

PRAIRIE PROVINCES WATER BOARD

REPORT #6

PRECIPITATION AND STREAMFLOW
IN THE MOUNTAIN AND FOOTHILL REGION
OF THE SASKATCHEWAN RIVER BASIN

by

A. H. LAYCOCK



Prepared at the request and
for the information of the
PRAIRIE PROVINCES WATER BOARD

From data supplied by:
EASTERN ROCKIES FOREST CONSERVATION BOARD
FEDERAL WATER RESOURCES BRANCH
FEDERAL METEOROLOGICAL DIVISION

Motherwell Bldg.,
Regina, Sask.
January, 1957.

GB
709.P7
R46
no. 6

PRAIRIE PROVINCES WATER BOARD

REPORT #6

PRECIPITATION AND STREAMFLOW
IN THE MOUNTAIN AND FOOTHILL REGION
OF THE SASKATCHEWAN RIVER BASIN

by

A. H. LAYCOCK

O O G B



Prepared at the request and
for the information of the
PRAIRIE PROVINCES WATER BOARD

From data supplied by:
EASTERN ROCKIES FOREST CONSERVATION BOARD
FEDERAL WATER RESOURCES BRANCH
FEDERAL METEOROLOGICAL DIVISION

Motherwell Bldg.,
Regina, Sask.
January, 1957.

Sent on request

PRAIRIE PROVINCES WATER BOARD

Motherwell Building,
Regina, Saskatchewan,
January 16, 1957.

Members,
Prairie Provinces Water Board.

Gentlemen:

Transmitted herewith is Water Board Report #6 entitled
"Precipitation and Streamflow in the Mountain and Foothill Region
of the Saskatchewan River Basin".

This report was prepared to partially fulfill one of the
duties of the Board as set out in Section 4(a) of the Water Board
Agreement dated July 28, 1948, which is "to collate and analyze the
data now available relating to the water and associated resources of
interprovincial streams with respect to their utilization for irrigation
drainage, storage, power, industrial, municipal, navigation and other
purposes.

This investigation was undertaken for the Water Board by the
P.F.R.A. Hydrology Division (Federal Department of Agriculture). The
study was made and the report written by Mr. A. H. Laycock (now c/o
Geography Division, Department of Political Economy, University of
Alberta) whose meteorological knowledge of these regions is unique.
Much of the report is based on original data supplied through the
courtesy of the Eastern Rockies Forest Conservation Board.

Yours very truly,



W. M. BERRY,
Engineering Secretary.

ACKNOWLEDGEMENTS

The author acknowledges his indebtedness to Mr. W. M. Barry, Engineering Secretary of the Prairie Provinces Water Board, for initiating this study and for helping in its development; to Mr. G. Tunstell and staff of the Eastern Rockies Forest Conservation Board for data and supplementary information and for reviewing the report; to Mr. E. P. Collier and staff of the Federal Water Resources Branch, Calgary, for data and suggestions; and to Mr. W. M. Davidson for his careful drafting work.

Thanks are also due the Alberta Forest Service, the Federal Parks Branch, Mr. C. S. Heidel of the U.S. Geological Survey, and Dr. C. W. Thornthwaite for data, advice and approach.

A. H. Laycock

Edmonton, Alberta,
August, 1956.

TABLE OF CONTENTS

	Page
I Introduction	1
II The Region	2
III Sources of Information	3
IV Annual Precipitation, Evapotranspiration and Streamflow	4
V Seasonal Precipitation, Evapotranspiration and Streamflow	6
VI Possibilities of Streamflow Improvement	8
VII Precipitation and Water Yield Regions	12
VIII Bibliography	16

APPENDICES

A. Sources of Information	19
B. Annual Precipitation, Evapotranspiration and Streamflow	24
C. Seasonal Precipitation, Evapotranspiration and Water yield	28
D. Seasonal Streamflow	32
E. Hypothetical Flow Curves - Region 3	34

FIGURES

- Figure 1. Precipitation and Water Yield Regions
2. Precipitation and Streamflow Stations 1954
 3. Annual Precipitation 1921 - 1950
 4. Precipitation 1953
 5. Precipitation 1954
 6. Annual Evapotranspiration Normal 1921 - 1950
 7. Annual Water Yield Normal 1920 - 1950
 8. Water Yield October 1952 - September 1953
 9. Water Yield October 1953 - September 1954
 10. Precipitation and Evapotranspiration for Selected Stations 1953, 1954 and Normal
 11. Precipitation and Evapotranspiration for Selected Stations 1953, 1954 and Normal
 12. Streamflow Selected Stations by months 1953, 1954 and Normal
 13. Streamflow Selected Stations by Months 1953, 1954 and Normal
 14. Annual Precipitation and Streamflow at Selected Stations

I PRECIPITATION AND STREAMFLOW IN THE MOUNTAIN AND FOOTHILL REGION OF THE SASKATCHEWAN RIVER BASIN

The mountain and foothill regions are the chief reliable sources of streamflow in the Saskatchewan River Basin. A need for information concerning the origins and nature of this streamflow has developed with the expansion of demands for water in the Prairies.

This report (1) outlines the approximate patterns of precipitation and streamflow within these source regions and (2) suggests ways in which watershed management might affect and be affected by the patterns outlined.

The descriptions of precipitation and streamflow are based upon (1) a greater supply of data than has previously been available, and (2) the local application of recent studies concerning the relationship of precipitation to streamflow, (e.g., bibliography, items #8, 9, 16, 23) and the distribution of precipitation in mountain areas (e.g., #12, 22, 26).

The precipitation and streamflow of 1953 and 1954 are mapped and described and "normal" patterns are interpolated from these and from the less comprehensive data of the period 1921-1950. Most of the major patterns are shown in maps and graphs which should receive frequent reference, for many of the descriptions and interpretations are based directly upon them. The above patterns indicate that watershed problems and possibilities vary appreciably within the mountain and foothill regions. Subregions with like characteristics are mapped and described.

II THE REGION

The boundaries of the region under study (see figure #1) are approximately (1) the 4,000' contour in the east where the foothills merge into the plains, (2) the drainage divide between the North Saskatchewan and Athabasca basins in the north, (3) the continental drainage divide in the west, and (4) the drainage divide between the South Saskatchewan and Missouri basins in the south.

This region is relatively narrow in the south where the plains and low foothills give way abruptly to a narrow belt of high fault-block mountains on which the continental divide is located. In the north the dividing ranges of the west are succeeded by a series of only slightly lower parallel ranges to the east. This belt of mountains is then succeeded by a relatively wide belt of foothills and mountain outliers of various heights and then by the undulating plain.

Intense glacial, Periglacial, and fluvial activity have left most mountain ranges and foothill ridge tops bare or only thinly covered with coarse residual soils. Most mountain valleys, and the lower foothill slopes and valleys, contain deep glacial and water-borne deposits. Water retention and detention storage capacities thus vary greatly.

