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DEPARTMENT OF MINES AND NATURAL RESOURCES

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HYDROMETEOROLOGICAL NETWORKS AND FLOOD FORECASTING PROCEDURES FOR OPERATION OF THE RED RIVER FLOODWAY

Winnipeg, Manitoba,
October, 1971.

Prepared by:
Planning Division.

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INTRODUCTION

The Red River has a history of periodic flooding which has caused, from time to time, large property damage and human misery to the people of Manitoba. After the major flood during the spring of 1950, a concerted effort was made to develop methods whereby some advance warning could be given of potentially dangerous flood situations. A full-scale study of the Red River was undertaken by the Canada Department of Resources and Development, entitled "Red River Basin Investigation" (R.R.B.I.). Although a few modifications and additions have been made by the Manitoba Water Resources Branch, the methods outlined in the R.R.B.I. report are still being used for flood forecasting in conjunction with the operation of the Red River Floodway.

To facilitate the efficient operation of flood control works and to supply as much advance flood danger warning as possible, a Flood Forecasting Committee was established in 1954. The Committee is composed of technically qualified representatives of all three levels of government who scrutinize and approve all information obtained from contributing agencies in both Canada and the United States and on the basis of these data, prepare forecasts of spring runoff potential for use of the Government of Manitoba. Although the main concern of the Committee is flooding on the Red River, spring peaks are also forecast on the main tributary of the Red River in Manitoba - the Assiniboine River. The Committee holds two regular meetings each year - one in February and one in March and as many more meetings as are deemed necessary depending on the severity of flood conditions from year to year. It is the aim of this report to describe the methods used in deriving these flood forecasts.

The drainage basin of the Red and Assiniboine Rivers, together with existing flood control works and dams, is shown on Figure 1.

HYDROMETEOROLOGICAL NETWORKS FOR OPERATION OF THE RED RIVER FLOODWAY

1. Precipitation

Precipitation data in the Canadian portion of the Red River and Assiniboine River Basins are compiled by the Water Resources Branch of the Manitoba Department of Mines and Natural Resources from the network of climatological and meteorological stations maintained by the Meteorological Branch, Canada Department of Transport. Precipitation data from the portion of Red River Basin in the U.S.A. is compiled from the climatological station network maintained by the Environmental Science Service Administration (E.S.S.A.), United States Department of Commerce. The stations in these networks used in connection with operation of the Floodway are shown in Tables I and II.

2. Soil Moisture

Soil moisture throughout the Canadian portion of the Red River Basin at freeze-up each year is determined by the Manitoba Water Resources Branch. These surveys began in 1955. The locations of soil moisture survey stations in the Red River Basin, excluding the Assiniboine River Basin, are shown in Table III. The Soil Moisture network in the Assiniboine River Basin is shown in Table IV.

3. Snow Survey

Snow surveys are conducted by the Manitoba Water Resources Branch in mid-February and mid-March throughout Manitoba and portions of Saskatchewan. These surveys began in 1952. The locations of the snow survey stations in the Red River Basin are shown in Table V. Table VI lists the snow survey stations in the Assiniboine River Basin.

In addition to the snow surveys undertaken by the Manitoba Water Resources Branch, data are obtained from the snow survey network maintained by

E.S.S.A. in the U.S. portion of the Red River Basin. Stations comprising this network are listed in Table VII.

4. Hydrometric

A hydrometric network is co-operatively maintained in the Canadian portion of the Red River Basin by the Water Survey of Canada and the Manitoba Water Resources Branch.

The hydrometric stations from which up to date data are collected and compiled by the Water Resources Branch in the Canadian portion of the Red River Basin insofar as operation of the Red River Floodway is concerned are shown in Tables VIII and IX.

In the United States portion of the Red River Basin a comprehensive hydrometric network is maintained by the United States Geological Survey. The stations in this network from which data are compiled by the Manitoba Water Resources Branch are shown in Table X.

In addition to the above information, more intensive information on the above-named parameters is obtained from four small watersheds within the Red River Basin and two small watersheds in the Assiniboine River Basin which are used as index areas to provide early indications of the rate and amount of runoff from the winter snow pack. These index areas are described in detail in the following section.

FLOOD FORECASTING PROCEDURES - RED AND ASSINIBOINE RIVERS

A. Preliminary Forecasts (prepared in Late February and Late March)

1. Red River

a) Evaluation of Forecast Parameters

(i) Soil Moisture and Snow Surveys

Soil moisture survey information has not been used quantitatively in the forecast system to date. However, it does provide a qualitative assessment of the moisture conditions of the watershed near the time of freeze-up. Similarly, the results of snow surveys are not being used directly in the models developed for forecasting runoff. However, the information is critically examined and estimates of potential runoff are made using a range of runoff coefficients and these results are compared to the forecasts derived from the runoff-precipitation model. The snow survey results also give an indication of the over-winter depletion of the snow pack, which can be quite substantial under certain meteorological conditions.

(ii) Soil Priming Index

For the Red River Basin, winter streamflow at Emerson measured by the Water Survey of Canada is used as an index of antecedent soil moisture conditions. Natural flows are computed using information on reservoir releases supplied by the United States Army Corps of Engineers at St. Paul Minnesota. Mean monthly natural flows at Emerson are determined for the months of October through January. The sum of these monthly flows is then compared to the long-term mean of natural flows for this period. Expressed as a percent, this constitutes the Soil Priming Index for the Red River Basin above Emerson.

(iii) Winter and Spring Precipitation

Monthly winter precipitation for the Red River Basin above Emerson is determined by the Thiessen Polygon Method using the stations listed in

Table I. The period of accumulation is assumed to be from the time of freeze-up to March 31st. Unless the time of freeze-up comes unusually late, the total precipitation for the month of November is included into the estimate of the snowpack. Since the preliminary forecasts are issued prior to March 31st, it is necessary to estimate the snowfall from the time of the forecast until March 31st. This estimate simply consists of the long term mean precipitation for the period in question. In addition, precipitation during the melt period must also be estimated. This estimate is made on the basis of melt period precipitation which has occurred during the period 1915 to date.

(iv) Melt Index

The degree-day method with a base of 32 degrees is used. A mass curve of degree-days is drawn for the index station which is Fargo, North Dakota. Preliminary forecasts make use of the average melt index for the period 1915 to date.

b) Preliminary Forecast Procedures

(i) Graphical Method

Forecasts of runoff volume at Emerson are prepared using the graphical model in the R.R.B.I. report. This co-axial relationship is shown on Figure 2. The four parameters required to forecast the runoff are determined by the methods outlined above. Two values of runoff are calculated according to two conditions:

Condition 1 - Normal precipitation and temperatures during melt period.

and Condition 2 - (somewhat more severe) - Precipitation and temperatures during melt period = $\frac{1}{2}$ Normal + $\frac{1}{2}$ Maximum on Record.

Applying these forecasts of runoff to a unit hydrograph developed from data presented in the R.R.B.I. report and shown in Table XI, and by adding the estimated base flow of 2000 cfs., a peak flow at Emerson is obtained. The

corresponding peak stage is computed from stage-discharge data provided by the Water Survey of Canada. A peak stage relationship, which has been modified from that in the R.R.B.I. report to take cognizance of rating curve changes since 1950, is used to estimate the peak stage at Winnipeg that would result without flood control works. The peak stage relationship is shown on Figure 3. The effect of flood control works is computed and a forecast is made for the peak stage at Winnipeg.

