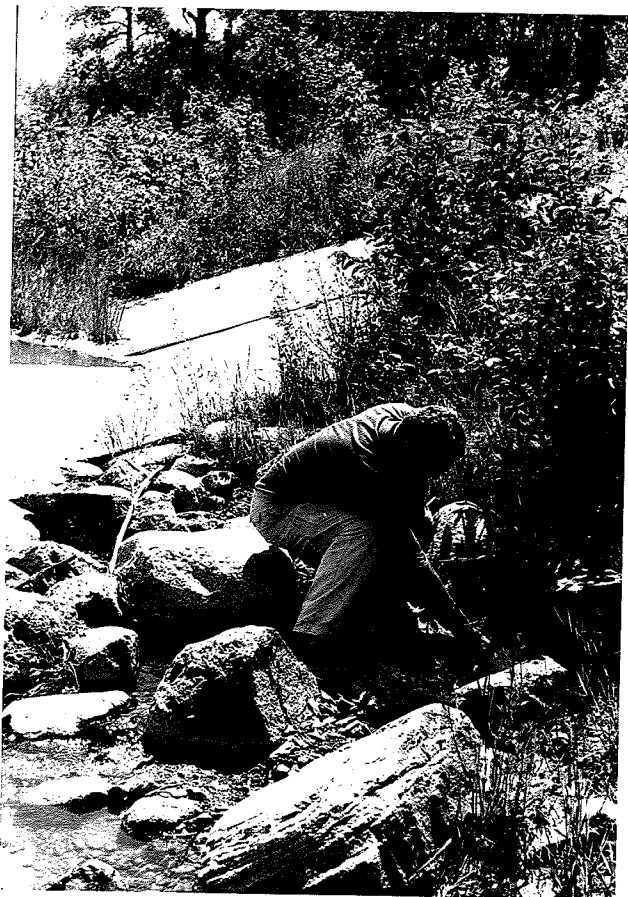
Fig. 24 - Spring YY in the
bed of Wilson Creek
at the weir.
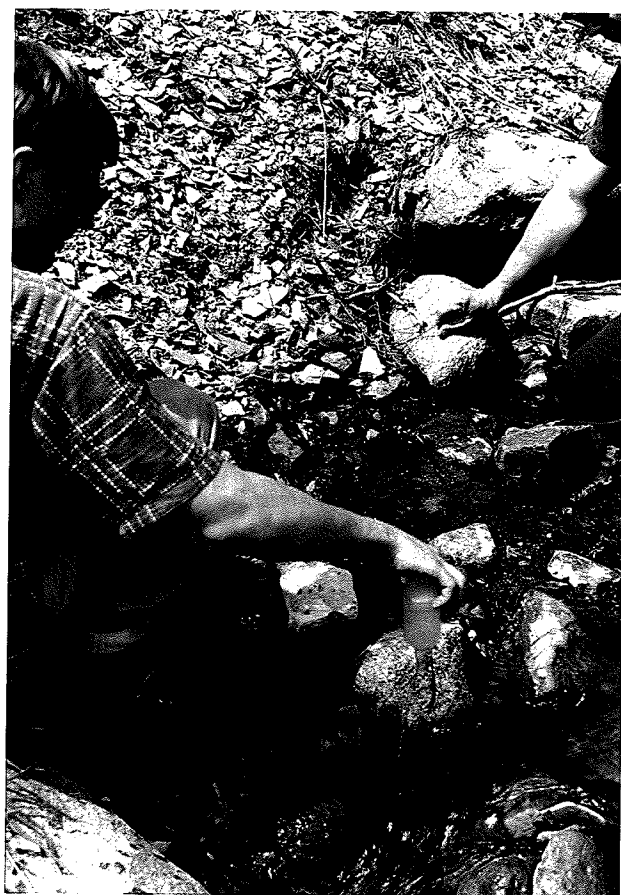
Fig. 25 - Spring M at
the base of a
shale bank in
Packhorse Creek.

though, it is only surmised.

The so-called small tributaries entering
the main stream vary in size from seepage lines (e.g.
on Bald Hill Creek - fig. 26), to considerable flows
(e.g. Spring G - fig. 27). They are often very
difficult to locate, particularly as they often enter
as seepage over large areas of the bank (e.g. XX and WW),
or under large boulders as in the upper portions on the
western upland. Some of these streams form 'deltas'
on the banks of the stream (e.g. spring T1 - on
Packhorse Creek at station 465+00). Here it seemed
likely that at flood time much water, and silt was
transported, as quite a large area away from the stream
was very muddy and almost devoid of vegetation. The
actual stream, however, was small.

Ardee Creek, a larger tributary of Packhorse
Creek (Plate 1) does not enter the main stream under
normal flow conditions. At first it appeared to be a
completely dry valley, well formed and full of boulders.
The valley and well developed stream bed enters the main
stream on the outside of a now abandoned meander. The
water from the creek is obviously flowing beneath all
the boulders, since it appears as quite a strong flow
a few feet from the present stream course. There is the

Fig. 26 - Seepage line, Bald
Hill Creek (typically
covered with horsetails).
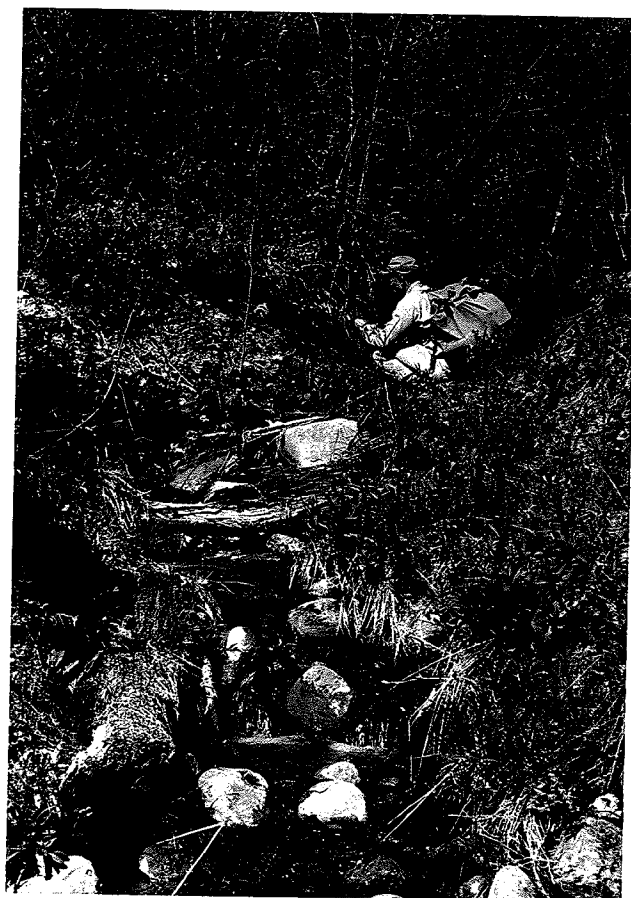
Fig. 27 - Spring G, a large
tributary entering
Packhorse Creek.

possibilty that, with the diversion of the main stream
and consequent lowering of the bed, the base level
for Ardee Creek has dropped, and, instead of cutting
down (perhaps not possible owing to the small stream
size and large boulders), it now flows as a sub-surface
stream.

The relationship between the spring flow and
the weather conditions can be surmised. Those springs
appearing on the surface of the clay as seepage will be
very susceptible to weather conditions. Generally
where there is a flow, the water chemistry continuously
changes, but a certain amount of evaporation is
inevitable, lowering the discharge considerably and
causing minerals to be deposited. This occurs because
of evaporation and because of the higher temperatures on
the surface altering some of the chemical characteristics.
Rainfall will cause the reverse. Direct runoff rapidly
increases the apparent discharge and dilutes the water.
Later percolation gives rise to water flowing for some
distance underground, yet not part of the main body of
groundwater, so perpetuating the increased discharge for
a while after the storm ceases. Obviously this will also
occur in all the other springs, but where there is dense
vegetation, direct runoff will be much less, as will the

effect of direct sunlight.

2. Chemical characteristics.

Chlorides and sulphates were used to characterise the water as they are both very soluble and do not precipitate out easily. They are not present in substantial quantities in the soil to change the concentration on the passage of water through the soil zones. It is in these zones that calcium, magnesium, and bicarbonate are easily taken into solution by the water, and in contrast they are also precipitated with any slight change in oxygen content, pH, or temperature of the water. There are various small tributaries entering the main stream which are currently depositing calcium (e.g. spring H into Pack-horse Creek at station 411+00).

Using sulphate as a characterising ion (chloride is present in too small a quantity), the springs can be classified into two groups, those which have a low sulphate content (less than 60 parts per millon) and those which have high sulphate content (greater than 100 ppm.). There are no springs with sulphate contents between 60 and 100 ppm, hence the choice of the boundary. There are one or two springs with highly variable sulphate content. With only two

samples the significance of this is somewhat dubious.
A breakdown of the chemical constituents in each
spring, is summarized in figure 28.

It is possible to group the types of spring
and relate them to the sulphate content. The first
group, those with a sulphate content of less than 60
ppm is composed almost entirely of the small creeks
entering the main stream, with three exceptions - one
from a bentonite band (spring Z), and two from bank
seepage (Al and B). Al is of interest in itself, due
to its high iron content. It seeps from a bank some
20 feet above the stream. Within a few inches a thick
red mud has been deposited, and the iron content has
changed considerably (fig. 29). No significant change
in the pH is apparent. It seems here that when the
groundwater (containing ferrous ions) comes into
contact with the air, precipitation of ferric hydroxide
occurs.

$$(2Fe^{2+} + 4HCO_3 + H_2O + \tfrac{1}{2}O_2 = 2Fe(OH)_3 + 4CO_2)$$
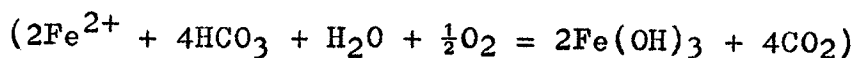
(Hem 1959 p. 60.)

The second group, those with a sulphate
content greater than 100 ppm, consisted of the licks,
the remainder from bank seepage, those out of the shale
directly, and those from the stream bed (fig. 30).
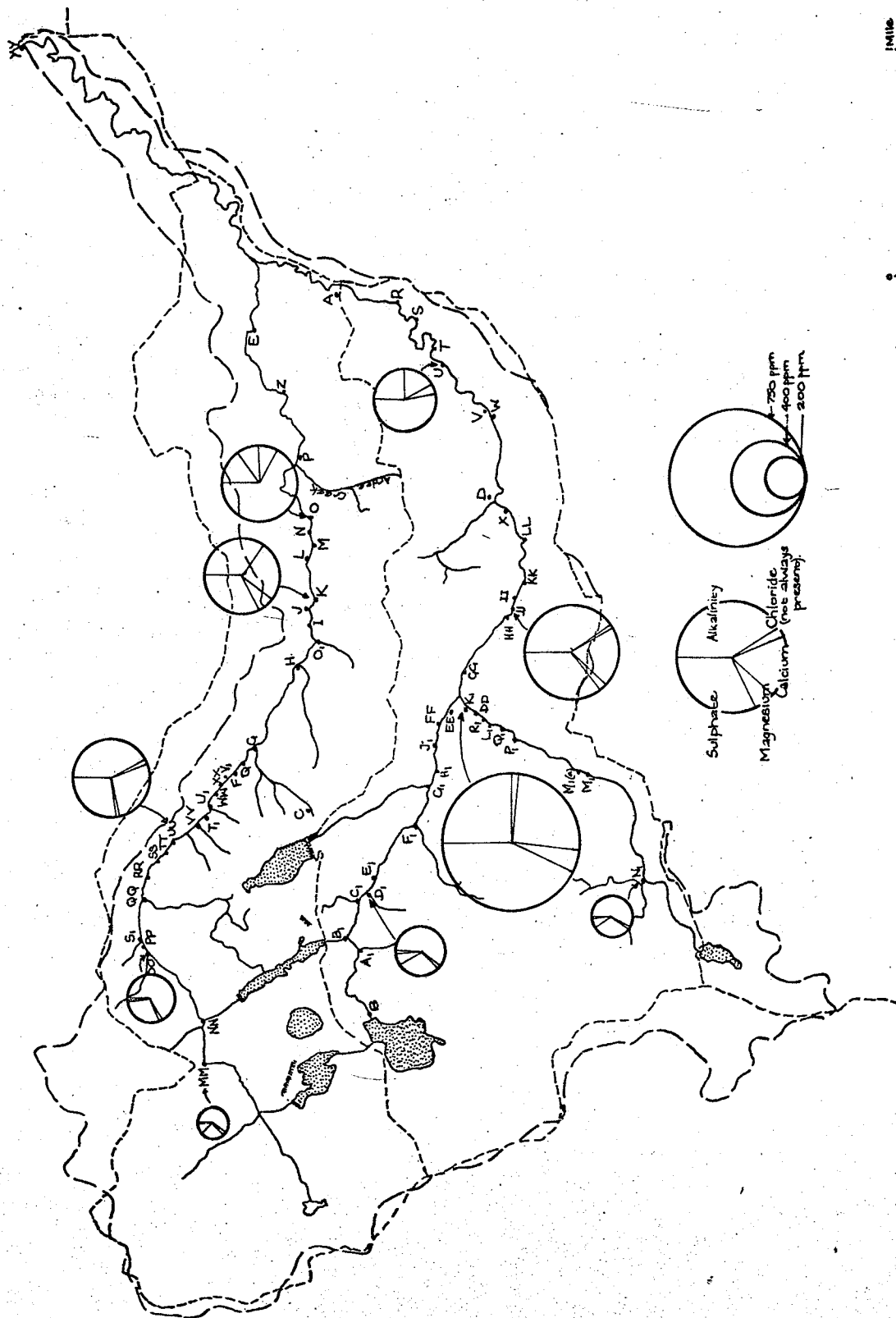
Fig. 28 — Location of springs in Wilson Creek Watershed, and

a summary of the chemistry.