Most of this relatively humid mountain and foothill region is forested although grasslands are present in particularly the southern foothills and in some of the lower eastern mountain valleys. Severe and relatively frequent fires, and some logging activity, have left most of the forested area in young growth and immature non-commercial stands. The grasslands and some forest areas are grazed by cattle, some sheep, and game.

III SOURCES OF INFORMATION

Information on precipitation, evapotranspiration, and streamflow has been obtained from a wide range of direct and indirect sources, (see Appendix A). Precipitation measurements and streamflow data are the basis for most of the maps included in this report. Interpolated and indirect information have been used to establish local patterns of precipitation and streamflow. With minor allowances the formula "precipitation minus evapotranspiration equals water yield" \star has been applied extensively. Evapotranspiration has been determined particularly according to Thornthwaite (#33). Wherever two of the factors were known (or could be estimated within reasonable limits,) the third could be determined by use of the formula.

A study of the synoptic charts of most of the period January 1950 - December 1954, has indicated the type of storms present in the different subregions. Topographic parameters using elevation, aspect, slope, etc., have been employed in the determination of local variations of precipitation.

Personal observations and discussions with government and other personnel engaged in meteorologic and hydrologic work in these regions have been used to confirm rather than establish the nature of patterns of precipitation and streamflow. These sources, and surveys in related fields, have been important in providing background for such aspects as water quality, erosion damage, land use etc.

\star Water yield - the amount of water available for streamflow.

IV ANNUAL PRECIPITATION, EVAPOTRANSPIRATION AND STREAMFLOW

The normal annual precipitation for the period 1921-1950 is characterized by heavier precipitation (1) in back range than in eastern areas, (2) in front range and foothill areas than in eastern intermountain valleys or plains areas, and (3) in the more elevated than in the low lying areas. The high back range areas normally receive well over 50 inches of precipitation annually while low lying eastern intermountain valleys, and plains areas to the east of the foothills, normally receive less than 25 inches (See figure 3). Every year has significant regional variations. The major variations of 1953 and 1954 may be noted by comparing figures 4 and 5 with figure 3. These are explained in Appendix B.

Actual evapotranspiration is apparently greatest in foothill areas where it is locally in excess of 20 inches per year. It is normally less than this in the warmer plains to the east because precipitation is deficient, at least seasonally. It is normally less in the more elevated areas to the west because of low temperatures, limited local soil moisture storage capacities, and local seasonal precipitation deficiencies (see figure 6 and Appendix B).

Streamflow varies greatly within these regions for water yield is the balance of precipitation less evapotranspiration, - two highly variable elements (See Appendix A). Normal water yields are greatest in the high back range areas where precipitation is high and evapotranspiration is low; moderately high in the mountain areas to the east where precipitation is lower and evapotranspiration is generally higher; and low in the lower foothills and plains where precipitation is almost balanced by evapotranspiration (Figure 7). Water yields thus range from over 50

inches per year in many high back range areas to almost nil in some eastern intermountain, foothill and plains areas.

Variations from the normal patterns are far greater in the eastern than in the western areas. The patterns of 1952- 53 and 1953-54 are noted (figures 8 and 9 and Appendix B).

V SEASONAL PRECIPITATION, EVAPOTRANSPIRATION AND STREAMFLOW

The patterns of seasonal precipitation, evapotranspiration and streamflow vary appreciably within the mountain and foothill regions (see figures 10, 11, 12 and 13 and Appendices C & D).

In back range areas winter snowfall is greater than summer rainfall. Most of it is available for streamflow when it melts particularly in June and July. Some of the lower areas contribute significantly in May and some high areas provide delayed meltwater in August. Evapotranspiration is concentrated in the summer months and it then largely balances current rainfall except in areas of low moisture storage and use.

The eastern mountain areas have greater spring and summer rainfall than winter snowfall except possibly in the most elevated portions. Much of this rainfall is evaporated or transpired, except in rocky areas, and the snows provide the greater part of the streamflow. Melting is slightly earlier than in the generally more elevated areas to the west.

The precipitation regime has a pronounced spring and early summer peak on the eastern slope of the front range. Much of this moisture is evaporated or transpired and only minor surpluses are available for streamflow except in areas of limited storage. Winter snowfall is relatively light but surpluses are available, usually in April, May, and sometimes early June. Spring rains vary appreciably in amount and floods may occur. Fortunately, these rains usually occur after the period of maximum local snowmelt.

The foothills and plains margins do not receive sufficient precipitation in a normal year for more than minor amounts of runoff to take place except where storage capacities are low or vegetative covers are less than optional. Runoff does occur in most years from these areas, particularly during the snowmelting period (March to May) and following intense or prolonged rains in early spring. In the wetter years runoff may be significant, particularly in the snowmelt period, in June, and occasionally later in Summer.

Floods may occur since the proportional variation from normal is large although yields are small in contrast with those of back range areas.

The effects of latitude are much less important than those of elevation and topographic position. Rainfall is normally greatest in May and early June in the south and in late June and July in the north. Snowfall appears to be a slightly larger proportion of total precipitation in the south than in the north. Evapotranspiration potentials are greater in the south (for equivalent elevations) because of higher temperatures but late summer moisture deficiencies are also greater in the south thus actual evapotranspiration is as great if not greater in northern lowlands. Streamflow tends to be more concentrated in the spring in the south than in the north due to the greater relative snowmelt and earlier rains. Summer flow in the south is low, for potential evapotranspiration greatly exceeds precipitation. Only very exceptional rainstorms produce much surplus for streamflow after refilling depleted storage. Summer precipitation is normally greater in the north and heavy storms can produce major runoff because storage is much less depleted prior to such storms.

The precipitation, evapotranspiration, and streamflow patterns of 1953 and 1954 indicate that both years had greater winter snowfall and summer rainfall, smaller evapotranspiration, and greater streamflow in most regions than was normal for the period 1921-1950. Seasonal variations were appreciable however, and are noted in Appendices C and D.

VI POSSIBILITIES OF STREAMFLOW IMPROVEMENT

In most watersheds it is physically possible to increase annual water yields, improve seasonal flow regimen or improve water qualities by changing the vegetative cover, constructing artificial reservoirs and by other means.

(a) Increase of Annual Water Yield

Water from this region is used for domestic, municipal, industrial, irrigation, water power and other purposes in the prairies. By far the greatest consumptive use, at present and potentially, is by irrigation. Increases in water yield if favorable in regime and quality, could potentially be utilized.

It has been noted previously that precipitation minus evapotranspiration equals water yield (Section III and Appendix A). Water yield might thus be increased if we increase precipitation or decrease evapotranspiration. Precipitation might be increased by cloud seeding and by other mechanical means but the results to date indicate that these means are not highly effective and are relatively expensive (#27b, etc.).