(ii) Statistical Method

A statistical analysis of 30 high flow years of the Red River at Emerson was carried out by the Water Resources Branch in 1970. The 30 cases were selected from the period of record between 1913 and 1970. The following parameters, used as independent variables in the multi-linear regression analyses, were evaluated for the Red River Basin above Emerson:

(M.I.) Melt Index

(W.P.) Winter Precipitation

(M.P.) Melt Period Precipitation

(S.I.) Soil Priming Index

Melt indices were determined from mass diagrams of degree-days at Grand Forks, North Dakota; degree-days were calculated on a base of 32 degrees. Precipitation over the basin was found on a monthly basis (or parts of a month when necessary) by calculating the arithmetic mean of the available records. The arithmetic mean was used for simplicity after several test cases revealed little difference between this and the corresponding values obtained by the Thiessen Polygon method. The period of snow accumulation was taken from the time of freeze-up to the break-up. For the analysis of peak flows, precipitation occurring later than two days prior to the date of the peak was excluded from the melt period precipitation. Values for the

Soil Priming Index were calculated from natural flows at Emerson in the same manner as in the graphical method.

The following predictive equations resulted from the analysis:

Eqn. 1 Runoff = -1.04655 - 0.0096 (M.I.) + 0.27292 (W.P.) (inches) + 0.35696 (M.P.) + 0.00239 (S.I.)

Multiple correlation coeff. = 0.89
Standard Error of Estimate = 0.28

Eqn. 2 Peak = -25488 + 729 (M.I.) + 9404 (W.P.) + 12944 (M.P.) + 75 (S.I.) (cfs.)

Multiple correlation coeff. = 0.85
Standard Error of Estimate = 9455

The estimated peak flow at Emerson is obtained either directly from equation 2 or by applying an appropriate unit hydrograph to the forecast runoff. The peak stage at Winnipeg is then estimated as described under "Graphical Method".

2. Assiniboine River

a) Evaluation of Forecast Parameters

(i) Soil Moisture and Snow Surveys

As in the case of the Red River Basin, the results of these surveys have not been used directly in forecasting up to this time, but provide useful, qualitative information.

(ii) Ground Water Index

An index of antecedent soil moisture conditions is obtained from the precipitation stations listed in Table II. The method used generally follows procedures as outlined in "Report - Conservation and Flood Control - Assiniboine River" prepared by the Prairie Farm Rehabilitation Administration (P.F.R.A.) in 1952. Monthly precipitation for the months June - October is determined by the Thiessen Polygon method. The monthly precipitation values are then weighted by the following multiplying factors:

June	X 0.2
July	X 0.4
August	X 0.6
September	X 0.8
October	X 1.0

The sum of the weighted values is then compared to the same long-term mean value to obtain a percent of normal which constitutes the ground water index for that year.

(iii) Accumulated Precipitation

This parameter is calculated as outlined in the P.F.R.A. report in the following manner:

Accumulated precipitation = Pw + 2Pms + Pmr

where Pw = winter precipitation

Pms = snowfall during the melt period

Pmr = rainfall during the melt period.

Monthly precipitation is determined by the Thiessen Polygon method using the precipitation stations listed in Table II. The period of snow accumulation for Pw is assumed to be November 1st to March 31st. As in the case of the Red River procedures, snowfall from the time of the forecast to March 31st is obtained from long-term means. Values of Pms and Pmr used in preliminary forecasts are their long term mean.

(iv) Melting Index

The following relationships as outlined in the P.F.R.A. report are used:

Melting Index = Ti + 2Pmr $\pm$ (Z x 0.2)

where Ti = temperature index based on average number of degree-days/day for 16 index stations during the melt period (base 32 degrees)

Z = number of days before or after April 11th that the middle of the melting period occurred.

Preliminary forecasts make use of the long term mean melting index.

b) Preliminary Forecast Procedures

(1) Graphical Model

The graphical relationship developed in the 1952 P.F.R.A. report

is used to derive the most probably runoff coefficient. This relationship is shown on Figure 4. Three parameters are entered into the graphical model and these are calculated as outlined above. The runoff coefficient thus derived is used to compute the runoff based on the snowpack. Estimates of peak flow at Brandon, Portage la Prairie and Headingley are computed by means of basic hydrographs and peak stage relationships. Table XII shows basic hydrographs for various sub-basins within the Assiniboine River watershed. Millwood Rivers and Brandon hydrographs are used in conjunction with the curve for Basins 1 to 5 in Figure 4, while Tantallon and Wawanesa are used with the curve for Basins 6 to 10.

(ii) Additional Forecast Procedures

A forecast procedure for the drainage area of the Assiniboine River between Brandon and Portage la Prairie was developed by the Water Resources Branch in 1970. Multiple linear regression analyses were carried out on data from 15 flood years during the period 1923-1969. The following four parameters are used as independent variables in the analyses:

(M.I.) Melt Index

(W.P.) Winter Precipitation

(M.P.) Melt Period Precipitation

(A.P.I.) Antecedent Precipitation Index

One of the predictive equations derived is as follows:

Runoff = 0.53920 - 0.14398 (M.I.) + 0.52438 (W.P.)

(inches) + 0.20948 (M.P.) + 0.40816 (A.P.I.)

Multiple Correlation coefficient = 0.97

Standard Error of Estimate = 0.10

For preliminary forecasts, M.I., M.P. and a small part of W.P. are estimated from their long-term mean. The runoff thus calculated is applied

to an appropriate unit hydrograph to yield the forecast hydrograph of flow for the drainage area. Estimated flows of the Assiniboine River at Brandon and the Souris River at Wawanesa are routed by the Muskingum method to Portage la Prairie and added to the forecast hydrograph obtained above to yield the final anticipated flows at Portage la Prairie.

3. Accuracy of Preliminary Forecasts

The graphical model used in preliminary forecasting of runoff volumes for the basin of the Red River above Emerson, shows a correlation of 0.88 between the forecast and actual values. This correlation is based upon a sample of 34 years of data in which the parameters used in the model were calculated from known data. The standard error of estimate is 0.28 inches of runoff while the mean runoff is 0.87 inches.

The correlation between actual peak flows at Emerson and those forecast during March according to Condition 1 is 0.71. This correlation is based upon seventeen spring forecasts issued since 1954. The standard error of estimate is 12,980 c.f.s. and the mean peak is 26,650 c.f.s.

The correlation between actual peak flows on the Assiniboine River at Headingley and the March forecast peak according to Condition 1 is 0.91 . The standard error of estimate is 2,330 c.f.s. and the mean peak for the seventeen cases is 10,820 c.f.s.

A summary of forecast and actual peak flows for the Red River at James Avenue in Winnipeg is shown on Figure 5. The histograms labelled "NORMAL" and "EXTREME" refer to Conditions number 1 and 2 respectively, as explained under Preliminary Forecast Procedures of the Red River.

The accuracies of the statistical forecast methods are indicated above, together with their predictive equations. It should be emphasized that the statistical method has not been used thus far in issuing preliminary

forecasts on the Red River, rather the graphical method is used.

Errors in preliminary forecasts have no effect on the operation of the Red River Floodway since the actual operation of flood control works is based upon operational forecasts which are described in the following sections.

