UNIVERSITY OF MANITOBA

FORT GARRY, MANITOBA

"AN INVESTIGATION OF SOIL MOISTURE RETENTION IN THE RED AND ASSINIBOINE RIVER DRAINAGE BASINS AS AN AID TO FLOOD PREDICTION."

A THESIS

Presented to the Faculty of Graduate Studies and Research

University of Manitoba

In Partial Fulfillment

Of the Requirements for the Degree of

MASTER OF SCIENCE

IN

CIVIL ENGINEERING

by

MERVYN MINDESS

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Mervyn Mindess

Mervyn Mindess

ABSTRACT

Title of Thesis: "AN INVESTIGATION OF SOIL MOISTURE RETENTION IN THE RED AND ASSINIBOINE RIVER BASINS AS AN AID TO SPRING FLOOD PREDICTION"

Author's Name: MERVYN KINDESS

Summary: A new approach to the problem of spring flood prediction was necessary in order to provide a check on other methods. The new approach took into account important factors that had heretofore been neglected.

The rational, or infiltration, approach was investigated, and although exact quantitative analyses could not as yet be made the method showed great promise, and was quick and easy to apply. The study carried out gave encouraging results and indicated the advisibility of further study.

TABLE OF CONTENTS

OBJECT

The object of this thesis is to report on soil moisture studies made in the Red and Assiniboine River drainage basins in the autumn seasons of 1953 to 1955 inclusive.

From studies made of various physical properties of the soils sampled during the autumn field trips, it is hoped to derive a method for establishing some relationships on the effect of antecedent moisture conditions on soil moisture retention capacity, with the view that this might be another aid in the rather complex problem of spring flood forecasting for the Southern Manitoba Region. However, it must be stated here that the author is more concerned with the soil properties and behaviour, and the indication of methods used, than with rigorous hydrological analyses.

Soil studies carried out here will also form the groundwork for continuous annual records of soil moisture and moisture retention capacity. As in other hydrological studies, a set of long term records would be of great value.

Finally, from experience gained in making this investigation, recommendations will be made for relocation of soil test holes in order to get better and more representative results, and for improvement of techniques in order to eliminate some errors made in the present and past studies.

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INTRODUCTION

In the Red and Assiniboine River drainage basins low winter temperatures permit an almost complete accumulation of snowfall, and the advent of warm weather in the spring produces a period of heavy runoff caused by the melting snow and often complicated by spring rains. This spring runoff constitutes the highest rate of stream flow in each year.

Flood damage in the Red and Assiniboine River basins can be extremely high, as was clearly demonstrated in the disastrous 1948 and 1950 floods. Apart from disrupting communications, transportation and public utility services, floods cause widespread flooding of farm lands, inundate roads and bridges, and damage homes and businesses in both rural and urban centres.

If the amount of runoff could be predicted in these basins, flood (stage) predictions could be made. These flood forecasts would have to be issued in advance, so that flood defences could be mobilized. Even if permanent flood control structures are non-existent, advance preparation such as dyking and sand-bagging in low level areas, and preparation of pumping stations can do much to reduce and alleviate flood damage. With proper warning a large amount of damage in urban areas can be prevented by moving household effects, personal goods, warehouse stocks and movable equipment and machinery to safe places. Reservoirs all over the basin may be emptied when a flood threatens, and then operated to reduce river stages wherever possible.

The problem of spring flood forecasting in the Red River basin has been intensively studied in the past. The most recent and most exhaustive of these investigations was carried out by a Board set up after the 1950 flood, under the auspices of the Federal Water Resources Division.

One of the results of this Board's investigations was a coaxial graphical correlation method of predicting runoff from snowmelt. The factors taken into account were the rate of melting as expressed by the number of degree days per day above freezing; the precipitation in the form of accumulated snowfall and rain during the snowmelt runoff period; and the average stream flow from the period October to January inclusive, expressed as a percentage of the long term mean flow during this period. This latter factor is an excellent indication of ground water flow, but has been designated as the soil priming index, which is a definite misnomer, since it gives no indication of the moisture retention capacity of the watershed soil above the ground water table and the capillary fringe. However, this graphical method does have the advantage of being quick and easy to apply, and gives fairly good results.

Despite this, it was deemed necessary to try another approach to the problem of spring runoff prediction, and to give more study to one of the factors which was previously just glossed over, namely the moisture retention capacity of the soil. Therefore, the present study was instigated by the Water Resources Branch of the Department of Mines and Natural Resources, Province of Manitoba in the fall of 1953, and is being carried out under the auspices of this Branch. It is hoped that the results of this study will provide a check on the results obtained by the graphical method, and that they might serve as an adjunct to them.

GENERAL CONSIDERATIONS

Characteristics of the Drainage Basins

There are many interdependent factors controlling the amount and rate of spring runoff in a drainage basin. Some of the most important factors, which remain practically constant from year to year, are the characteristics of the drainage basin itself.

The slope of a drainage basin affects infiltration, surface runoff, soil moisture, and ground water contribution to stream flow. It is one of the major factors controlling the time of overland flow to stream channels, and is of direct importance in relation to flood magnitude. The Red River has a gradual, fairly uniform slope of only about one-half foot per mile, which certainly allows a maximum of infiltration to take place.

The orientation of a drainage basin influences the amount of heat received from the sun and thus affects transpiration and evaporation losses and snow thaw. Northward flowing streams such as the Red River are prone to periodic spring flooding due to the fact that the southern portion of the basin tends to thaw out before the northern portion of the basin.

Topography has a marked effect on flood runoff, even from watersheds that are so flat as to require artificial drainage for successful agriculture. With a few minor exceptions, the topography in the Red and Assiniboine River basins is conducive to a slow runoff.

The pattern and arrangement of the natural stream channels, or the drainage net, affects the efficiency of the drainage from the basin and therefore the characteristics of the resulting hydrograph. The basins being considered have dendritic, or branching drainage patterns, which typically develop over horizontal sedimentary beds, and which provide fairly efficient drainage.

Another very important feature of the drainage net is the indication this factor gives of the soil and surface conditions existing in the drainage basin, because the character and extent of nature's carving of stream channels through erosive processes is related to and restricted by the type of materials in the basin from which the channels are carved.

The Red and Assiniboine River drainage systems are carved from the sedimentary lacustrine deposits resulting from the last glacial age, of which much of the central plains of North America consist. These lacustrine deposits are underlain by boulder till, which in some places occurs at or near the surface. The soil mantle covering the basins naturally is a reflection of the parent material, which contributes the soil minerals affecting the texture and the water retention capacity of the soil.

The general soil types in the basins have been determined by a number of factors. These factors are the climate or the temperature and moisture within the soil; the vegetation, which in part affects the soil climate during growth and is the primary source of the organic matter; the position in which the soil is found in relation to topography (i.e. top of a knoll, down in a depression); the internal drainage, or the presence or absence of ground water within the soil;

the age, or length of time during which the soil has been under the influence of the soil forming processes; and, since the areas being considered are primarily agricultural regions, the modifying effects of cultivation or the works of man.

Moisture in the Soil

Watershed soils have a definite or limited water-holding capacity, usually expressed as a percentage of oven-dry weight or volume of the soil (degree of saturation). Above this degree of saturation, all water added to the soil profile will percolate down to the ground water or be lost in surface runoff. If the soil moisture is below this value, any water added to the soil must first fill the soil moisture reservoir before deep percolation or excessive runoff will occur. Water moves freely through the soil under the control of gravity only after the soil particles or rock surfaces have been coated with "water of adhesion".

Soil moisture is held in the upper soil layers by molecular attraction. The water stored in the soil above the ground-water table occurs as attached films on the surfaces of openings between soil particles, and as wedge-shaped bodies at the junctures between interstices. This explains the very important fact that soil structure is more important as affecting hydrologic properties than soil composition, although the two are definitely interrelated. Soil structure near the surface can and often does change seasonally due to shrinking, swelling and frost heave.

In general, the ability of soil to retain water of surface origin decreases with depth. This is particularly true in the Red and Assiniboine River basins where organic and silty soils are underlain at a depth of approximately five feet by thick strata of relatively impervious clays.

At certain distances below the surface, the soil pores are saturated with water. The line of complete saturation is sometimes called the ground-water surface or water table. However, this term is misleading, because every soil is in a state of complete capillary saturation up to some elevation above the water table. The water table is not a fixed surface, fluctuating according to the amount of accruing soil moisture. The water table concept does not apply to relatively impermeable materials such as clay, but only in coarse-grained materials, and therefore it cannot be applied to most of the areas under study.

The capillary fringe lies above the water table and in contact with it. Capillary water is the water held in this fringe by capillarity, which is defined as the property of tubes with hair-like openings, when immersed in water, to raise and hold water above the static level of the water in which they are immersed.

Infiltration of Water Into the Soil

Infiltration, or percolation, is the process whereby water enters the surface strata of the soil and moves downward toward the water table. It is affected by the moisture content of the soil, since liquid and/or gas permeabilities through a soil are universal functions of the degree of liquid saturation.

Infiltration is also greatly affected by the shrinking or swelling of the colloidal material in the soil. Most finely textured soils such as organic silts and clay contain some colloidal materials. Upon wetting these colloids swell and tend to block off the pores through which the water enters the soil. The physical properties of clay are more affected by wetting than are those of any other type of soil. It has a maximum absorptive capacity of more than fifty per cent of its volume, and absorption is accompanied by expansion of the clay body.

Macrostructures resulting from animal borings, decay of vegetal roots and the dissolution of materials aid infiltration.

Temperature changes influence infiltration to some very small extent, since the infiltration capacity increases with temperature.

Other factors affecting infiltration are amount and type of vegetal cover, state of cultivation, and compression of entrapped air.

The amount of infiltration into a soil column of a given depth is equivalent to the amount of water percolating through the column, and, in addition, the amount retained within the column. This latter amount is limited by the available storage.

Studies carried out at the Vicksburg Infiltration Project show that for a given soil, regardless of antecedent moisture conditions, the infiltration rate levels off at the same low value. (See following figure). However, the lower the initial soil moisture content, and thus the more storage available, the longer it will be before the low, steady value is reached. The antecedent available storage is of importance only during the initial period of relatively high rates. Thereafter, the rate is governed by the low permeability of the soil. The rate at which water can enter the soil is of importance only for a very short time at the beginning of melting and runoff, when entry of water into storage permits higher infiltration rates. As a soil becomes saturated and its pores are filled, percolation and infiltration rates are reduced.

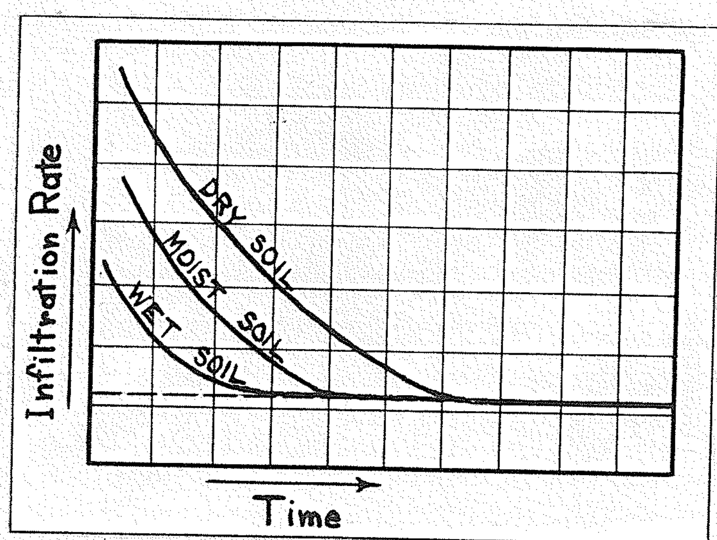


Figure 1
Infiltration rate versus time after
surface water application.

Frost in the Soil

Frozen subsurface water is called frost. Its occurrence in the ground is a matter of major concern to anyone attempting to evaluate spring runoff. The depth and duration of frost in the ground depends on a number of complex, interrelated factors such as temperature, soil type, soil moisture content, depth of snow cover and vegetal cover.

Soil structure and grain size determine the character of the frost formation which occurs in the soil. Coarse-grained soils such as sands, sandy silts, and soils with high organic content usually develop a honey-comb type of frost which is relatively permeable and has little effect on infiltration. Dense, compacted soils and fine-grained soils such as clays and clayey silts freeze into dense, highly impervious masses. Silty and clayey soils exhibit the most frost heave.

The most important factor influencing the depth of frost formation is the depth of snow cover. A thick snow blanket is a good insulator and does not allow frost to form to any great depth. In the winter of 1955-56 there was an above average depth of snow cover in the Red and Assiniboine River basins, and the depth of frost was in no case greater than three feet. In other years with little or no snow cover frost has extended as far down as seven or eight feet.

A freezing of soils to depths of three or four feet draws water into the freezing zone from the soil beneath. Capillary action does not account for this upward movement of soil water into the freezing zone, since there is no free surface or meniscus. The rise of water is attributed to the force of molecular attraction acting in fine-textured soils to replace molecules of water extracted by growing ice crystals from film or capillary moisture. Water, which has a surprising tensile strength, is drawn to the freezing zone and builds ice lenses, which invariably accompany frost heave. These ice lenses tend to develop at more or less regular intervals, and it has been found that the combined thickness of the ice lenses equals approximately the amount of frost heave, which can be appreciable.

Since the soil layer below the freezing zone is slightly warmer than the soil at the base of this zone, heat flows upward, and some melting from the bottom up takes place during warm spells and in the spring.

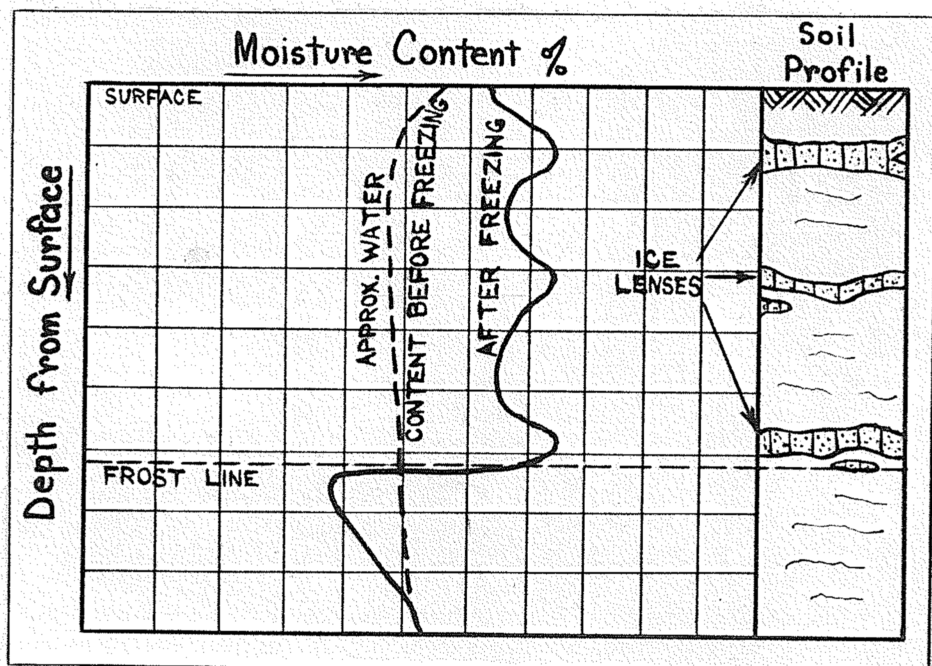


Figure 2
Change of water content in the soil due to freezing.

The Melting of Snow

When snow melts it deposits water on the ground surface and results in runoff in much the same manner as rainfall. Snow which remains on the ground for long periods gradually increases in density as the result of packing, alternate thawing and freezing, and the presence of melt water. For runoff to occur from snowmelt the snow must first "ripen", or gather free water.

Snow is melted by heat derived from the atmosphere, warm rainfall, radiation, and the soil. The rate of melting of the snow is a function of the number of degree-days of temperature above 32° F.

PROCEDURE

Soil samples were taken at selected sites in the Red and Assiniboine River drainage basins in the autumn seasons of 1953, 1954 and 1955 and in early March of 1956. In 1953 both undisturbed samples and moisture content samples were taken to a depth of $4\frac{1}{2}$ feet at twenty-two different locations. In 1954 moisture content samples only were taken to a depth of $3\frac{1}{2}$ feet, at the previous twenty-two locations plus seven new ones. Two field trips were made in 1955, one in September and one in November. The September soil samples indicate soil moisture conditions at the end of the summer, and the November samples, which were taken when there was some small amount of frost in the ground and some snow on the ground, show the soil moisture conditions at freeze-up.

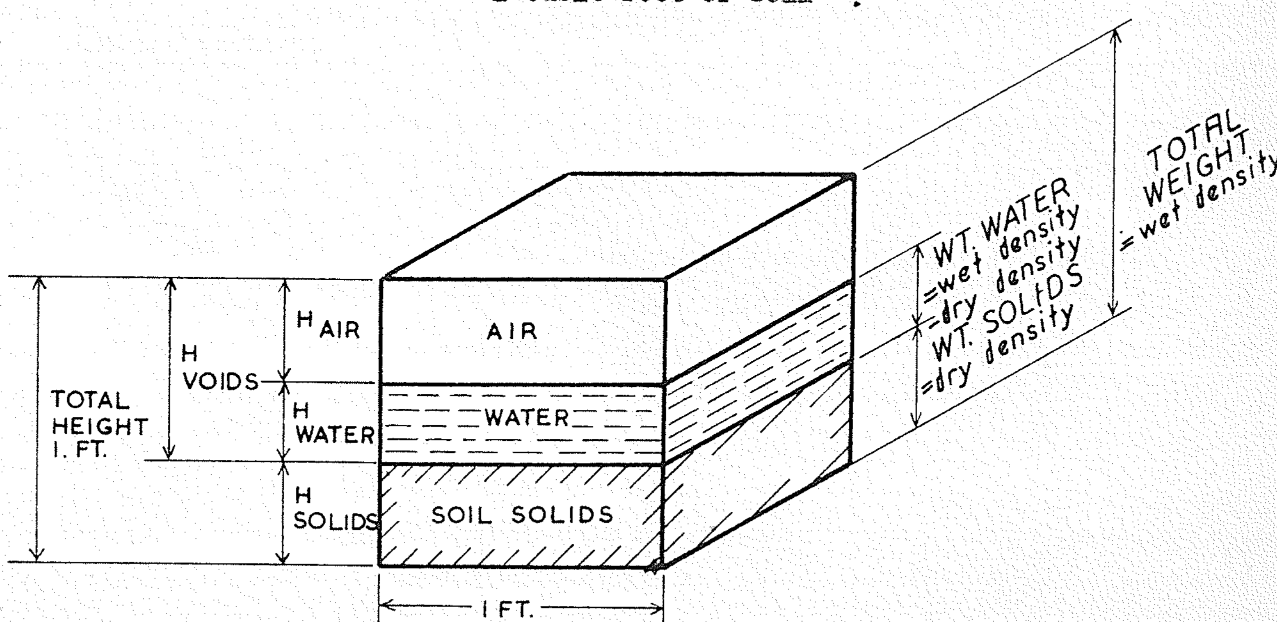
As a check on the hypothesis that soil moisture conditions remain practically unchanged from freeze-up to spring thaw, moisture content samples were taken at several of the previous sites throughout the area under study, at the beginning of March, 1956. In addition, the depth and the nature of the snow over the hole, the existence or non-existence of an ice lens between the bottom of the snow layer and the ground surface, and the depth of frost were noted. Since augering, even with a one-inch auger, was well-nigh impossible, these samples had to be taken by digging a small trench with an axe and a steel ice pick.

Undisturbed samples were obtained in approximately ten-inch lengths in hand-driven, three-inch diameter Shelby tubes. Moisture content samples were augered out and placed in small moisture content tins, which were then sealed with cellulose tape. All samples were brought to the University Soils Laboratory for testing.

Moisture contents of all samples were obtained in the standard fashion, and the wet and dry densities of the undisturbed samples were found. In addition to this, specific gravity tests in accordance with A.S.T.M. specifications were run on most of the September, 1955 samples. A few Atterberg limit tests were made on certain fine-grained soil samples and some hydrometer grain size tests were also carried out, following procedures set forth in the A.S.T.M. Standards.