Evapotranspiration losses have been reduced significantly by the partial removal of the vegetative cover and by the more efficient use of storage capacities (e.g., #9, 18, 24).

Evapotranspiration losses may be reduced by amounts up to the retention storage capacity of the soil between root depth (normally to several feet) and the depth of effective evaporation (normally less than one inch) if the vegetative cover is removed. Such reductions may be achieved only as long as no cover is present, and lesser reductions are usually obtained to the degree that new roots do not re-occupy the soil to former root depth in the following years. The complete removal of the

cover (by burning or intensive cutting) is rarely attempted because of the effect of such removal upon flow regime, flooding, erosion, sedimentation and alternate uses of the watershed. Increases in water yields of up to 4 and more inches per year have been accomplished by partial cutting in dense conifer stands (Fraser, Colorado), and by the removal of deep rooted aspen and preservation of the shallow rooted ground cover (#9). The removal of stream bank and other vegetation drawing upon telluric or riparian water has also been effective.

The storage capacities of some deposits below root depth can be used more effectively if water spreading on fans and terraces, or ditching to unused detention storage reservoirs, is practised.

Artificial storage in reservoirs may result in increased stream-flow in some years but normally yields will be reduced slightly because of the evaporation losses.

The possibilities of water yield increases in this region are minor (except very locally), for the burned over nature of the region is such that yields are now relatively high and normal regrowth (with fire protection) will result in reduced yields. Yield improvement action is not very effective or long term in results and is generally very expensive except where it is associated with commercial cutting.

(b) Improvement of Flow Regime

Irrigation demands for water are greatest in summer and require storage (natural or artificial) of spring flow for use during normal low flow periods in July, August and sometimes later. Domestic, municipal, most industrial and some other uses require more even flow with a maximum in summer. Water power developments require relatively even flow and storage for increases in the fall and winter seasons. One of the most important objectives of regime improvement is the avoidance of flood damage.

A buildup of vegetative cover may result in (1) delayed snow melting, (2) improved infiltration capacities thus less surface runoff, (3) greater surface detention storage and reduced rates of surface runoff, and (4) gradual improvement of soil moisture storage capacities. All of these will result in reduced and delayed high water periods and will normally result in increased summer flow. The increase in transpiration losses may result in decreased annual and seasonal yields, though this too may be desirable if flood control is the important objective (see Appendix E).

Vegetative buildup is most effective in areas (1) of shallow soils (in the terms of figures 10 and 11 - transpiration increases result in increases in moisture deficiency to a greater degree than in yield reduction), (2) of soils with low infiltration capacities, and (3) with relatively frequent storms of high intensity and long duration (those that most frequently result in severe flood and erosion damage). These conditions are present in the southern foothill and front range areas to a greater degree than in other parts of the region.

Plants that obtain much of their moisture requirements from ground water, particularly telluric and riparian, (in marshy areas, along some streams etc.) contribute little to high water level reduction and crest delay yet they use relatively large amounts of water in summer. The reduction of these losses should help in the improvement of flow regimen. The controlled drainage of marshes might be helpful in this regard.

Artificial storage in reservoirs is the most effective single way in which to improve flow regimen. It is relatively expensive and sites suitable for storage of large volumes are relatively few in number

but it will probably become of increasing importance in the future because large known volumes can be retained for delivery at desired rates when required. Management of vegetative cover is complementary to it in that extra storage is provided and silting is kept at a minimum.

A normal sequence of development of water conservation measures for regime improvement would begin with vegetative management, then add and emphasize artificial storage and finally, if demands are adequate, sacrifice vegetative cover and water quality for yield increases and establish complete artificial storage control.

(c) Improvement of Water Quality

Sediment loads, particularly during high water, may be excessive for most uses. The clogging of reservoirs, canals and soil may greatly affect irrigation development. Domestic, municipal, industrial, hydro-electric power, navigation, commercial fishing, recreation and other uses have corresponding demands for relatively clear water.

The control of vegetative cover for flow regime improvement usually results in improvement of water quality. Sediment loads are relatively small if local surface erosion is kept at a minimum and streamflow variations are moderate. The limitation of accelerated erosion is particularly important. The prevention of fire and limitations upon excessive grazing and cutting are most effective in those areas subject to intense rains of relatively long duration.

The problems and possibilities of yield, regime and quality maintenance and improvement vary greatly regionally. Some of the more outstanding variations will be reviewed briefly in the following section.

VII PRECIPITATION AND WATER YIELD REGIONS

The major differences in precipitation and water yield patterns, and in the physical potential for improvement, can be described and discussed most effectively if regions with distinct characteristics are mapped. These characteristics must be significant yet the diversity within a mountain and foothill area such as this makes a high degree of generalization necessary. Seventeen regions have been mapped (figure 1) and some of the major features can be summarized.

In figure 1, regions 1a, 2a, 4a, and 7a have the greatest total precipitation, a greater winter snowfall than summer rainfall, rainfall of high frequency but generally low intensity, low evapotranspiration (because of high elevation, low temperatures, and presence of large areas with limited storage capacities) and very high and dependable water yields. Region 1a is most exposed to the east and receives the greatest rainfall intensities of these regions, particularly in spring. Rainfall maxima are latest in the north, and earliest in the south where summer droughts may occur in valley areas. Snowmelt is also later in the north. Streamflow has a later and less peaked maximum in the north than in the south. Differences in elevation, aspect, exposure to specific storm types and other factors explain the selection of local boundaries.

In the above regions, water yield increases might be obtained by timber cutting in some of the lower lying glacial valleys and drift basins. Such cutting would probably not result in excessive erosion except on steep slopes for rainfall intensities are relatively low. The areas of mature timber are small and such increases would be minor. Flow regimen and water qualities are not subject to appreciable improvement

by vegetative means though both could be damaged by extensive fires or indiscriminate use. Artificial storage is possible in cirques and some glacial valleys. There are a large number of possible sites but most have very limited capacities and are relatively inaccessible.

Regions 2b, 4b and 7b have mountain areas that receive large amounts of precipitation but there are also large valley areas which receive relatively little. Some of these valleys are drier in many years than the lower foothills and plains margin to the east. With the partial exception of the higher and western mountain portions, these regions receive more rain than snow. The rains are of relatively low intensity though high frequency. Evapotranspiration is greater than in the regions to the west and water yields are generally much smaller. Summer droughts are common, particularly in the south. Rainfall has an earlier maximum and snow melt is slightly earlier in the south than in the north. Streamflow is obtained chiefly from snowmelt and the heavier rains on the mountains, and the contribution of valley areas is slight. Streamflow is earlier, more variable and more concentrated in spring and early summer than in regions to the west. Some improvement in regime and quality will take place as the extensive fire damaged forests develop, but minor yield reductions can also be expected. Artificial storage sites are numerous but most are again small. Several large reservoir sites are present in the flatter valleys of some of the larger streams where these break through the front range.