B. Operational Forecasts (When Runoff Has Commenced)

1. Red River

a) U.S. Data

E.S.S.A. forecasts for Emerson are generally used although modificiations may be made after interpretation of hydrometric data from stations shown in Table X. During major floods, the Water Resources Branch has an employee stationed at Fargo to provide liaison between United States agencies and the Manitoba Water Resources Branch and to ensure that pertinent up-to-date information is exchanged.

b) Index Areas

A very useful tool in runoff forecasting from snow melt is the index area. This is particularly true in large basins having prolonged runoff characteristics such as the Red and Assiniboine River Basins. Runoff from snow melt in small tributary drainage basins is usually over well before the time when runoff is well advanced over the whole basin. By measuring the available snowpack along with the precipitation during the runoff period and comparing the available moisture to the measured runoff, the percentage runoff is determined. The runoff coefficient thus obtained can be applied over large areas and an appraisal can be made of the expected runoff and peak flows.

To provide an estimate of runoff coefficients in the Red River Basin, four index areas are used: the south branch of the Buffalo River

at Sabin, Minnesota; the Tongue River at Akra, North Dakota; Dead Horse Creek at Morden, Manitoba; and Rosengart Coulee near Sarto, Manitoba. Detailed snow surveys are made on these areas just prior to runoff. These are followed by an intensive hydrometric program after runoff has commenced. Estimates of the runoff coefficient are made and corrected as runoff progresses. These runoff coefficients are applied to larger areas and estimates of peak flows at various points along the Red River are made. The Tongue River and Rosengart Coulee have not proven as satisfactory as the South Branch of the Buffalo River and Dead Horse Creek and an attempt will be made to establish more satisfactory index areas in these vicinities.

c) Hydrometric Data

Hydrometric data are obtained at the stations shown in Table VIII. These data are used in updating and modifying forecast magnitude and date of peak flows on the Red River.

d) Canadian Tributary Runoff

An estimate of the tributary runoff hydrographs for those major streams downstream from Emerson is made using snow survey data and various runoff coefficients. Unit hydrographs shown in the R.R.B.I. report are used for the western tributaries, whereas unit hydrographs as revised by the Manitoba Water Resources Branch are used for the eastern tributaries. As the runoff progresses and data as to the runoff situation becomes available, forecast tributary runoff is adjusted.

e) River Routing

Routings are undertaken on a digital computer using the Muskingum method. Emerson flows, tributary flows and estimated ungauged flows are routed from Emerson to Ste. Agathe and from Ste. Agathe to Winnipeg. The flows thus derived are added to the expected natural flows on the Assiniboine

River at Headingley and to local gauged and ungauged flows entering the system near Winnipeg to derive the total flow and associated stage at Winnipeg which would have resulted without the use of flood control works. The flow to be diverted through the Red River Floodway is then determined in a manner which ensures that water levels above the floodway inlet will not exceed levels which would have occurred under natural conditions. The remaining flow through the City is added to the anticipated flow on the Assiniboine River after the effects of the Shellmouth Reservoir and the Portage Diversion have been considered. This yields the anticipated flow and associated stage at Winnipeg with flood control works in use.

2. Assiniboine River

Hydrometric gauging stations for the Assiniboine River are listed in Table IX. The preliminary forecast issued in March is updated using hydrometric data as it arrives. Oak Creek near Stockton and Conjuring Creek near Russell are closely observed as index areas as a check on melt rates and runoff coefficients. Hydrometric data are assembled each day from the stations listed in Table IX, and runoff rates are modified daily on the basis of these data.

Flashy runoff frequently results from the drainage area of the Assiniboine River between Brandon and Portage la Prairie. The forecast procedures for this area, described under "Preliminary Forecasts" are applied to facilitate operation of the Portage Diversion.

A river routing procedure to be used in the operational forecasting of the Assiniboine River flood flows is being developed at the present time.

3. Accuracy of Forecasts

Since operational forecasts are revised from day to day as necessary, it is difficult to describe the accuracy of these forecasts. However, it would be correct to say that generally the earlier operational forecasts verify better than the preliminary forecasts and that the accuracy of the operational forecasts increases with time as more information becomes available. The operation of the Red River Floodway as well as of other flood control works is based on the flood situation at the time and on the latest available forecasts.

TABLE I

Precipitation Stations - Red River Basin

U.S. Portion

Ada
Adams
Amenia
Angus
Argyle
Campbell
Colgate
Cooperstown
Crookston
Detroit Lakes
Elbow Lake
Enderlin
Fargo
Fergus Falls
Fosston
Forman
Gonvick
Goodridge
Grafton
Grand Forks
Hallock
Hankinson
Harvey
Hawley
Herman
High Landing
Hillsboro
Langdon
Larimore
Lisbon
Litchville
Mahnomen
Mayville
McHenry
McLeod
McVille
Oklee
Ottertail
Park River
Pelican Rapids
Pembina
Petersburg
Red Lake Falls
Red Lake Ind. Ag.
Roseau
Sharon
Sheyenne
Thief Lake Refuge
Thief River Falls
Trail
Valley City
Wahpeton
Wheaton

Canada Portion

Altona
Boissevain
Emerson
Graysville
Morden (Exp. Farm)
Morris (Exp. St.)
Ste. Genevieve
Sprague
Winnipeg

TABLE II

Precipitation Stations - Assiniboine River Basin

Baldur
Birtle
Bottineau
Brandon
Broadview
Carberry
Carlyle
Caron
Ceylon
Chaplin
Crosby
Cypress River
Davidson
Dauphin
Deerwood
Dilke
Estevan
Francis
Foam Lake
Grenfell
Hubbard
Indian Head
Kamsack
Lumsden
Melita
Midale
Minnedosa
Minor
Mohall
Moose Jaw
Ninette
Pilger
Portage la Prairie
Regina
Rivers
Rugby
Russell
Semans
Souris
St. Alphonse
Strasbourg
Towner
Treherne
Tugaske
Virden
Waskada
Whitewood
Yellowgrass
Yorkton

TABLE III

Soil Moisture Stations - Red River Basin in Manitoba.

Station No.	Station Location
R - I - 1	St. Norbert
R - I - 2	Fannystelle
R - I - 3	Rathwell
R - I - 4	Killarney
R - I - 5	Turtle Mountain
R - I - 6	Morden
R - I - 7	Lowe Farm
R - I - 8	Letellier
R - I - 9	La Riviere
R - II - 1	Ste. Anne
R - II - 2	Steinbach
R - II - 3	Dominion City
R - II - 4	Stuartburn

TABLE IV

Soil Moisture Stations

Assiniboine River Basin in Manitoba and Saskatchewan

Station No.	Station Location
A - I - 1	Millwood
A - I - 2	Runnymede
A - I - 3	Yorkton
A - I - 4	Canora
A - I - 5	Theodore
A - II - 1	Broadview
A - II - 2	Lipton
A - II - 3	Regina
A - III - 1	Melita
A - III - 2	Carlyle
A - III - 3	Benson
A - III - 4	Estevan
A - III - 5	Weyburn
A - III - 6	Radville
A - IV - 1	Brandon
A - IV - 2	Shoal Lake
A - IV - 3	Virden
A - IV - 4	Moosomin
A - V - 1	Minnedosa
A - V - 2	Wasagaming
A - VI - 1	Portage la Prairie
A - VI - 2	Cypress River