Knowing the unit weight or density, the moisture content and the specific gravity of each sample, the relative heights in inches per foot of soil of soil solids, voids, water and air could then be easily calculated. A diagrammatic representation of this is shown:

1 cubic foot of soil



$$H_{solids} = \frac{\text{dry density}}{\text{S.G. x unit wt. of water}} \times 12 \text{ inches.}$$

$$H_{voids} = 12'' - H_{solids}$$

$$H_{water} = \frac{(\text{wet density} - \text{dry density})}{\text{unit weight of water}} \times 12 \text{ inches.}$$

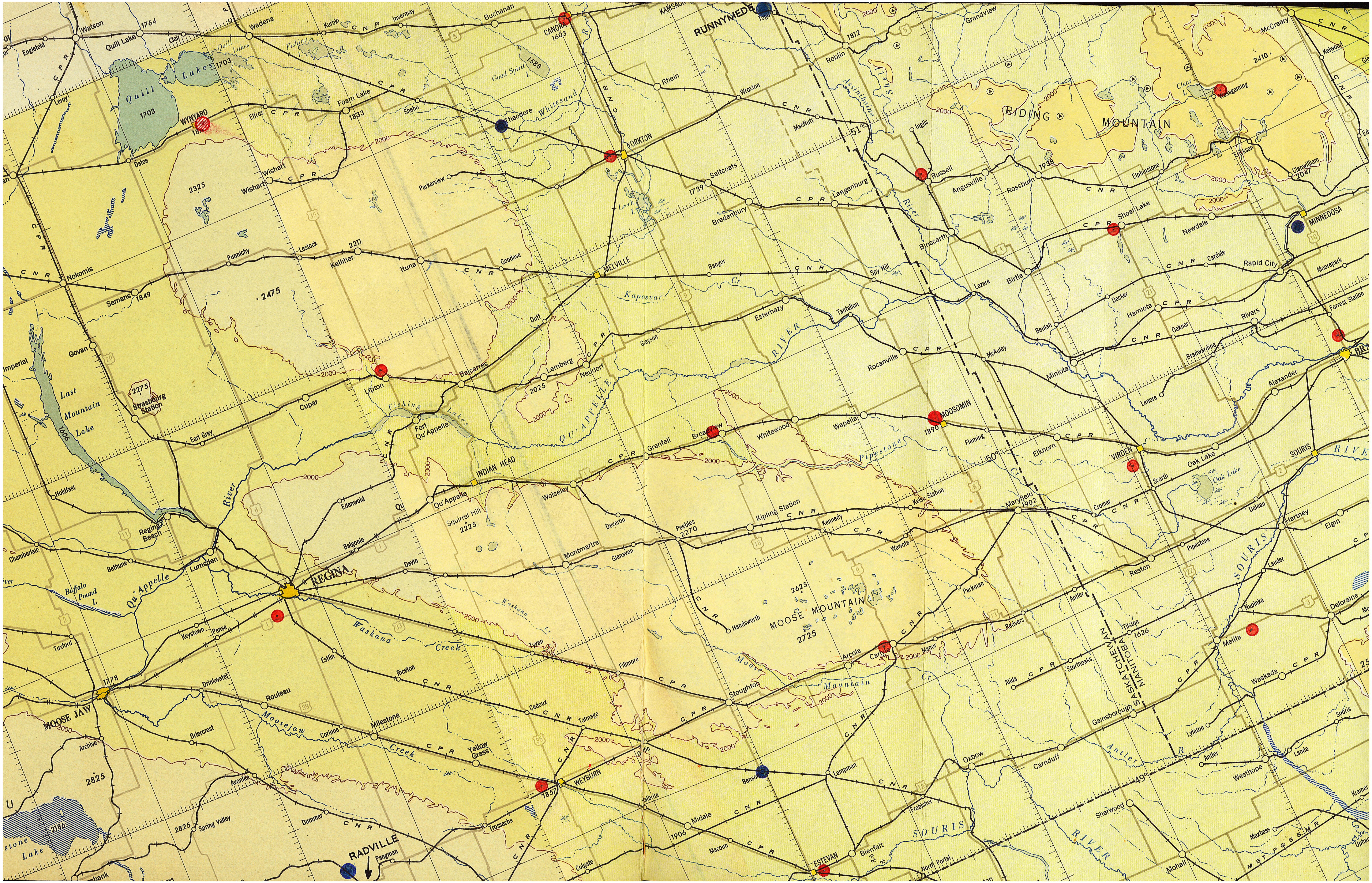
$$H_{air} = H_{voids} - H_{water}$$

$$\text{Degree of Saturation} = \frac{H_{water}}{H_{voids}} \times 100\ \%.$$

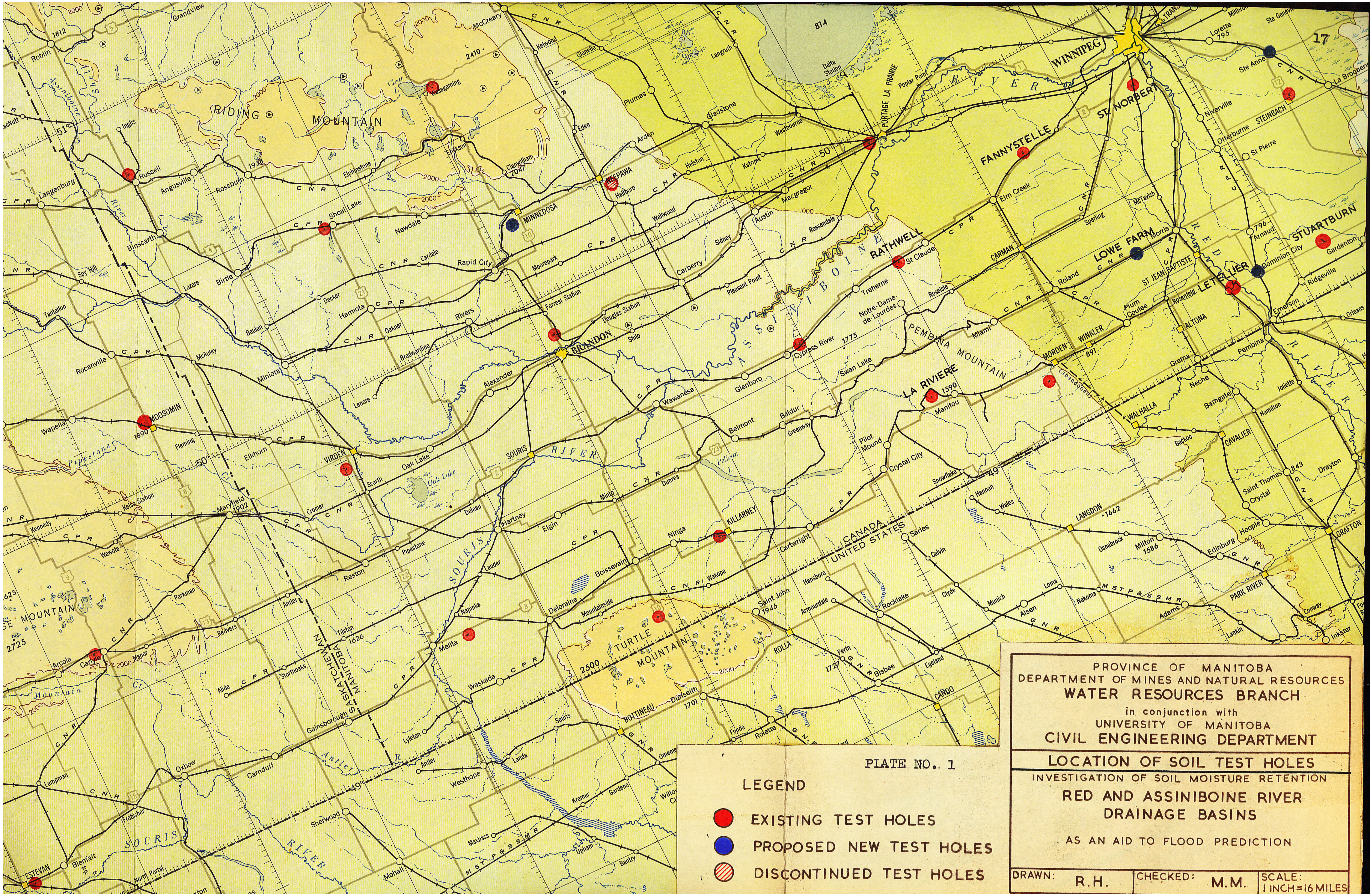
The soil test holes were grouped according to the drainage basins in which they are located, and their locations are listed in this order in the following section.

All of the significant data is presented on the following data sheets.

Using this data, complete analyses of the 1955 spring runoff from three small drainage basins for which complete hydrologic data was available were made, using the rational or infiltration method. Detailed explanations and the results of these analyses are presented in a following section.



Watson
Quill Lake
Wadena
Kuroki
Invermay
Buchanan
Canora
Kamsack
RUNNYMEDE
Roblin
Grandview
McCreary
Quill Lakes
Wynyard
Foam Lake
Elfros
Dafoe
Leroy
Sheho
Theodore
Whitesand
Good Spirit L.
YORKTON
Rhein
Wroxton
MacNutt
Inglis
RIDING MOUNTAIN
Russell
Angusville
Rossburn
Elphinstone
Erickson
Clanwilliam
Wishart
Punnichy
Lestock
Kelliher
Ituna
Goodeve
Parkerview
Saltcoats
Bredenbury
Langenburg
Binscarth
Shoal Lake
Newdale
MINNEDOSA
Nokomis
Semans
Govan
Imperial
MELVILLE
Bangor
Spy Hill
Lazare
Birtle
Cardale
Rapid City
Strasbourg Station
Last Mountain Lake
Earl Grey
Cupar
Lipton
Balcarres
Lemberg
Neudorf
Duff
Grayson
Esterhazy
Tantallon
Rocanville
McAuley
Miniota
Hamiota
Decker
Oakner
Rivers
Beulah
Bradwardine
Alexander
Fort Qu'Appelle
Fishing Lakes
QU'APPELLE
Broadview
Whitewood
Wapella
MOOSOMIN
Fleming
Elkhorn
VIRDEN
Oak Lake
SOURIS
INDIAN HEAD
Grenfell
Wolseley
Qu'Appelle
Squirrel Hill
Edenwold
Balgonie
Holdfast
Regina Beach
Chamberlain
Bethune
Lumsden
REGINA
Davin
Montmartre
Glenavon
Peebles
Kipling Station
Kennedy
Wawota
Maryfield
Kelso Station
Cromer
Reston
Pipestone
Hartney
Elgin
Buffalo Pound
Keystown
Pense
Waskana Creek
Handsworth
MOOSE MOUNTAIN
Carlyle
Arcola
Manor
Parkman
Redvers
Antler
SASKATCHEWAN
MANITOBA
Tilston
Melita
Napinka
Deloraine
Lauder
Tuxford
MOOSE JAW
Drinkwater
Estlin
Riceton
Tyvan
Fillmore
Stoughton
Alida
Storthoaks
Gainsborough
Waskada
Lyleton
Rouleau
Milestone
Yellow Grass
Cedoux
Talmage
Briercrest
Moosejaw Creek
Corinne
Archive
Avonlea
WEYBURN
Benson
Lampman
Oxbow
Carnduff
Antler
Sherwood
Landa
Dummer
Spring Valley
Trossachs
RADVILLE
Pangman
Midale
Macoun
Halbrite
ESTEVAN
Bienfait
Frobisher
North Portal
SOURIS RIVER
Colgate
Mohall
Maxbass
Westhope



PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH
in conjunction with
UNIVERSITY OF MANITOBA
CIVIL ENGINEERING DEPARTMENT
LOCATION OF SOIL TEST HOLES
INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER
DRAINAGE BASINS
AS AN AID TO FLOOD PREDICTION
DRAWN: R.H.
CHECKED: M.M.
SCALE: 1 INCH=16 MILES
PLATE NO. 1
LEGEND
EXISTING TEST HOLES
PROPOSED NEW TEST HOLES
DISCONTINUED TEST HOLES
RIDING MOUNTAIN
TURTLE MOUNTAIN
PEMBINA MOUNTAIN
WINNIPEG
BRANDON
PORTAGE LA PRAIRIE
ST NORBERT
FANNYSTELLE
RATHWELL
LA RIVIERE
LOWE FARM
LETELLIER
STUARTBURN
MINNEDOSA
RUSSELL
MOOSOMIN
KILLARNEY
CANADA
UNITED STATES
SASKATCHEWAN
MANITOBA

DATA

CLASSIFICATION OF SOIL TEST HOLES

All portions of the Red and Assiniboine River drainage basins under study consist of either grain farming areas or mixed grain farming and grazing areas, interspersed occasionally with uncleared and undeveloped plots of land. Nearly all of the test holes are right in cultivated fields or in pastures, since in each case this was considered to be representative of the general vicinity in which the test hole is located.

LOCATION	DRAINAGE BASIN	GENERAL TOPOGRAPHY
Steinbach	Seine River	Level to very gently sloping. Imperfect drainage.
Stuartburn	Roseau River	Flat to slightly undulating. Imperfect drainage.
Letellier	Red River	Generally level. Imperfect drainage.
Morden	Plum Creek and then to Red River	Generally flat. High water table.
Turtle Mountain	Just above the headwaters of the Pembina River	Hilly. Rough topography, and rolling slopes channelled with ravines.
Killarney	Pembina River	Gently rolling.
La Riviere	Pembina River	Broadly rolling.
Fannystelle	La Salle River	Flat. Imperfect drainage.
St. Norbert	La Salle River (and Red River)	Well drained.

LOCATION	DRAINAGE BASIN	GENERAL TOPOGRAPHY
Wynyard	Quill Lakes. Is in a dead storage area	Very gently rolling.
Neepawa	Drains to Lake Manitoba	Undulating region of underlying sands and gravels. Low organic matter.
Regina	Waskana Creek and then to Qu'Appelle River	Gently to moderately undulating. Clay region.
Lipton	Qu'Appelle River	Very gently rolling.
Broadview	Qu'Appelle River	Very gently rolling.
Weyburn	Headwaters of Souris River	Gently to moderately undulating.
Estevan	Souris River	Gently to moderately undulating.
Carlyle	Moose Mountain Creek and then to Souris River	Gently to moderately undulating.
Melita	Souris River	Strongly undulating. Region is sandy and gravelly. Much bush.
Cànora	Headwaters of Assiniboine River	Gently to moderately undulating.
Yorkton	Whitesand River and then to Assiniboine River	Gently to moderately undulating.
Russell	Assiniboine River	Undulating. Occasional sloughs.
Moosomin	Assiniboine River	Gently to moderately undulating.
Virden	Bosshill and Gopher Creeks and then to Assiniboine River	Slightly undulating.

LOCATION	DRAINAGE BASIN	GENERAL TOPOGRAPHY
Shoal Lake	Above headwaters of Oak River, which flows into the Assiniboine River	Undulating. Occasional sloughs
Wasagaming	Clear Lake to Minnedosa River and then to Assiniboine River	Smooth to hilly. Water erosion acute.
Brandon	Assiniboine River	Smooth to rolling.
Cypress River	Assiniboine River	Smooth to rolling.
Rathwell	Assiniboine River	Smooth to flat, but drainage good to fair.
Portage la Prairie	Assiniboine River	Smooth and gently undulating, but excellent drainage.

The descriptions of topography in the above table represent average slopes of the land as follows:

Topography	Slope %
Level to depressional	0 - 1
Gently undulating to	1 - 2.5
Moderately undulating	2.5 - 6
Strongly undulating to	6 +
Very gently rolling	2 - 6
Gently rolling to	4 - 8
Moderately rolling	8 - 15
Strongly rolling	15 +
Hilly	25 +

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
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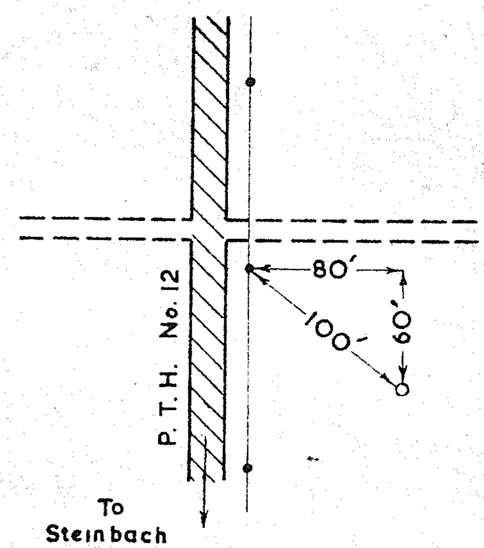
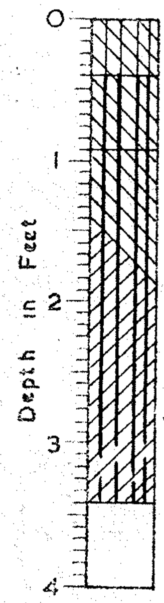
LOCATION: STEINBACH HOLE No. R-12

LOCATION SKETCH



0.1 mile north of Steinbach on
Hyw. No.12 to Winnipeg.

TEST HOLE LOG



Black organic clayey silt
S.G. = 2.61
Dark brown organic clayey silt.

S.G. = 2.70
Light brown nugget structure clayey silt changing to grey clayey silt.

Some pockets of yellow silt
S.G. = 2.72

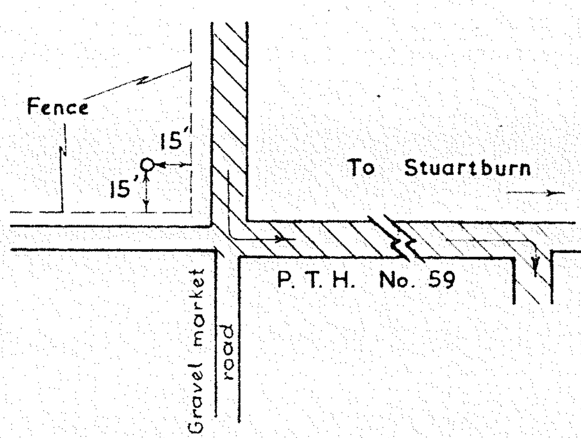
Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" -11"	26.0	6.80	5.20	4.27	0.93	82.2%	
		18	7.8	-	-	-	-	-	
		24 -34	19.2	6.01	5.99	3.06	2.93	51.1	
		42	36.9	-	-	-	-	-	
		48 -56	33.1	5.74	6.26	5.03	1.23	81.1	
1954	Nov.	0	43.0	-	-	-	-	-	
		12	32.0	-	-	-	-	100	Approx. value
		18	32.1	-	-	-	-	-	
		42	34.6	-	-	-	-	-	
1955	Sept.	0 -9	14.6	5.57	6.43	2.12	4.31	33.0	Discrepancy in
		9 -20	10.5	6.11	5.89	1.73	4.16	29.4	height of solids
		20-30	9.1	6.96	5.04	1.73	3.31	34.4	at 30" depth is
		30-39	23.8	6.41	5.59	4.12	1.47	73.6	due to the two
1955	Nov.	6	33.4	5.57	6.43	4.85	1.58	75.5	samples at this
		12	31.1	6.11	5.89	5.37	0.52	91.1	depth not being
		18	33.9	-	-	-	-	-	the same.
		30	38.6	5.47	6.53	6.53	0.00	100.0	
1956	March	6	33.5	5.57	6.43	4.86	1.57	75.7	Moisture
		12	33.8	6.11	5.89	5.47	0.42	93.0	Unchanged
		18	32.4						Depth of frost
		26	34.5	5.47	6.53	5.84	0.69	89.4	= 23 inches

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

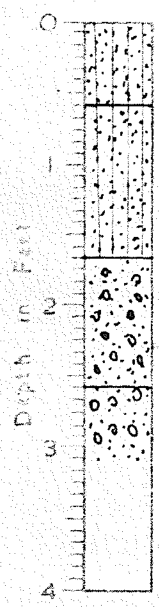
LOCATION: STUARTBURN HOLE No. R - 8

LOCATION SKETCH



Jct. Hwy. No. 59 & road to Stuartburn.

TEST HOLE LOG



Black organic silty sand
S.G. = 2.59

Dark sand, small amount of silt.
S.G. = 2.60

Light brown sand and pebble size gravel
Small amount of silt
S.G. = 2.65

Gravel 6" - 1" size and sand

Note: Many large boulders in area.

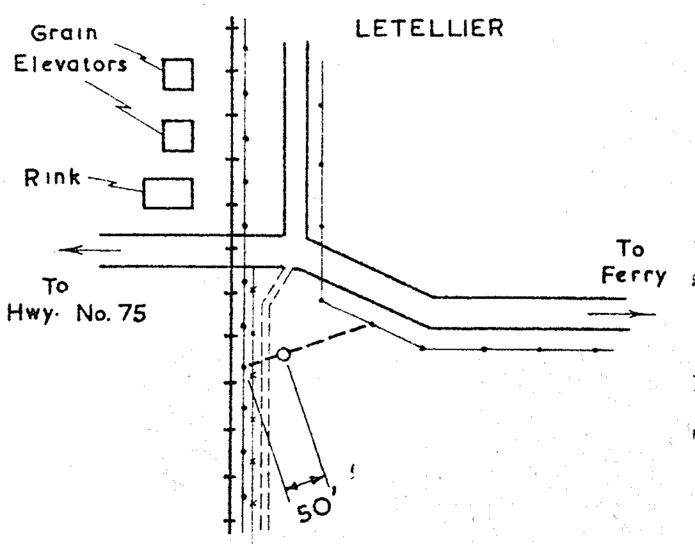
Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0"-11"	13.5	8.10	3.90	2.90	1.00	74.4%	
		13	8.6	-	-	-	-	-	
1954	Nov.	0	27.3	-	-	-	-	-	
		12	10.4	-	-	-	-	57	Approximate value
		18	9.6	-	-	-	-	-	
		42	6.7	-	-	-	-	-	
1955	Sept.	0 -10	11.2	5.83	6.17	1.69	4.48	27.4	
		10-22	6.9	6.85	5.15	1.23	3.92	23.8	
		22-31	2.8	7.30	4.70	0.53	4.17	11.3	
1955	Nov.	6	34.4	5.83	6.17	5.20	0.97	84.3	
		12	35.5	6.85	5.15	5.06	0.09	98.3	
		18	21.3	-	-	-	-	-	
		30	14.7	7.30	4.70	2.85	1.85	60.7	

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

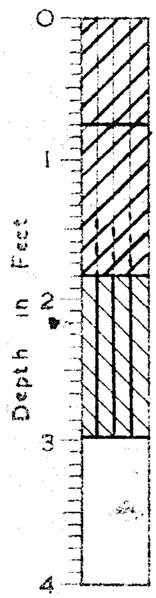
LOCATION: LETELLIER HOLE No. R — 9

LOCATION SKETCH



1.8 mile west of Red River on east-west road to Dominion City.