Fig. 29 - Spring A$_1$ at the source. N.B. thick red deposits a few inches from the source (by the thermometer).

	Bank Seepage	Shale	Bentonite	Stream Bed	Creeks
					VV MM NN
SO_4	A_1				OO PP S_1
less	B		Z		QQ A DD
than					C_1 M_1 M_1(a)
60 ppm					B_1 D_1 E_1
					F_1 C G_1
					J_1 FF N_1
					T_1

	RR SS	U N		YY V	Ardee Creek
SO_4	TT UU	R S		W	XX O
more	U_1 V_1	T X			G H
than	D F	L M			O_1 K
100 ppm	JJ I				O L
	HH E				P KK
	U II				GG EE
	R_1 K_1				WW H_1
	L_1				

Fig. 30 – Diagram to illustrate the distribution of spring types and their chemistry.

C. Hydrological and Geochemical Analysis of Wilson Creek.

Stream water in the creeks was sampled at
five points daily as shown on figure 17 (page 29). To
supplement these five points W5, W6, W7 were taken once
a week, and after every rain storm (due to their
positioning in relation to the work of the project staff).
W1, W3 and W4 were taken weekly.

Once during the summer the creeks were metered
throughout their courses. On 19 June, when Packhorse
Creek was metered, above the junction with Bald Hill
Creek the discharge varied from 0.49 cfs to 2.10 cfs,
and similarly in Bald Hill Creek at the junction, the
discharge was 2.81 cfs, yet at Wilson Creek weir the
discharge was almost double the sum - 7.00 cfs (fig. 31),
indicating a high groundwater flow into the area between
the junction and the weir at that time. Lack of data
prevents scientific analysis. Further study in this
field would prove useful.

Chemical determinations of calcium, magnesium,
bicarbonate, chloride, iron, and sulphate were
conducted on all water samples collected between May and
July 1968. Apart from two weeks at the end of May and
beginning of June, the testing was carried out as soon
after sampling as was possible, since there is a certain

Fig. 31 - Metering of the Creeks

Bald Hill - 19 June 1968

South Branch at junction with N. Branch	0.49 cfs.
North Branch at junction with S. Branch	0.98 cfs.
Shale Bank 1	1.66 cfs.
Crest Gauge 6	1.87 cfs.
Crest Gauge 5	2.14 cfs.
Junction with Packhorse	2.10 cfs.
Packhorse junction with B.H.C.	2.81 cfs.
Wilson Creek at the weir	7.00 cfs.

Packhorse Creek - 20 and 24 June 1968

20 June	(Crest Gauge 10	0.61 cfs.
	(Station 476 + 87	0.96 cfs.
24 June	(Crest Gauge 11	0.71 cfs.
	(Station 409 + 50	0.88 cfs.
	(Shale Bank 20 (343 + 50)	1.09 cfs.
	(Junction with Bald Hill Creek	1.55 cfs.
	(Wilson Creek at the weir	3.20 cfs.

amount of die-away of the chemical content on storage.
This is obviously more prevalent for some chemicals
than others, but precautions were taken in order to
obtain results as accurate as possible in all chemicals.

The variation of the chemical quality of the
stream, in relation to time (the fluctuations of the
hydrograph) is well illustrated in figure 15 (page 25).
Both the total chemical content and that of individual
ions increase with distance from the source (fig. 32).
By the end of June, and onwards, Packhorse Creek is
generally higher in chemical content than Wilson Creek
at the weir. Figure 15 also indicates that Packhorse
Creek varies more immediately with storms than does
Wilson Creek. Not only does the concentration fall
earlier, but it also rises earlier at the end of a storm,
and often to a higher level than Wilson Creek.

The conductivity has been used here to
illustrate the general characteristics, since it is a
measure of the total chemical content of the water.
Sulphate was also used in the hydrograph analysis.
Sulphate was chosen as it gives a higher dilution in
storms than any other chemical, as well as being an
indication of the groundwater component in the stream.
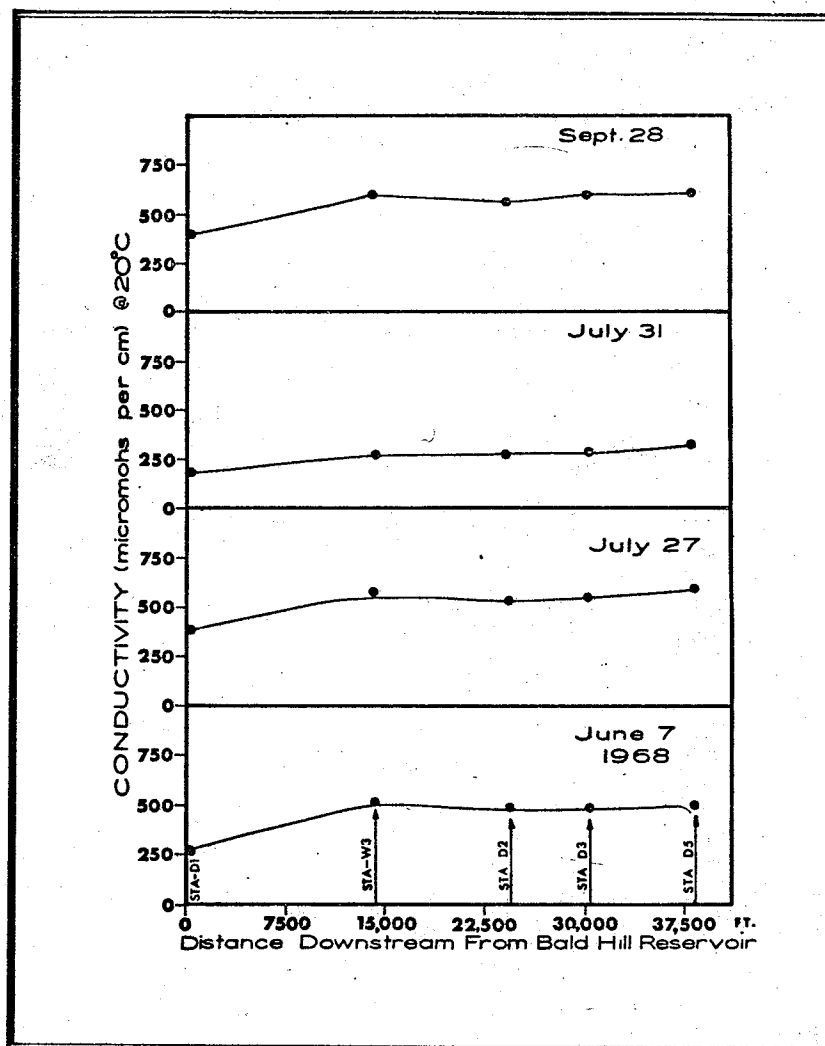
Fig. 32 - Graphs illustrating the increase
in chemical content in the stream
with increase in distance from the
source.

Chloride contents in the stream water are insignificantly
small. While the sulphates vary in the springs, they
obviously originate from them, since in the headwaters
(Bald Hill dam etc.) the sulphate content is almost non-
existant.

D. Conclusions.

From the piezometer data it appears unlikely
that deep groundwater is flowing into the stream, since
there is a definite downward hydraulic gradient in the
piezometers. In addition, by comparing the chloride
content of the springs with that of the piezometers, it
becomes very clear that spring water is not from deep,
or "out-of-basin" groundwater, but from "in-basin"
groundwater. As can be seen from the sulphate content,
this varies from water entering from the soil zone, with
low sulphate content, to water from the deeper zones,
which having been in the ground for a longer period,
contains greater quantities of all chemicals.

IV. STORM HYDROLOGY

A. Summary of Summer Storms.

The most typical summer precipitation on the
Wilson Creek watershed is sudden and intense convect-
ional rain, separated by long dry periods. In the
summer of 1968 a much higher rainfall occurred than
is usually experienced, however, there are high runoff
peaks during the months June through August. May and
September proved relatively dry.

From the summer's hydrographs (fig. 15, page 25)
it appears that, although several storms have similar
rainfalls, the discharge varies considerably,
indicating that flood peaks are related not only to the
rainfall, but to other factors such as soil moisture,
previous precipitation, intensity of rainfall, etc.

In the basin it is apparent that the groundwater
is an integral part of the discharge. This was
illustrated by the simulated flood of 16 August in which
a beaver dam was released at the head of Bald Hill Creek.
Allowing for a certain amount of bank storage, the
beaver dammed water passed through the watershed in a
short time. It took one and a half hours to completely

empty the beaver pond, the wave front taking

approximately two hours to reach Wilson Creek weir.

The flood had completely passed the weir 12 hours later.

The release indicated that increased groundwater

discharge must take place during the storm in order to

sustain the discharge for days after the precipitation

has ended.

B. Hydrograph Analysis.

1. Previous methods.

The separation of discharge caused by storms, from

groundwater discharge is required in analysing flood

peaks, but accurate methods are not presently avail-

able. Several approximate methods are summarised in

Rainfall-Runoff (Gray and Wigham 1966 pp. 7.21-7.22).

The following technique was used on the storm of 28

June through 7 July as a basis for comparison with the

geochemical techniques (fig. 34, page58). It involved

the extension of the base flow recession curve (obtained)

from the analysis of all the storms of 1968) back under

the peak of the hydrograph. The peak of the groundwater

inflow is determined arbitrarily, and the rising limb is

assumed to be a straight line from the start of runoff

to the peak.

2. Geochemical techniques.

Kunkle (1965) used the specific conductance of the streamflow as a basis for the separation of the hydrograph. As the specific conductance is an indication of total chemical content, both soil zone and groundwater components were combined. Alkalinity (bicarbonates in the case of Wilson Creek) and calcium, both of which are present in the soil are washed out during a storm from both the saturated and unsaturated zone.

In this study, sulphate was used as an indication of groundwater inflow, since chloride is not present in appreciable quantities in stream flow.

In the Wilson Creek basin water stored for any length of time in the ground, becomes rich in sulphate. During a storm water enters the ground, and since the sulphate content of water is increased only slowly, it is low in sulphate content. Groundwater discharge into the stream in a flood peak can be the sulphate rich groundwater, or the "fresh" water, or a mixture.

The sulphate content of the stream water can be used as the basis for calculation of the groundwater discharge into a flood peak. In such a calculation it is assumed that the sulphate concentration undergoes a

linear dilution during the storm as a result of the
flow of rain water into the ground. In this way it is
to be assumed that the sulphate concentration in its
dilute form (C) is an indication of the minimum
groundwater flow (Qg) during a flood peak. Thus the
groundwater discharge may be calculated using

$$Qg = \frac{Q \quad x \quad C}{Cg}$$

where Q is the stream discharge and Cg is the sulphate
concentration following a linear dilution during the
storm (i.e. from the concentration before the storm to
that after the storm). Where such a linear dilution
occurs (all except the storm of 7 - 12 June) it is an
indication that the groundwater discharge during the
storm is a combination of the newly infiltrating water
and the stored groundwater. The groundwater inflow thus
calculated is illustrated in the storm hydrographs
(fig. 33 and 34). For comparitive purposes the
conductivity derived curves are included for each storm,
and the alkalinity for the storm of 30 June to 6 July.