TABLE V

Snow Survey Stations - Red River Basin in Manitoba

Station No.	Station Location
C - 1	Fannystelle
C - 2	Rathwell
C - 12	Turtle Mountain
C - 13	Killarney
C - 14	La Riviere
C - 15	La Riviere
C - 16	Morden
C - 17	Carman
C - 18	St. Norbert
D - 12	Gretna
D - 13	Morris
D - 1	Beausejour
D - 7	Ste. Anne
D - 8	Sandilands F.R.
D - 9	Vassar
D - 10	Stuartburn
D - 11	Dominion City
D - 14	St. Pierre

TABLE VI

Snow Survey Stations

Assiniboine River Basin in Saskatchewan and Manitoba

Station No. 1	Station Location
A - 15	Watson
A - 17	Wynyard
A - 18	Sheho
A - 19	Yorkton
B - 6	Russell
B - 7	Roblin
B - 8	Madge Lake S.
B - 9	Madge Lake N.
B - 10	Kamsack
B - 11	Canora
B - 12	Tall Pines, Porcupine F.R.
A - 9	Broadview
A - 10	Indian Head
A - 11	Regina
A - 12	Moose Jaw
A - 13	Penzance
A - 14	Watrous
A - 20	Churchbridge
A - 6	Kenton
A - 7	Virden
A - 8	Moosomin
B - 4	Shoal Lake
B - 5	Birtle
B - 3	Minnedosa
B - 26	Riding Mountain
B - 27	Wasagaming
A - 5	Rivers
C - 4	Wawanesa
C - 5	Souris
C - 6	Sinclair
C - 7	Carlyle
C - 8	Hume
C - 9	Estevan
C - 10	Oxbow
C - 11	Melita
A - 1	Portage la Prairie
A - 4	Brandon
C - 3	Cypress River

TABLE VII

Snow Survey Stations - Red River Basin in the United States

Abercrombie
Crookston
Fargo
Grand Forks
High Landing
Pembina
Wahpeton
Bald Hill
White Rock Dam
Park River
Ada
Argyle
Cavalier
Amenia
Agassiz Refuge
Campbell
Chaffey
Colgate
Detroit Lakes
Halstad
Drayton
Fosston
Foreman
Hallock
Larimore
Lisbon
Mayville
Mahnomen
McLeod
Thief River Falls
Walhalla
Valley City

TABLE VIII

HYDROMETRIC STATIONS - RED RIVER BASIN IN CANADA

Red River

	Station No.	Latitude	Longitude
James Ave. Pumping Station		49° 53' 56"	97° 07' 47"
South Perimeter Bridge		49° 47' 10"	97° 08' 13"
Below Floodway Inlet		49° 45' 20"	97° 08' 10"
Above Floodway Inlet		49° 45' 10"	97° 08' 00"
St. Adolphe		49° 40' 27"	97° 06' 55"
Ste. Agathe	050C012	49° 33' 40"	97° 10' 52"
Morris	050C006	49° 21' 30"	97° 21' 00"
St. Jean		49° 16' 07"	97° 20' 56"
Letellier	050C010	49° 07' 54"	97° 15' 16"
Emerson	050C001	49° 00' 30"	97° 12' 40"
Aubigny		49° 27' 34"	97° 16' 15"

Red River Tributaries

Roseau River @ Langside Bridge	050D001	49° 11' 53"	97° 03' 15"
Roseau River @ Gardenton	050D004	49° 05' 16"	96° 41' 15"
Roseau River @ International Building	050D007	49° 00' 10"	96° 29' 40"
Seine River Diversion @ P.T.H. #59	050H008	49° 41' 40"	96° 59' 19"
Seine River @ Prairie Grove	050H006	49° 46' 15"	96° 56' 10"
Seine River @ P.T.H. #59		49° 45' 53"	97° 01' 42"
Prairie Grove Drain @ P.T.H. #59		49° 41' 40"	96° 59' 19"
Main Drain 4A @ Dominion City	050D028	49° 08' 01"	97° 08' 42"
La Salle River E 33-8-2E		49° 41' 38"	97° 15' 48"
La Salle River @ Sanford	050G001	49° 40' 52"	97° 25' 48"
La Salle River @ Elie		49° 54' 48"	97° 45' 27"
Morris River @ Morris	050F001	49° 21' 50"	97° 22' 15"
Plum River @ St. Jean		49° 16' 04"	97° 21' 12"
Tourond Creek @ P.T.H. #59		49° 31' 50"	96° 58' 50"
Rat River @ Otterbourne	050E001	49° 27' 42"	97° 00' 26"
Dead Horse Creek @ Morden	050C015	49° 11' 34"	98° 06' 40"
Rosengart Drain NE 32-5-6E		49° 26' 48"	96° 44' 01"
Rosengart Drain E 26-5-6E		49° 24' 31"	96° 39' 40"
Rosengart Drain E of P.T.H. 12		49° 23' 38"	96° 41' 02"
Rosengart Drain S 35-5-6E		49° 24' 54"	96° 40' 48"

TABLE IX

HYDROMETRIC STATIONS - ASSINIBOINE RIVER BASIN

Assiniboine River

	Station No.	Latitude	Longitude
Kamsack	05MD004	51° 33' 38"	101° 54' 40"
Shellmouth Dam		50° 57' 58"	101° 25' 21"
Roblin		51° 13' 38"	101° 38' 39"
Millwood		50° 41' 25"	101° 26' 09"
Russell	05ME001	50° 48' 35"	101° 26' 10"
St. Lazare		50° 26' 38"	101° 20' 10"
Virden		49° 50' 31"	100° 48' 01"
Griswold		49° 50' 33"	100° 27' 20"
Brandon	05MH001	49° 51' 02"	99° 56' 12"
Holland	05MH005	49° 41' 40"	98° 53' 20"
Portage la Prairie	05MJ003	49° 56' 09"	98° 16' 48"
Baie St. Paul		50° 02' 37"	97° 52' 11"
Headingly	05MJ001	49° 52' 09"	97° 24' 10"
Hood Bridge		49° 51' 38"	98° 26' 43"
Southport		49° 56' 06"	98° 16' 56"
Miniota	05ME006	101° 02' 08"	50° 06' 39"
Rossendale	05MJ005	49° 45' 32"	98° 38' 32"

Assiniboine River Tributaries

Au'Appelle River @ Tantallon	05MJ003	50° 31' 58"	101° 50' 13"
Minnedosa River @ Minnedosa	05MF001	50° 21' 28"	99° 54' 00"
Minnedosa River @ Rivers	05MF020	50° 01' 37"	100° 01' 58"
Souris River @ Wawanesa	05NG001	49° 36' 05"	99° 40' 55"
Sturgeon Creek near Grace Hospital	05MJ004	49° 52' 35"	99° 02' 00"