TEST HOLE LOG



Black organic silty clay some roots S.G. = 2.58

Grey organic silty clay S.G. = 2.70
Yellow silt pockets @ 18"

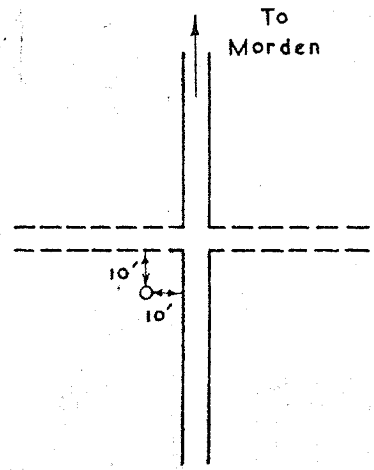
Light brown changing to yellow clayey silt.
S.G. = 2.72

Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" -12"	29.0	4.89	7.11	3.74	3.37	52.5%	
		18	27.7	-	-	-	-	-	
		25 -35	28.6	4.55	6.45	4.21	2.24	65.4	
		42	30.8	-	-	-	-	-	
		44 -52	29.6	5.30	6.70	4.16	2.54	62.1	
1954	Nov.	0	42.5	-	-	-	-	-	
		12	29.1	-	-	-	-	77	Approx. value
		18	24.6	-	-	-	-	-	
		42	24.7	-	-	-	-	-	
1955	Sept.	0 -10	18.8	6.17	5.83	2.99	2.84	51.4	
		10-22	29.6	6.29	5.71	4.98	0.73	87.3	
		22-32	19.7	7.35	4.65	3.94	0.71	84.6	
1955	Nov.	6	29.6	6.17	5.83	4.71	1.12	80.9	
		12	29.9	6.29	5.71	4.94	0.77	86.5	
		18	28.4	-	-	-	-	-	
		30	24.9	7.02	4.98	4.98	0.00	100.0	
1956	March	7	32.2	6.17	5.83	5.13	0.70	88.0	Same total
		12	33.2	6.29	5.71	5.21	0.50	91.2	moisture in soil
		18	28.3						Depth of frost
		28	21.7	7.02	4.98	4.34	0.64	87.2	= 25 inches

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

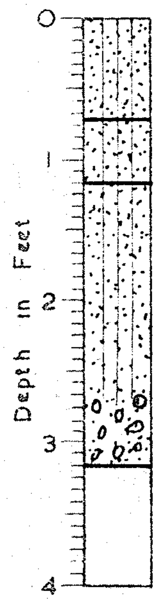
LOCATION: MORDEN HOLE No. R — 7

LOCATION SKETCH



4 mile south and 1 mile west of Morden on North-Star road.

TEST HOLE LOG



Black organic silty sand S.G. = 2.59

Dark organic sand, some silt S.G. = 2.60

Light brown sand slightly silty. S.G. = 2.60

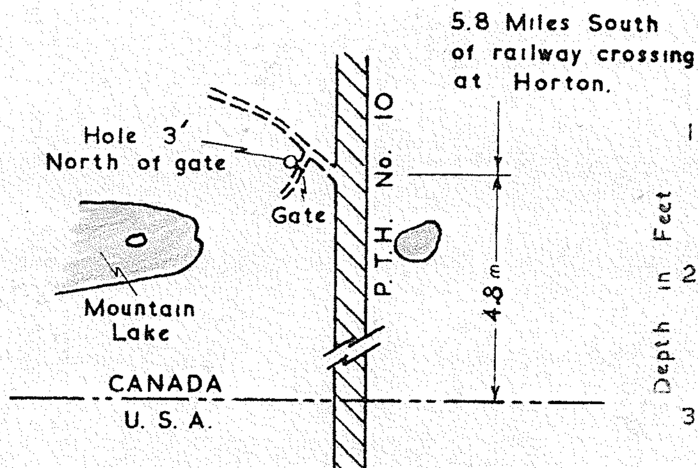
Sand, some stones. S.G. -- 2.605

Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" -12"	54.4	5.08	6.92	6.33	0.58	91.5%	
		18	19.9	-	-	-	-	-	
		24 - 36	21.6	7.19	4.81	4.12	0.09	85.5	
		42	14.9	-	-	-	-	-	
1954	Nov.	0	115.0	-	-	-	-	-	
		12	57.4	-	-	-	-	97	Approx. value
		18	45.6	-	-	-	-	-	
		42	21.6	-	-	-	-	-	
1955	Sept.	0 -10½	7.5	5.97	6.03	1.16	4.87	19.2	
		10½-22	4.9	6.08	5.92	0.72	5.20	13.1	
		22 -31	5.0	6.05	5.95	0.79	5.16	13.2	
		31 -37	5.2	6.64	5.36	0.90	4.46	16.8	
1955	Nov.	6	93.2	5.30	6.70	6.70	0.00	100% + free water	
		12	42.8	6.08	5.92	5.58	0.34	94.2	
		18	27.7	-	-	-	-	-	
		30	17.3	6.35	5.65	2.86	2.79	50.7	
1956	March	7	103.6	-	-	-	0.00	100% + free water	
		12	50.7	-	-	-	0.00	100.0	Increased
		18	38.8						Considerably
		30	28.2	6.35	5.65	4.66	0.99	82.5	Only 6" of frost

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

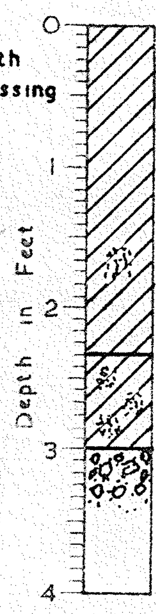
LOCATION: TURTLE MOUNTAIN — HOLE No. R — 3

LOCATION SKETCH



5.8 mile south on No.10 of Railway crossing of Horton.

TEST HOLE LOG



Dark nugget-structure clay
S.G. = 2.65

Pocket of course sand @ 20"
S.G. = 2.68

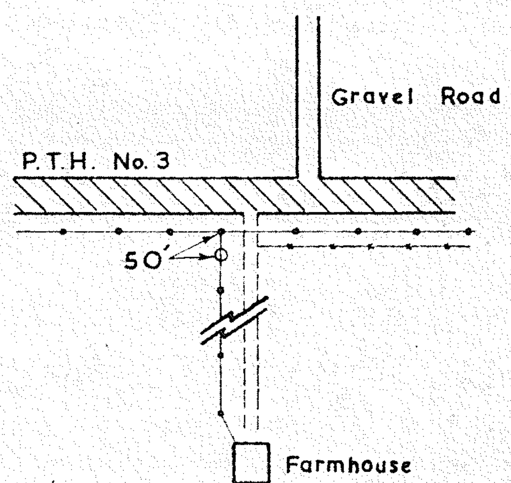
Dark stratified clay with pockets of course sand
Gravel starts @ 36"

Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil: Solids	Voids	Water	Air	Degree of Saturation	Comments
1954	Nov.	0"	40.5	-	-	-	-	-	
		12	26.8	-	-	-	-	-	
		18	12.9	-	-	-	-	-	
		42	20.4	-	-	-	-	-	
1955	Sept.	0-9½	11.2	5.67	6.33	1.69	4.64	26.7%	No November
		9½-20	7.8	6.98	5.02	1.42	3.60	28.4	moisture contents
		20 -31	8.2	7.39	4.61	1.67	2.94	36.3	taken.
									Very little run-
									off expected from
									this area. Many
									sloughs and lakes.

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

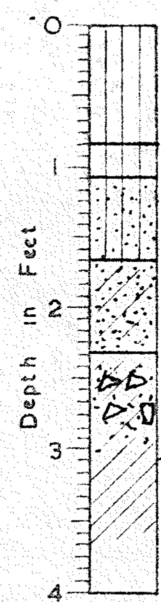
LOCATION: KILLARNEY HOLE No. R – 4

LOCATION SKETCH



3.75 miles west of Killarney Bridge
on P.T.H. No. 3.

TEST HOLE LOG



Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" -11"	32.2	6.30	5.70	5.09	0.61	89.3%	
		18	9.7	-	-	-	-	-	
		24 -35	6.5	-	-	-	-	-	sample damaged
		42	13.2	-	-	-	-	-	
		44 -55	15.6	7.78	4.22	3.21	1.01	76.4	
1954	Nov.	0	33.0	-	-	-	-	-	
		12	22.8	-	-	-	-	-	
		18	17.0	-	-	-	-	-	
		42	8.8	-	-	-	-	-	
1955	Sept.	0 -10	14.6	6.84	5.16	2.58	2.58	50.0	First sample compressed during sampling.
		10 -20	13.1	6.60	5.40	2.31	3.09	42.8	
		20 -28	15.3	Not Available					
		28 -37	15.4	7.64	4.36	3.16	1.20	72.3	
1955	Nov.	6	24.0	6.84	5.16	4.23	0.93	82.0	
		12	19.1	6.60	5.40	3.55	1.85	65.8	
		18	21.0	-	-	-	-	-	
		30	21.2	7.64	4.36	4.30	0.06	98.6	

MNR-wp-52

Sheet ___ of ___

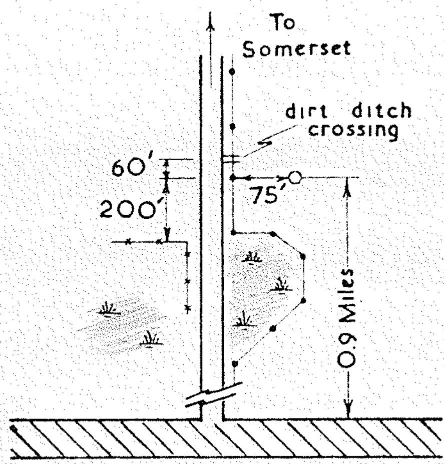
INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES

WATER RESOURCES BRANCH

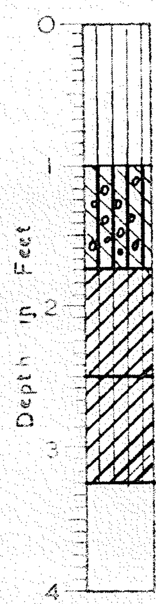
LOCATION: LA RIVIERE   HOLE No. R – 6

LOCATION SKETCH



2.3 mile east of La Riviere on Hwy.No. 3 and 0.9 mile north on Somerset road.

TEST HOLE LOG



Black organic silt
S.G. = 2.53

Grey-brown clayey silt slightly sandy, some small stones S.G. = 2.56

Silty clay
S.G. = 2.68

Grey silty clay containing small fragments of shale S.G. = 2.68

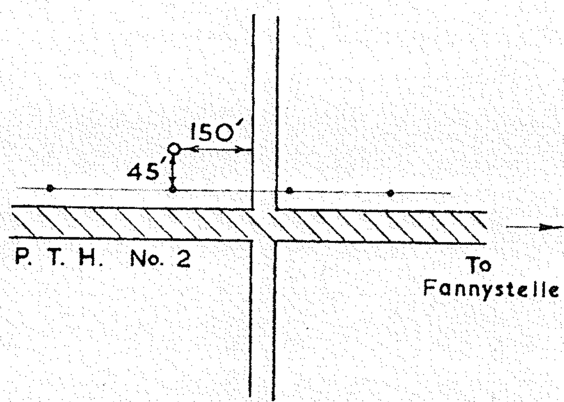
Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" -11"	9.2	6.83	5.17	5.10	0.07	98.6 %	
		18	20.2	-	-	-	-		
		24 -35	26.1	5.98	6.02	4.21	1.81	69.9	
		42	32.4	-	-	-	-	-	
1954	Nov.	0	42.0	-	-	-	-	-	
		12	43.3	-	-	-	-	-	
		18	36.3	-	-	-	-	-	
		42	32.0	-	-	-	-	-	
1955	Sept.	0 -11	24.1	5.58	6.42	3.40	3.02	53.0	
		11 -21	23.2	6.64	5.36	3.93	1.43	73.3	
		21 -28	23.9	6.40	5.60	4.05	1.55	72.3	
		28 -35	32.2	6.46	5.54	5.30	0.24	95.7	
1955	Nov.	6	34.4	5.58	6.42	4.85	1.57	75.6	
		12	29.4	6.64	5.36	4.58	0.78	85.4	
		18	24.6	-	-	-	-	-	
		30	23.2	6.46	5.54	3.78	1.76	68.2	

MNR-wp-52

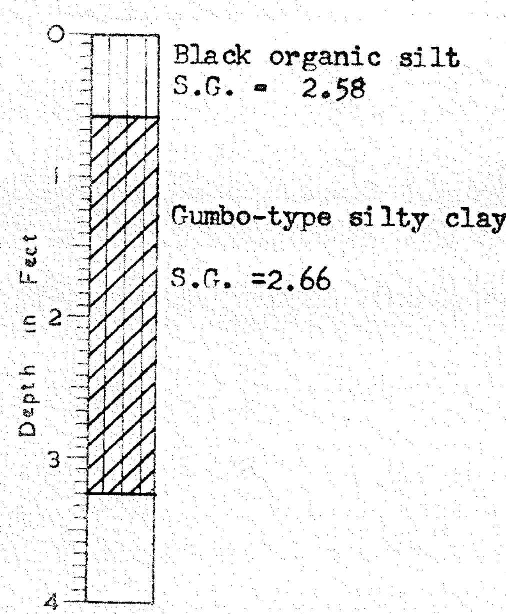
INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

LOCATION: FANNYSTELLE HOLE No. R – 1

LOCATION SKETCH



TEST HOLE LOG



1 mile west of Fannystelle on new P.T.H. # 2
First crossroad west.

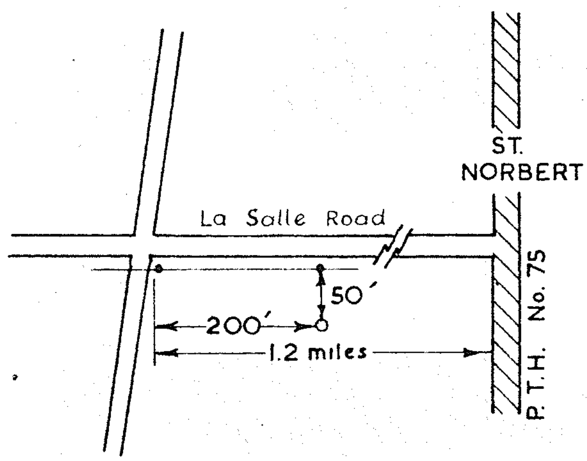
Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil: Solids	Voids	Water	Air	Degree of Saturation	Comments
1953	Fall	0" -11"	42.0	5.63	6.37	5.95	0.42	93.5 %	
		16	36.1	-	-	-	-	-	
		30 -41	30.1	6.23	5.77	5.09	0.68	88.5	
		42	32.9	-	-	-	-	-	
		48 -58	29.5	6.40	5.60	5.11	0.49	91.3	
1954	Nov.	0	49.6	-	-	-	-	-	
		12	39.7	-	-	-	-	88	Approx. value
		18	35.3	-	-	-	-	-	
		42	34.9	-	-	-	-	-	
1955	Sept.	0" -11"	30.9	5.70	6.30	4.55	1.75	72.2	
		11 - 21	31.0	5.85	6.15	4.82	1.33	78.5	
		23 -31	28.1	5.60	6.40	4.21	2.19	65.8	
		31 -38	27.2	5.99	6.01	4.35	1.66	72.3	
1955	Nov.	6	48.0	5.70	6.30	7.06	0.00	100%	≠free moisture
		14	39.2	5.85	6.15	6.04	0.11	98.2	
		18	38.4	-	-	-	-	-	
		30	31.4	5.80	6.20	4.85	1.35	78.2	

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

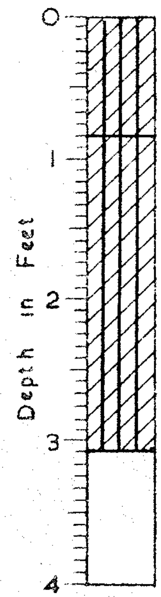
LOCATION: ST. NORBERT HOLE No. R – 10

LOCATION SKETCH



1.2 mile west of St. Norbert
junction of road to Dam

TEST HOLE LOG



Black organic coarse grained clayey silt. Some roots
S.G. = 2.52

Grey clayey silt
S.G. = 2.53

Grey lumpy clayey silt
S.G. = 2.62

Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" - 12"	21.8	7.19	4.81	4.06	0.75	84.5%	
		19	19.9	-	-	-	-	-	
		24 -36	20.4	7.10	4.90	3.94	0.96	80.5	
		42	26.6	-	-	-	-	-	
1954	Nov.	0	54.1	-	-	-	-	-	
		12	32.7	-	-	-	-	-	
		18	30.2	-	-	-	-	-	
		42	26.9	-	-	-	-	-	
1955	Sept.	0 -10½	20.5	6.83	5.17	3.53	1.64	68.3	Discrepancies
		11½-23½	17.9	6.69	5.31	3.02	2.29	56.9	in height of
		25-36	17.7	7.18	4.82	3.33	1.49	69.0	solids at 1'-2'
									depth is due to
1955	Nov.	6	29.5	6.83	5.17	5.08	0.09	98.2	the Sept. & Nov.
		12	36.3	6.49	5.51	5.51	0.00	100.0	soil samples dif-
		18	29.0	-	-	-	-	-	fering slightly
		30	25.2	7.18	4.82	4.74	0.08	98.3	(different S.G)
1956	March	6	18.3	6.83	5.17	3.15	2.02	61.0	Moisture
		12	20.5	6.49	5.51	3.40	2.11	61.5	decreased
		18	20.8						Depth of frost
		31	23.6	7.18	4.82	4.44	0.38	92.1	= 28 inches

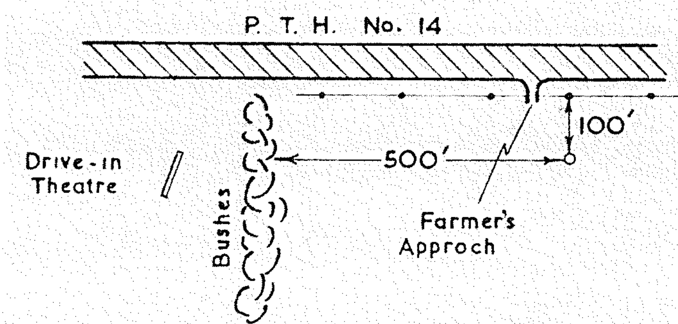
INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES

WATER RESOURCES BRANCH

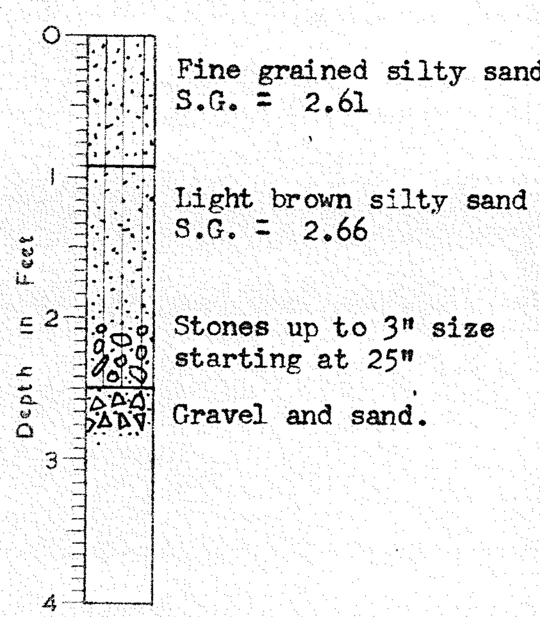
LOCATION: WYNYARD HOLE No. A – 8

LOCATION SKETCH



1.8 mile east of Wynyard Turnoff.