The studies undertaken in 1968 were exploratory
only and data was not gathered that indicates the rapid
drop in chemical content during the rising limb of the
hydrograph. A complete analysis of the curve of the 15
to 18 August storm (fig. 33) is impossible due to the

WILSON CREEK 1968

LONG-TERM GROUNDWATER STORAGE COMPONENT
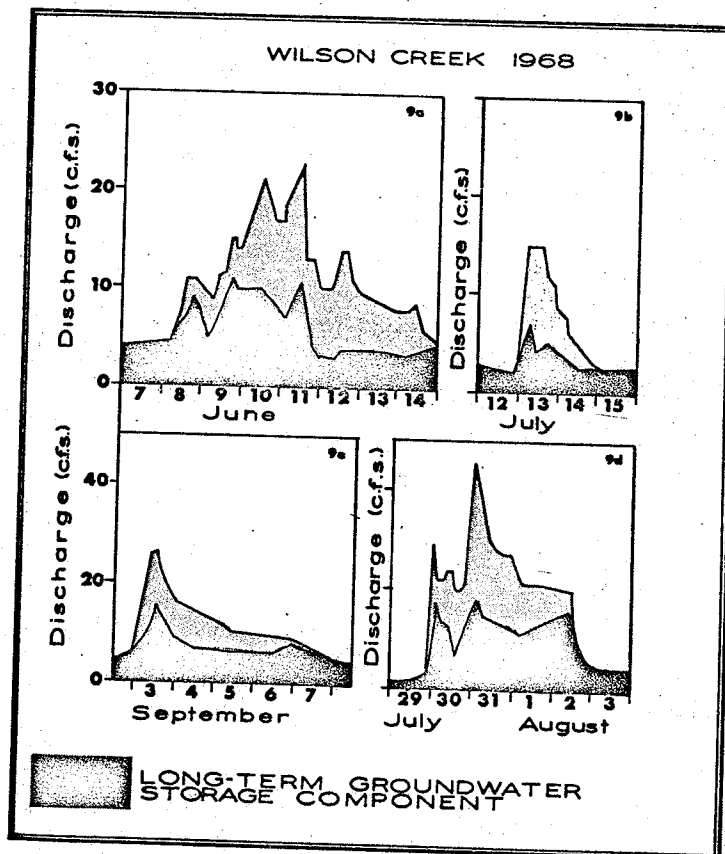
Fig. 33 (a) – Storms of summer 1968
illustrating base-flow
separation, by geochemical
techniques.
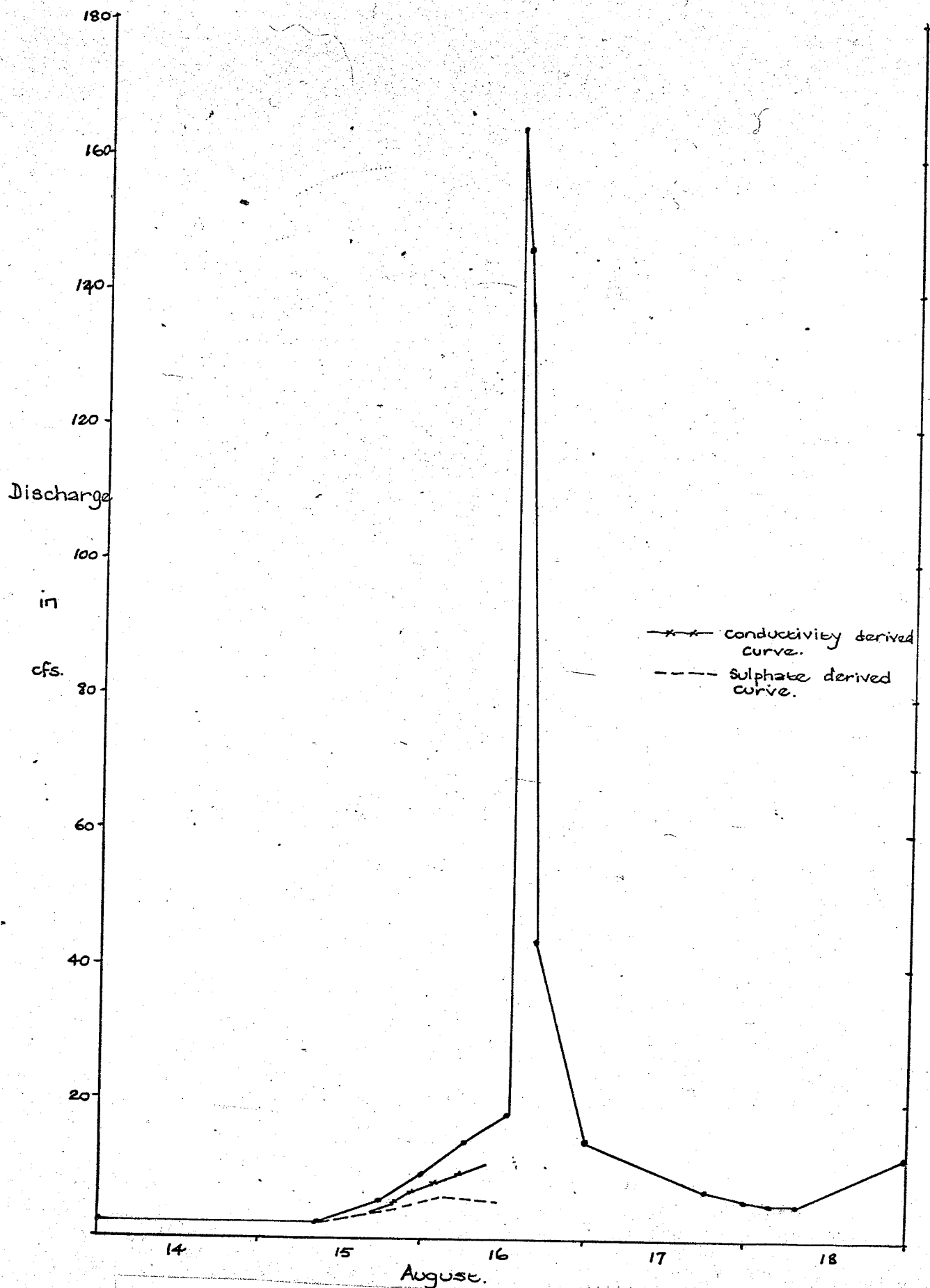
Fig. 33 (b) - Storm of 16 August 1968 to illustrate
the separation of the rising limb.

WILSON
CREEK
1968

Total Discharge

Long-Term
Groundwater
Storage Component
$(SO_4^{--}$ Dilution Base)

Leaching Interflow
And Transient
Groundwater
Component
(Conductivity
Dilution Base)

Approximate
Separations

| 28 | 29 | 30 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

JUNE   JULY
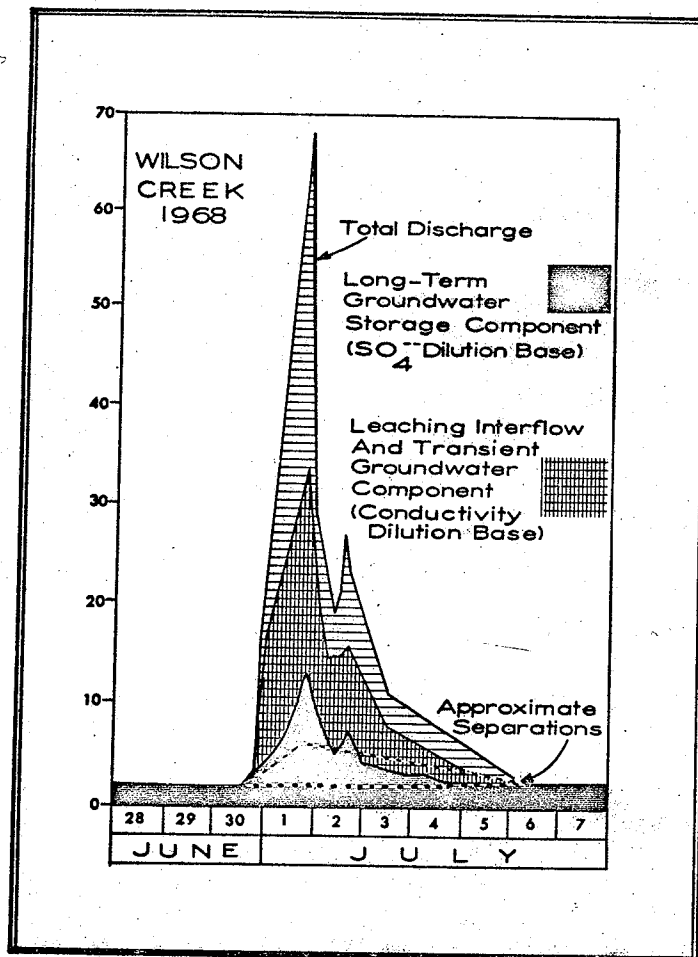
Fig. 34 - Graph of the storm 28 June - 7 July

to compare one of the mathematical

techniques and the geochemical methods.

interference caused by the simulated storm. However, the early part of the hydrograph for this storm does indicated clearly the curve to be expected.

The geochemical separation technique may be applied to complex storms with several peaks (fig. 33) as well, which are difficult to separate using the more conventional methods.

There are two storms which do not follow the pattern — these being that of 26 -29 May and 8 - 14 June. In the first the sulphate derived curve for groundwater inflow gives a greater discharge than that derived using the conductivity. This, it seems, is possible since it is the first storm of the year, and snow had only recently melted. The rainfall was not high, and it seems that the peak is derived almost entirely from water which has been stored in the ground all winter, and which is consequently rich in sulphate, while the superficial water will only have picked up the usual amount of calcium and bicarbonate.

The storm of 8 - 14 June has several peaks, the first peak having a very high sulphate content. The ground for the storm of 26 - 29 May was partly frozen (snow still being present in a number of places). It is probable that this storm is the first major recharge,

thus displacing water with a high sulphate content
through the first part of the storm which eventually
cleared the groundwater system of the water stored all
winter.

C. Conclusions.

The problem posed involves the application of
the characterising ion of the groundwater (discovered
in the first problem) to the evolving of an accurate
method of base flow separation. From the consistent
results, allowing for the anomalies discussed, it is
evident that the technique provides an accurate
calculation of the minimum base flow during a storm
peak (assuming limited dilution of the groundwater
component). Further investigation of flow in the
unsaturated zone and the rate of sulphate assimilation
in the soil will provide more complete analysis.

V. CONCLUSION

The inter-relationships between groundwater discharge and streamflow in the Wilson Creek watershed were the subject of the research programme which took place May to September 1968 inclusive. At first, it was necessary to determine whether the major dissolved ions in the stream at a section and in a down stream direction could be related to the source water which accumulates in the stream to form the discharge. The second problem was to determine whether one or more of the major ion concentrations in the flow could be used to evaluate quantitatively the groundwater and inter-flow contribution during the rising and falling limb of a peakflow hydrograph.

It was found that, due to a downward hydraulic gradient in the piezometers, there is no deep ground-water discharge into the watershed. In addition, chemical analyses indicate a local groundwater source. The chloride content in the streams and springs do not resemble that of the deep piezometers, which have a very high chloride content. The sulphate content of the streams seems to originate from the local groundwater reservoirs discharging into the streams through the numerous springs and seeps. The sulphate in the upper

reaches is negligible, while further downstream after the addition of sulphate rich tributaries, the stream contains appreciable quantities.

From the investigation it appears also that sulphate is a suitable characterising ion to facilitate accurate hydrograph separation. Utilising a relationship between groundwater discharge (Qg) and stream flow (Q), actual concentration (C), and base flow concentration (Cg) (determined by assuming a line of linear dilution) such that

$$Qg = \frac{Q \times C}{Cg}$$

it was found that consistent results were obtained for hydrograph separation both for simple storms, and those with several peaks. This method assumes a limited dilution of the groundwater component. Further investigation into the flow in the unsaturated zone, and the rate of sulphate assimilation in the soil will provide more complete analysis.

There a number of other recommendations for future investigations to obtain greater accuracy in this evaluation. A continuous recording of conductivity and more detailed sulphate samples during storms at Wilson Creek weir would help to establish the groundwater

behaviour during the rising limb - at the moment only speculatory.   Detailed piezometer data across the valley would prove useful in that the movement of groundwater within the local reservoir could then be determined more accurately.