TABLE X

Hydrometric Stations - Red River Basin in the United States

Marsh River	@ Ada
Marsh River	@ Shelley
Wild Rice River	@ Ada
Wild Rice River	@ Abercrombie
Wild Rice River	@ Twin Valley
Sandhill River	@ Climax
Clearwater River	@ Red Lake Falls
Clearwater River	@ Plummer
Lost River	@ Oklee
Little Pembina R.	near Walhalla
Sheyenne River	@ Kindred
Sheyenne River	@ Cooperstown
Sheyenne River	@ Lisbon
Sheyenne River	@ Valley City
Sheyenne River	@ West Fargo
Sprague River	@ Sprague
Buffalo River	@ Dillworth
Buffalo River	@ Hawley
Buffalo River	@ Sabin
Buffalo River	@ Downe
Wild Rice River	@ Hendrum
Cart Creek	@ Mountain
Cart Creek	@ Crystal
Forest River	@ Whitman
Forest River	@ Fordville
Forest River	@ Minto
Park River	@ Union
Park River	@ Grafton
Park River (N.Br.)	@ Garden
Park River (S.Br.)	@ below Homme Dam
Park River	@ Adams
Maple River	@ Hope
Maple River	@ Mapleton
Antelope Creek	@ Dwight
Rush River	@ Armenia
Middle River	@ Argyle
Ruffy Brook R.	@ Manvel
Rapid River	@ Baudette
Red Lake River	@ Gooderich
Red Lake River	@ Crookston
Red Lake River	@ Red Lake
Herzog Creek	@ Concrete
Tongue River	@ Akra
Goose River	@ Mayville
Goose River	@ Portland
Goose River	@ Hillsboro
Moose River	@ Gatze
Thief River	@ Thief River Falls
S. Branch Two Rivers	@ Pelon
S. Branch Two Rivers	@ Lake Bronson
S. Branch Two Rivers	@ Hallock
Red River	@ Grand Forks
Red River	@ Fargo
Red River	@ Oslo
Red River	@ Drayton
Red River	@ Wahpeton
Red River	@ Halstad
Red River	@ Pembina
Roseau River	@ Roseau Lake
Roseau River	@ Roseau
Roseau River	@ Badger
Roseau River	@ Caribou
Roseau River	@ Ross
Roseau River	@ Malung
Roseau River	below South Forks

TABLE XI

Unit Hydrographs at Emerson, Manitoba

(Based on Plates 19 and 20 Appendix C - R.F.B.I. 1952)

Day	Time-Base of Unit Hydrograph						
	12-Hour c.f.s.	24-Hour c.f.s.	36-Hour c.f.s.	48-Hour c.f.s.	60-Hour c.f.s.	72-Hour c.f.s.	84-Hour c.f.s.
0	0	0	0	0	0	0	0
1	500	350	250	190	150	120	110
2	1,200	1,000	830	690	550	460	390
3	2,800	2,450	2,030	1,730	1,340	1,160	990
4	5,100	4,550	3,970	3,500	3,040	2,670	2,360
5	8,300	7,500	6,700	6,030	5,380	4,830	4,310
6	12,700	11,600	10,500	9,550	8,660	7,880	7,160
7	18,200	16,800	15,530	14,280	13,080	12,020	11,030
8	23,300	22,250	20,900	19,600	18,220	16,930	15,700
9	29,400	28,100	26,500	25,180	23,780	22,430	21,470
10	32,600	32,050	31,160	30,080	28,720	27,370	26,140
11	34,400	34,100	33,600	33,080	32,310	31,420	30,260
12	36,300	35,900	35,400	35,000	34,520	34,020	33,360
13	35,300	35,600	35,800	35,750	35,480	35,200	34,830
14	34,300	34,600	34,800	35,100	35,340	35,370	35,230
15	32,400	32,850	33,300	33,730	34,040	34,350	34,630
16	29,900	30,500	31,100	31,680	32,200	32,650	33,030
17	26,800	27,500	28,300	29,000	29,680	30,280	30,860
18	23,900	24,550	25,300	26,030	26,800	27,520	28,210
19	21,200	21,850	22,500	23,200	23,920	24,630	25,290
20	19,100	19,550	20,100	20,700	21,340	21,980	22,670
21	17,400	17,700	18,200	18,630	19,140	19,700	20,300
22	15,300	15,800	16,300	16,750	17,220	17,680	18,190
23	13,700	14,050	14,500	14,930	15,420	15,850	16,310
24	12,600	12,800	13,000	13,330	13,800	14,220	14,670
25	11,300	11,600	12,000	12,200	12,500	12,820	13,170
26	10,300	10,550	10,800	11,080	11,380	11,650	11,940
27	9,500	9,700	9,900	10,130	10,360	10,620	10,900
28	8,800	9,000	9,200	9,350	9,540	9,750	9,830
29	8,200	8,300	8,500	8,650	8,820	9,000	9,190
30	7,500	7,650	7,800	7,980	8,140	8,320	8,490
31	7,100	7,200	7,300	7,430	7,580	7,720	7,870
32	6,600	6,700	6,800	6,950	7,060	7,180	7,330
33	6,200	6,250	6,400	6,480	6,600	6,720	6,830
34	5,700	5,800	5,900	6,030	6,140	6,250	6,370
35	5,400	5,500	5,600	5,650	5,760	5,850	5,910
36	5,100	5,200	5,270	5,300	5,420	5,500	5,600
37	4,800	4,850	4,930	5,030	5,100	5,180	5,260
38	4,500	4,600	4,670	4,730	4,800	4,880	4,960
39	4,200	4,250	4,330	4,430	4,500	4,570	4,640
40	3,900	3,950	4,030	4,100	4,180	4,270	4,340
41	3,700	3,750	3,800	3,850	3,920	3,980	4,060
42	3,400	3,500	3,570	3,630	3,680	3,730	3,800
43	3,200	3,250	3,300	3,380	3,440	3,500	3,560
44	3,000	3,050	3,100	3,150	3,200	3,270	3,330
45	2,800	2,850	2,900	2,950	3,000	3,050	3,100