Regions 1b, 3a, 3c, 5a, 6a, and 8a have only moderate amounts of precipitation, except in the higher areas, and the greater part of this is received as rainfall. Rainfall is moderately frequent, usually light, and of short duration. In some years it may be very intense and

of long duration, in a few storms, particularly in the south. Rainfall amounts vary appreciably seasonally and from one year to the next. Summer droughts are most frequent and intense in the south where the earliest rainfall maxima occur. Evapotranspiration is moderately high, sometimes locally equalling precipitation, and water yields vary appreciably. Streamflow is highly concentrated in the snowmelt and spring rain periods though heavy rains occasionally cause heavy runoff in summer in the north. Much of the sediment of mountain streams is added in these regions. Some valleys receive rainfall of lesser intensities in regions 5a and 8a where mountain outliers and high foothills shield them in the east. Lesser protection is afforded by moderately high foothills in region 6a and by the Porcupine Hills to the east of part of region 3a.

In the above regions, water yields might be improved slightly by the controlled drainage of marshes. The reduction of vegetative cover by cutting, intensive grazing, etc., would, in most areas and all but the wettest years, result in negligible yield changes. The reduction in transpiration by deep-rooted plants would be balanced by evaporation and added use of water by shallow-rooted plants. The improvement of flow regimes and water quality might be appreciable with a long term buildup of the forest and grassland vegetative covers. These regions contain some artificial storage sites, particularly in the north, but reservoirs on streams subject to floods might fill with sediment quite rapidly.

Regions 3b, 5b, 6b, and 8b receive the greater part of their precipitation as rain. The precipitation is similar in pattern to that of the regions immediately to the west except that intensities are generally less, droughts are longer and more intense (especially in the south), and it is almost entirely evaporated or transpired from most of the area in

drier years. Water yields are marginal and highly variable. Streamflow is derived from snowmelt, exceptional rains, and precipitation upon the small areas with limited storage capacities. It occurs in short period peaks and many local streams are dry in many summers. The possibilities of increasing yield in any but the wetter years are negligible. Some marsh drainage, and removal of cover drawing upon streams that pass through these regions, could result in minor increases. The protection and improvement of vegetative cover could result in gradual regime and quality improvement. Artificial storage sites are few in number and small in capacity.

VIII BIBLIOGRAPHY

1. American Geophysical Union, "Annotated Bibliography on Hydrology 1941 - 1950 (United States and Canada)". Bureau of Reclamation, Dept. of the interior, Washington 1952, 408 pp.
2. Canada, Department of Agriculture, P.F.R.A. Hydrology Division,
 - (a) Report #1 "Full Development Possibilities in the South Saskatchewan River Basin", Regina, 1952, 44pp.
 - (b) Report #9 "Water Supply and Utilization in the Bow River Watershed", Regina, 1955, 50 pp.
3. Canada, Department of Northern Affairs and Natural Resources, (etc.) Water Resources Division.
 - (a) "Water Resources Papers, Arctic and Western Hudson Bay Drainage," 1920 - 1951, Ottawa.
 - (b) Preliminary hydrometric data 1951 - 1954 (unpublished, files in Calgary Office).
4. Canada, Department of Northern Affairs and National Resources, National Parks Branch. Selected meteorological data, Banff, Jasper and Waterton Parks (unpublished) 1953 and 1954.
5. Canada, Department of Transport, Meteorological Division, "Monthly Record" 1921 - 1954.
6. Canada, Department of Transport, Meteorological Division, Meteorological Records Office, Toronto. Selected data (unpublished, personal communication).
7. Colman, E. A. "Soil Surveying on Wildlands: The Problem and One Solution", Journal of Forestry, Vol. 46, No. 10 (October 1948) pp 755-762.
8. Colman, E. A. "Vegetation and Watershed Management", The Ronald Press Co., N.Y. 1953, 412 pp.
9. Croft, A.R. and Monninger, L.V. "Evapotranspiration and Other Water Losses on Some Aspen Forest Types in Relation to Water Available For Stream Flow". Transactions, American Geophysical Union, Vol. 34 #4 (August 1953) pp 563 - 574.
10. Croft, A.R. (Chairman) "Report of Committee on Evaporation and Transpiration, 1952-1953. Transactions, American Geophysical Union, Vol. 35 #1 (February 1954) pp 164-167.
11. Eastern Rockies Forest Conservation Board
 - (a) Soil and Watershed Survey Reports 1952, 1953 and 1954 by A. H. Laycock (typewritten).
 - (b) "Precipitation in the Forest Reserve, Its Distribution and Relationships to Watershed" by A. H. Laycock (typewritten) 1954.

11. (c) "Water Supply of the Saskatchewan River: Its Source Use and Conservation, by A. H. Laycock (typewritten) 1954.
(d) Precipitation data 1952-1954 (mimeo. tables compiled by A. H. Laycock.
12. Fletcher, H. C. and Rich L. R., "Classifying Southwestern Watersheds on the Basis of Water Yields", Journal of Forestry, Vol. 53 #3 (March 1955 pp 196-202.
13. Fletcher, R.D. "Hydrometeorology in the United States", Compendium of Meteorology, American Meteorological Society, Boston 1951, pp 1033-1047.
14. Foster, E.E. "Rainfall and Runoff" MacMillan Co. N.Y. 1948, 487 pp.
15. Hoyt, W.G. (et al) "Studies of relations of Rainfall and Run-off in the United States", U.S. Dept. of the Interior, Geological Survey, Water Supply Paper 772, Washington 1936, 301 pp.
16. Lassen L., H. W. Lull and B. Frank "Some Plant - Soil - Water Relations in Watershed Management", U.S. Dept. of Agriculture. Circular #910, Washington 1952, 64 pp.
17. Linsley, R.K. Jr., M. A. Kohler and J.L.H. Paulhus, "Applied Hydrology" McGraw-Hill Book Co. Inc., N.Y. 1949, 689 pp.
18. Lull H. W. (compiler) "Evapo-Transpiration: Excerpts from Selected References" U.S. Forest Service, Southern Forest Experiment Station, Occasional Paper #131, Vicksburg Miss. 1953, 117 pp.
19. Prairie Provinces Water Board
 - (a) Report #1 "Summary Report of Recorded and Natural Monthly Flows at Certain Points on the Saskatchewan River System" Regina 1950, 41 pp.
 - (b) Report #5 "Evaporation from Lakes and Reservoirs on the Canadian Prairies 1921 - 1950", Regina 1952, 58 pp.
20. Rowe, P.B. and E. A. Colman "Disposition of Rainfall in Two Mountain Areas of California", Dept. of Agriculture, U.S. Technical Bulletin, #1048, Washington 1951, 84 pp.
21. Russell, B. "Report on Surface Water Supplies and Water Power of Alberta - Their Present and Ultimate Uses" Alberta Dept. of Agriculture, Water Resources Division, Edmonton 1948, 95 pp.
22. Russler, B. H. and W. C. Spreen "Topographically Adjusted Normal Isohyetal Maps for Western Colorado" U.S. Weather Bureau, Technical Paper #4, Washington 1947 pp.