TEST HOLE LOG



Yr.	Date	Depth	% Moisture	Height in inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" -11"	29.4	5.73	6.27	4.38	1.87	70.0%	
		18	16.3	-	-	-	-	-	
		24 -35	18.5	7.48	4.52	3.70	0.82	82.0	
		42	13.0	-	-	-	-	-	
1954	Nov.	0	26.9	6.25	5.75	3.54	2.21	61.6	
		12	16.6	-	-	-	-	77	Approx. value
		18	9.5	7.36	4.64	1.86	2.78	40.2	
		42	10.5	-	-	-	-	-	
1955	Sept.	0 -11	7.3	6.25	5.75	1.19	4.56	20.7	Sampling tubes could not penetrate deeper than 25".
		14 -25	3.9	7.36	4.64	0.76	3.88	16.4	
1955	Nov.	6	12.2	6.25	5.75	1.99	3.76	34.6	
		12	8.9	-	-	-	-	-	
		18	11.2	7.36	4.64	2.19	2.45	47.2	
		30	11.6	-	-	-	-	-	

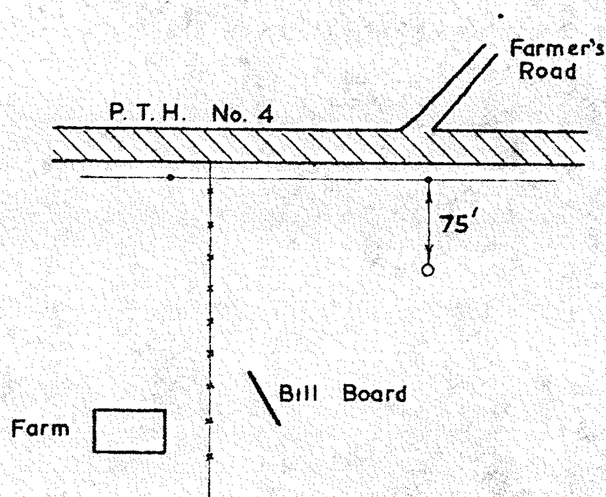
INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES

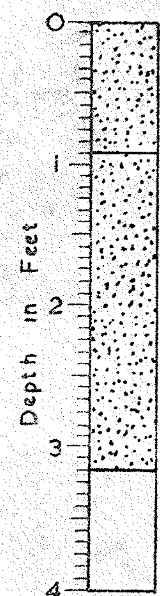
WATER RESOURCES BRANCH

LOCATION: NEEPAWA HOLE No. W – 6

LOCATION SKETCH



TEST HOLE LOG



Dark brown organic sand S.G. = 2.62

Pure fine sand S.G. = 2.65

Fine, light-coloured sand. S.G. = 2.65

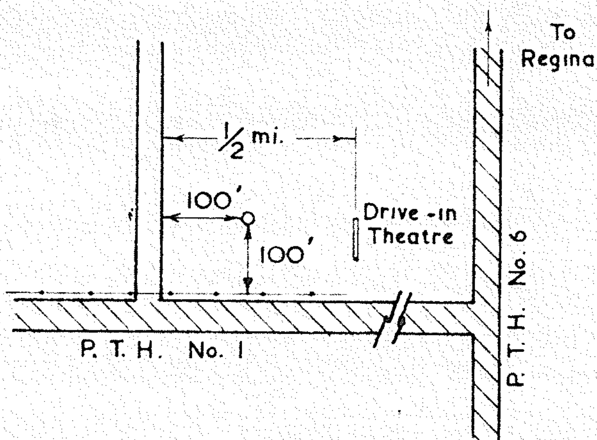
1.2 mile east of Neepawa
measured from second concrete
Bridge east of town, crossing the Whitemud R.

Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" -11"	8.8	6.96	5.04	1.62	3.42	32.1%	
		18	2.6	-	-	-	-	-	
		24 -35	2.3	7.25	4.75	0.44	4.31	9.3	
		42	3.3	-	-	-	-	-	
		47 -58	1.7	-	-	-	-	-	Sample damaged
1954	Nov.	0	12.4	-	-	-	-	-	
		12	9.4	-	-	-	-	37	Approx. value
		18	7.8	-	-	-	-	-	
		42	3.8	-	-	-	-	-	
1955	Sept.	0 -11	6.0	6.63	5.37	1.04	4.33	19.4	
		13 -24	4.9	7.21	4.79	0.94	3.85	19.6	
		26 -37	4.2	7.43	4.57	0.83	3.74	18.1	
1955	Nov.	6	10.5	6.63	5.37	1.82	3.55	33.9	
		12	10.0	-	-	-	-	-	
		18	7.9	7.21	4.79	1.51	3.28	31.5	
		30	11.6	7.43	4.57	2.28	2.29	49.9	

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

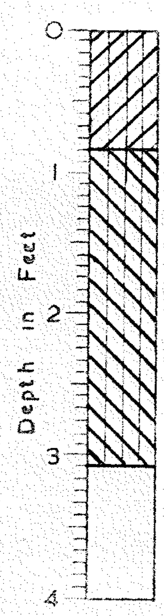
LOCATION: REGINA HOLE No. A – 4

LOCATION SKETCH



2.1. mile west of south jct.
Hyw. No.6. and Hyw. No.1

TEST HOLE LOG



Grey-black hugget-structure silty clay
S.G. = 2.61

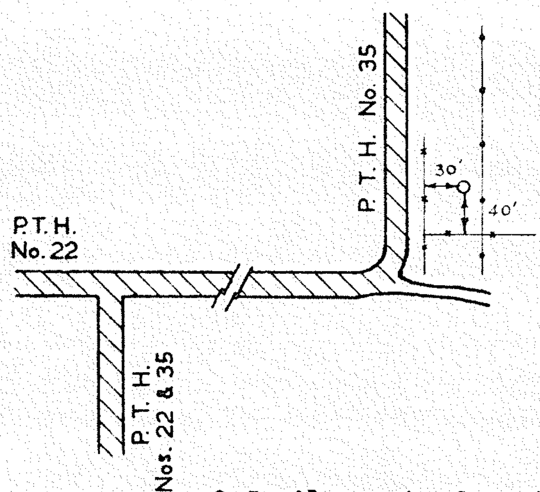
Gumbo-type brown silty clay
S.G. = 2.71

Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil: Solids	Voids	Water	Air	Degree of Saturation	Comments
1953	Fall	0" -11"	27.7	6.61	5.41	5.00	0.41	92.4%	
		18	28.1	-	-	-	-	-	
		24 -30	25.7	6.73	5.27	4.68	0.59	89.0	
		42	29.5	-	-	-	-	-	
		45 -50	29.7	6.37	5.63	4.99	0.64	88.6	
1954	Nov.	0	45.6	-	-	-	0.00	100.	
		12	37.6	-	-	-	-	-	
		18	36.0	6.04	5.96	5.87	0.09	98.5	
		42	32.6	-	-	-	-	-	
1955	Sept.	0 -11	31.4	6.05	5.95	4.95	1.00	83.2	
		12 -23	32.2	6.04	5.96	5.25	0.71	88.1	
		25 -35	27.8	6.35	5.65	4.80	0.85	85.0	
1955	Nov.	6	37.7	6.05	5.95	5.95	0.00	100.0	
		12	34.3	6.04	5.96	5.46	0.50	91.6	
		18	32.7	-	-	-	-	-	
		30	29.8	6.35	5.65	5.14	0.51	91.0	

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

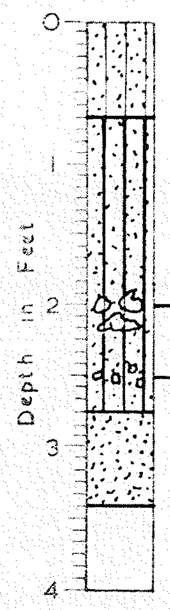
LOCATION: LIPTON HOLE No. Nº – 9

LOCATION SKETCH



0.5 mile east of north jct. on Hyw. No.22 and Hyw. No.35.

TEST HOLE LOG



Black organic sandy silt S.G. = 2.60

Brown sandy silt S.G. = 2.65

Pockets of sand @ 24"

Pebbles up to ¼" size @ 30"

Very fine light brown sand S.G. = 2.65

Note: Fairly rough topography, much bush..

Yr.	Date	Depth	% Moisture	Height in inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1954	Nov.	0"	26.2	-	-	-	-	-	
		12	23.6	-	-	-	-	-	
		18	27.5	-	-	-	-	-	
		42	17.6	-	-	-	-	-	
1955	Sept.	0" -10½"	32.0	6.46	5.54	5.37	0.17	97.0 %	
		13 -26	14.8	7.30	4.70	2.86	1.84	60.9	
		26 -37½	16.3	7.32	4.68	3.16	1.52	67.5	
1955	Nov.	6	11.2	6.46	5.54	1.88	3.66	34.0	
		12	10.9	-	-	-	-	-	
		18	15.9	7.30	4.70	3.07	1.63	65.4	
		30	18.9	7.32	4.68	3.66	1.02	78.2	

WR-wp-52

Sheet ___ of ___

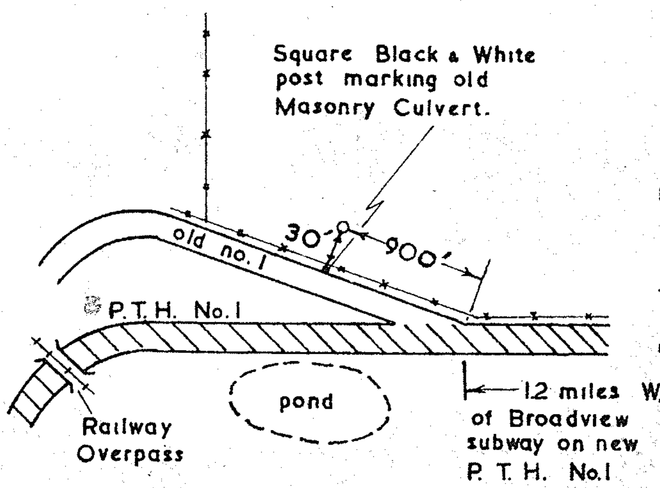
INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES

WATER RESOURCES BRANCH

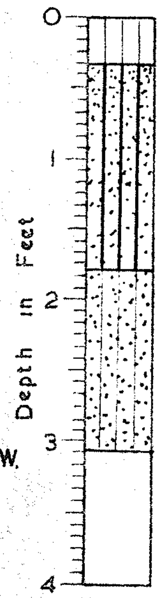
LOCATION: BROADVIEW HOLE No. A - 2

LOCATION SKETCH



1.2 mile west of Broadview subway on new No.1. Highway.

TEST HOLE LOG



Black organic silt
S.G. = 2.60

Brown sandy silt and yellow silt

S.G. = 2.65

Sand, some yellow silt.
S.G. = 2.65

Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" -11"	24.6	4.31	7.69	2.86	4.83	59.2%	
		18	9.3	-	-	-	-	-	
		24 -35	11.9	6.42	5.58	2.06	3.52	59.6	
		42	19.7	-	-	-	-	-	
		44 -55	14.6	5.76	6.24	2.26	3.98	56.8	
1954	Nov.	0	43.0	-	-	-	-	-	
		12	22.8	-	-	-	-	84	Approx. value
		18	13.6	-	-	-	-	-	
		42	26.0	-	-	-	-	-	
1955	Sept.	0 -11	24.4	6.56	5.44	4.16	1.28	76.5	
		12 -23	18.9	7.48	4.52	3.74	0.78	82.7	
		25 -36	15.1	7.48	4.52	2.99	1.53	66.1	
1955	Nov.	6	27.2	6.56	5.44	4.64	0.80	85.3	
		12	22.4	7.48	4.52	3.86	0.66	85.3	
		18	16.6	-	-	-	-	-	
		30	22.6	7.48	4.52	4.48	0.04	99.0	
1956	March	7	36.9	-	-	-	0.00	100.0	Depth of frost
		12	19.8	7.48	4.52	3.92	0.60	86.7	= 26 inches
		19	35.4	(Probably in error)					No ice adjacent
		27	22.0	7.48	4.52	4.35	0.17	96.4	to ground surface

WR-wp-52

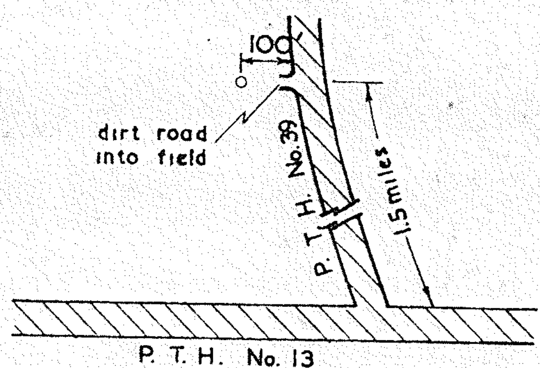
Sheet __ of __

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES

WATER RESOURCES BRANCH

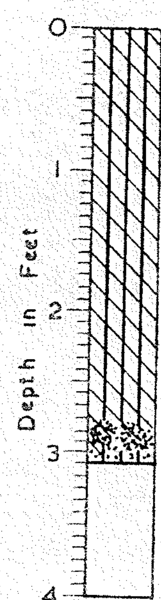
LOCATION: WEYBURN HOLE No. 7

LOCATION SKETCH



1.5 mile N.W. of jct. of P.T.H. No. 13 & No.39 100' S.W. of No. 39 road's edge.

TEST HOLE LOG



Light brown clayey silt.
S.G. = 2.56
changing to brown clayey silt

S.G. = 2.66
Pocket of white sand @ 36"

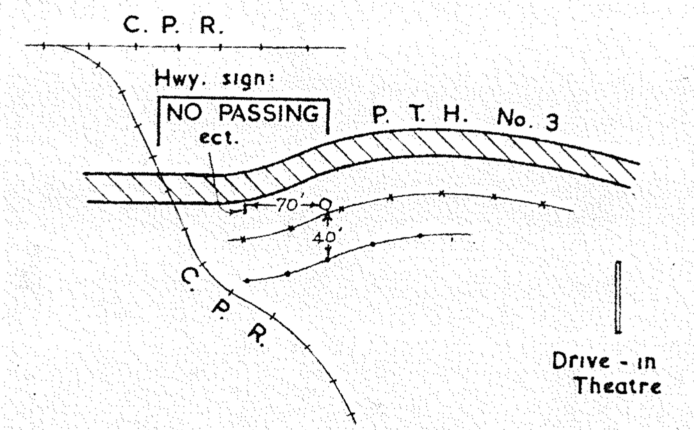
Yr.	Date	Depth	% Moisture	Height in inches per Foot of Soil: Solids	Voids	Water	Air	Degree of Saturation	Comments
1953	Fall	0"-11"	29.9	6.40	5.60	5.12	0.48	91.5%	
		18	29.1	-	-	-	-	-	
		24 -35	24.5	6.90	5.10	4.52	0.58	88.5	
		42	14.8	-	-	-	-	-	
		45 -55	14.9	8.28	3.72	3.29	0.43	88.5	
1954	Nov.	0	26.5	6.33	5.67	4.28	1.39	75.5	
		12	29.4	-	-	-	-	81	Approximate value
		18	23.9	6.84	5.16	4.34	0.82	84.0	
		42	21.7	-	-	-	-	-	
1955	Sept.	0-11	18.8	6.33	5.67	3.04	2.63	53.6	
		13-24	19.4	6.84	5.16	3.52	1.64	68.1	
		25-36½	20.6	7.04	4.96	3.86	1.10	77.8	
1955	Nov.	6	21.5	6.33	5.67	3.48	2.19	61.4	
		12	20.2	-	-	-	-	-	
		18	18.5	6.84	5.16	3.36	1.80	65.0	
		30	26.2	7.04	4.96	4.90	0.06	98.8	

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES

WATER RESOURCES BRANCH

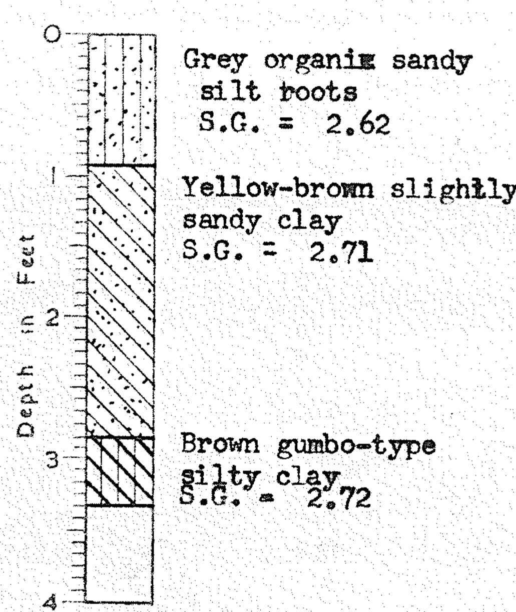
LOCATION: **ESTEVAN** HOLE No. 6

LOCATION SKETCH



1.2 mile east Estevan 800' south east of 1st railway crossing.

TEST HOLE LOG



Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" - 11"	12.7	7.85	4.15	2.50	1.65	60.3.%	Sample damaged
		18	13.6	-	-	-	-	-	
		24 -35	15.3	8.21	3.79	3.34	0.45	88.1	
		42	15.4	-	-	-	-	-	
		47 -58	14.8	8.37	3.63	3.27	0.36	90.3	
1954	Nov.	0	50.0	6.28	5.72	5.70	0.02	99.7	
		12	19.3	-	-	-	-	93	Approx. value
		18	14.5	7.61	4.39	3.06	1.33	69.6	
		42	21.7	-	-	-	-	-	
1955	Sept.	0 -11½	7.6	6.28	5.72	1.25	4.47	21.8	
		12½-25	16.5	7.61	4.39	3.45	0.94	78.6	
		25 -37	14.1	8.16	3.84	3.12	0.72	81.3	
1955	Nov.	6	18.8	6.28	5.72	3.09	2.63	54.0	
		12	17.2	-	-	-	-	-	
		18	14.8	7.61	4.39	3.34	1.05	76.1	
		30	14.6	8.16	3.84	3.24	0.60	84.4	

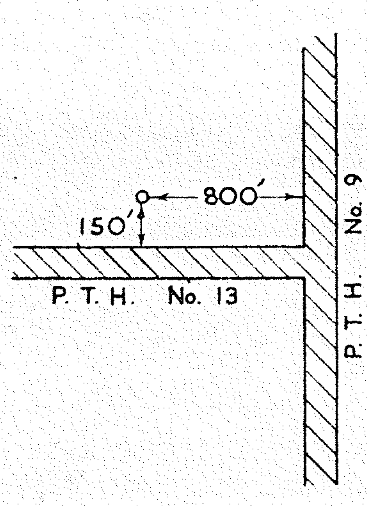
INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES

WATER RESOURCES BRANCH

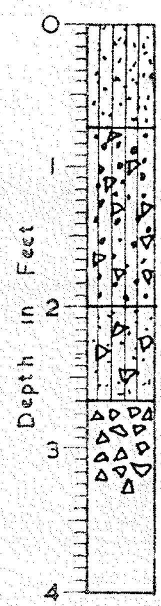
LOCATION: CARLYLE HOLE No. A — 31

LOCATION SKETCH



0.5 mile west Carlyle
800' west of jct. P.T.H.
No.9. & No.13.

TEST HOLE LOG



Grey organic sandy silt
S.G. = 2.62

Coarse silty sand with
gravel up to ½" size

Pocket of alkaline silt
@ 20"
S.G. = 2.66

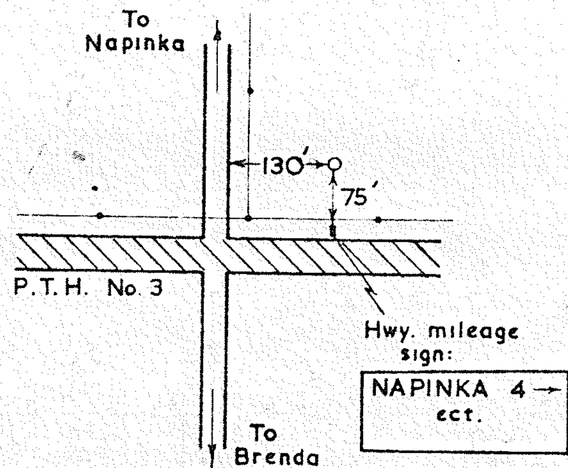
Sand and gravel, some
silt. S.G. = 2.67
Coarse gravel below 32"

Yr.	Date	Depth	% Moisture	Height in inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1954	Nov.	0	35.3	6.48	5.52	4.25	1.27	77.0%	
		12	14.7	-	-	-	-	-	
		18	14.7	7.75	4.25	3.02	1.23	71.0	
1955	Sept.	0" -11"	11.3	6.48	5.52	1.92	3.60	34.8%	
		13 -24	3.9	7.74	4.26	0.80	3.46	18.8	
		24 -32	15.7	7.75	4.25	3.24	1.01	76.3	
1955	Nov.	6	19.8	6.48	5.52	3.36	2.16	60.9	Gravel prevented
		12	7.9	7.74	4.26	4.11	0.15	96.5	deeper augering.
		18	29.6	-	-	-	-	-	Deeper strata
									probably
									saturated.

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

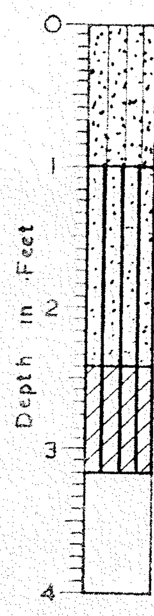
LOCATION: MELITA HOLE No. A — 35

LOCATION SKETCH



6.8 mile east Melita
at jct. of Napinka road.