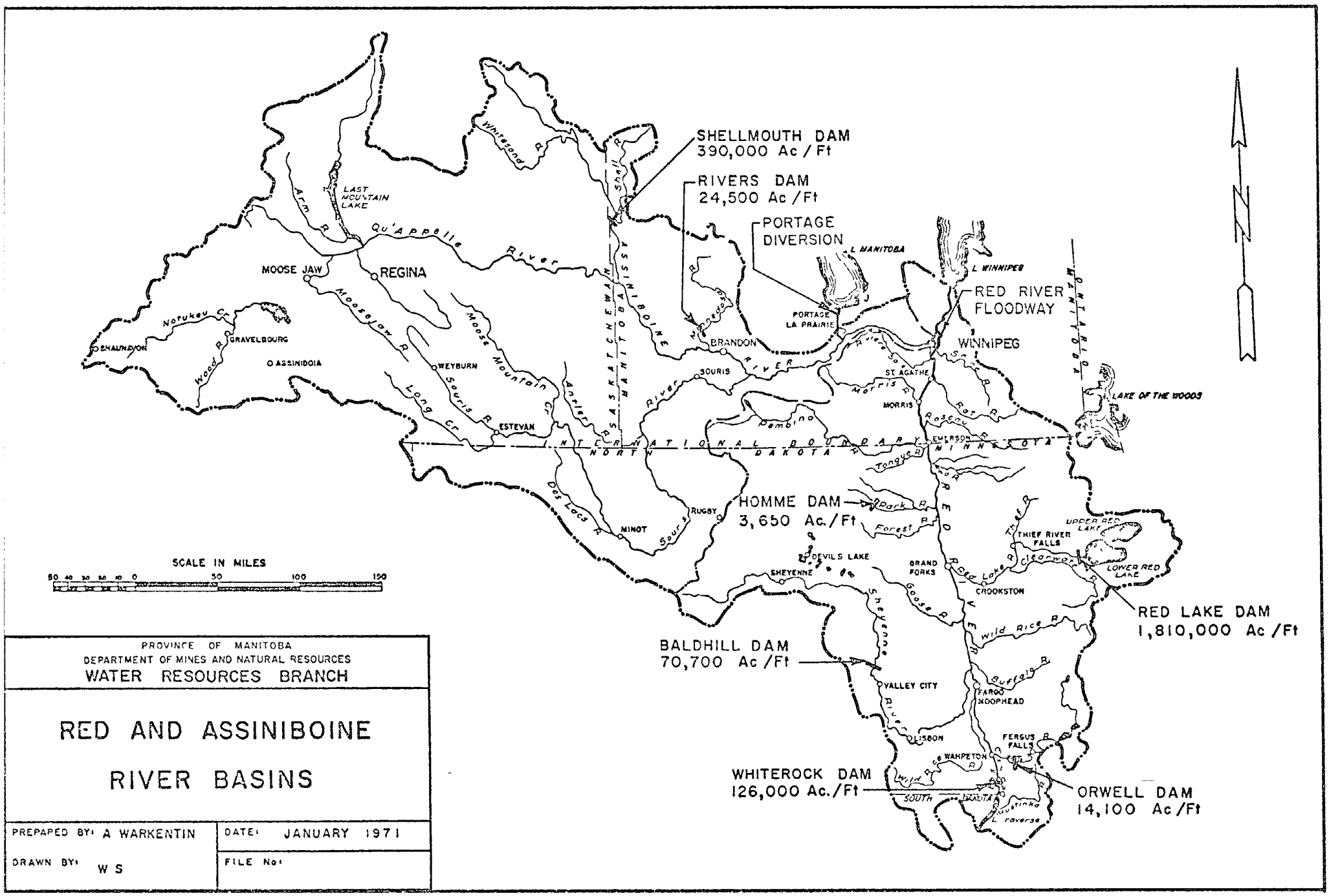
TABLE XII

Basic Hydrographs for Sub-Basins of the Assiniboine River

(Based on 1952 P.F.R.A. Report)

Runoff Equivalent in C.F.S per Square Mile

Day	Millwood	Brandon	Rivers	Tantallon	Wawanesa
0	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00
4	0.00	0.10	0.00	0.00	0.00
5	0.00	0.16	0.00	0 00	0.00
6	0.00	0.24	0.00	0.00	0.00
7	0.03	0.32	0.00	0.00	0.00
8	0.06	0.42	0.04	0.00	0.00
9	0.08	0.54	0.08	0.00	0.01
10	0.12	0.70	0.13	0.00	0.02
11	0.15	0.92	0.18	0.00	0.03
12	0.20	1.38	0.24	0 00	0 05
13	0.24	1.80	0.30	0 00	0.06
14	0.30	2.18	0.38	0.03	0.08
15	0.37	2.51	0.44	0.06	0.10
16	0.45	2.36	0.54	0.10	0.12
17	0.60	2.18	0.61	0.13	0.16
18	0.78	1.96	0.70	0.18	0.20
19	1.04	1.70	0.82	0.24	0.24
20	1.30	1.34	1.00	0.26	0.30
21	1.54	1.04	1.50	0.29	0.37
22	1.72	0.90	1.80	0.31	0.44
23	1.64	0.77	1.74	0.34	0.52
24	1.55	0.66	1.68	0.37	0.58
25	1.35	0.59	1.60	0.39	0.59
26	1.19	0.51	1.50	0.42	0.60
27	1.08	0.45	1.38	0.44	0 90
28	1.00	0.39	1.22	0.46	0.60
29	0.92	0.33	1.10	0.47	0.59
30	0.86	0.29	1.00	0.48	0.58
31	0.81	0.23	0.89	0.48	0.56
32	0.76	0.17	0.79	0.48	0.55
33	0.72	0.10	0.70	0.48	0.54
34	0.68	0.00	0.63	0.47	0.52
35	0.63		0.57	0,47	0.51
36	0.58		0.51	0.47	0.50
37	0.54		0.45	0.46	0.49
38	0.49		0.40	0.46	0.48
39	0.45		0.34	0.45	0.47
40	0.40		0.30	0.45	0.46
41	0.36		0.26	0.44	0.45
42	0.32		0.22	0.44	0.44
43	0.27		0.19	0.43	0.43
44	0.23		0.16	0.42	0.42
45	0.10		0.13	0.41	0.42
46	0.15		0.11	0.41	0.41
47	0.12		0.09	0.41	0.41
48	0.09		0.07	0.40	0.40
49	0.06		0.05	0.39	0.40
50	0.04		0.03	0.38	0.39



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

RED AND ASSINIBOINE RIVER BASINS

PREPAPED BY: A WARKENTIN	DATE: JANUARY 1971
DRAWN BY: W S	FILE No:

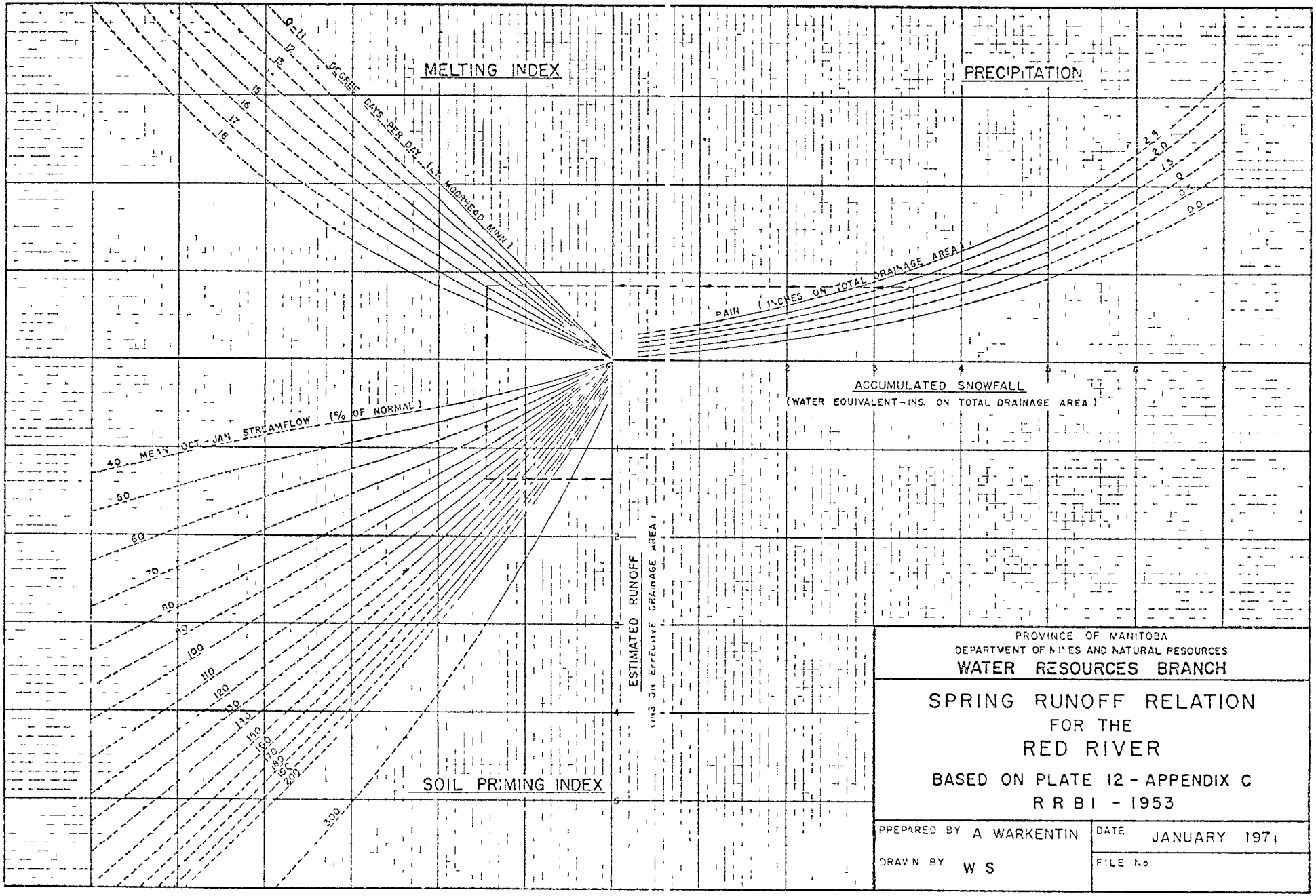

MELTING INDEX
9-11 DEGREE DAYS PER DAY (AT MOORHEAD MINN.)
12
13
15
16
17
18
PRECIPITATION
RAIN (INCHES ON TOTAL DRAINAGE AREA)
0
1
2
3
ACCUMULATED SNOWFALL
(WATER EQUIVALENT-INS. ON TOTAL DRAINAGE AREA)
MELT OCT-JAN STREAMFLOW (% OF NORMAL)
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
300
ESTIMATED RUNOFF
(INS. ON EFFECTIVE DRAINAGE AREA)
SOIL PRIMING INDEX
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH
SPRING RUNOFF RELATION
FOR THE
RED RIVER
BASED ON PLATE 12 - APPENDIX C
R R B I - 1953
PREPARED BY A WARKENTIN
DATE JANUARY 1971
DRAWN BY W S
FILE No

FIG. 2

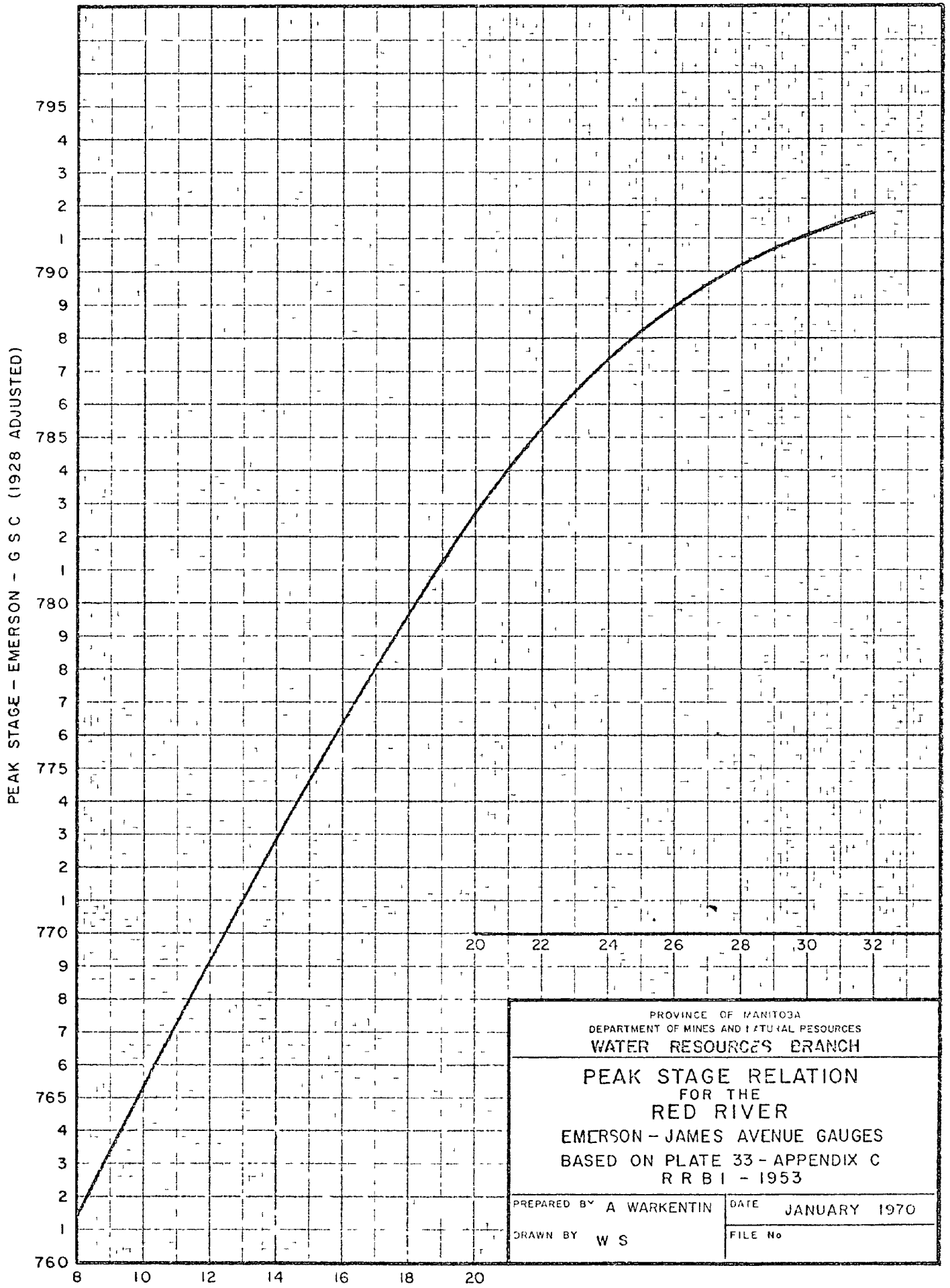
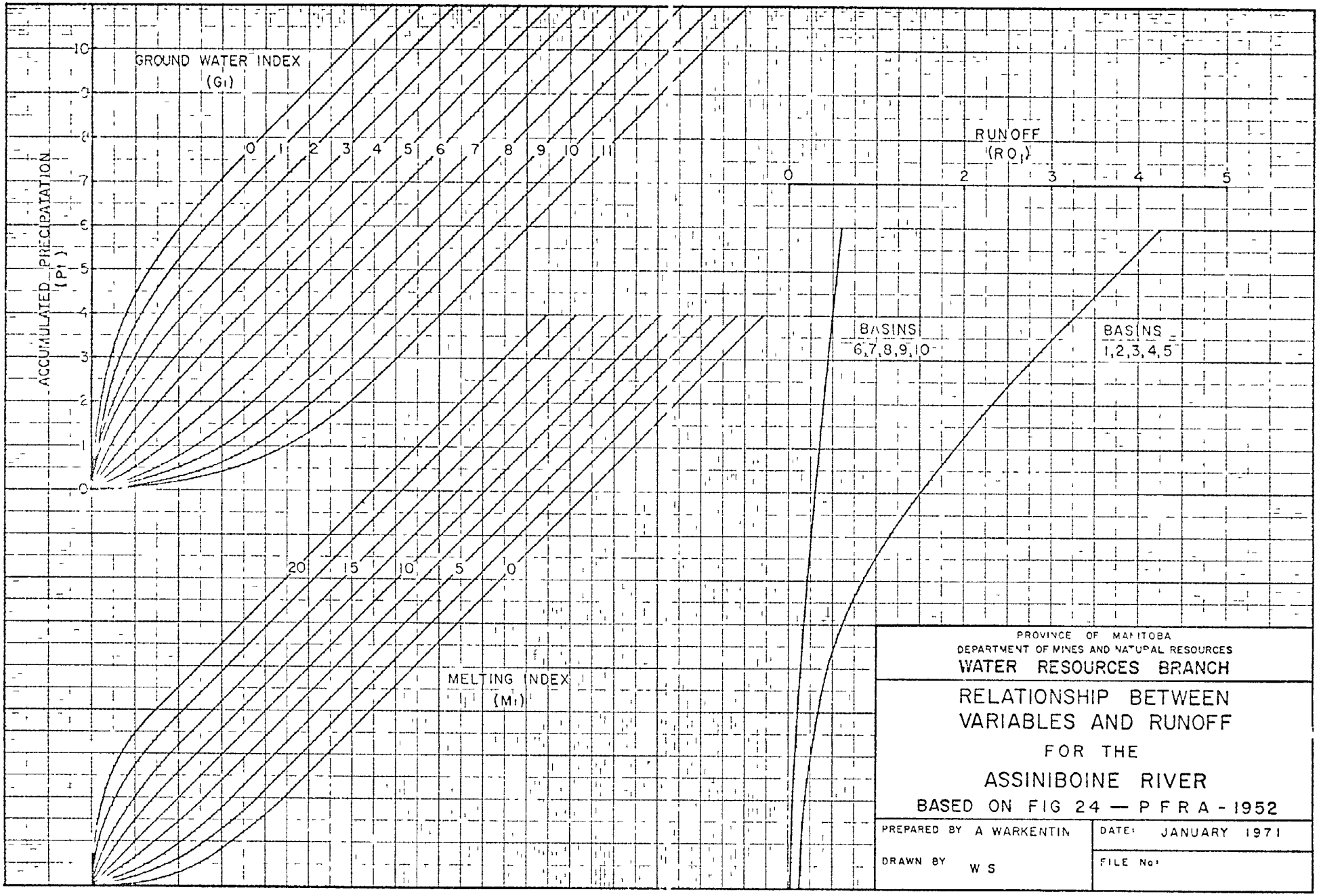