23. Thornthwaite, C. W. "An Approach Toward a Rational Classification of Climate" *Geographical Review*, Vol. 38 #1 (February 1948) pp 55-94.
24. Thornthwaite, C. W., and J.R. Mather (editors) "Estimating Soil Tractionability from Climate Data", *The Johns Hopkins University Laboratory of Climatology, Publications in Climatology Vol. 7, #3*, Centerton, N.J. 1954, pp 369-447.
25. Thornthwaite, C. W. and J. R. Mather "The Water Budget and its Use in Irrigation", *U.S. Dept. of Agriculture Yearbook 1955* (mimeographed advance copy) 18 pp.
26. Troxell, H.C. and H.M. Stafford "Natural Water Losses in Mountain Drainage Areas of Southern California" *Transactions, American Geophysical Union*, Vol. 30 #5 (October 1949) pp 752-758.
27. United States, Dept. of Commerce, Weather Bureau
 - (a) *Climatological Data, Montana, Annual Summaries 1953 and 1954* (Vol. 56 pp 208-219 and Vol. 57 pp 212-223) Washington 1954 and 1955.
 - (b) *Research Papers #30, 31 and 33 on "Artificial Productions of Precipitation"* 61, 58 and 46 pp, Washington 1948, 1949.
28. United States, Dept. of the Interior, Geological Survey
 - (a) *Water Supply Papers, Missouri and St. Mary River Basins*, selected 1920-1951.
 - (b) *Selected data 1951-1954* (unpublished, personal communication with C. S. Heidel, Helena Office).
29. Veihmeyer, F. J. "Use of Water by Native Vegetation Versus Grasses and Forbs on Watersheds" *Transactions, American Geophysical Union*, Vol. 34 #2 (April 1953) pp 201-212.
30. Wilm, H. G. and E. G. Dunford "Problem Analysis" *Rocky Mountain Forest and Range Experiment Station, Division of Forest Influences*. Fort Collins, Col., 1941, 51 pp (mimeo).

APPENDIX ASOURCES OF INFORMATION

The sources of information used in this paper are of three types: (1) direct measurement data; (2) observations of quantities and effects; and (3) evaluation of relationships.

Each is reviewed under the headings of precipitation, evapotranspiration, and water yield.

Precipitation

The most complete data have been obtained from the Canadian Meteorological Division (5 & 6) and the United States Weather Bureau (27a). Eighteen Canadian and two American weather stations with standard rain gauges are present in this mountain and foothill region, but most of these are located in the outer foothills and low lying mountain valleys. Additional data from Canadian and American stations adjoining the region have been used in the location of isohyets (lines joining points of equal Precipitation) and in the interpretation of other information.

The National Parks and Alberta Forest Services have weather instruments at some of the wardens and ranger stations. Unfortunately, very few of these have precipitation records for more than parts of each year; the records are frequently only approximate; and most stations are located in sheltered low lying valleys. The partial records are of some value in that patterns established by other means can be at least partially confirmed.

The Eastern Rockies Forest Conservation Board arranged for the erection of one hundred storage gauges in the Forest Reserve on sites located in the period October 1952 - August 1954. Data for twenty-five of these may be used for 1953 and seventy-seven for 1954. Allowances must be made for instrument and other errors, and for variable intervals between readings, but this network is probably the best single source of information on relative precipitation in the region.

A storage gauge is maintained by the United States Weather Bureau near Grinnell Glacier in Glacier Park. Useful supplementary data on snowfall is obtained from the United States Geological Surveys and from the Canadian Water Resources Branch (e.g., snow survey reports).

Additional information on particularly the relative distribution of snowfall has been obtained from miscellaneous snow sampling measurements by A. H. Laycock, conversations with wardens, rangers, skiers and other interested persons, observation of snow pack in the mountains in winter and spring, and examination of the location of ice fields, glaciers, and snow fields. To some degree, the distribution of vegetative cover is indicative of differences in precipitation. The freshness and intensity of recent glacial activity also suggests that some areas have experienced greater snowfalls than others. Information of this nature serves more to confirm than establish patterns of precipitation, and is of limited value in the determination of absolute quantities.

Indirect sources of information have been very important in this study. Streamflow measurements are available for many of the region's streams and rivers. These indicate that some areas have water yields well above those which might be expected if precipitation records were representative of the respective basins. For example, in the year October 1953 - September 1954, the average water yield of the Bow basin above Banff was over 28.5 inches yet the precipitation in Banff (24.7 inches) and Lake Louise (37.1 inches) during this period was not sufficient to account for it and for estimated evapotranspiration. Similarly the water yield of the Waterton River at Waterton Park (45.1 inches), at the International Boundary (70.5 inches), and of Boundary Creek (56.3 inches) could not have been obtained from the precipitation received at Waterton Park headquarters (48.6 inches). On the other hand, the precipitation near Grinnell Glacier in the period July 31, 1953 to August 4, 1954 of 138.2 inches might be slightly greater than the average for the basin of Grinnell Creek which had a yield of approximately 106 inches. The difference may have been partially due to change of volume of the glacier in this period.

The above examples show that the establishment of even approximate relationships between precipitation and water yield would be of value. Such relationships have been assumed and used.

The relative amounts of precipitation received within these areas have been established to some degree by the use of an empirical approach based upon a rational selection of topographic parameters such as elevation, directional aspect, slope, etc. An attempt has been made to isolate and evaluate particularly the orographic components of precipitation. Unfortunately the data are still too sketchy for proper application of multiple-correlation techniques, but general patterns of precipitation distribution that fit in well with established data may be suggested.

The six-hour synoptic charts of the Dominion Weather Office in Calgary have been reviewed for the greater part of the period January 1950 - December 1954. The various types of storms (cyclonic, convectional and orographic - and combinations) that have released moisture from moist air masses (mP and mT) have been noted and the major storm tracks have been charted (by months). Some of the major storms have been studied in greater detail and the frequency, intensity and duration of storms of various types have been estimated for the various parts of the region.

EVAPOTRANSPIRATION

It is generally assumed that almost all of the precipitation on large basins that is not returned to the atmosphere by evapotranspiration is discharged as streamflow (#8, 14 and 17). Subsurface flow from one basin to another is probably of negligible proportions, particularly in a region such as this where the divides are so well defined and artesian flow is generally very localized.