TEST HOLE LOG



Black organic silt, slightly sandy, some decomposed vegetable matter
S.G. = 2.53

Grey silt, slightly sandy.
S.G. = 2.62

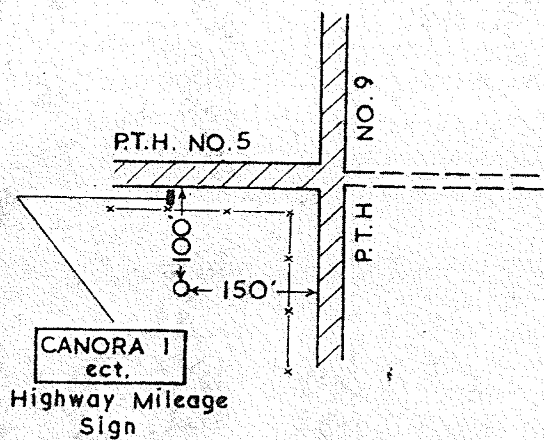
Yellow clayey silt
S.G. = 2.67

Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" -11"	12.0	7.14	4.86	2.27	2.59	46.7%	
		18	5.8	-	-	-	-	-	
		24 -35	4.2	7.35	4.65	0.78	3.87	16.8	
		42	5.0	-	-	-	-	-	
		46 -56	11.1	7.79	4.21	2.28	1.93	54.2	
1954	Nov.	0	30.6	-	-	-	-	-	
		12	12.9	-	-	-	-	50	Approx. value.
		18	10.4	-	-	-	-	-	
		42	19.6	-	-	-	-	-	
1955	Sept.	0 -10½	11.8	7.60	4.40	2.27	2.13	51.6	Samples were com-
		10½-21	17.2	7.49	4.51	3.35	1.16	74.2	pressed during
		21 -31	21.0	7.52	4.48	4.15	0.33	92.5	sampling. These
		31 -37	18.9	7.45	4.55	3.77	0.78	82.9	values are pes-
1955	Nov.	6	22.4	7.60	4.40	4.30	0.10	97.7	simistic and on
		12	24.0	7.49	4.51	4.32	0.19	95.8	the safe side
		18	20.4	-	-	-	-	-	
		30	23.0	7.44	4.56	4.56	0.00	100.0	

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

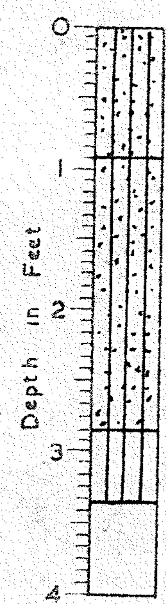
LOCATION: CANORA — HOLE No. A – 24

LOCATION SKETCH



At north junction of P.T.H. No. 5 and No. 9.

TEST HOLE LOG



Black organic sandy silt.
S.G. = 2.58

Brown sandy silt of same texture.
S.G. = 2.65

Yellow silt
S.G. = 2.67

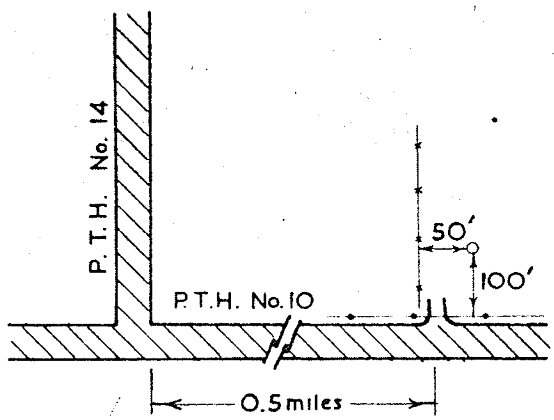
Yr.	Date	Depth	% Moisture	Height in inches per Foot of Soil: Solids	Voids	Water	Air	Degree of Saturation	Comments
1954	Nov.	0"	32.9	6.16	5.84	4.67	1.17	80.0 %	
		12	25.8	-	-	-	-	-	
		18	22.6	7.10	4.90	4.25	0.65	86.8	
		42	17.2	-	-	-	-	-	
1955	Sept.	0" -11"	18.9	6.16	5.84	3.00	2.84	51.4	
		13 -25	21.1	7.10	4.90	3.97	0.93	81.0	
		26 -36	21.8	7.25	4.75	4.20	0.55	88.5	
1955	Nov.	6	28.4	6.16	5.84	4.51	1.33	77.3	
		12	21.7	-	-	-	-	-	
		18	17.2	7.10	4.90	3.24	1.66	66.2	
		30	18.9	7.25	4.75	3.64	1.11	76.7	

INVESTIGATION OF SOIL MOISTURE RETENTION
- RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

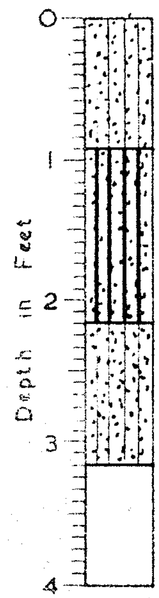
LOCATION: YORKTON HOLE No. A – 10

LOCATION SKETCH



0.5 mile east of jct. Hyw. No. 10. and Hyw. No.14.

TEST HOLE LOG



Black organic sandy silt S.G. = 2.62

Grey sandy silt, pockets of pure fine sand. S.G. = 2.65

Sand, some clay or silt S.G. = 2.66

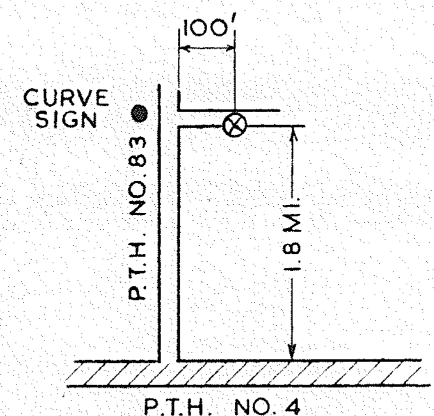
Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" -11"	28.0	6.96	5.04	5.04	0.00	100 %	Assumed
		18	25.2	-	-	-	-	100	saturation
		-	-	-	-	-	-	100	
1954	Nov.	0	38.6	-	-	-	0.00	100	
		12	22.7	-	-	-	-	81	Approx. value
		18	33.8	-	-	-	-	100	
		42	23.7	-	-	-	-	-	
1955	Sept.	0" -11½	12.4	6.40	5.60	2.08	3.52	37.2	
		13 -25	9.8	6.60	5.40	1.71	3.69	31.6	
		27 -37	18.0	6.65	5.35	3.18	2.17	59.5	
1955	Nov.	6	33.4	6.40	5.60	5.60	0.00	100.0	
		12	21.8	-	-	-	-	-	
		18	19.6	6.60	5.40	3.42	1.98	63.4	
		30	18.5	6.65	5.35	3.27	2.08	61.2	
1956	March	6	23.9	6.40	5.60	4.01	1.59	71.5	Moisture migrated down, but is relative-
		12	20.4						ly unchanged. Depth
		18	21.4	6.60	5.40	3.46	1.94	64.0	of frost = 24"
		27	22.9	6.65	5.35	4.05	1.30	75.6	

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

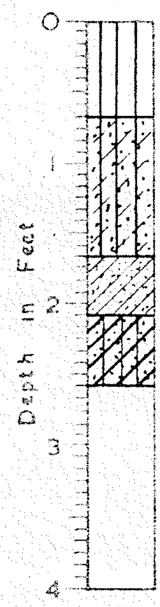
LOCATION: RUSSELL HOLE No. A-21

LOCATION SKETCH



1.8 mile north of north jct.
Hyw. No.4. and Hyw. No.83

TEST HOLE LOG



Black organic silt
S.G. = 2.53

Brown sandy silt, some clay S.G. = 2.67

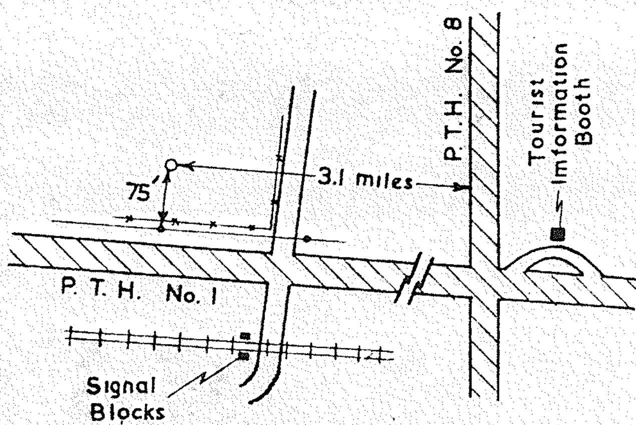
Light brown clayey sand
S.G. = 2.67
Brown silty clay, some fine sand S.G. =2.71

Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1954	Nov.	0	35.7	5.64	6.36	4.86	1.50	76.5 %	
		12	32.4	-	-	-	-	-	
		18	31.5	6.10	5.90	5.23	0.67	88.5	
		42	29.7	-	-	-	-	-	
1955	Nov.	0" -8"	26.7	5.64	6.36	3.81	2.55	59.9%	No soil samples taken in Sept.
		9 -20	19.1	6.10	5.90	3.11	2.79	52.7	
		20 -25	12.0	6.17	5.83	1.98	3.85	34.0	
		26 -31	18.4	6.24	5.76	3.11	2.65	54.0	

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

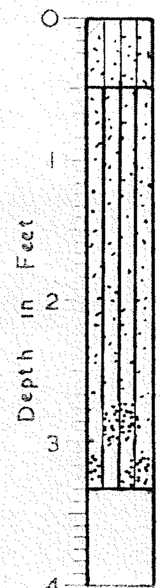
LOCATION: MOOSOMIN HOLE No. A – I

LOCATION SKETCH



3.1 mile west of jct. No.1 and No.8. P.T.H.

TEST HOLE LOG



Black changing to yellowish black organic sandy silt
S.G. = 2.61

Yellow sandy silt slightly alkaline

S.G. = 2.66

Pockets of pure sand @ 36"
S.G. = 2.67

Note: A number of sloughs having alkaline material in this region. Rolling topography in general

Yr.	Date	Depth	% Moisture	Height in inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" -11"	22.1	7.10	4.90	4.31	0.59	88.0%	
		18	19.0	-	-	-	-	-	
		24 -35	25.2	7.05	4.95	4.70	0.25	95.0	
		42	9.3	-	-	-	-	-	
		45 -55	12.8	8.34	3.68	2.82	0.86	76.7	
1954	Nov.	0	29.3	-	-	-	-	-	
		12	20.8	-	-	-	-	83	Approx. value
		18	21.2	-	-	-	-	-	
		42	22.6	-	-	-	-	-	
1955	Sept.	0 -11	22.2	6.79	5.21	3.94	1.27	75.6	
		13 -23	20.4	7.23	4.77	3.92	0.85	82.1	
		24 -36	16.0	7.31	4.69	3.12	1.57	66.6	
1955	Nov.	6	29.4	6.79	5.21	5.21	0.00	100.0	
		12	16.7	-	-	-	-	-	
		18	19.9	7.23	4.77	3.83	0.94	80.2	
		30	16.6	7.31	4.69	3.24	1.45	69.2	

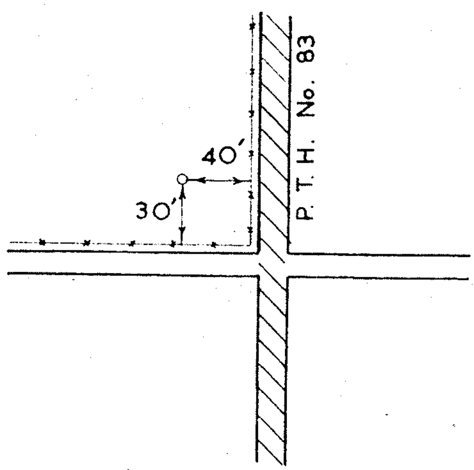
NR-wp-52

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

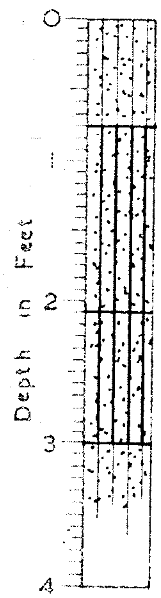
LOCATION: VIRDEN HOLE No. A – 12

LOCATION SKETCH



2.2 mile south of Maryfield
road on west side 50' south
of north boundary N.E. 5-10-26 W

TEST HOLE LOG



Black organic sandy silt
S.G. = 2.61

Light brown sandy silt S.G. = 2.66

Yellow sandy silt
S.G. = 2.67

Fine-grained yellow sand and silt

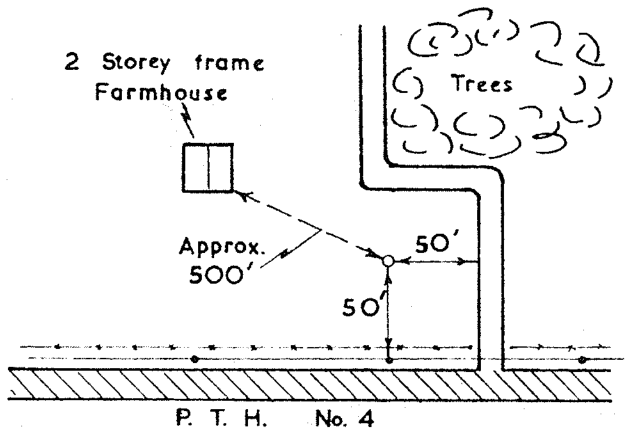
Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0" -11"	25.4	6.08	5.92	4.11	1.81	69.5%	
		18	21.6	-	-	-	-	-	
		24 -35	25.9	6.62	5.38	4.31	1.07	80.0	
		42	28.0	-	-	-	-	-	
		45 -55	24.4.	6.47	5.53	4.80	0.73	86.8	
1954	Nov.	0	28.5	-	-	-	-	-	
		12	27.2	-	-	-	-	74	Approx. value
		18	23.5	-	-	-	-	-	
		42	31.7	-	-	-	-	-	
1955	Sept.	0" -11	21.0	6.56	5.44	3.60	1.84	66.2	
		12 -25	23.8	6.70	5.30	4.24	1.06	80.0	
		25 -36	15.6	7.64	4.36	3.18	1.18	73.0	
1955	Nov.	6	31.2	6.56	5.44	5.34	0.10	98.2	
		12	24.2	6.70	5.30	4.04	1.26	76.3	
		18	21.1	-	-	-	-	-	
		30	19.0	7.64	4.36	3.87	0.49	88.7	
1956	March	7	20.0	6.56	5.44	3.42	2.02	63.0	Depth of frost
		12	21.7	6.70	5.30	5.24	0.06	98.9	= 25". Ice lenses
		18	37.1						in soil near
		26	31.5	-	-	-	0.00	100.0	surface

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

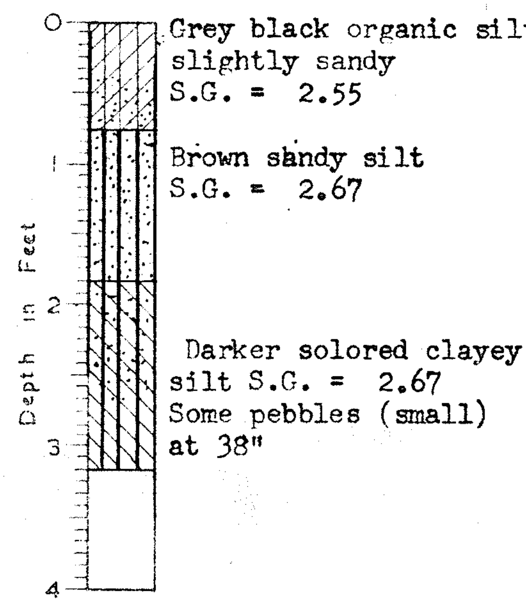
LOCATION: SHOAL LAKE HOLE No. A – 19

LOCATION SKETCH



1 mile west of Shoal Lake

TEST HOLE LOG



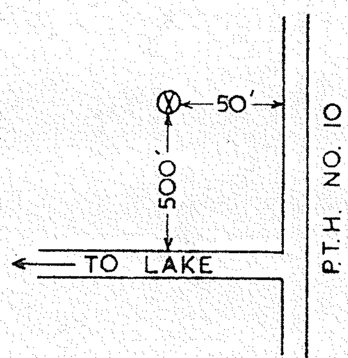
Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	2" -13"	22.3	7.42	4.58	4.32	0.26	94.1%	
		18	22.8	-	-	-	-	-	
		26 -36	21.0	7.48	4.52	4.15	0.41	92.0	
		42	27.5	-	-	-	-	-	
		48 -58	20.4	7.75	4.25	4.17	0.08	98.1	
1954	Nov.	0	67.4	-	-	-	0.00	100	
		12	26.8	-	-	-	-	-	
		18	30.3	6.40	5.60	5.17	0.43	92.4	
		42	30.0	-	-	-	-	-	
1955	Sept.	0 -11	26.8	6.50	5.50	4.45	1.05	81.0	Taken during a
		14 -25	22.5	6.40	5.60	3.84	1.76	68.6	heavy rain
		25 -37	21.8	6.70	5.30	3.90	1.40	73.6	
1955	Nov.	6	29.9	6.50	5.50	4.96	0.54	90.2	
		12	26.8	-	-	-	-	-	
		18	32.7	6.40	5.60	5.59	0.01	99.8	
1956	March	6	52.2	-	-	-	0.00	100.0	Depth of frost
		12	22.4						= 12"
		18	23.8	6.40	5.60	4.43	1.17	77.4	30½" of snow
		31	21.0	6.70	5.30	3.76	1.54	71.0	over hole

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

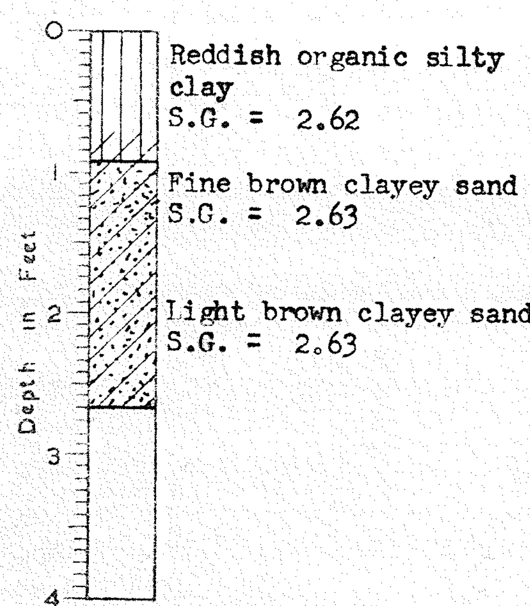
LOCATION: WASAGAMING HOLE No. A-25

LOCATION SKETCH



1.5 mile north of Wasagaming.

TEST HOLE LOG



Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1954	Nov.	0"	23.6	6.00	6.00	3.72	2.28	62.0 %	
		12	21.5	-	-	-	-	-	
		18	14.7	6.79	5.21	3.23	1.98	62.0	
		42	11.2	-	-	-	-	-	
1955	Nov.	0" -11"	19.2	6.00	6.00	3.02	2.98	50.3%	No soil samples taken in Sept.
		11 -21	13.4	6.79	5.21	2.39	2.82	45.8	
		21 -31	13.1	6.85	5.15	2.36	2.79	45.8	

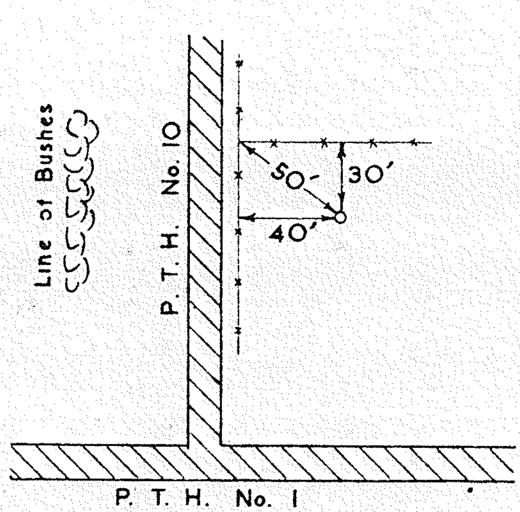
INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES

WATER RESOURCES BRANCH

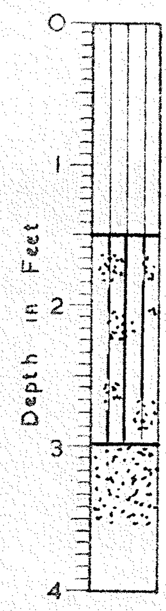
LOCATION: BRANDON   HOLE No. A — 16

LOCATION SKETCH



1.5 mile north junction.
No.1. north of Brandon.