The Wilson Creek watershed is well instrumented and accessible.   It is an area of potential not only for pure academic studies, but also in the field of applied hydrology, which was the original reason for its development by the government.

APPENDICES.

APPENDIX A

METHODS

A. Meterological Recording

B. Hydrologic Data

    1. Surface hydrology

    2. Groundwater hydrology

    3. Springs

C. Chemical Analysis.

METHODS

Field techniques applied in order to
gather quantitative data for the investigation of
the problems posed included meteorological recordings,
hydrological observations and chemical analysis. In
all field work, the maps used were the 1:12,000 map of
the watershed, provided by the project staff, and the
occasional use of the engineers' survey of the
longitudinal section of the stream, to give accurate
location of sampled springs, and tributaries.

A. Meteorological recording.

Rainfall is measured continuously on several
recording rain gauges, thus giving a good coverage of
the watershed of the intensities of rain. In addition
to the recording rain gauges, there are 34 standard
gauges to give a complete cover of the rainfall
distribution throughout the basin. This is important
in the case of storms, since the precipitation varies
areally in spite of the small size.

B. Hydrologic data.

Hydrologic data was gathered for three areas
- the surface hydrology, the groundwater hydrology, and
the springs.

(i) Surface water sampling.

Five daily samples (D1, D2, D3, D4 and D5), six weekly samples (W1, W3, W4, W5, W6, W7), and seven monthly samples (M1, M2, M3, M4, M5, M6, M6a) were taken from the streams for chemical analysis. Sampling was a simple procedure consisting of taking the water temperature ($^{\circ}$F), and collecting some water in a numbered polyethylene bottle, at particular preselected sampling points, after first having thoroughly rinsed the container used. For the location of the sampling points, see figure 17, page 29.

Four principal stage recorders are being used to obtain continuous records of the flow of the creeks at the four points (Bald Hill dam, Packhorse Creek weir, Conway Creek weir, and Wilson Creek weir.) (Plate I). Each consists of a well, with intakes at various levels, with a recorder and a tape gauge in each well. In addition to readings in the well a staff gauge is used in the stream at a known and unvarying elevation in the stream, thus enabling discrepancies between the well and stream readings to be eradicated.

In addition to these wells, a trapezoidal concrete control section was constructed in Wilson Creek, just inside the Riding Mountain National Park, to give

a stable section for measurements. It has a base
width of 30 feet and side slopes 3:1. The apron and
side slopes were keyed into the creek bottom and banks
with concrete cutoff walls which are 3 feet deep.

The section is 20 feet long, with a two foot
wide notch to take low flows. (Fig. 35). A cable car
has been installed so that at high flows discharge
readings can be taken accurately over a known cross
section with a current meter. There is also a cable car
at Packhorse Creek, in conjunction with a trapezoidal
concrete section there for the same purpose.

In order to discover where increments of water
enter the stream, readings throughout the creeks were
taken with a pygmy current meter.

(ii) Groundwater hydrology.

Equipment in the watershed consisted of
piezometers and wells, well recorders and an M scope.
The wells are 6 inches in diameter, lined to an average
depth of 10 feet with iron pipe, the water percolating
in from the lower section. The 2 inch diameter
piezometers are fully lined, with a $2\frac{1}{2}$ foot section at
the base designed to allow movement of water through the

Fig. 35 - Wilson Creek weir, with a 2 foot notch.

piezometer (fig. 36). They were installed in 1965* to investigate groundwater level fluctuations. While the siting is adequate for this purpose, it is inadequate for an investigation into the ground water contribution to stream flow, since only two nests are within a reasonable elevation from the stream.

The well recorders are battery driven instruments, with a float and weight for continuously recording fluctuations in the water level of the wells. These are only installed over the shallower 6 inch wells (GSI, GS2, and GS5). The M scope consists of a cable ending in a sensitive probe, which, on entering the water registers on a dial at the end of the cable the increase in conductivity. It is battery operated also, and the cable marked off in 5 feet sections, enabling, with the aid of a steel tape, the exact elevation of the water level in the piezometer to be determined.

Samples of water from the 6 inch wells (GS1, GS2, GS5) were obtained using a commercial sampler (fig. 37). The piezometers, with a diameter of only 2 inches, required the construction of a special sampler

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* The drilling logs and installation logs are available. PFRA Winnipeg.

PIPE PLUG

2" ID STANDARD
BLACK STEEL PIPE

DRILL HOLE DIAMETER
$5\frac{5}{8}$" (in places $4\frac{3}{4}$")

CONCRETE GROUTING

SOLID STEEL BASKET

SLOTTED PIPE
WELL POINT

5"

12"

6"

12"

6"

6"

$1\frac{1}{2}$ inches

NOTE: SIZE
OF BASKET
MODIFIED TO
SMALLER
FIT DRILL
HOLES.

WELD

HACK SAW SLOTS
($\frac{1}{3}$ through pipe
and staggered)
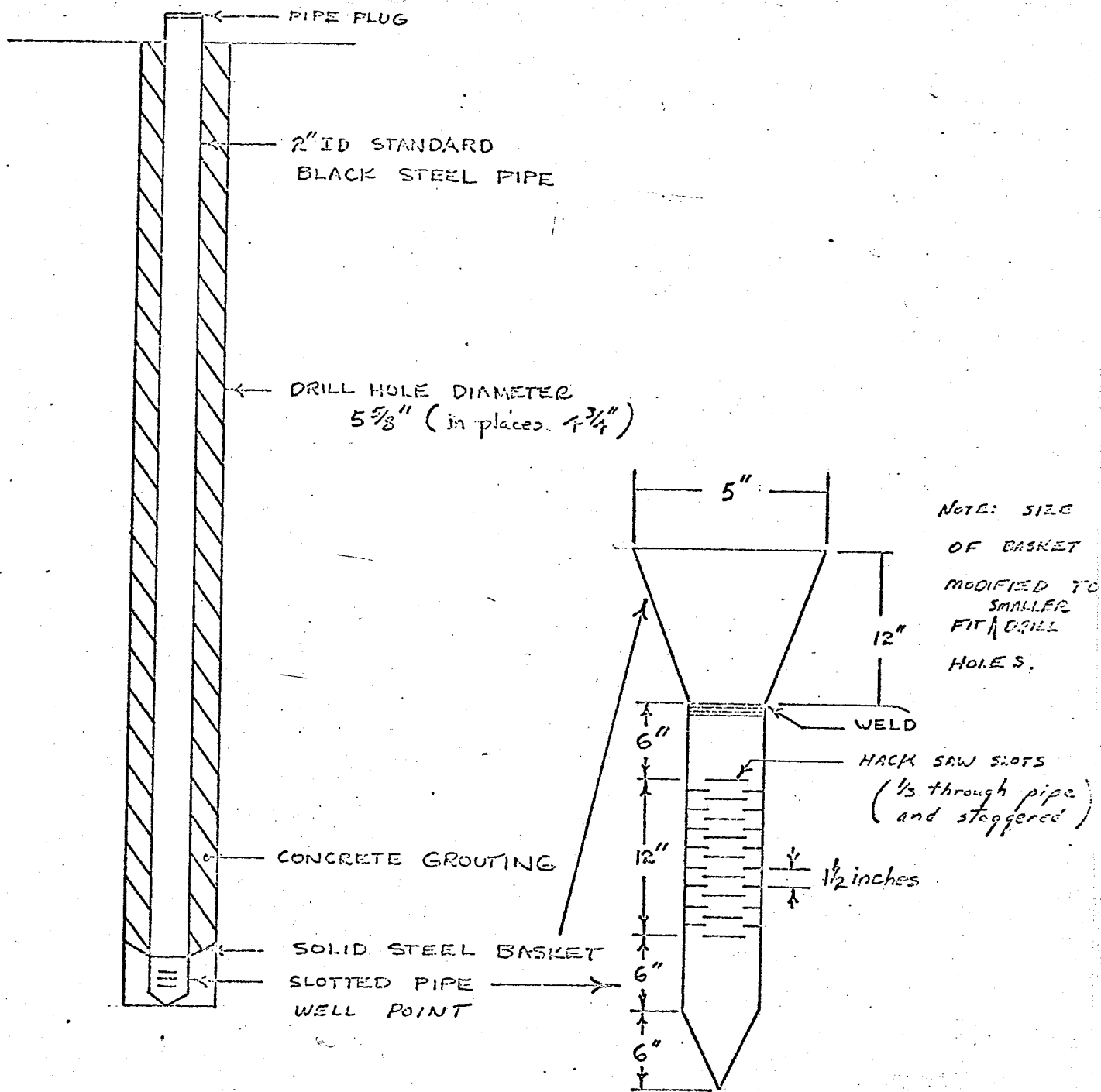
FIGURE 36:   TYPICAL PIEZOMETER INSTALLATION
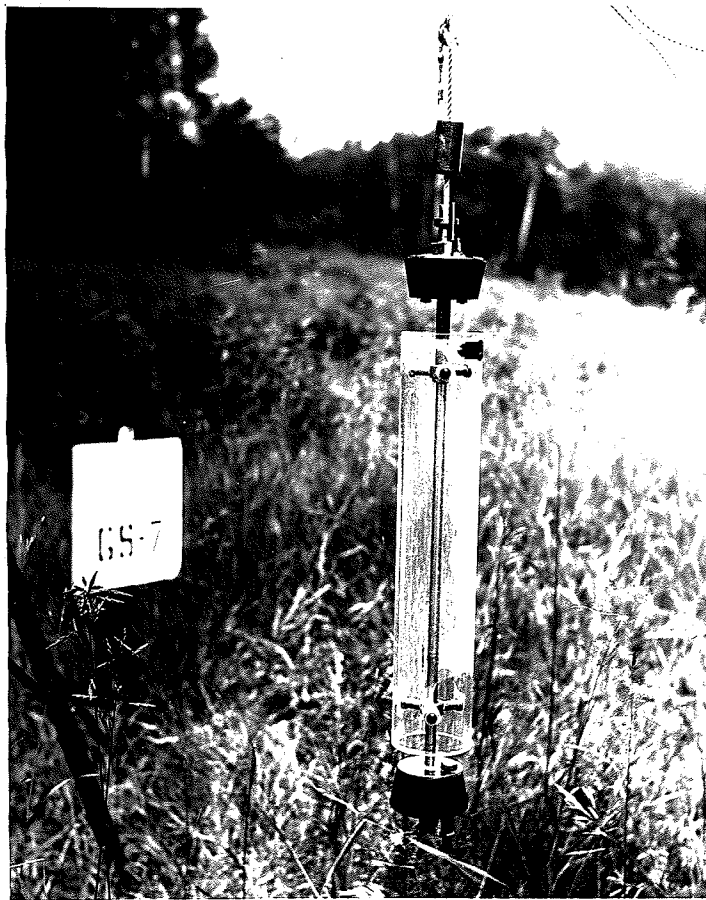
Fig. 37 – The commercial well sampler.

Fig. 38 – The deep piezometer sampler.

(fig. 38). This consisted essentially of a stainless steel pipe ($1\frac{3}{4}$ inches in diameter) with a screw tap at the bottom, and a solenoid operated plunger at the top (fig. 39). The solenoid was activated by a 12 volt battery.

In addition to water samples, temperatures were taken at a series of known levels down the piezometers with a thermocouple and 300 feet of cable. (fig. 40).

Fig. 40 - Temperature Gradient in GS6.

Depth in well in ft.	Temp. °F.	Depth in well in ft.	Temp. °F.
20	45	140	45
30	43.2.	160	45.5.
40	43.5.	180	46
50	44	200	46.5.
70	44	220	47
100	44	240	47
120	44.5.	250	48

(iii) The Springs.

Many springs were sampled, and small tributaries, though not all owing to the nature of the terrain. Each of the sampled springs was located as

$\frac{7}{16}"\phi$ HOLE

$\frac{1}{4}"\phi$ HOLES

ELECTRICAL CONNECTION TO SOLENOID

4-INT.-24 D.C. SOLENOID COIL: 24 V.D.C. DUTY CYCLE: INTERMITTENT

$\frac{5}{8}"\phi$ RUBBER PLUNGER

$\frac{7}{32}" \times \frac{1}{2}" \times 2\frac{1}{2}"$ STRIPS

$2\frac{1}{2}"$

$3\frac{1}{2}"$

$1"$

$1\frac{1}{2}"$

SAMPLER HEAD

1.3'

Fig. 39 - J.E.T. deep piezometer sampler (October 1968).