It can be demonstrated that by far the greater part of this evapotranspiration and streamflow occur in the same year as the precipitation and that net storage variation from one year to the next is relatively small in amount (Figures 12 and 13 and Appendix D). If minor allowances

are made for such storage changes, we can use the formula: precipitation minus evapotranspiration equals water yield, - to establish the value of the missing factor for any year. In this way (1) streamflow data may be used to establish mean precipitation for a basin area in which precipitation data are deficient, (2) precipitation data may be used to establish approximate water yields from basins and parts of basins, and (3) precipitation and streamflow data may be used to confirm the estimates of evapotranspiration established by other means.

The major problem in the application of this formula is the determination of evapotranspiration. Numerous studies have been conducted and approximate relationships have been established (18).

A very useful approach is that of C.W. Thornthwaite (23). He regards transpiration as a physical process controlled largely by the supply of solar energy available for evaporation of water from plant surface (10, p 167). If soil moisture is not limiting, the growth is optimal for the amount of heat available, the type of plant cover should have little effect on the amount of evapotranspiration from a given area. (23 and 24) Formulas have been developed by which potential evapotranspiration can be determined from temperature data. If one assumes that the soil is capable of storing four inches of moisture, which may be used by plants in lieu of current precipitation, and subtracts subsequent moisture deficiencies from potential evapotranspiration, actual evapotranspiration is approximated (Figures 10 and 11. These graphs are reviewed in later sections).

The formulas for potential evapotranspiration using monthly data appear to be very good for our purposes although winter evaporation might be indicated more adequately if shorter periods were used and warm spell losses were accounted for. Wind and other variables might also be considered. Actual evapotranspiration estimates have been modified by allowances for the following factors: (1) storage capacities range from almost nil to well over four inches; (2) detention storage (between saturation and field capacity - approximately that which is lost by gravity flow) is given very low value; and retention storage (between field capacity and the wilting point --that which is held against gravity but is available for plant growth) is stressed \star ; (3) root depth varies with specie, age of stand, stand density, soil texture and structure, water table etc.-- the intensity and recency of damage by fire, cutting, and grazing are particularly important; (4) all basins have at least small areas with low storage capacities and will thus have some runoff and reduced actual evapotranspiration; (5) runoff may occur before storage capacities are filled if precipitation

\star Colman (#7) uses a table which is reasonably applicable here.

<u>Moisture Content (inches of water per foot of soil depth)</u>			
<u>Soil Texture Class</u>	<u>Wilting Point</u>	<u>Field Capacity</u>	<u>Pore Saturation</u>
Sand	0.4	0.9	5.0
Sandy loam	0.7	1.8	5.0
Loam	1.1	2.7	5.0
Clay loam	1.7	3.4	5.4
Clay	2.5	5.0	5.4

intensities exceed infiltration capacities or if snow melts rapidly on frozen unsaturated soil; (6) plants may use soil moisture at less than optimum rates near the wilting point; and (7) plants may withdraw water from the water table and from streams during periods of general water deficiency and may thus reduce water yields, particularly where marshy areas and low stream-side terraces are widespread.

The importance of evapotranspiration as a factor may be illustrated by an example. Let us assume that the north facing and south facing slopes of a foothill ridge receive 20 inches of precipitation. The evapotranspiration on the south and north slopes is assumed to be 18 and 14 inches respectively. The water yield of the north slope would thus be three times as great as that of the south slope. If precipitation is much greater than evapotranspiration, the relative effect upon yield of such variations is much smaller.

Actual and potential evapotranspiration measurements have not been made in this region. The evaporation from free water surfaces has been measured for recent years in a few sites in and adjoining the south-eastern part of the region and estimates of these losses are available for the plains regions (#19b). Temperature and wind data are available for most of the Canadian Meteorological Division and United States Weather Bureau stations. Additional data are available for some of the other weather stations. Normal lapse rates of temperature have been used in the estimation of summer temperatures at elevations above those at which stations are located.

Water Yield

The primary sources of data on water yield are the streamflow records of the Canadian Water Resources Division (3a and b) and the United States Geological Survey (#28a and b). Records of varying length are available for 54 stations within and immediately to the east of this region for recent years. Seven of these stations are located on the North Saskatchewan and its tributaries, two are on the Red Deer, twenty are on the Bow and its tributaries, seven are on the Oldman and its wholly Canadian tributaries, nine are in Canada on streams which have at least parts of their basins in the United States and nine are within the United States. Additional stations have been operated at different locations on the above rivers and streams, and on other tributaries, for varying lengths of time in the past. Other stations on streams outside the region also supply useful information. Some of the above stations are operated by power companies and municipalities; and organizations such as the Eastern Rockies Forest Conservation Board have contributed to the cost of installation and/or maintenance of others. Stations gauging irrigation canal and return flow are not included in the above lists although allowance must be made for the water used.

Personal observations and discussions with personnel of the Water Resources Division, Alberta Forest Service and other offices have helped to establish and confirm streamflow patterns, particularly those relating to regime, quality, flood and sedimentation damage, erosion etc. The application of the research and observations of other regions to these areas is helpful, particularly if local conditions are given due consideration.

The formula, precipitation minus evapotranspiration equals water yields, is of considerable value in the determination of seasonal and total yields from parts of basins. For example, the water yield of the Bow River basin above Banff was 28.55 inches in the year October 1953 - September 1954. The actual yields probably ranged from almost nil from some of the drier parts of the basin near Banff to almost 100 inches from some high areas on the dividing ranges near Bow Lake and Lake Louise. These local patterns of water yield have been estimated and mapped very roughly on the basis of the precipitation-evapotranspiration relationships.

APPENDIX B

ANNUAL PRECIPITATION, EVAPOTRANSPIRATION AND STREAMFLOW

Annual Precipitation

The variations in precipitation from one year to the next appear to depend on the frequency and duration of influx of mP and mT air, and the degree to which this air is subjected to orographic, cyclonic and convectional uplift.

The mT air enters the region infrequently in most years (late spring and summer) at low levels from the east. Storms of relatively high intensity and long duration may occur in the plains, foothill and from range areas - particularly in the south. These storms rarely penetrate effectively beyond the front range although they may supply as much as one-half of the precipitation received in the foothills in some years.

The mP air has lost much of its moisture in crossing the mountain ranges of British Columbia. It predominates in much of the year and storms are frequent. These are usually light or of short duration. Some of the most effective storms are cold front cyclonic which move upslope from the north east. These release precipitation in the back ranges as well as in front range and foothill areas. "Rain shadow" areas south-west and west of the front ranges experience only low intensity falls.

The greatest amounts of precipitation from mP air are received in the back-range areas near the continental divide in winter. This is "spill-over" snowfall (flakes fall downwind of the area in which they are formed) and snowfall that is released from eastward flowing air that rises and cools beyond the divide (over local pockets of cold air present in enclosed valleys, up the "polar front", up ranges which rise to higher levels than passes in the divide, or in continuation of the uplift impelled by the rise up the western slope of the dividing range).