TEST HOLE LOG



Grey organic silt
S.G. = 2.56

Grey silt, pockets of fine yellow sand.
S.G. =2.60

Very fine-grained yellow sand
S.G. = 2.63

Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0-11	19.4	6.22	5.78	3.10	2.68	53.5 %	
		18	19.8	-	-	-	-	-	
		24-35	15.3	8.28	3.72	3.22	0.50	86.6	
		42	22.2	-	-	-	-	-	
		48-54	16.7	7.48	4.52	3.71	0.81	82.2	
1954	Nov.	0	20.8	-	-	-	-	-	
		12	25.5	-	-	-	-	71	Approximate value
		18	24.2	-	-	-	-	-	
		42	26.0	-	-	-	-	-	
1955	Sept.	0"-11"	29.7	6.24	5.76	4.74	1.02	82.2%	
		13 -26	26.9	6.70	5.30	4.69	0.61	88.5	
		26 -36	23.2	6.83	5.17	4.16	1.01	80.5	
1955	Nov.	6"	31.4	6.24	5.76	5.01	0.75	87.0	
		13"	26.8	6.70	5.30	4.67	0.63	88.1	
		10"	26.8	-	-	-	-	-	
		31"	24.0	6.83	5.17	4.31	0.86	83.4	

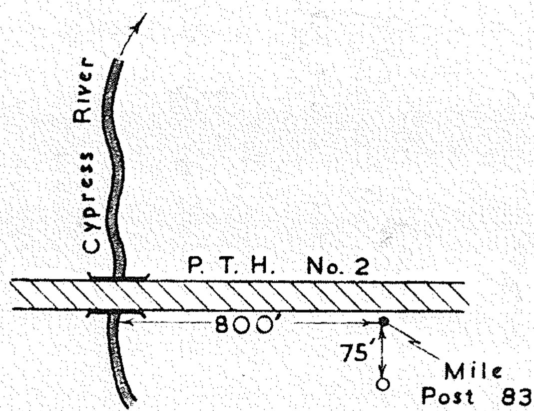
INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES

WATER RESOURCES BRANCH

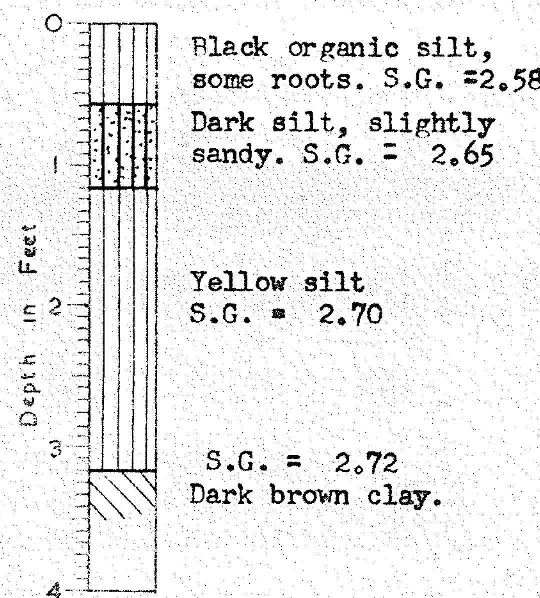
LOCATION: CYPRESS RIVER HOLE No. A — 27

LOCATION SKETCH



Summit 800' east
Cypress River Bridge.

TEST HOLE LOG

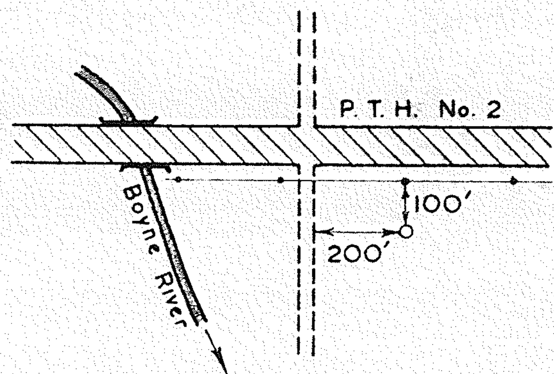


Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0"–11"	24.6	4.31	7.69	2.86	4.83	59.2%	
		18	11.3	-	-	-	-	-	
		24"–35"	11.9	6.42	5.58	2.06	3.52	59.6	
		42	17.7	-	-	-	-	-	
		44"–55"	14.6	5.76	6.24	2.26	3.98	56.8	
1954	Nov.	0	48.7	-	-	-	-	-	
		12	21.4	-	-	-	-	54	Approximate value
		18	16.4	-	-	-	-	-	
		42	16.0	-	-	-	-	-	
1955	Sept.	0"–7"	13.8	7.09	4.91	2.52	2.39	51.4 ←	Assumed values, this was only a bag sample.
		7"–19"	13.1	7.02	4.98	2.43	2.55	48.8	
		19"–28"	21.5	6.90	5.10	4.02	1.08	78.8	
		28"–31"	19.1	6.99	5.01	3.60	1.41	71.8	
		31"–40"	19.6	6.90	5.10	3.67	1.43	72.0	
1955	Nov.	6"	25.1	7.09	4.91	4.58	0.33	93.2	
		12"	20.5	7.02	4.98	3.81	1.17	76.5	
		19"	18.5	6.90	5.10	3.44	1.66	67.5	
		30"	20.2	6.99	5.01	3.83	1.18	76.4	

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

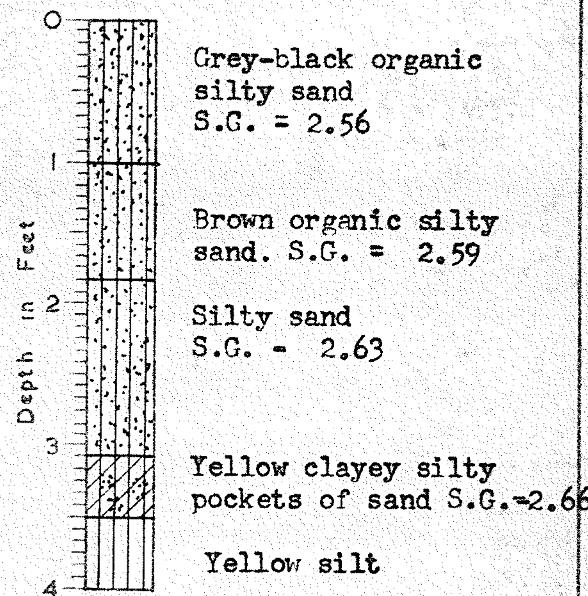
LOCATION: RATHWELL HOLE No. R – 2

LOCATION SKETCH



2 miles east Rathwell at road-crossing east of Boyne River Bridge.

TEST HOLE LOG



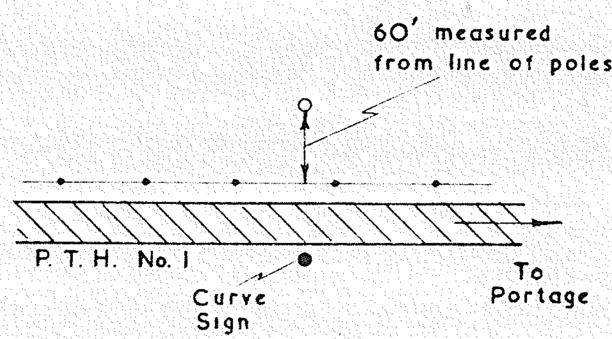
Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1954	Nov.	0	17.0	-	-	-	-	-	
		12	19.2	-	-	-	-	-	
		18	18.9	-	-	-	-	-	
		42	27.9	-	-	-	-	-	
1955	Sept.	0" -11"	12.5	6.79	5.21	2.18	3.03	41.8%	
		13 -25	7.7	7.41	4.59	1.48	3.11	32.2	
		26 -37	8.9	7.35	4.65	1.72	2.93	37.0	
		37 -42	18.1	7.43	4.57	3.57	1.00	78.2	
1955	Nov.	6	26.5	6.79	5.21	4.61	0.60	88.5	
		12	14.9	-	-	-	-	-	
		19	12.5	7.41	4.59	2.40	2.19	52.3	
		30	9.2	7.35	4.65	1.78	2.87	38.3	

INVESTIGATION OF SOIL MOISTURE RETENTION
RED AND ASSINIBOINE RIVER BASINS
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES

WATER RESOURCES BRANCH

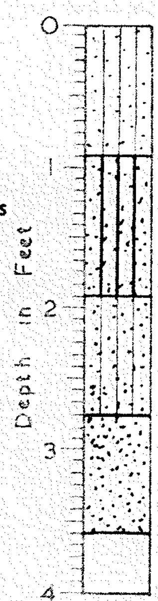
LOCATION: PORTAGE LA PRAIRIE HOLE No. A – 13

LOCATION SKETCH



1 mile west of Portage from main
C.N.R. railway crossing

TEST HOLE LOG



Black organic sandy silt S.G. = 2.58

Sandy silt S.G. = 2.64

Brown sand, some silt S.G. = 2.65

Light brown, fine sand. S.G. =2.65

Yr.	Date	Depth	% Moisture	Height in Inches per Foot of Soil				Degree of Saturation	Comments
				Solids	Voids	Water	Air		
1953	Fall	0"– 11"	22.3	5.78	6.22	3.46	2.76	57.6%	
		18	15.6	–	–	–	–	–	
		24 -35	7.75	7.22	4.78	1.49	3.29	31.2	
		42	15.1	–	–	–	–	–	
		44 -55	21.7	7.30	4.70	4.22	0.48	89.6	
1954	Nov.	0	33.0	–	–	–	–	–	
		12	22.2	–	–	–	–	57	Approx.value
		18	16.8	–	–	–	–	–	
		42	16.1	–	–	–	–	–	
1955	Sept.	0 -11	10.1	5.96	6.04	1.55	4.49	25.7	
		11 -23	18.1	6.80	5.20	3.25	1.90	62.5	
		23 -33	18.4	6.86	5.14	3.34	1.80	65.0	
		33 -40	15.0	6.99	5.01	2.78	2.23	55.5	
1955	Nov.	6	23.8	5.96	6.04	3.66	2.38	60.7	
		12	22.7	6.80	5.20	5.18	0.02	99.6	
		18	35.0	–	–	–	–	–	
		30	25.0	6.86	5.14	4.54	0.60	88.3	

ERRORS

The preceding data is subject to error. Probable errors in order of importance are:

Compression of the "undisturbed samples" during sampling and removal from sampling tubes. Unfortunately, with the type of sampling equipment used, little can be done to improve techniques and to eliminate this source of error.

Swelling of the soil with increased moisture in the field. This effect was particularly noticeable on the soil samples taken in March, 1956.

Free water clinging to the moisture content samples, resulting in higher apparent moisture contents.

The same type of material not being recovered at any given site on different field trips. To prevent this from happening again, all the test hole sites were quite definitely located and well described during the field trips of September, 1955.

Experimental errors in weighing and measuring.

METHOD OF ANALYSIS

The infiltration or rational approach, which was used in this study, is exceedingly simple, consisting of starting with the total available water for runoff and subtracting all losses, such as infiltration into the ground, evaporation, depression storage and others. Runoff is the residual quantity.

Total Available Water for Runoff

The total water available for runoff is determined by summing the water equivalent of the snow on the basin and the additional precipitation occurring up to and during runoff. Since forecasts would be made well in advance of the actual runoff, the additional precipitation would not actually be known. It is usually taken to be the long term mean precipitation over the drainage basin during the runoff period. This is obtained from meteorological records.

From the latest available snow survey results prior to spring runoff, the water equivalent of the snow at various points throughout the watershed is obtained. The equivalent depth of water on each separately considered subdivision of the basin is then found from an isohyetal map or by the Thiessen Polygon method, described in any standard textbook on hydrology.

By using the above-described method, losses due to evaporation of snow are automatically eliminated, and the only losses to be considered are those occurring just prior to and during runoff.

The losses are due to the following:

Evaporation and Transpiration

Evaporation from both land and water areas in a drainage basin, although a very difficult factor to evaluate, is important in the determination of runoff from the drainage basin. Evaporation varies with the nature of the soil and subsoil, temperature, wind, topography, vegetal cover, season and rainfall. Horton has stated that the amount of evaporation depends on what he termed the "evaporation opportunity", which is determined by the quantity of moisture available for evaporation.

Transpiration is defined as the process of vaporization of water from the breathing pores of leaves and other vegetable surfaces. It depends upon the rate at which soil moisture can be supplied to the root system.

From November to April the temperature is low, plant life is dormant, the ground is frozen most of the time, and hence ground-water evaporation may be considered to be negligible. However, there definitely is some evaporation from snow and from runoff water, although the amount is very difficult to determine.

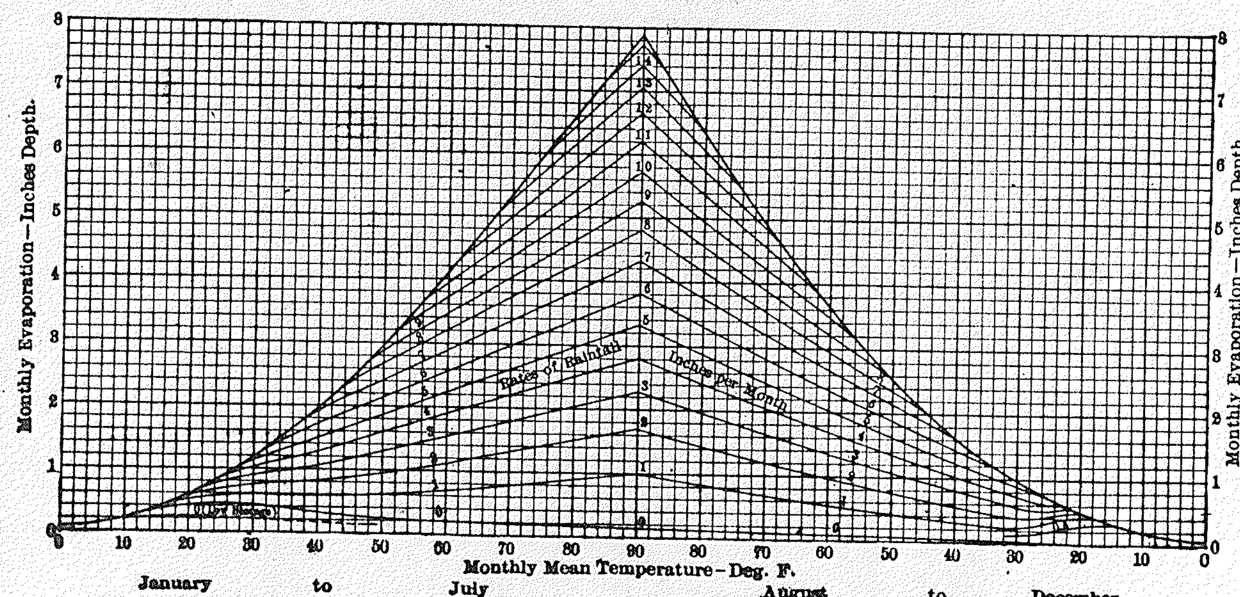
A. F. Meyer, a noted authority on the subject, has stated: "Full evaporation, corresponding to the given monthly temperature, is possible throughout the winter. After the temperature rises above 20 degrees, in spring, a considerable constant evaporation is still possible, irrespective of precipitation."

As previously explained, evaporation during the winter need not be considered. Evaporation in the spring during runoff, when temperatures climb above freezing, is an important factor. The best and simplest method of approximating this amount of evaporation is by using a chart developed by Meyer. Plate No. 2 is a reproduction of this chart. By entering the chart with either the known or the expected mean monthly temperature and the known or expected monthly rainfall, the monthly evaporation in inches depth over the drainage basin can be determined for the appropriate time of year.

Transpiration losses are negligible, even during spring runoff, and need not be considered at all.

CHART FOR ESTIMATING EVAPORATION FROM A DRAINAGE BASIN

(AS DEVELOPED BY A.F. MEYER)



EVAPORATION FROM LAND AREAS FOR VARIOUS TEMPERATURES AND RATES OF RAINFALL.

PLATE NO. 2

Drawn : R. H.

Checked : M.M.

Surface Detention and Depression Storage

Surface detention is water in temporary storage as a sheet over the basin. This is not to be confused with depression storage, which in no way contributes to surface runoff, and consists of water retained in puddles, ditches and other depressions in the soil surface.

It is practically impossible to evaluate these factors, although they probably account for quite a bit of water.

Infiltration or Ground-Water Increment

The ability of a soil to absorb water depends on two factors. The first is the available storage space in the soil. The second is the ability of the soil to transmit water to lower strata or to the water table. Both of these factors are included in the concept of "infiltration capacity", which may be defined as the maximum rate at which a given soil in a given condition can absorb water as it is applied.

Anyone who has ever seen permeameter experiments in operation knows that in such experiments, even though the soil is saturated, it can still transmit water in response to head differences. Thus, even though the watershed surface soils may be completely saturated, they may still be able to transmit some water to underlying strata.

In dry years, or even in years of normal average moisture conditions, the underlying clay from a depth of say five feet below the surface to a depth of approximately ten or twelve feet is not saturated. Although the amount of water that could be absorbed by the clay is low in comparison with the water absorbed by upper soil layers in becoming saturated, it should still be considered. In wet years, of course, no water would be absorbed by the underlying clay, since a six or seven foot layer of saturated clay would prevent any further downward moisture migration. A very significant point here is the fact that capillary action can occur in any direction, down as well as up. Therefore the rate of absorption by the clay is not governed by its very low permeability, but is considerably accelerated by the capillary effect. The rate of course decreases as more water is absorbed.

At certain locations such as Stuartburn, Neepawa, Wynyard and Carlyle, where the boulder till lies near the surface and the soils are very permeable, it is quite likely that the soil mantle would never reach saturation because the water would drain through as fast as it was applied. In these cases the amount of water transmitted to the water tables below would exceed the amount absorbed by the upper soil layers, and would be a very significant quantity.

From the foregoing it can be seen that the total infiltration, unfortunately, cannot be evaluated quantitatively. The trial procedure that was followed in this study was to make an estimate of the depth to which complete saturation of the soil would have occurred if no water were transmitted through the upper layers of the soil to lower depths, and assuming that the soil structure does not change by swelling or in any other manner. The factors taken into account in making this estimate were soil type, antecedent soil moisture conditions and occurrence of frost in the ground. In cases where no other information was available, soil moisture conditions indicated by the autumn soil survey were assumed to remain unchanged over the winter until the beginning of spring thaw. The procedure herein described will be clarified by the following sample calculations for the complete analyses of three different drainage basins.

Surface Runoff

The general ground-water equation for a watershed may be written in the form

$$S = P_t - (E + I + D)$$

where S = surface runoff discharging from the watershed through stream flow

P_t = total water applied to the watershed through precipitation

E = the evapo-transpiration

I = the infiltration, or ground-water increment

D = depression storage, surface detention and any other unaccountable losses

The quantity 'S' calculated by use of the above formula does not include the base flow, and gives only the total volume of runoff. The problem of determining the peak flow or the peak of the hydrograph still remains. However, this is a problem for the hydrologist and is not attempted here.