CAR RADIATOR TAP

SAMPLE CONTAINER
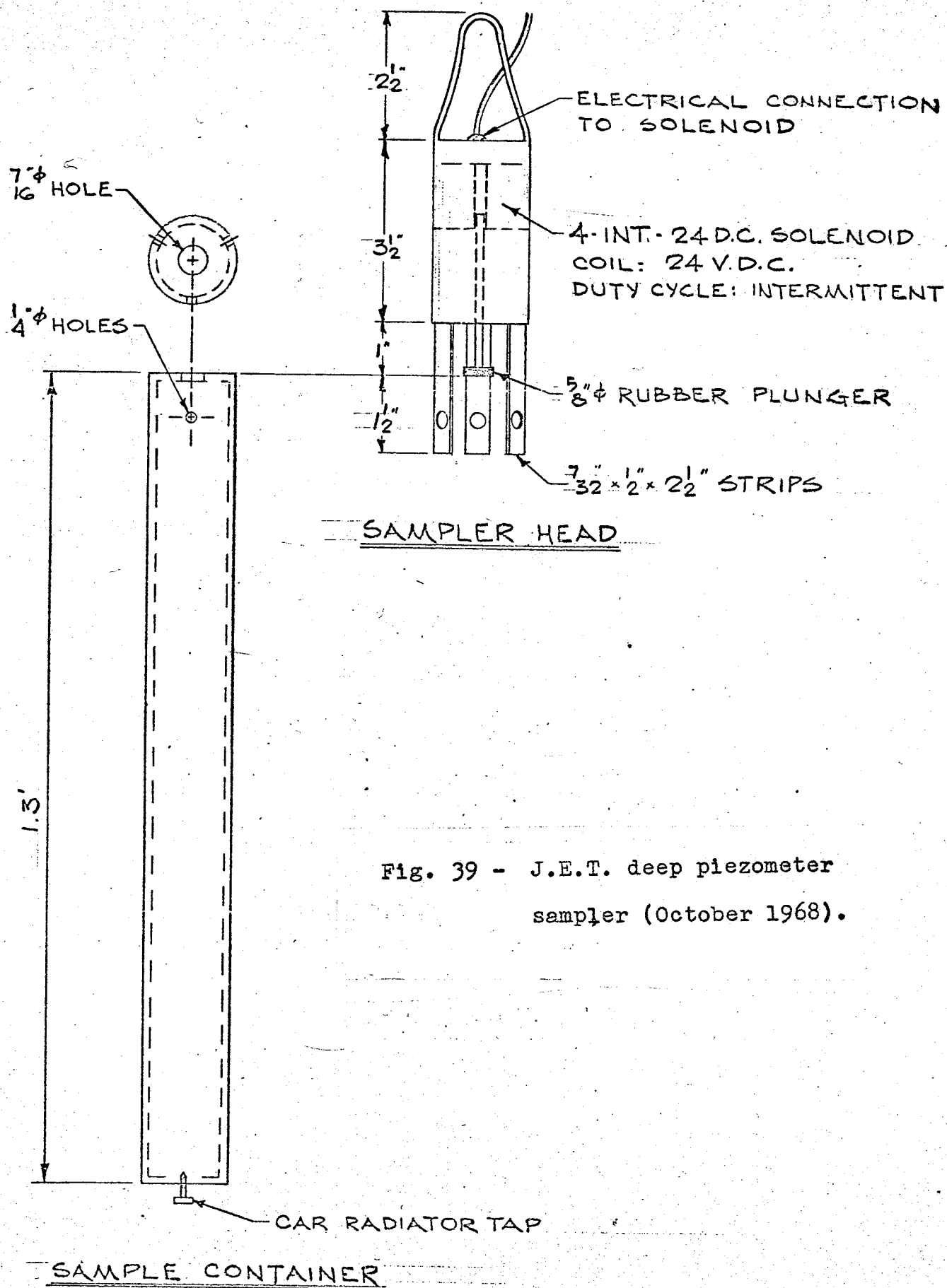
accurately as possible and placed on a map with the aid of survey reports.

C. Chemical Analysis.

For the most part this consisted of analysing all the water samples for calcium, magnesium, iron, chloride, sulphate, and hardness (bicarbonate, carbonate, and hydroxide), with a geochemical kit in the field laboratory (fig. 41). (For detailed equipment list see Appendix D.)

The geochemical kit is equipped to be operated easily in a field laboratory, but lacks the accuracy of true laboratory analysis. Often small samples (for ease in manipulation) are required and, particularly when the chemical content was very low (e.g. chloride), the introduction of quite large errors was inevitable. Thus with this in mind any calculations using calcium, magnesium, bicarbonate, carbonate, hydroxide, or iron, must allow for error. It was found that, with care, the sulphate results were relatively accurate (within 10%).

In addition to the chemical analysis, the electrical conductivity of all samples was taken, using a conductivity meter (error $\pm$ 10%), in the laboratory. Also pH was tested at the sampling points with a pH

Fig. 41 - Geochemical field laboratory.

Fig. 42 - pH meter.

meter (fig. 42). This was done at the sampling points since pH varies rapidly with exposure to air, and with increase in temperature (particularly in the case of the wells). The creeks were also tested in the field, but there was found to be not too much variation.

All samples were filtered after testing in the field laboratory, except in some circumstances noted in the results. Data from the sampling programmes summarised in Appendix B.

APPENDIX B

Geochemical Data

(Ions in ppm., or mg/litre,

conductivity in micromhos.)

(Na   –   Sodium

HCO_3 –   Bicarbonate

Cl   –   Chloride

Ca   –   Calcium

Mg   –   Magnesium

Fe   –   Iron

SO_4 –   Sulphate)

DATE		Na.	HCO$_3$	Cl	Ca	Mg	Fe	SO$_4$	Conductivity
May	21	1-2	67	2.5	32	9	0.01	6	175
	22	1	61	.725	40	10	.1	4	200
	23	1-2	73		40	12	.01	5	189
	24	1	73		40	15	0.06	5	181
	25	1	73		40	15	0.1	5	200
	26	2-3	92		48	19	0.09	5	210
	27	1	85		44	28	0.04	4	205
	28	1	85		44	34	0.01	5	220
	29	1-2	98		36	39	0.05	4	225
	30		98	1.25	40	12	0.09	3	221
	31		122	2.5	40	15	0.09	4	241
June	1		110	1.5	44	12	0.1	5	225
	2		98	2.3	40	17	0.11	4	231
	3		85	2.25	40	12		2	240
	4		104	1.5	48	10		2	241
	5		104		48	15		2	255
	6		98		48	15		1	270
	7		110	1.5	56	12		1	276
	8		110	1.5	44	19		0	279
	9		85	1.5	40	17		0	235
	10		79	1.5	40	17		0	220
	11		73	2.25	44	10		0	215
	12		85	1.88	36	15		0	215

DATE	Na.	HCO3	Cl	Ca	Mg	Fe	SO4	Conductivity
June 13		79		40	18		1	215
14		98		40	12		1	233
15		91		44	12		1	235
16		91		44	15		3	240
17		91		48	12		2	270
18		98		48	12		0	260
19		85		48	19		0	271
20		104		48	15		0	295
21		122		52	19		1	287
22		122		52	19		0	315
23		140		72	7		0	300
24		128		56	17		0	350
25		134	14.38	58	18		0	319
26		146	2.5	64	15		0	369
27		140	3.75	60	24		3	385
28		146	2.5	68	17	0.38	0	368
29		153	1.25	80	10	0,38	1	360
30		146	1.58	76	12	0.45	0	375
July 1		79	2.5	52	15		3	208
2		67		48	0		0	185
3		61		40	2		0	180
4		61		44	5		0	190
5		116		52	19		0	300

DATE	Na.	HCO3	Cl	Ca	Mg	Fe	SO4	Conductivity
July 6		116	2.5	64	5	0.35	0	320
7		122		62	11		0	340
8		98		48	15		0	270
9		104		52	10		2	285
10		110		52	17		1	300
11		122		60	12		1	320
12		128	3.8	68	13	0.45	0	345
13		92		44	15		0	250
14		98		44	17		2	250
15		104		48	15		2	275
16		110		52	17		0	290
17		110		56	15		1	310
18		122		56	17		0	320
19		104	6.25	52	19	0.38	4	353
20		116	10.0	52	24		2	353
21		140	10.0	56	17		5	325
22		128	3.75	56	19		4	353
23		122	2.50	56	19		5	358
24		128	3.75	60	17		5	361
25		128	5.0	56	24		4	402
26		134	3.75	60	29	0.55	4	368
27		128		64	19		7	368
28		122	5.0	60	17		6	372

DATE	Na.	HCO$_3$	Cl	Ca	Mg	Fe	SO$_4$	Conductivity
July 29							4	368
30							7	199
31							6	183
Aug. 1							5	175
2		67	2.0	36	307	0	4	200
3							4	300
4							3	280
5							4	268
6							5	289
7								
8						0.41	6	275
9		110	2.5	60	12	0.44	5	290
10							5	280
11							5	305
12							5	250
13							6	250
14							5	290
15				56	15	0.54	4	310
16							5	230
17							4	222
18							4	240
19							4	230
20							4	240

DATE	Na.	HCO$_3$	Cl	Ca	Mg	Fe	SO$_4$	Conductivity
Aug. 21							5	240
22		104	3.13	44	12	0.25	4	290
23							5	268
24							1	245
25							1	280
26							1	281
27							1	272
28							4	315
29							1	315
30		122		60	15		5	332
31							2	318
Sept. 1							2	310
2							3	350
3							4	240
4							10	256
5							11	263
6							9	257
7							9	265
8							10	273
9							12	272
10							12	260
11							12	261
12							9	279

DATE	Na.	HCO$_3$	Cl	Ca	Mg	Fe	SO$_4$	Conduc-tivity
Sept. 13							13	288
14							12	273
15							9	364
16							11	328
17							9	369
18							12	379
19							12	421
20							8	386
21							10	367
22							14	322
23							14	333
24							13	318
25							7	345
26							13	318
27							7	428
28							11	398
29							11	410
30							11	398

DATE		Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
May	21	6	88	1.25	56	15	0.15	38	280
	22	7	92	1.88	60	15	0.04	52	285
	23	11	98		72	17	0.01	80	350
	24	10	113		68	36	0	75	345
	25	10	134		80	39	0	90	382
	26	14	146		84	46	0	95	389
	27	10	128		96	33	0	100	390
	28	11	134		96	33	0	89	408
	29		171		96	39	0	82	404
	30		146	1.88	76	12	0.06	90	400
	31		159	1.00	68	19	0	91	410
June	1		146	1.5	68	19	0.04	73	400
	2		159	2.25	68	17	0.01	78	429
	3		134	1.5	72	17		72	448
	4		140	1.5	72	19		79	460
	5		140		84	15		74	475
	6		140		80	22		98	485
	7		134	7.25	76	24		100	495
	8		134	1.5	72	19		88	460
	9		116	2.25	68	17		39	389
	10		104	1.5	60	17		34	349
	11		104	2.25	62	13		22	330
	12		116	2.25	56	12		27	331

DATE	Na.	HCO$_3$	Cl	Ca	Mg	Fe	SO$_4$	Conductivity
June 13		116		60	19		25	345
14		128		64	17		45	389
15		134		76	17		70	432
16		146		76	24		72	450
17		140		76	22		83	480
18		143		80	22		75	472
19		153		80	24		80	500
20		146		80	22		86	520
21		146		76	24		95	500
22		159		84	22		125	530
23		153		80	24		97	490
24		153		78	26		100	550
25		171	11.88	80	24		100	498
26		153	5.7	84	19		110	550
27		159	3.75	76	22		125	560
28		146	3.75	92	17	0	100	510
29		153	2.5	84	27	0.04	130	525
30		128	4.38	64	12	0.1	175	515
July 1		110	2.5	56	19		25	318
2		110		48	15		15	286
3		92		52	19		18	318
4		92		60	15		20	325
5		128		68	17		60	415