PEAK STAGE - EMERSON - G S C (1928 ADJUSTED)
795
4
3
2
1
790
9
8
7
6
785
4
3
2
1
780
9
8
7
6
775
4
3
2
1
770
9
8
7
6
765
4
3
2
1
760
8
10
12
14
16
18
20
22
24
26
28
30
32
PEAK STAGE - JAMES AVENUE (FEET ABOVE CITY DATUM)
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH
PEAK STAGE RELATION
FOR THE
RED RIVER
EMERSON - JAMES AVENUE GAUGES
BASED ON PLATE 33 - APPENDIX C
R R B I - 1953
PREPARED BY A WARKENTIN
DATE JANUARY 1970
DRAWN BY W S
FILE No

FIG. 3



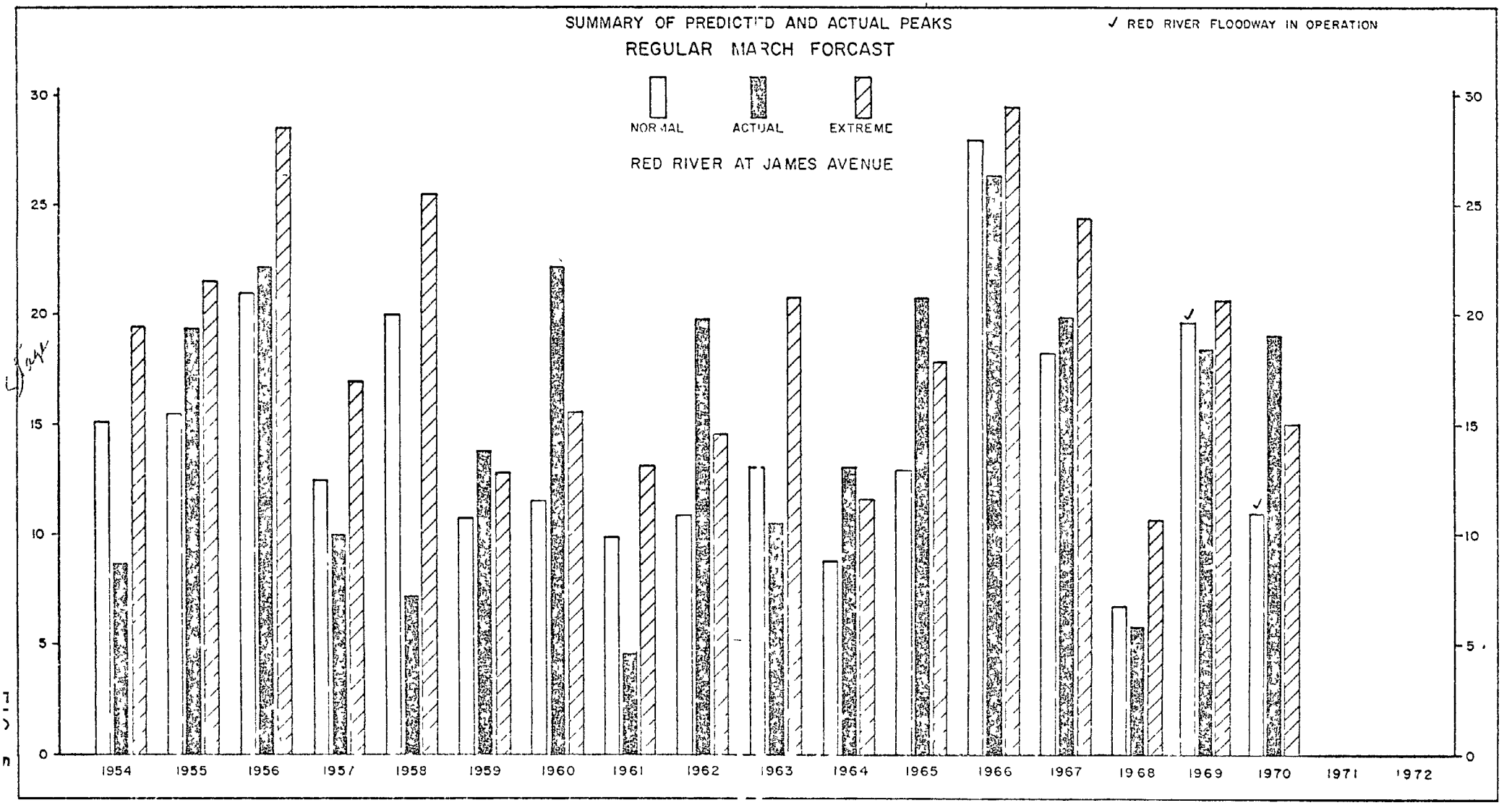
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER RESOURCES BRANCH

RELATIONSHIP BETWEEN VARIABLES AND RUNOFF FOR THE ASSINIBOINE RIVER

BASED ON FIG 24 — P F R A - 1952

PREPARED BY A WARKENTIN	DATE: JANUARY 1971
DRAWN BY W S	FILE No:

FIG. 4


SUMMARY OF PREDICTED AND ACTUAL PEAKS
REGULAR MARCH FORCAST
✓ RED RIVER FLOODWAY IN OPERATION
NORMAL
ACTUAL
EXTREME
RED RIVER AT JAMES AVENUE
30
25
20
15
10
5
0
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972