Precipitation may fall from mP air in other types of storms, such as those resulting from the passage of "upper air lows", and it may be quite significant, but distribution patterns are generally less obvious. Precipitation from continental and arctic air masses is probably negligible although cooling of maritime air by uplift over polar air masses is important.

Normal Annual Precipitation 1921-1950

The normal for the period 1921 - 1950 is now being used by the Meteorological Division for comparative purposes (#6). This normal is used in this paper (Figure 3) although it is slightly above the longer term normal of those stations with longer periods of record and is significantly below the normal of the period following 1950.

mP or maritime Pacific air is mild and moderately moist having originated over the Pacific Ocea. mT or maritime Tropical air is warm and moist originating over the Tropical Atlantic and Gulf of Mexico.

Annual Streamflow

Streamflow varies in amount with all of the variations of precipitation and evapotranspiration. Precipitation is highly important but for a given annual precipitation there is greater streamflow: (1) in the south, where spring and early summer precipitation surpluses are large and summers are relatively drier than in the north; (2) in rocky mountain areas where storage is limited, than in mountain basins and foothill areas with deep surface deposits and dense vegetative covers where storage and evapotranspiration are relatively high; (3) in front range areas where precipitation intensities frequently exceed infiltration capacities, than in eastern intermountain valleys where most rains are of low intensity; and (4) on cool north facing slopes, than on warm south facing slopes - if different vegetative covers and storage capacities do not compensate. Some of the major regional variations in water yield are mapped (Figure 7).

Variations from one year to the next are generally much greater in foothill and eastern mountain valley areas than in the higher areas. Willow Creek has a far more variable streamflow than the Bow River at Banff (figure 14). Bow River at Ghost Dam is more variable than at Banff and variability increases as one goes downstream on the Waterton River (Figure 14). Water yields are less in the eastern areas of low precipitation and high evapotranspiration than in the west. In a dry year (e.g., 1949 on Willow Creek - Figure 14), 18" of rainfall less 16½" of evapotranspiration equals 1½" of water yield. In a wet year (e.g., 1951 on Willow Creek - Figure 14), 32" of rainfall less 24" of evapotranspiration equals 8" of water yield. If the rainfall is heavily concentrated in a short period and summer moisture deficiencies are high, a relatively low annual precipitation may produce very large yields. Thus 19" of rainfall less 9" of evapotranspiration equals 10" of water yield (e.g., 1953 on Willow Creek - Figure 14). *

Precipitation and evapotranspiration are less variable, and the difference between them (water yield) is normally much greater and more dependable in the west than in the east.

The streamflow patterns of October 1952 - September 1953 show a greater variation from normal than either precipitation or evapotranspiration patterns would show for comparable periods (Figures 7 and 8). In June the high precipitation of particularly the southern front range, foothill and plains region followed a moderately wet and cool spring thus moisture storage capacities were full and relatively large surpluses resulted. The remainder of the year was moderately dry in the south but the early surpluses resulted in well above normal streamflow. The high snowfall of the previous winter in especially the southern back range areas added greatly to total streamflow.

* It is probable that the precipitation at Lyndon was less representative of that of Willow Creek Basin in 1953 than in 1949 and 1951.

Streamflow in October 1953 - September 1954 was again above normal but the chief relative change was present in the northern front range and foothill areas. (See Figures 7 and 9). The heavy August and early September rains fell upon soils that had little unused storage capacity and late summer streamflow rose to levels almost as high as (locally greater than) in June and early July. In the south, the lighter rains were spent very largely in recharging depleted storage, and streamflow responded to only a small degree. The heavy winter snowfall in particularly the southern back range areas, again accounted for the greater part of flow volumes.

APPENDIX C

SEASONAL PRECIPITATION, EVAPOTRANSPIRATION AND WATER YIELD

General

The maps of the patterns of annual precipitation, evapotranspiration and water yield are supplemented by graphs of the seasonal patterns in different parts of the region (Figures 10 and 11). These graphs illustrate (as closely as the degree of representativeness of the stations permit) the seasonal patterns from west to east across the region and the local variations to the north and south.

The station diagrams of monthly precipitation and potential evapotranspiration, soil moisture recharge, water surplus, soil moisture utilization and water deficiency are modelled after, and use the formulas of C. W. Thornthwaite (#23). The assumption that soil moisture storage is available and is freely useable by plants to an amount of four inches provides a useful basis for station comparisons though variables are recognized, (see Appendix A).

The graph "Lake Louise Normal" (Figure 10a) may be used as an example. In it, the precipitation curve is a solid line indicating mean monthly precipitation for the period 1921 - 1950 (a mean annual total of 27.1 inches) and the calculated mean monthly potential evapotranspiration curve is indicated by a dashed line (16.9" -- based on mean monthly temperatures -- assumed to be 0 at less than 32°F). In the normal year, precipitation exceeds potential evapotranspiration after approximately the end of September. The excess is used in soil moisture recharge until late November when the storage capacity of 4 inches is reached (some of this may not enter the soil until snow melts in spring). The excess after this date (4.4 inches to the end of December and 8.2 inches more from then to early May) is available for eventual runoff. This 12.6 inches is the water yield at the station for the year. Potential evapotranspiration exceeds precipitation after early May and the 4 inches of moisture in storage has been utilized by plants by late July. Between late July and the end of September the plants live on less than optimum moisture supplies to the amount of 2.4 inches -- the water deficiency at the station. Actual evapotranspiration then is 16.9 inches less 2.4 inches or 14.5 inches, and precipitation (27.1 inches) less evapotranspiration (14.5 inches) equals water yield (12.6 inches).

It should be noted that the mountain and inner foothill stations in the following series generally receive much less precipitation than most areas around them and that only the foothills and plains stations are moderately representative of their areas (See Figures 1 and 2 for locations).

Seasonal Variations - West to East

(1) Lake Louise (Figure 10a) - This station has a relatively flat normal precipitation curve with a winter maximum. A moisture deficiency is present in late summer even though total precipitation (27.1 inches) is relatively high. Actual storage capacities in this area average less than 4 inches.

The relatively heavy winter snowfalls of 1953 and 1954 are typical of those of back range areas in these years. April cold front snowfall was moderately high. The heavy June precipitation of southern foothill areas in 1953 had little if any effect here though the cold front (higher level) storms of August 1954 were noticeable. Moisture surpluses were large in both years though deficiencies were still present.

(2) Banff (Figure 10b) - This is an eastern intermountain region station with an early summer precipitation maximum. The major differences between this and a back range area are that winter snowfall is appreciably smaller and evapotranspiration is slightly larger. These results in smaller surpluses available for streamflow (2.4 inches or less than 20% as great as that at Lake Louise). The moisture deficiency is larger, largely because of greater evapotranspiration losses.