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conduc-tivity
July 6		140	3.13	80	12	0.03	80	530
7		134		80	12		80	525
8		146		72	22		75	490
9		146		80	17		85	500
10		146		80	19		102	510
11		153		80	19		110	525
12		140	3.8	76	24	0.02	100	540
13		122		64	17		23	380
14		140		76	15		42	430
15		146		76	17		65	500
16		134		80	17		87	500
17		146		76	24		80	535
18		140		80	24		82	520
19		140	6.2	76	19	0.05	97	540
20		165	7.5	76	24		105	530
21		159		80	19		115	488
22		153		84	22		120	545
23		153		86	13		78	550
24		146		84	17		92	550
25		165		84	24		99	570
26		134	5.00	80	17	0.05	92	524
27		140		76	24		135	539
28		146		80	19		115	550

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
July 29							120	522
30							27	282
31							26	269
Aug. 1							24	293
2		92	2.5	52	15	0.1	20	330
3							21	335
4							69	452
5							42	435
6							58	450
7								
8							63	470
9		140	2.5	72	22	0.05	68	458
10							68	465
11							78	500
12							75	380
13							70	395
14							90	470
15				76	17	0.09	91	480
16								
17							58	328
18							50	380
19							45	350
20							59	380

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
Aug. 21							55	390
22		104	3.13	60	15	0.29	63	450
23							78	460
24							19	358
25							34	450
26							49	485
27							59	493
28							82	530
29							92	530
30		165		84	24		80	540
31							75	510
Sept. 1							60	500
2							88	550
3							71	320
4							44	352
5							47	379
6							43	379
7							48	418
8							52	441
9							$=$ 60	464
10							53	469
11							64	481
12							64	505

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conduc-tivity
Sept.13							71	510
14							29	372
15							70	521
16							78	485
17							78	533
18							82	555
19							80	640
20							79	536
21							84	511
22							81	486
23							91	492
24							88	460
25							87	500
26							88	451
27							83	600
28							90	575
29							84	580
30							94	595

DATE		Na.	HCO3	Cl.	Ca	Mg	Fe	SO4	Conduc-tivity
May	21	9	88	4.23	56	15	.08	50	280
	22	9	92	1.88	60	17	.03	65	305
	23	14	104		68	19	.01	85	361
	24	11.6	110		72	34	.05	85	359
	25	14	134		80	39	.05	85	400
	26	16-17	140		84	40	0	110	408
	27	14	134		96	39	0	90	405
	28	14	128		96	33	0	100	419
	29	14	171		96	39	0	82	408
	30		146	1.25	68	17	0.05	89	405
	31		171	1.5	64	19	0.05	99	424
June	1		146	1.0	64	19	0.02	80	411
	2		134	2.25	72	15	0.05	91	440
	3		128	2.25	68	19		89	455
	4		134	1.5	72	19		101	462
	5		140		76	19		102	480
	6		128		74	23		130	490
	7		134	1.5	76	19		120	500
	8		128	1.5	72	17		110	470
	9		116	1.5	64	19		38	379
	10		104	1.5	54	16		24	341
	11		104	2.25	52	17		28	330
	12		110	2.25	56	17		25	340

DATE	Na.	HCO$_3$	Cl	Ca	Mg	Fe	SO$_4$	Conductivity
June 13		116		60	17		32	368
14		128		64	17		53	399
15		134		88	10		95	440
16		140		80	17		85	450
17		134		76	19		100	477
18		134		76	24		85	470
19		153		80	21		80	500
20		146		76	19		110	520
21		143		84	19		125	505
22		156		68	29		100	525
23		153		84	17		120	505
24		159		72	27		125	550
25		153	3.5	80	24		125	510
26		146	4.4	80	24		125	550
27		146	4.4	76	19		125	560
28		153	5.0	80	21	0	135	515
29		149	3.13	84	19	0	110	525
30		153	4.38	84	15	0.07	140	550
July 1		104	2.5	60	17		19	298
2		98		60	7		18	298
3		104		56	15		21	340
4		110		64	15		38	360
5		122		84	12		70	430

DATE	Na.	HCO3	Cl	Ca	Mg	Fe	SO4	Conduc-tivity
July 6		134	3.75	72	19	0.02	85	540
7		140		74	18		100	525
8		134		72	17		80	460
9		140		72	19		75	485
10		146		76	17		110	510
11		140		72	22		95	510
12		146	3.1	80	19	0	110	540
13		128		60	19		28	385
14		128		76	15		42	435
15		140		80	12		75	500
16		140		76	19		118	490
17		140		76	24		90	540
18		146		76	22		95	525
19		134	6.25	72	24	0.04	120	570
20		146	5.00	72	27		140	540
21		159		76	19		125	500
22		153		76	24		125	555
23		146		76	17		105	560
24		140		84	19		120	560
25		158		84	19		120	580
26		140	5.0	80	22	0.02	120	540
27		140		76	24		150	550
28		134		76	22		145	560

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conduc-tivity
July 29							145	537
30							28	311
31							26	283
Aug. 1							30	328
2	110	5.0		52	19	0.05	30	370
3							39	372
4							80	479
5							69	462
6							75	485
7							60	475
8							70	490
9	146	3.25		84	15	0.05	95	470
10							100	490
11							90	525
12							100	410
13							90	410
14							125	490
15				72	17	0.03	110	465
16								
17							59	355
18							70	410
19							50	365
20							53	398

DATE	Na.	HCO$_3$	Cl	Ca	Mg	Fe	SO$_4$	Conductivity
Aug. 21							62	415
22		98	3.5	60	15	0.39	71	462
23							88	472
24							38	400
25							41	480
26							60	495
27							62	500
28							110	540
29							115	550
30		159		84	22		100	550
31							105	530
Sept. 1							78	515
2							110	560
3							50	355
4							39	379
5							48	410
6							48	403
7							54	437
8							57	458
9							64	486
10							60	505
11							75	505
12							85	525

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
Sept.13							83	529
14							43	411
15							88	541
16							95	501
17							89	550
18							96	580
19							105	695
20							89	555
21							110	533
22							115	513
23							110	503
24							120	475
25							95	512
26							115	468
27							105	620
28							100	600
29							105	605
30							125	625

DATE		Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conduc-tivity
May	21	8-9	98	2.5	64	12	.10	55	298
	22	10	85	1.88	60	17	.05	70	303
	23	16	92		72	15	0.0	99	372
	24	15	113		72	34	0.01	95	365
	25	16	128		80	39	0.05	120	400
	26	21	134		80	43	0.04	115	418
	27	16	122		104	28	0.02	120	405
	28	17	134		96	33	0	95	425
	29	16-17	146		96	27	0	100	409
	30		159	1.25	72	15	0.02	94	410
	31		159	1.0	64	17	0	85	431
June	1		146	0.75	68	15	0	99	420
	2		159	1.5	68	17		89	443
	3		134	1.88	68	19		80	478
	4		134	2.25	72	19		120	470
	5		128		76	22		120	490
	6		122		80	15		135	495
	7		128	1.5	72	19		130	510
	8		122	2.25	68	22		130	488
	9		116	2.25	56	22		28	359
	10		98	1.5	52	15		18	320
	11		104	2.25	56	15		22	325
	12		104	2.25	56	15		32	349

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
June 13		122		64	17		47	390
14		128		64	19		70	415
15		134		76	15		95	442
16		128		72	19		75	450
17		116		76	19		115	475
18		128		76	22		110	470
19		128		78	17		125	500
20		134		74	21		110	515
21		140		72	22		130	505
22		143		76	22		150	540
23		140		80	22		140	515
24		140		76	22		135	560
25		146	2.5	80	22		150	518
26		140	3.1	80	24		140	575
27		146	5.0	80	22		155	580
28		140	5.0	76	19	0	130	520
29		140	4.38	80	24	0.02	150	550
30		140	3.75	76	22	0.05	175	570
July 1		98	2.25	48	15		10	261
2		92		52	10		18	308
3		110		56	19		41	385
4		110		72	19		70	435
5		134		72	17		100	475

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
July 6		134	3.12	80	12	0	100	500
7		134		72	19		125	550
8		122		64	17		70	440
9		122		68	19		95	475
10		134		72	19		120	510
11		134		72	19		140	520
12		134	4.1	80	19	0.02	130	550
13		122		60	17		28	372
14		134		72	15		60	442
15		122		72	17		100	500
16		134		76	17		120	510
17		140		72	22		125	550
18		134		76	24		120	535
19		146	6.2	72	19	0.05	145	600
20		146	3.75	72	29		145	550
21		146		72	22		170	518
22		140		80	27		140	575
23		134		76	19		145	590
24		140		76	24		145	580
25		146		76	29		150	615
26		140	6.25	80	29	0.05	150	560
27		140		80	22		170	570
28		146		80	22		200	600

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
July 29							180	560
30							33	352
31							24	300
Aug. 1							47	381
2		122	3.11	72	17	0.05	80	470
3							90	485
4							120	510
5							102	510
6							105	520
7							89	495
8							100	520
9		153	5.0	88	17	0.04	125	512
10							130	525
11							130	555
12							145	440
13							145	440
14							150	520
15					84	12	125	530
16								
17							60	402
18							61	440
19							35	375
20							33	415

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
Aug. 21							72	432
22		101	3.5	60	17	0.01	68	482
23							78	488
24							79	470
25							63	490
26							76	515
27							100	515
28							125	560
29							120	560
30		159		92	17		120	575
31							125	550
Sept. 1							100	540
2							130	590
3							29	357
4							42	414
5							53	448
6							48	434
7							60	465
8							63	488
9							75	512
10							85	560
11							98	535
12							105	550

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conduc-tivity
Sept.13							110	555
14							120	565
15							120	595
16							125	529
17							120	570
18							125	600
19							130	650
20							120	565
21							140	555
22							145	538
23							145	530
24·							148	499
25							130	535
26							150	485
27							130	645
28							135	630
29							135	655
30							150	650

DATE		Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
May	21	10	85	1.25	56	15	.04	63	280
	22	10	92	1.88	64	17	.04	72	310
	23	14	110		80	15	0.0	92	380
	24	12	116		76	32	0.02	90	370
	25	14	140		80	44	0	99	415
	26	18-19	146		88	46	0	90	426
	27	15	134		104	22	0	100	410
	28	15	128		104	34	0	110	432
	29	15	171		96	33	0	83	428
	30		159	1.88	72	19	0.08	75	421
	31		159	1.0	72	15	0.04	92	445
June	1		171	1.0	68	19	0	75	431
	2		134	1.50	68	19		80	455
	3		134	1.88	72	19		80	478
	4		146	2.25	76	19		90	485
	5		140		80	19		100	495
	6		134		80	22		120	510
	7		140	2.25	84	19		125	515
	8		134	1.5	76	19		115	485
	9		122	1.5	64	17		40	399
	10		101	1.5	60	13		28	348
	11		110	3.0	52	17		25	348
	12		119	2.62	60	17		32	352

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conduc-tivity
June 13		122		64	17		45	381
14		134		64	24		48	402
15		146		76	19		85	451
16		134		76	19		90	460
17		134		80	22		115	485
18		153		78	23		90	499
19		146		72	22		95	502
20		153		80	22		115	520
21		159		84	19		110	520
22		159		76	24		120	540
23		153		84	17		110	510
24		159		80	15		120	560
25		159	5.0	88	12		100	515
26		165	4.3	84	10		100	565
27		153	3.75	84	16		130	580
28		159	4.3	86	21	0	102	525
29		156	2.5	84	22	0	105	525
30		165	4.38	84	15	0	100	560
July 1		116	3.13	56	17		19	305
2		104		56	17		20	318
3		110		60	15		32	361
4		110		72	17		33	380
5		134		80	17		50	440

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
July 6		146	4.13	80	7	0.05	87	550
7		140		78	18		75	535
8		134		72	16		60	460
9		146		76	19		90	505
10		140		76	22		100	525
11		149		80	22		95	535
12		146	4.1	84	19	0.02	110	550
13		128		68	17		32	410
14		140		72	19		50	455
15		146		76	22		82	520
16		134		80	19		80	540
17		153		84	19		80	550
18		153		80	22		95	540
19		146	7.5	80	19	0.05	100	590
20		165	6.25	80	27		120	550
21		159	12.5	80	22		120	518
22		165	5.0	84	22		115	570
23		146	6.25	84	15		120	580
24		159	5.0	88	12		115	570
25		146	3.75	80	27		96	615
26		153	6.25	88	17	0.02	93	560
27		159		88	17		120	570
28		153	6.25	92	5		140	590

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
July 29							105	555
30							35	327
31							32	312
Aug. 1							33	347
2		104	2.5	60	15	0.08	43	395
3							42	400
4							81	495
5							89	490
6							81	500
7								
8							85	510
9		153	2.5	88	17	0.02	90	495
10							74	508
11							93	545
12							120	420
13							95	430
14							103	500
15				80	12		110	490
16							32	340
17							50	370
18							51	410
19							50	380
20								