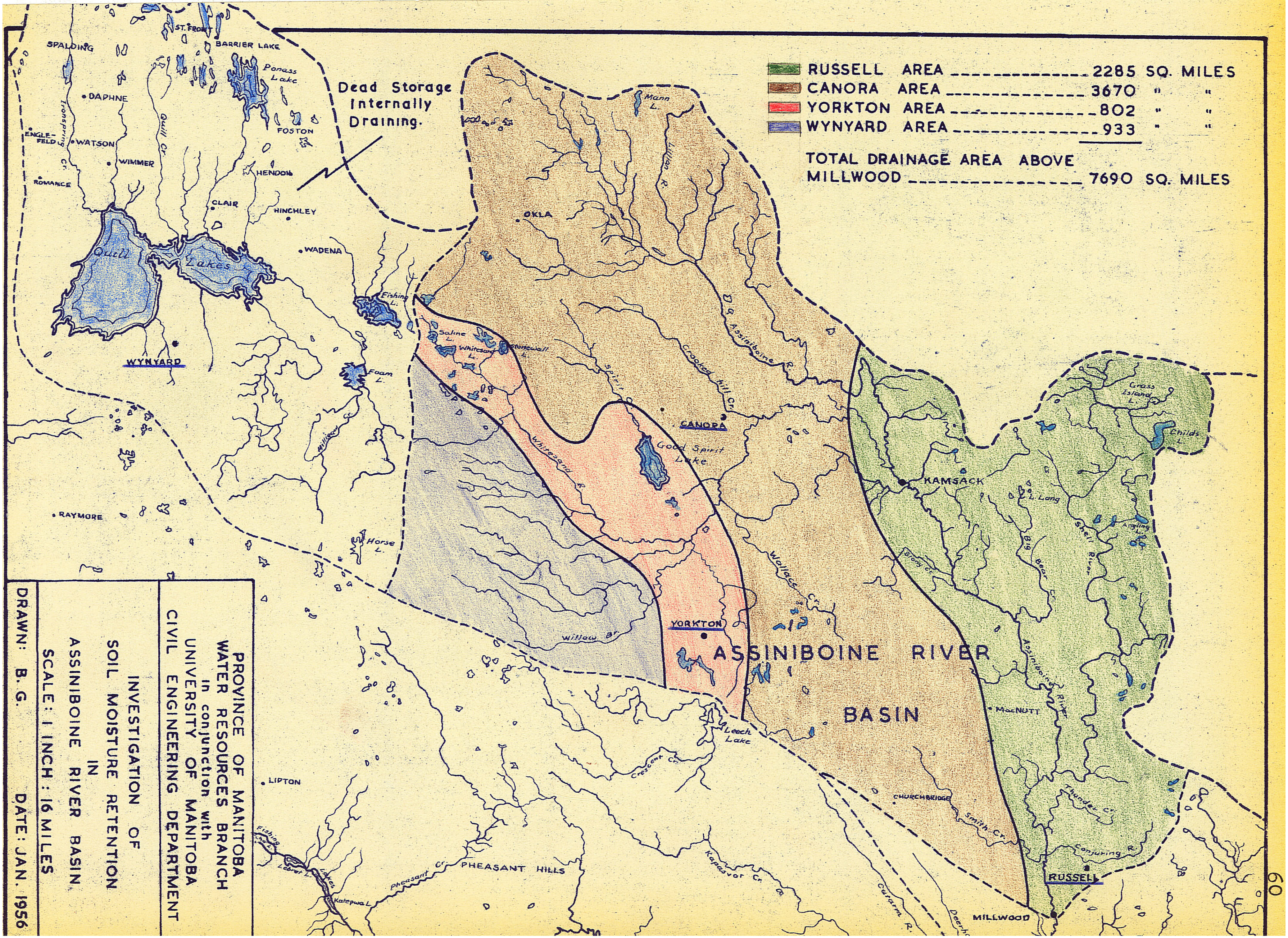
Nowhere in this analysis was temperature taken seriously into account. To quote from Appendix "C" of the Red River Basin Investigation report:

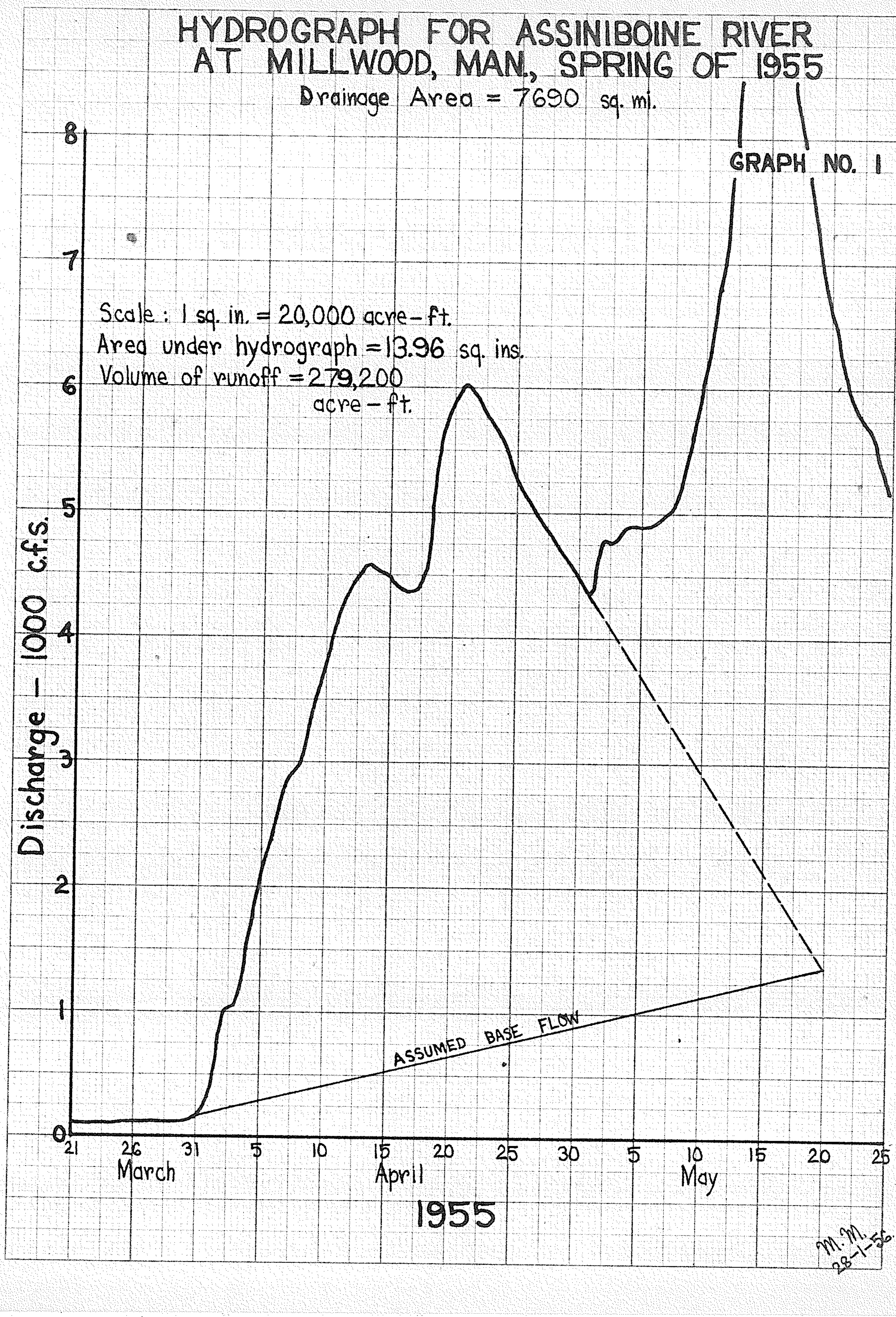
"In general, the difference in infiltration and evaporation losses occurring from a slow or rapid melt would not be large, and it is concluded that temperatures would have only a minor influence on the volume of runoff."

SAMPLE CALCULATIONS

In order to ascertain the validity of the infiltration approach to the problem of predicting spring runoff, analyses were made of three different basins for which the actual runoff could be computed, and on which fairly high discharges were recorded. In each case, from actual daily discharge measurements taken at the gauging station, the hydrograph for spring runoff was plotted. Using standard empirical methods described in texts on hydrology, the effect of spring rains occurring after the peak snowmelt runoff was eliminated, and the surface runoff was separated from the base flow. From the area under the hydrograph, the spring runoff was then computed.

Using agricultural soil survey maps as a guide, each of the three watersheds was also divided into small sub-areas. The general soil type and character throughout each sub-area was considered to be the same as that of the soil test hole in or near the sub-area, or in other words conditions at any test hole were assumed to be representative of the entire sub-area in which the test hole is located. Each sub-area was assigned a weight equal to the percentage that sub-area is of the total area.


RUSSELL AREA ---------- 2285 SQ. MILES
CANORA AREA ---------- 3670 " "
YORKTON AREA ---------- 802 " "
WYNYARD AREA ---------- 933 " "
TOTAL DRAINAGE AREA ABOVE MILLWOOD ---------- 7690 SQ. MILES
Dead Storage Internally Draining.
ASSINIBOINE RIVER BASIN
RUSSELL
MILLWOOD
KAMSACK
CANORA
YORKTON
OKLA
WYNYARD
WADENA
HINCHLEY
CLAIR
HENDON
FOSTON
WIMMER
WATSON
DAPHNE
SPALDING
ROMANCE
ENGLEFELD
RAYMORE
LIPTON
CHURCHBRIDGE
MacNUTT
PHEASANT HILLS
Quill Lakes
Good Spirit Lake
Leech Lake
Barrier Lake
Ponass Lake
Assiniboine R.
Shell River
Whitesand R.
Wallace Cr.
Crooked hill Cr.
Smith Cr.
Thunder Cr.
Conjuring R.
Pheasant Cr.
Kapasvor Cr.
Quill Cr.
PROVINCE OF MANITOBA
WATER RESOURCES BRANCH
in conjunction with
UNIVERSITY OF MANITOBA
CIVIL ENGINEERING DEPARTMENT
INVESTIGATION OF
SOIL MOISTURE RETENTION
IN
ASSINIBOINE RIVER BASIN
SCALE: 1 INCH : 16 MILES
DRAWN: B. G.
DATE: JAN. 1956


HYDROGRAPH FOR ASSINIBOINE RIVER
AT MILLWOOD, MAN., SPRING OF 1955
Drainage Area = 7690 sq. mi.
GRAPH NO. 1
Scale: 1 sq. in. = 20,000 acre-ft.
Area under hydrograph = 13.96 sq. ins.
Volume of runoff = 279,200
acre-ft.
Discharge - 1000 c.f.s.
0
1
2
3
4
5
6
7
8
ASSUMED BASE FLOW
21
26
31
5
10
15
20
25
30
5
10
15
20
25
March
April
May
1955
M.M.
28-1-56.

EXAMPLE 1. Assiniboine River above Millwood, Man.

$$\text{Station weight} = \frac{\text{Station area}}{\text{Total area of watershed}}$$

The station weights are:

$$\text{Wynyard} = \frac{933}{7690} = .121$$

$$\text{Yorkton} = \frac{802}{7690} = .104$$

$$\text{Canora} = \frac{3670}{7690} = .477$$

$$\text{Russell} = \frac{2285}{7690} = .298$$

$$\overline{1.000}$$

The infiltration capacity at each hole was calculated, using previously computed soil test data giving the height in inches of air per foot of soil.

In view of the fact that the mean temperature remained above 32° for some days prior to start of runoff, there was opportunity for the soil to thaw. Once runoff started this thawing progressed at a much higher rate. Therefore, the upper soil layers that would be affected by infiltration were assumed to have very little frost and to behave as unfrozen soils.

The Assiniboine River is a slow-moving stream, and the period of snowmelt runoff from this basin was 50 days. This would certainly allow a maximum of infiltration to occur, because the longer the run-off period, the greater the opportunity for infiltration. Had the time for runoff been shorter, saturations to somewhat shallower depths would have been assumed.

Wynyard area:

1. Very gently rolling topography, conducive to slow runoff.
2. Sandy and gravelly soil of high permeability.
3. Soil behaves as though it were unfrozen.

For the above stated reasons, the equivalent depth of soil saturation was assumed to be 24 inches.

Height of air per foot of soil in top foot	=	2.21"
Height of air per foot of soil in second foot	=	2.78"
Total	=	4.99"
Less 10% for probable soil moisture increase during the winter	=	.50"
Possible infiltration capacity	:	4.49"

Yorkton area:

1. Silty sand, quite permeable.
2. Gently to moderately undulating topography.
3. Top foot is 100% saturated, but it was assumed that infiltration had occurred, allowing for some infiltration.

The equivalent depth of soil saturation was assumed to be 18 inches.

Top foot saturated, height of air per foot	=	0.00"
Height of air from 12" - 18" = $\frac{6}{12} \times 1.51$	=	0.75"
Total	=	0.75"
Less 10%	=	.08"
Possible infiltration capacity	:	0.67"

Russell area:

1. Silty and clayey material, fairly low permeability.

2. Undulating topography, sloughs, which indicate possible high depression storage capacity.

Assumed depth of saturation = 18 inches

Height of air per foot of soil in top foot	=	1.50"
Height of air from 12" - 18" = $\frac{6}{12} \times 0.67$	=	0.34"
Total	=	1.84"
Less 10%	=	.18"
Possible infiltration capacity	:	1.66"

Canora area:

1. Sandy silt, medium permeability.

2. Gently to moderately undulating topography.

The equivalent depth of soil saturation was assumed to be 18 inches.

Height of air per foot of soil in top foot	=	1.17"
Height of air from 12" - 18" = $\frac{6}{12} \times 0.65$	=	0.33"
Total	=	1.50"
Less 10%	=	.15"
Possible infiltration capacity	:	1.35"

To find the uniform depth of possible infiltration over the whole basin, the weighted mean of the above calculated values was taken:

Wynyard :	.121 x 4.49 =	0.54"
Yorkton :	.104 x 0.67 =	0.07"
Russell :	.298 x 1.66 =	0.49"
Canora :	.477 x 1.35 =	0.64"
Total possible infiltration =		1.74"

During the runoff period in the month of April the average temperature in this basin was 41° F. There were also 2.4 inches of rain during this period. Therefore, from Meyer's chart (Plate No. 2) the evaporation from the basin was 0.98 inches.

From actual records:

Total water available for runoff:	snow	2.62"
	rain	1.37"
Total =		3.99"

Actual total runoff (from hydrograph)

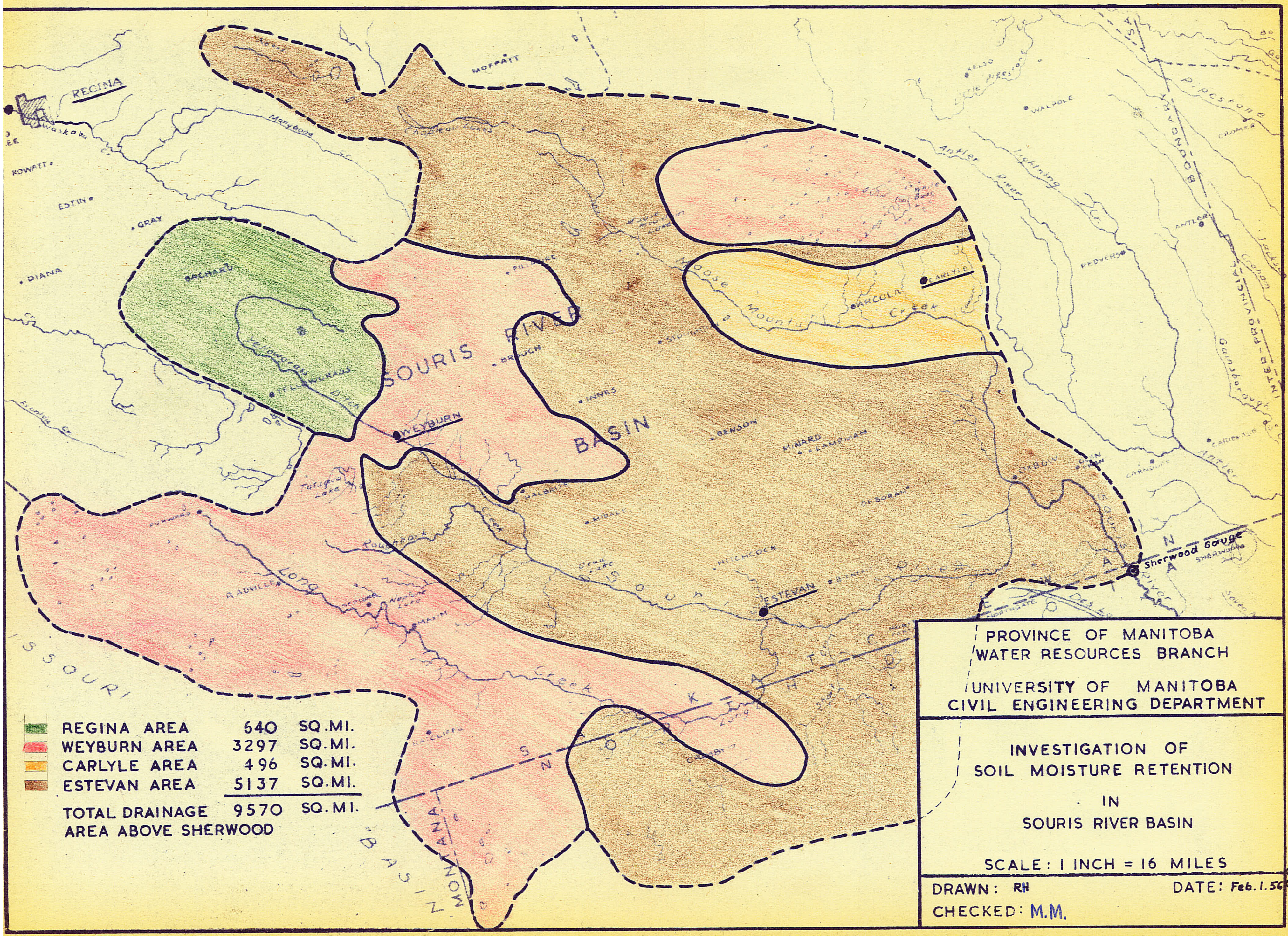
$$= \frac{279,200 \times 12}{7,690 \times 640} = 0.69''$$

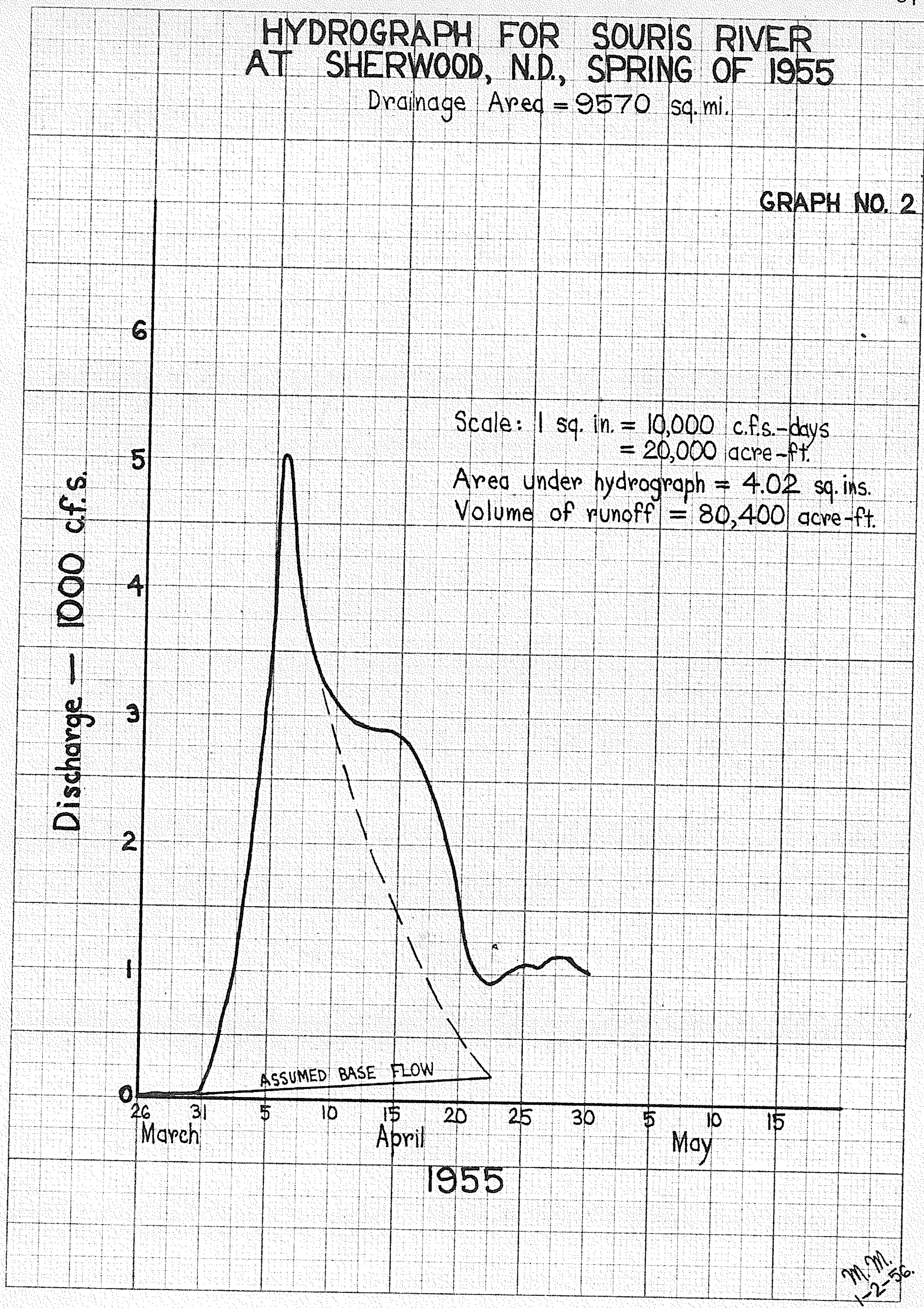
The general ground-water equation for the watershed was then applied:

$$S = P_t - (I + E + D)$$

$$0.69 = 3.99 - (1.74 + 0.98 + D)$$

$$D = 0.58''$$


PROVINCE OF MANITOBA
WATER RESOURCES BRANCH
UNIVERSITY OF MANITOBA
CIVIL ENGINEERING DEPARTMENT
INVESTIGATION OF
SOIL MOISTURE RETENTION
IN
SOURIS RIVER BASIN
SCALE: 1 INCH = 16 MILES
DRAWN: RH
DATE: Feb. 1.56
CHECKED: M.M.
REGINA AREA 640 SQ.MI.
WEYBURN AREA 3297 SQ.MI.
CARLYLE AREA 496 SQ.MI.
ESTEVAN AREA 5137 SQ.MI.
TOTAL DRAINAGE AREA ABOVE SHERWOOD 9570 SQ.MI.
SOURIS RIVER BASIN
REGINA
WEYBURN
ESTEVAN
CARLYLE
ARCOLA
Moose Mountain Creek
Long Creek
Sherwood Gauge
MISSOURI BASIN
MONTANA
NORTH DAKOTA
INTER-PROVINCIAL BOUNDARY
Antler River
Pipestone
Lightning Cr.
MOFFATT
DIANA
GRAY
ESTIN
KOWATT
BRAUGH
INNES
BENSON
HITCHCOCK
MIDALE
RADVILLE
Yellowgrass Ditch
BECHARD
KELSO
WALDOLE
ANTLER
CARNDUFF
OXBOW
Gainsborough
Wascana Cr.