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
Aug. 21							68	430
22		98	3.13	60	17	0.23	58	478
23								
24							45	410
25							46	480
26							65	532
27							68	512
28							90	550
29							115	555
30		159		88	15		91	570
31							100	540
Sept. 1							72	528
2							97	580
3							54	370
4							39	393
5							50	420
6							47	420
7							57	445
8							55	480
9							61	492
10							64	520
11							79	519
12							78	540

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conduc- tivity
Sept.13							80	548
14							45	437
15							63	520
16							92	511
17							89	560
18							89	580
19							95	670
20							85	555
21							115	545
22							120	520
23							96	515
24							105	481
25							92	529
26							110	479
27							90	630
28							100	605
29							95	620
30							120	620

W1

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
24.5.68	4	88		64	15	0.02	62	300
1.6.68		110	1.0	56	17	0.05	55	358
7.6.68		110	2.25	72	19		120	459
22.6.68		128		76	22		81	455
30.6.68		134	3.13	80	19	0.18	110	480
6.7.68		128	1.88	72	16	0.01	68	490
13.7.68		116		68	12		55	400
20.7.68		122	2.5	68	24	0.02	110	480
27.7.68		128	5.0	84	24	0.05	155	523
10,8.68		153		96	15	0.02	72	495
25.8.68		159		84	19		32	490
31.8.68		146		104	12		55	475
28.9.68							145	630

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conduc-tivity
24.5.68	5	116		76	17	0	80	345
1.6.68		159	1.0	72	15	0.01	59	400
7.6.68		159	1.5	84	27		88	515
22.6.68		183		64	41		92	550
30.6.68		183	3.75	92	5	0	90	565
6.7.68		153	2.5	80	15	0.01	52	540
13.7.68		122		64	17		14	355
20.7.68		165	6.25	84	27	0.06	85	540
27.7.68		165	6.25	88	24		86	580
10.8.68		153		88	19	0.05	37	470
25.8.68		140		80	19		19	438
31.8.68		171		96	19		60	490
14.9.68							24	359
28.9.68							60	600

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conduc- tivity
24.5.68	5	110		76	15	0	85	345
1.6.68		159	1.0	64	19	0.01	64	399
7.6.68		153	1.5	92	19		95	505
22.6.68		177		60	43		97	550
30.6.68		183	3.13	88	5	0.05	75	570
6.7.68		153	1.88	80	15	0.05	69	535
13.7.68		116		68	12		15	360
20.7.68		165	3.75	80	27	0.02	110	550
27.7.68		165	5.0	88	22		115	580
10.8.68		159		92	17	0.02	45	475
25.8.68		140		84	17		23	438
31.8.68		171		100	17		50	500
14.9.68							36	362
28.9.68							69	503

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
27.5.68	1	73		52	23	0.05	6	225
3.6.68		101	2.25	42	15		1	241
6.6.68		101		47	16		1	277
10.6.68		79	2.5	37	11		1	210
11.6.68		76	2.25	35	11		0	200
13.6.68		88		48	10		0	218
17.6.68		104		47	13		1	285
18.6.68		102		40	19		1	280
24.6.68		131		56	19		1	345
29.6.68		140	3.13	74	11		1	345
1.7.68		64	5.6	38	10		1	175
8.7.68		92		44	10		1	244
13.7.68		85		42	13		1	233
15.7.68		104		52	12		1	284
17.7.68		113		54	16		2	307
19.7.68		119	3.75	64	17	0.07	4	370
22.7.68		128		64	15		4	392
23.7.68		128		60	17		3	351
25.7.68		134		64	15		3	348
26.7.68		122	5.0	64	17	0.05	4	363
29.7.68							4	375
30.7.68							5	228
31.7.68							4	200

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conduc-tivity
5.8.68		43	2.5	44	22	0.15	4	280
17.8.68							3	225
19.8.68							3	250
20.8.68							4	245
24.8.68		92		44	17		2	252
26.8.68							1	298
29.8.68		128		60	17		2	332
31.8.68							9	351
2.9.68							14	128
9.9.68							9	315
16.9.68							7	372
23.9.68							7	357
30.9.68							8	398

DATE	Na.	HCO_3	Cl.	Ca	Mg	Fe	SO_4	Conductivity
27.5.68	1	31		20	12	0.05	3	90
3.6.68		37	2.25	20	7		0	110
6.6.68		37		22	11		0	129
10.6.68		37	1.87	20	7		0	115
11.6.68		40	1.5	20	15		0	114
13.6.68		43		22	6		0	114
17.6.68		49		20	15		0	135
18.6.68		55		22	6		0	128
24.6.68		43		24	17		4	153
29.6.68		49	2.5	32	5		1	149
1.7.68		49	3.13	24	12		0	126
7.7.68		49		20	12		0	135
8.7.68		43		20	7		0	122
13.7.68		43		24	7		0	125
15.7.68		49		20	10		0	140
17.7.68		49		28	7		0	150
22.7.68		49		28	10		8	165
23.7.68		49		28	7		6	158
25.7.68		55		28	24		8	153
26.7.68		61	3.75	24	17	0.71	7	169
29.7.68							6	165
30.7.68							5	140
31.7.68							6	122

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
5.8.68		43	24	10		0.50	5	116
16.8.68							7	128
17.8.68							6	130
19.8.68							8	135
20.8.68							8	130
24.8.68		55	20	12			0	140
26.8.68							0	152
29.8.68		67	28	12			0	160
31.8.68							17	167
2.9.68							8	291
3.9.68							15	140
9.9.68							16	139
16.9.68							18	169
23.9.68							14	175
30.9.68							18	190

DATE		Na.	HCO_3	Cl.	Ca	Mg	Fe	SO_4	pH.	Conductivity
GS1										
June	7		183	1.5	80	24		5		505
	21		207		84	27		5		505
	28		207	3.75	92	22	0.95	5	8.1	510
Aug.	2	19	153	23.75	56	27		7	7.7	570
	9	6	166	7.5	76	23	3.5	15	7.59	462
	23		122	5.0	56	10	0.28	15	7.4	445
	30		189	6.25			2.6	5	8.39	535
GS2										
June	6		55	3.75	20	15		120		352
	21		55		12	17		90		308
	28		55	8.13	12	17	1.25	90	8.91	308
Aug.	2	34	61	35	14	21	0.2	87	7.86	362
	9	41	67	32.5	24	12	3.0	175	7.72	390
	23		67	75	24	12	2.2	110	7.10	462
GS5										
May	31		18	1.9	4	4	2.5	8		67
June	7		24	2.25	8	2		3		90
	21		18		4	2		4		72
	28		12	1.88	6	4	3.5	2	6.73	76
Aug.	2	10	37	5.0	8	10	2.9	18	5.70	110
	9	7	24	5.0	6	11	3.0	25	6.65	90
	23		24	35	8	10	2.8	15	6.65	92

DATE	Na.	HCO3	Cl.	Ca	Mg	Fe	SO4	pH.	Conductivity
GS6									
July 12		104	7050	48	75	6.85	25	6.1	13,300
19		110	4450	80	90	3.8			13,700
26	3300	98	10,500	72	75	0.95	28		13,000
Aug. 2		85	4325	56	70	5.0	38	9.19	13,600
9	3100	98	8525	64	68	2.9	42	8.85	13,000
23		110	9050	76	87	0.39	20	9.69	13,450
GS7									
July 12		214	2750	8	24	0.05	32	6.1	5,750
19		256	635	4	0	2.7	87	9.55	2,700
26	670	275	1400	8	5	5.0	80	10.01	2,560
Aug. 2		275	675	4	5	3.0	125	10.51	2,650
9	500	305	1400	8	5	0.12	34	10.02	2,790
23		256	1300	8	7	0.62	68	10.20	2,820
GS8									
July 19		49	165	8	2	3.2		10.15	840
26	136	43	290	8	0	4.67		10.55	700
Aug. 2		49	145	6	9	0.65	175	10.31	725
9	144	61	225	8	2	1.5	220	10.38	670
23		55	160	8	2	0.95	210	10.20	660
GS9									
July 19		12	3125	60	87	0.75		6.75	8,400
26	1250	12	5950	52	58	4.20		6.72	6,250

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	pH.	Conductivity
Aug. 2		6	5150	98	30	5.0	56	6.63	7,600
9	1350	12	5000	96	24	2.0	43	7.08	7,700
23		18	4725	104	92	3.2	72	6.72	7,600
GS10									
July 19		98	10	4	15	3.6	46	8.41	830
26	52	92	30	8	10	5.0	34	8.33	352
Aug. 2		92	11.25	8	17	0.22	35	8.20	374
9	56	104	15	16	12	2.1	56	7.73	397
23		73	15	12	10	2.5	33	7.60	380
GS12									
July 19		195	13.75	12	5	4.0	190	8.2	850
26	150	177	13.75	12	2	5.0	160	8.3	725
Aug. 2		183	12.5	16	7	3.5	200	7.77	780
9	165	207	15	16		1.1	135	8.68	780
23		122	20	16	5	3.25	190	8.65	710
GS13									
July 19		24	6.25	8	5	2.5	44	9.45	130
26	29	37	7.5	8	0	2.95	74	9.52	165
Aug. 2		37	5.0	24	0	2.9	62	9.1	181
9	35	49	5.6	4	5	3.5	49	9.98	195
23		43	10	4	2	3.1	50	9.9	200
GS14									
July 19		476	6.25	244	2	5.0	27	12.04	3,320

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	pH.	Conductivity
July 26	51	439	8.75	248	19	5.0	17	11.56	3,045
Aug. 2		427	7.5	272	0	5.0	28	12.22	3,170
9	52	470	6.9	244	12	2.1	13	12.05	3,000
23		366	5.0	220	2	4.5	15	11.5	3,050
30		543	4.38	240	2	5.5	10	12.15	3,170
GS16									
July 12		165	2.5	26	4	0.15	15	8.45	510
26	84	153	7.5	16	22	5.0	14	7.9	475
Aug. 2		153	2.5	12	12	1.1	17	7.81	497
9	86	165	5.0	20	7	3.85	15	7.4	490
23		165	5.0	24	2	2.1	10	7.4	478

SPRINGS

DATE	Na.	HCO_3	Cl.	Ca	Mg	Fe	SO_4	Conductivity
MM		116	4	52	18		4	295
NN		156	3	68	22		4	374
OO		189	2	82	4		4	463
PP		171	2	78	17		5	450
S_1		250	2	116	2		6	610
QQ		162	3	76	22		10	440
RR		177	3	116	0		130	585
SS		217	2	200	11		320	1000
TT		177	4	148	22		250	755
UU		177	3	116	2		120	575
VV		174	3	94	5		44	520
T_1		183	4	100	29		68	940
U_1		159	2	168	29		325	750
WW		195	2	104	10		103	560
XX		228	9	118	6		285	950
V_1		232	5	96	7		170	750
F		217		72	34		288	1085
O_1		253		110	39		310	615
G		192		98	32		220	715
H		195		100	32		220	800
Q		183		112	0		140	1020
I		125		94	19		228	470
J		198		108	22		275	955

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conduc-tivity
K		143		106	29		138	600
L		15		8	4		140	165
M		128		76	19		108	550
N		49		60	18		265	560
O		58		38	36		273	580
P		37		8	7		125	310
Z		49		20	7		37	235
E		153	6	72	19		140	555
YY		207	7	100	2		140	690
A		61	4	26	11		7	250
R		101		44	12		130	445
S		49		34	11		200	360
T		92		54	18		200	525
U		88		58	15		190	495
V		78		50	14		158	410
W		125		64	18		95	440
D		85	5	60	13		141	240
X		173		88	22		223	725
LL		198	11	73	12		88	700
KK		204	5	106	28		182	800
II		256	6	112	5		325	1250
JJ		207	4	107	13		183	1000
HH		177	2	174	2		218	775

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
GG		162	3	158	10		265	755
K$_1$		192	8	188	39		320	1150
R$_1$		128	3	480	104		350	7100
DD		179	2	91	18		23	505
L$_1$		146		92	12		275	760
Q$_1$		128	3	440	109		375	6000
P$_1$		189	4	68	12		20	550
M$_1$(a)		226	3	96	0		9	615
M$_1$		177	3	82	12		10	490
N$_1$		119	3	62	17		2	310
EE		165	2	116	27		138	595
FF		177	3	100	10		45	520
J$_1$		177		80	15		8	470
H$_1$		183		108	7		120	600
G$_1$		177		84	22		2	470
F$_1$		183	3	96	0		20	500
C		229	2	96	60		27	500
E$_1$		171	3	84	19		5	425
D$_1$		171	3	80	24		2	435
C$_1$		177	3	80	22		2	430
B$_1$		195	3	84	27		3	480
A$_1$		253	2	116	26		39	712
B		312	3	139	26		54	760

DATE	Na.	HCO$_3$	Cl.	Ca	Mg	Fe	SO$_4$	Conductivity
Ardee Cr.		49		22	6		112	235

APPENDIX C

Location of Springs in Wilson Creek Watershed.

LOCATION OF SPRINGS IN WILSON CREEK WATERSHED.

A   At bottom of Jet Trail

B   Below Bald Hill dam

C   Below #27 rain gauge

D   Lick above junction of Conway Creek and Bald Hill
    Creek (same as W2).

YY From Wilson Creek weir.

PACKHORSE CREEK.

MM Narrow, small tributary below end of access road.

NN Right hand bank (RHB) just above crest gauge 10, and
    below W6 sampling point.

OO Left hand bank (LHB). Very clear water, coating stones
    with calcium. Station 503.50.

PP RHB, out from a scar, clear water, enters from under
    boulders.

S1 LHB, seeping through bank, clear water.

QQ Station 495.75 RHB.

RR Very gravelly, water coming from spring up the bank,
    flows in over the gravel.

SS Seeping out of a scar, not very good flow, horsetails,
    RHB.

TT Also out of scar, but better flow than SS, RHB.

UU Very small, out of RHB.

VV Fair sized stream, station 466.10 at junction, clear water, and thick deposits of calcium on stones.

T1 Small spring, forms a delta on top of a bank flat, good flow on top of the "delta". When it rains much water etc. must come down, as large area of mud formed Just upstream of 415.00.

WW Into main stream under a fan of boulders.

XX Again into main stream as a fan, 455,00.

U1 RHB, just down stream from a scar on the LHB, and just up stream from 452.00.

V1 LHB, just opposite crest gauge 11, thick vegetation over it.

F RHB, a large lick, just downstream of CG11.

Q RHB, not a strong flow, station 443.

G RHB, below rain gauge 27, good flow.

H RHB, station 411, murky, and depositing calcium, good flow. (SB 11).

O1 RHB, clear, and nice taste, 401.00, good sized stream.

I RHB, seeping from concave area up the bank, below SB7.

J 5' above stream, SB8, dripping.

K 390.40 good stream.

L Fast seepage out of SB11 - 10 - 15 yards of it.

M 376.10, seeps out of the end of SB11R.

N At end of SB12, leaves red deposit at the "confluence".

O Round corner from N, seems to be coming from the
other side of the SB12, and is slightly lower than
the main stream.

Ardee Creek dry, and into an abandoned meander, water
running at confluence of meander and main stream.

P After Ardee Creek, and before SB20, fair flow, may
be part of the creek (Ardee) seeping out further
down stream - the chemistry is similar, but not
identical.

Z At base of SB23, from a bentonite band.

E At sharp bend before Packhorse metering station, a
lick.

SOUTH BRANCH BALD HILL CREEK.

N1 Stream below raingauge 3.

M1 Station 28.00.

M1a About 20 feet below M1 on the same bank - LHB.

P1 Just below the slipped banks.

Q1 Just upstream of station 16.00. - i.e. about 16.80. -
RHB, mud slides all over, and downstream from the
orange sand cliff.

L1 A little shale exposed, at station 12.50. Last time
obscured by recent mud flow as a result of the
blowing of the beaver dam.

DD At station 11.00, a good flow.

R1 Lick on the LHB at approximately 9.00 - some iron
straining.

K1 Large lick at crest gauge 8.

EE Stream between the two branches - sample taken
where it crosses the deer path to crest gauge 9.

FF LHB North branch Bald Hill Creek, just downstream
of the crest gauge.

NORTH BRANCH BALD HILL CREEK.

A1 Very rich in iron, deep red mud make this
unmistakeable, good flow.

B1 At reference point 30, stream coming down from
pencil lake - station 258.00.

C1 LHB, at station 248.15 (centre line of draw) -
comes out over quite a large area, through stones
- from rain gauge 12.

D1 Well defined, full of boulders, fans out all around,
just downstream of 241.15.

E1 RHB, stream running.

F1 RHB, good flow, just below 234.00.

H1 LHB, at TP 69, clear water, calcium deposits, RHB,
Ca deposit not as heavy as some, just the small rocks
- may be just that the water is very clear.

J1 Good stream, very, very clear, good taste, confluence

at 209.00

G1 Creek coming in on the corner, clear water, 224.00.

Much water seeping in below J1 but no sample, as it is

probably seepage from EE.

BALD HILL CREEK BELOW THE JUNCTION.

GG Just below crest gauge 7

HH By lick, seepage out all over, 163.00

JJ A lick on the corner.

11 A lick on the RHB - 200' below JJ, which is 200'

below HH.

KK At station 151.90. RHB, 300' below 11.

LL Just above SB 1

X Seepage at foot of bank above Conway Junction.

W Between SB 11 and 10, below Bald Hill

V Opposite Reference Point 7, in the area of downcutting,

at SB 11.

U Near SB18 - the large spring with the can placed in

the outlet.

T In the corner of an abandoned meander, between SB20

and 19 approximately TP 25.

S In shale bank 21, from the fault in the centre.

R From the far end of SB 22.

APPENDIX D

Inventory of Chemical Analysis Laboratory.

INVENTORY OF CHEMICAL ANALYSIS LAB.

Hach kit - complete for testing Alkalinity, Chloride, Calcium, and Total hardness, Iron, Sulphate, and Magnesium.

pH meter

Conductivity meter

Piezometer sampler, cable and stand

Telethermometer and cable (temperature down wells)

C thermometer

Small thermometer for springs   )
) belonging to the PFRA
Metal thermometer for daily samples)

10 conical flasks (could do better with 12)

4 50ml graduates

2 25ml graduates

1 pipette (could do with 2)

1 plastic straw (to help with Fe and SO_4 tests)

At least 6 glass funnels

Funnel stand

Filter paper (largest size made!)

7 glass beakers of varying sizes

        1 400ml

        4 250ml

        1 100ml

3 50 ml burrettes and stand - need extra stand

1 10ml burrette - need stand

Kleenex

Washing up bowl

Washing up liquid

Bottle brush

Plastic bucket

Large distilled water container with tap

Vaseline - for greasing taps of burrettes

Boxes - for bottles

Washbottle - polyethylene

Minitimer clock (belonging to the PFRA.)

Marking pen - waterproof

Masking tape

Insulating tape.
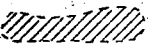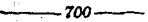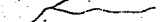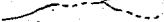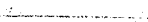
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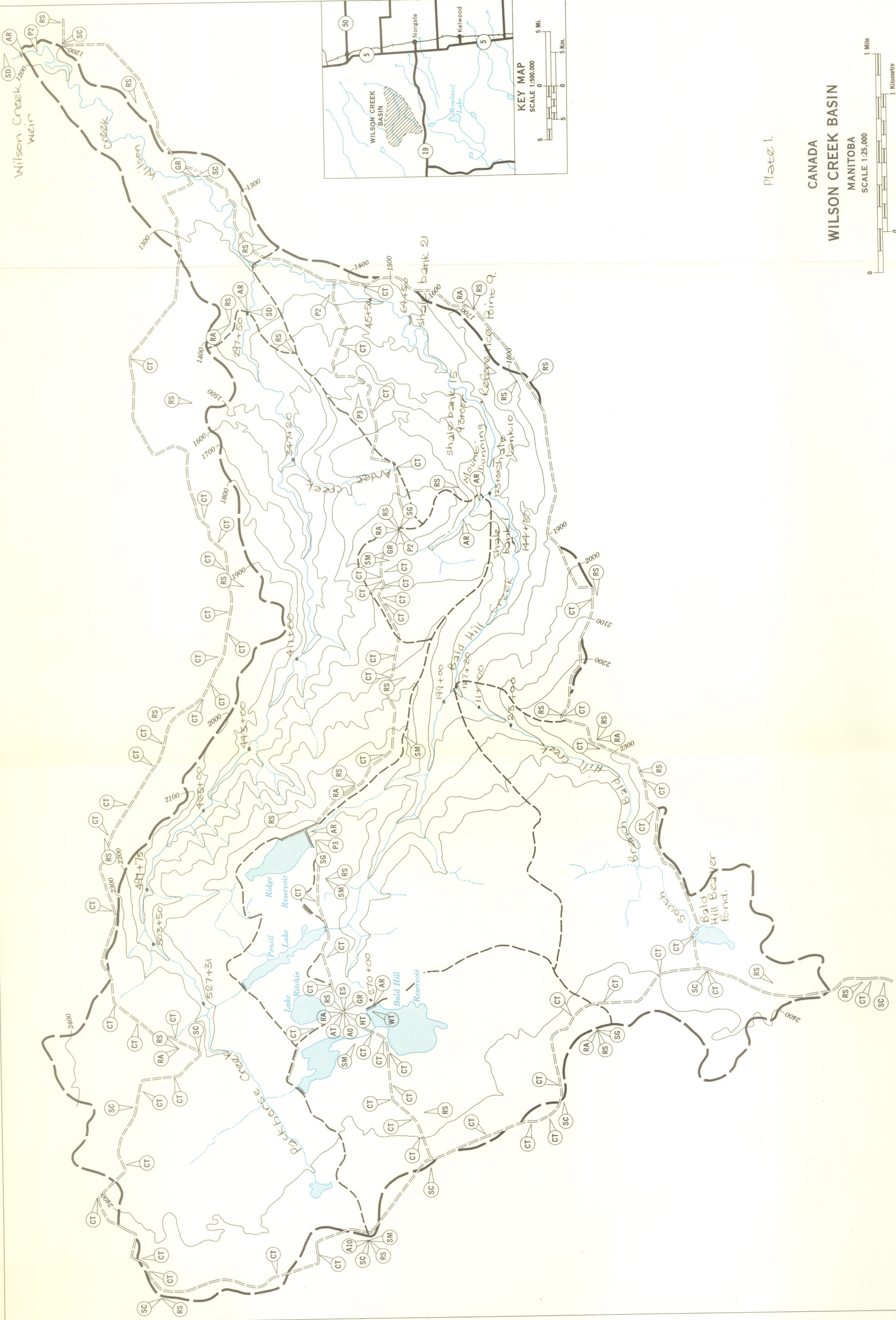
LEGEND

Canadian Research Basins, 1967

Symbol	Description
(hatched bar)	Drainage basin (key map only)
——700——	Contour (feet)
———	Basin boundary
— — —	Sub-basin boundary
(wavy line)	Perennial stream
(wavy dashed line)	Intermittent stream
(filled shape)	Lake, pond, slough
(shape with line)	Dam
═══════	Road, all weather
═ ═ ═ ═	Road, dry weather
═(25)═	Highway route marker
●	Towns
(AR)	Hydrometric station, artificial control, recording
(SD)	Sedimentation station
(GR)	Groundwater well, recording
(P*)	Piezometer (* is number of P in nest)
(SC)	Snow course
(SG)	Snow gauge
(RA)	Rain gauge, recording
(RS)	Rain gauge, standard
(HT)	Hygrothermograph
(A*)	Anemometer (* is height above ground in meters)
(ES)	Evaporation station
(SM)	Soil moisture site

KEY MAP

SCALE 1:500,000

50

Norgate

Kelwood

5

5

5

19

WILSON CREEK BASIN

Rowland Lake

5 Mi.

5 Km.

CANADA

WILSON CREEK BASIN

MANITOBA

SCALE 1:25,000

Plate 1.

1 Mile

1 Kilometre

LATITUDE 50°43'55"N

LATITUDE 50°40'20"N

Wilson Creek Weir

Wilson Creek

Wilson Creek

Anderson Creek

Ridge Reservoir

Pencil Lake

Lake Ritchie

Bald Hill Reservoir

Bald Hill

Bald Hill Creek

South Branch

Packhouse Creek

Bald Hill Beaver Pond.

Mount Junning

Shale bank

Refuge cabins area

1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400

297+50
344+20
445+00
465+00
491+15
503+50
527+31
199+00
197+20
113+00
144+50
255+98
270+00