HYDROGRAPH FOR SOURIS RIVER
AT SHERWOOD, N.D., SPRING OF 1955
Drainage Area = 9570 sq. mi.
GRAPH NO. 2
Scale: 1 sq. in. = 10,000 c.f.s.-days
= 20,000 acre-ft.
Area under hydrograph = 4.02 sq. ins.
Volume of runoff = 80,400 acre-ft.
Discharge — 1000 c.f.s.
0
1
2
3
4
5
6
ASSUMED BASE FLOW
26
31
5
10
15
20
25
30
5
10
15
March
April
May
1955
M.M.
1-2-56.

EXAMPLE 2. Souris River above Sherwood, N.D.

The station weights are:

Regina	=	$\frac{640}{9570}$	=	.067
Weyburn	=	$\frac{3297}{9570}$	=	.344
Estevan	=	$\frac{5137}{9570}$	=	.537
Carlyle	=	$\frac{496}{9570}$	=	.052
				1.000

Although this watershed is larger than the part of the Assiniboine River basin considered in the previous example, the total period of snowmelt runoff was only 23 days, which decreased the opportunity for deep infiltration.

Temperatures were higher than in the Assiniboine River basin, since this watershed is farther south. Therefore, there was probably little or no frost in the ground.

With these facts in mind, the infiltration capacity at each hole was calculated, using previously computed soil test data giving the height in inches of air per foot of soil.

Regina area:

1. Gently undulating topography.
2. Heavy clay, very low permeability.

The equivalent depth of soil saturation was assumed to be 9 inches.

But the top fifteen inches of soil were already saturated, and therefore the height of air per foot of soil = 0.00"

Possible infiltration capacity : 0.00"

Weyburn area:

1. Gently undulating topography.
2. Relatively impermeable clayey silt.

Assumed depth of soil saturation = 12 inches

Height of air in top foot of soil	=	1.39"
Less 10% for probable soil moisture increase during the winter	=	.14"
Possible infiltration capacity :		1.25"

Estevan area:

1. Gently to moderately undulating topography.
2. Silty and clayey soil of low permeability.

Assumed depth of soil saturation = 12 inches.

Height of air in top foot of soil	=	0.00"
Possible infiltration capacity :		0.00"

Carlyle area:

1. Gently to moderately undulating topography.
2. Permeable soil, fairly high moisture content.

Assumed depth of soil saturation = 18 inches.

Height of air in top foot of soil	=	1.27"
Height of air from 12" - 18" = $\frac{6}{12} \times 1.24$	=	0.62"
Total	=	1.89"
Less 10%	=	.19"
Possible infiltration capacity :		1.70"

The weighted mean was then taken, to find the uniform depth of infiltration over the whole basin:

Regina	:	.067 x 0.00	=	0.00"
Weyburn	:	.344 x 1.25	=	0.43"
Estevan	:	.537 x 0.00	=	0.00"
Carlyle	:	.052 x 1.70	=	0.09"
Total possible infiltration			=	0.52"

The peak flow actually occurred just six days after the start of runoff, but it is quite reasonable to consider evaporation losses during a 15-day period.

The average temperature during runoff was 42° F. The monthly rainfall was 1.5 inches. Therefore, from Meyer's chart the monthly evaporation was 0.70 inches. The evaporation during the 15-day period was $\frac{15}{30} \times 0.70 = 0.35$ inches.

From actual records:

Total water available for runoff:	snow	1.43"
	rain	.06"
	Total =	1.49"

Actual total runoff (from hydrograph)

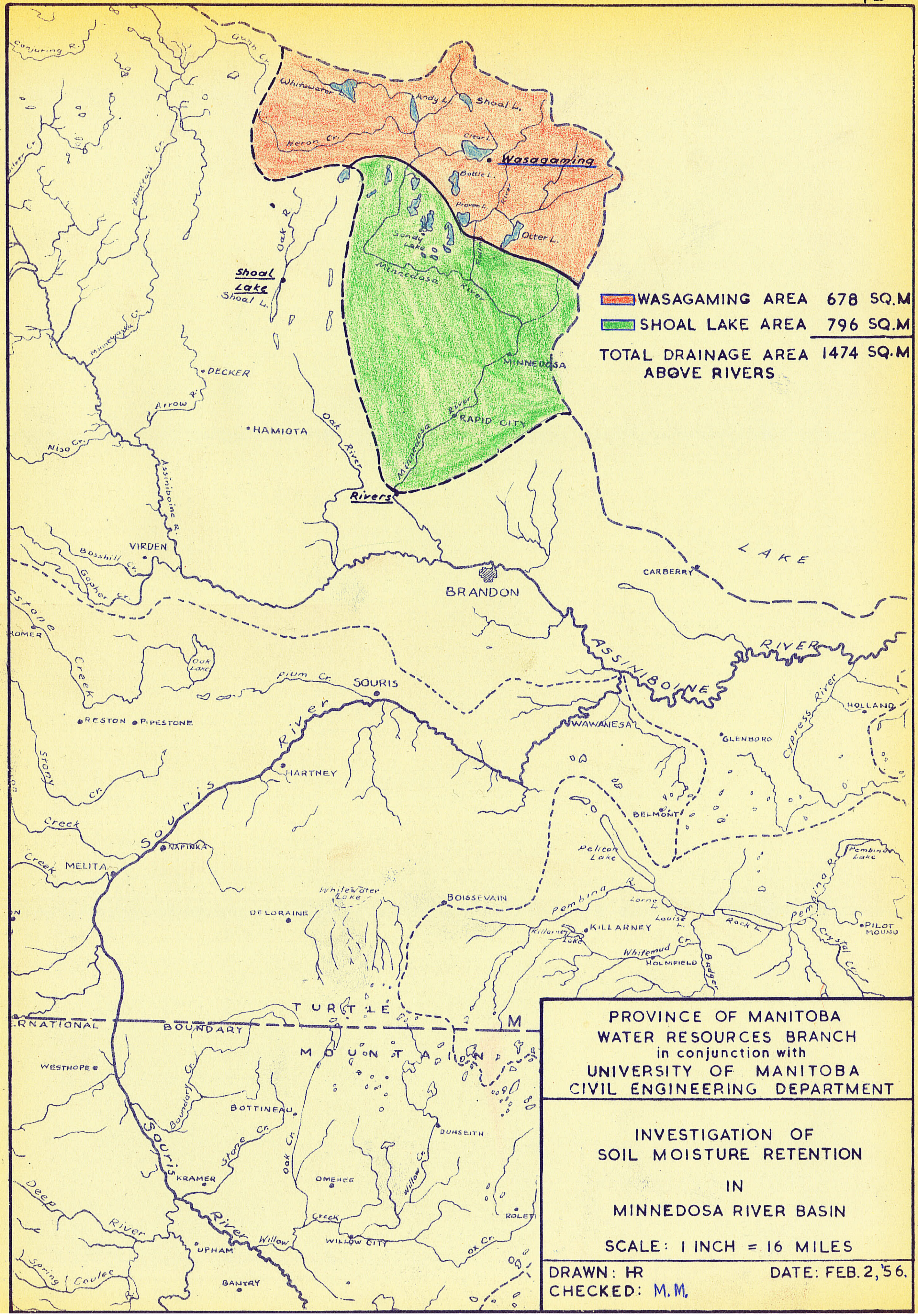
$$= \frac{80,400 \times 12}{9570 \times 640} = 0.16''$$

The general ground-water equation was then applied:

$$S = P_t - (I + E + D)$$

$$0.16 = 1.49 - (0.52 + 0.35 + D)$$

$$D = 0.46''$$

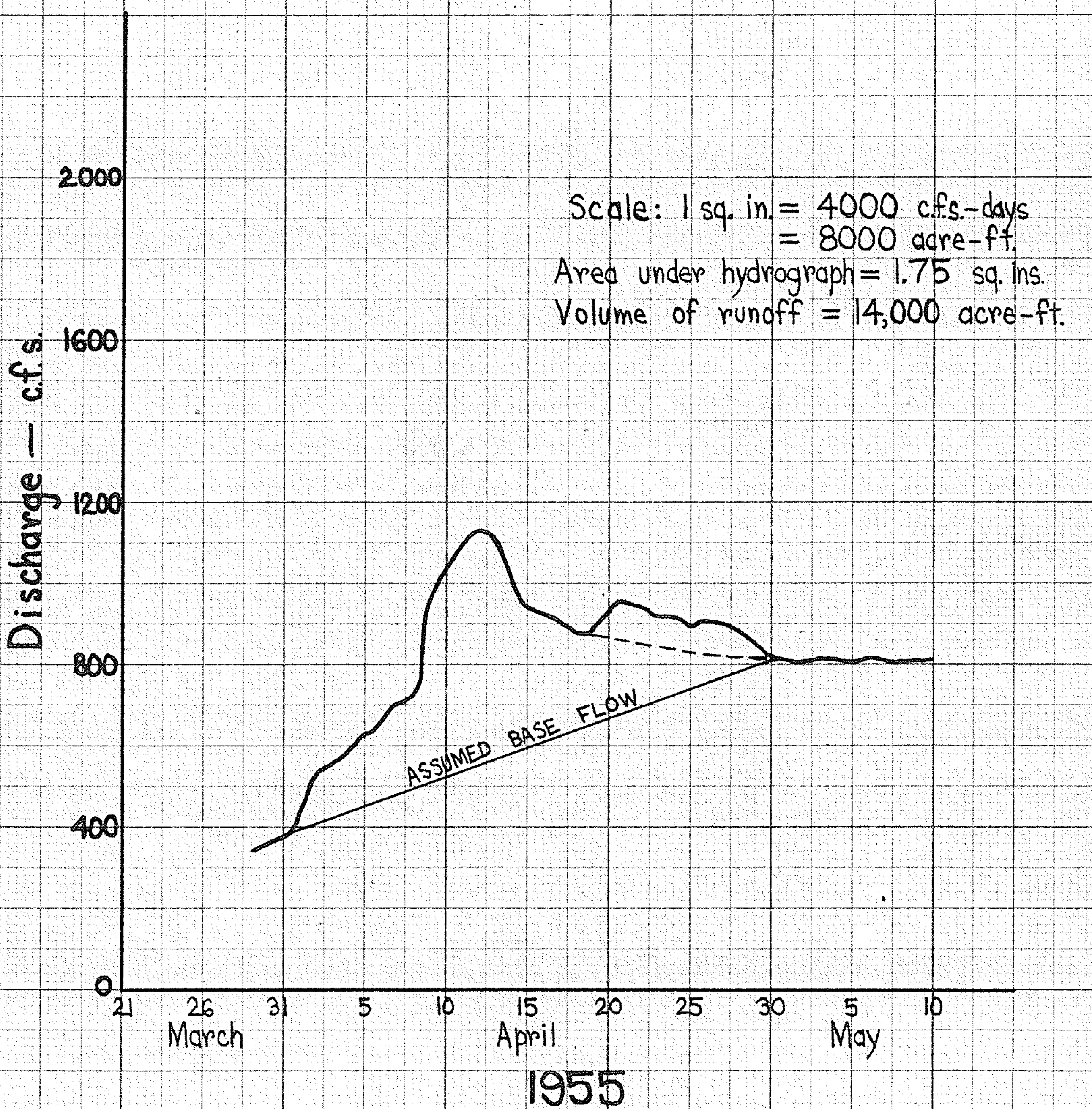


WASAGAMING AREA 678 SQ.M
SHOAL LAKE AREA 796 SQ.M
TOTAL DRAINAGE AREA ABOVE RIVERS 1474 SQ.M
Wasagaming
Shoal Lake
Rivers
Whitewater L.
Andy L.
Shoal L.
Heron Cr.
Clear L.
Bottle L.
Otter L.
Sandy Lake
Minnedosa River
MINNEDOSA
RAPID CITY
Oak R.
Oak River
Birdtail Cr.
Conjuring R.
Gunn Cr.
Minnewasta Cr.
DECKER
HAMIOTA
Arrow R.
Assiniboine R.
VIRDEN
Gopher Cr.
BRANDON
CARBERRY
LAKE
ASSINIBOINE
RIVER
Oak Lake
Plum Cr.
SOURIS
RESTON
PIPESTONE
WAWANESA
GLENBORO
Cypress River
HOLLAND
HARTNEY
Souris River
BELMONT
Pelican Lake
NAPINKA
MELITA
Whitewater Lake
BOISSEVAIN
DELORAINE
Pembina R.
Lorne L.
Louise L.
Rock L.
KILLARNEY
Killarney Lake
Whitemud Cr.
HOLMFIELD
Badger
Pembina Lake
PILOT MOUND
Crystal Cr.
TURTLE MOUNTAIN
INTERNATIONAL BOUNDARY
WESTHOPE
Boundary Cr.
BOTTINEAU
DUNSEITH
Stone Cr.
Oak Cr.
KRAMER
OMEMEE
Willow Cr.
ROLETTE
Deep River
Souris River
Willow Creek
WILLOW CITY
UPHAM
Spring Coulee
BANTRY
PROVINCE OF MANITOBA
WATER RESOURCES BRANCH
in conjunction with
UNIVERSITY OF MANITOBA
CIVIL ENGINEERING DEPARTMENT
INVESTIGATION OF
SOIL MOISTURE RETENTION
IN
MINNEDOSA RIVER BASIN
SCALE: 1 INCH = 16 MILES
DRAWN: HR
DATE: FEB. 2, '56.
CHECKED: M.M.

HYDROGRAPH FOR MINNEDOSA RIVER AT RIVERS, MAN., SPRING OF 1955

Drainage Area = 1474 sq. mi.

GRAPH NO. 3



M.M.
4-2-56

EXAMPLE 3. Minnedosa River above Rivers, Man.

The station weights are:

$$\text{Wasagaming} = \frac{678}{1474} = .460$$

$$\text{Shoal Lake} = \frac{796}{1474} = .540$$

$$1.000$$

Temperature conditions were practically the same as in the Assiniboine River basin. The ground was assumed to be unfrozen.

The snowmelt runoff, in its initial stages, was slowed somewhat by an ice jam, and the total period of runoff was 30 days.

The infiltration capacity of the soil was calculated:

Wasagaming area:

1. Hilly topography, conducive to very rapid runoff and very little surface detention.
2. Clay overlying clayey sand and also some sandy regions. Medium permeability.

Assumed depth of saturation = 9 inches.

Height of air in top 9 inches = $\frac{9}{12} \times 2.28$	=	1.71"
Less 10% for probable soil moisture increase during the winter	=	.17"
Possible infiltration capacity :		1.54"

Shoal Lake area:

1. Undulating topography, sloughs, indicating possible high depression storage capacity.
2. Silty soil of medium permeability.

Assumed depth of saturation = 24 inches.

Height of air in top foot of soil	=	0.00"
Height of air in top second of soil	=	0.43"
Total	=	0.43"
Less 10%	=	.04"
Possible infiltration capacity	:	0.39"

The weighted mean was then taken, to find the uniform depth of infiltration over the basin:

Wasagaming : .460 x 1.54 = 0.71"

Shoal Lake : .540 x 0.39 = 0.21"

Total possible infiltration = 0.92"

The average temperature in the basin during runoff was 44° F., and the monthly rainfall was 1.46 inches. From Meyer's chart, the evaporation from the basin = 0.75 inches.

From actual records:

Total water available for runoff: snow 2.42"

rain none

Actual total runoff (from hydrograph)

$$= \frac{14,000 \times 12}{1474 \times 640} = 0.18''$$

The general ground-water equation was then applied:

$$S = P_t - (I + E + D)$$

$$0.18 = 2.42 - (0.92 + 0.75 + D)$$

$$D = 0.57''$$

The value 'D' represents losses that must be satisfied before runoff can occur, and therefore it is felt that 'D' for any particular basin will be fairly well a constant every year.

To forecast runoff from any of these basins in future years, a conservative value of 'D' slightly smaller than that found in the shown example for the basin could be used. If exactly the same analyses for some other years with known records, any variations of 'D' could be determined.

In future years, if the results of soil moisture surveys made in the spring of the year in March were used, the guess as to probable increase in soil moisture content would be eliminated and no such factor would enter into the calculations.

The key factor in the analyses was the empirical selection of the equivalent depth to which soil saturation could occur. The selections made in the three given examples seem to be justified, since they all gave reasonable results despite the fact that the analyses of the Souris and Minnedosa Rivers were greatly complicated by the existence of dams above the gauging stations, which have a regulatory effect on the flows.

RECOMMENDATIONS AND CONCLUSIONS

The infiltration method of forecasting spring runoff is quick and easy to apply, and can serve as a check on predictions of runoff volume obtained by other methods. This study has conclusively shown the importance of the storage of infiltered water in the soil as a factor affecting spring runoff. Unfortunately, although it is known that the earth mantle of a drainage basin has a storage capacity for water, and that this amount constitutes a very large part of the losses tending to reduce spring runoff, the amount has not as yet been determined quantitatively. The results so far are encouraging, show the validity of the approach, and indicate the advisability of further study. Soil studies in particular are necessary.

An important topic for future study is the determination of the limits of accuracy which can be expected when the infiltration method of spring flood forecasting is used. The only way to answer such questions as to whether any infiltration takes place during a gradual, intermittent thaw before the start of spring runoff is to perform more field soil tests. A closely controlled test plot of several acres in which a great many soil tests could be made, and from which runoff could be accurately measured, would supply data with which to settle many unanswered questions.

Several new soil test sites have been proposed (on the map on page 17) to give better coverage of the areas under study. The accuracy of the analysis would be greatly increased by having more soil test holes in any basin. It is recommended that undisturbed soil samples to a depth of at least three feet be taken at these new sites late in the autumn of 1956. At all other sites more undisturbed samples are preferable, and moisture content samples are necessary. These latter should be taken in the spring of 1957, possibly by the same party making the last March snow survey, or by an entirely separate group. This spring soil survey would also show exactly to what depths frost occurs in the ground at various places throughout the basins, and would eliminate much guesswork on this account.

In conclusion, this investigation clearly indicated that a purely theoretical flood forecasting method is still impossible due to the many complex, indeterminable factors. To quote a very appropriate statement made by R.H. Clark in his paper entitled, "Predicting the Runoff from Snowmelt" and presented in the Engineering Journal of April, 1955:

"Theoretical studies serve to indicate general physical laws and the relative magnitude of various influences. However, empirical methods are necessary in applying these laws and in evaluating the total effect of all the factors on each basin."

The use of empirical methods definitely does not preclude the development of an accurate flood forecasting technique in the not too distant future.

REFERENCES

1. Johnstone, Don and Cross, William P.; ELEMENTS OF APPLIED HYDROLOGY; First edition, Ronald Press, New York.

2. Meyer, Adolph R.; THE ELEMENTS OF HYDROLOGY; Second edition, John Wiley and Sons, New York, 1928.

3. Tolman, C. F.; GROUND WATER; McGraw-Hill, New York, 1937.

4. Morris, W. Victor; FORECASTING SNOWMELT RUNOFF; M. Sc. Thesis, 1954, Colorado A. and M. College, 87 pp. unpublished manuscript.

5. Wisler, C. O., and Brater, E. F.; HYDROLOGY; First edition, John Wiley and Sons, New York, 1954.

6. Foster, H. A.; RAINFALL AND RUNOFF; First edition, MacMillan, New York, 1948.

7. Linsley, R. K., Kohler, M.A., Paulhus, J. L. H.; APPLIED HYDROLOGY; First edition, McGraw-Hill, New York, 1949.

8. Trefethen, Joseph M.; GEOLOGY FOR ENGINEERS; First edition, D. Van Nostrand, Inc., New York, 1950.

9. Terzaghi, Karl and Peck, Ralph B.; SOIL MECHANICS IN ENGINEERING PRACTICE; First edition, John Wiley and Sons, New York, 1948.

10. REPORT ON INVESTIGATIONS INTO MEASURES FOR THE REDUCTION OF THE FLOOD HAZARD IN THE GREATER WINNIPEG AREA, APPENDIX "C"; Red River Basin Investigation, Water Resources Division, unpublished manuscript, 1953.

11. Mitchell, J. Moss, H. C. and Clayton, J. S.; Soil Survey of Southern Saskatchewan from Township 1 to 48 Inclusive, SOIL SURVEY REPORT NO. 12; Saskatchewan Department of Agriculture, 1947.

12. Ehrlich, W. A., Poyser, E. A., Pratt, L. E., and Ellis, J. H.; RECONNAISSANCE SOIL SURVEY OF WINNIPEG AND MORRIS MAP SHEET AREAS; Manitoba Soil Survey, Manitoba Department of Agriculture.

13. and 14. Ellis, J. H. and Shafer, Wm. H.; RECONNAISSANCE SOIL SURVEY OF SOUTH-CENTRAL MANITOBA and RECONNAISSANCE SOIL SURVEY OF SOUTH-WESTERN MANITOBA; Manitoba Soil Survey, Manitoba Department of Agriculture.

15. Irmay, S.; ON THE HYDRAULIC CONDUCTIVITY OF UNSATURATED SOILS; Transactions of the American Geophysical Union, Volume 35, No. 3, June 1954.

16. Reinhart, R. G. and Taylor, R. E.; INFILTRATION AND AVAILABLE STORAGE CAPACITY IN THE SOIL; Transactions of the American Geophysical Union, Volume 35, No. 5, October 1954.

17. Clark, R. H.; PREDICTING THE RUNOFF FROM SNOWMELT; pp. 434 - 441, The Engineering Journal, Volume 38, No. 4, April 1955.