Winter and spring snowfall was above average in both 1953 and 1954 and contributed to above average water yields. Some mT air may have contributed to the above average rainfall in June 1953 but the cold front rains of August 1954 were more important. These rains contributed to water yields only in areas of higher precipitation at higher elevations nearby, and in areas of limited storage capacities.

(3) Kananaskis (Figure 10c) - This is a front range - inner foothill station with a pronounced precipitation maximum in June, relatively high levels of summer rainfall, and little or no moisture deficit (the normal for the period 1921 - 1950 would probably have indicated a small one but data are not available for the full period). The total precipitation was 5.5 inches greater than at Banff but water yield was only 1.9 inches greater, very largely because of the absence of this moisture deficit which resulted in much greater local evapotranspiration.

Cold front precipitation in April of 1953 and 1954 was more intense here than in Banff which is on the lee side of the front ranges. June precipitation in 1953 was much greater, for the low level mT air did not penetrate effectively beyond the front range. The August 1954 precipitation was sufficient to recharge storage and provide an inch of runoff.

(4) Calgary (Figure 10d) - This station is representative of the foothill-plains margin areas which have relatively low winter precipitation and a June maximum. There is insufficient winter precipitation to fill storage capacities (other factors, such as runoff of snowmelt waters on frozen but unsaturated soil etc., should be considered separately) and there is no residual amount for runoff. Water deficiencies are moderately high, though it is of interest that the deficiencies at Banff are higher.

Water surpluses were produced by the relatively high winter and spring precipitation of both 1953 and 1954, the heavy June rains of 1953 and the heavier August rains of 1954. It is of interest that the latter two surpluses were almost the same even though the August rains were heavier. This was due to the difference (3 inches) in unfilled storage capacities before the rains began. (The use of daily rather than monthly data would have indicated larger surpluses than these but the major patterns of differences are correct).

(5) Gleichen (Figure 10e) - This station is representative of plains areas still farther to the east. The storage capacities are filled to approximately the same degree but the lower summer precipitation and the higher evapotranspiration result in much larger water deficiencies than in Calgary. Deficiencies of this order result in severe wilting of plants and supplementary water supplies (irrigation) are highly desirable.

Heavy snowfall and rain in spring and early summer may result in some runoff (as in 1953) but runoff in late summer is rare.

Seasonal Variations in the North and South

(1) Rocky Mountain House (Figure 11a) - This station is representative of northern foothill-plains margin areas. The precipitation curve in summer is very similar to that of evapotranspiration and moisture deficits are not normal. Storage refill requirements are not large and much of the winter snowfall is available for spring runoff. The lack of moisture deficiencies results in actual evapotranspiration totals as high or higher than in warm areas to the south and east. The later peak of maximum precipitation is characteristic of northern areas.

Relatively large surpluses were available for runoff in both 1953 and 1954. All of the excess of precipitation over evapotranspiration of June 1953 ran off because storage capacities were full. Half of the excess in August 1954 was required for soil moisture recharge. The balance available for runoff was still higher, however, than in the south where lower precipitation and greater withdrawals from storage were present.

(2) Nordegg (Figure 11b) - This station is located to the west of a belt of mountain outliers which partially block and modify storms from the east. Its normal precipitation and evapotranspiration curves are similar to those of Rocky Mountain House (both lower so that water yields are comparable) but variations are present in each year. The relative precipitation of the June 1953 and August 1954 storms for Nordegg and Rocky Mountain House indicate the effects of the mountain outliers.

(3) Lyndon (Figure 10f) - This station is on the eastern slope of the Porcupine Hills. Moisture deficiencies in late summer are normally moderately large. The storms of early June 1953 reached their maximum intensity in this general region and the high water yields resulted in severe flood damage. The storms of August 1954 were lighter than in the north and the excess of precipitation over evapotranspiration did little more than partially refill depleted storage.

(4) Waterton (Figure 11c) - This station is located in the southern foothill-front range area where it receives maximum intensity mT and cold front mP precipitation. In addition, it is sufficiently close to the dividing range to receive heavy snowfall from the west in many winters. Moisture deficiencies are present in most summers despite the high annual precipitation, and water yields are high. These yields are concentrated in a relatively short period of time because the early maximum of precipitation (early June or late May normally) occurs only shortly after or during the period of maximum snow melt which is also earlier than in the north.

(5) Lethbridge (Figure 11d) - This station is representative of southern plains areas where moisture deficiencies are large in middle and late summer, and irrigation is desirable. The relatively early spring rains (and late winter snowfall) frequently produce water surpluses in excess of those in areas to the north and east. Annual precipitation is more dependent upon occasional heavy rainstorms and has a lower dependable base supply than in the north. This results in greater variability from year to year and droughts may be severe.

(6) Cowley (Figure 11e) - This station is located on the plains-foothills margin to the west of Lethbridge. Precipitations and water surpluses are larger than at Lethbridge although actual evapotranspiration is larger because of the smaller moisture deficiencies. The large runoff from the June rains of 1953 may be noted in contrast to the lack of runoff from the August rains of the following year.

(7) Coleman (Figure 11f) - This station is located in the eastern intermountain region, close enough to the dividing range to experience heavy snowfalls in some winters yet sufficiently open to the east (Crowsnest Pass) to receive moderately heavy rains from mT air (June 1953). It is partially sheltered from the north-east thus some cold front storms are modified (August 1954).

APPENDIX DSEASONAL STREAMFLOWGeneral

The seasonal patterns of precipitation and evapotranspiration indicate that highly variable amounts of water are available for eventual streamflow from different parts of the region. Much of this surplus occurs as winter snowfall and is thus not available for streamflow until spring and summer temperatures are sufficient for melting to take place. Much of the excess is held for varying lengths of time in detention storage. Areas with very limited storage or infiltration capacities may have rapid surface runoff, and streamflow response to precipitation excess may be very rapid. The many variables result in appreciable differences in flow regime yet general patterns may be identified with regional examples.

Regional Variations

(1) Waterton River (Figure 12a) - The Waterton River is measured at three stations: (a) above Waterton Lake (a in graphs) in Glacier Park where the flow is of back range origin; (b) below Lower Waterton Lake (a plus b in graphs) where the flow includes runoff from front range areas; and (c) at Standoff (a plus b plus c in the graphs) on the foothills-plains margin where additional front range and foothill runoff is included.

The streamflow from the back range areas is high every year (see yield scale) though it tends to be concentrated in summer months. This may be attributed to the time of snow melting, far more than to seasonal rainfall, and to the limited soil moisture storage capacities. The smaller amounts of snow in the front range and foothill areas tend to melt earlier and current precipitation plays a more important role than in back range areas. Extremes of yield are more common (compare June flows of 1953 and 1954) because of: (1) the greater variation of rainfall than of snowfall (2) the greater reliance upon single storms or groups of storms than on the collected precipitation of a season and (3) the difference between precipitation and evapotranspiration is proportionally more variable. Most of the snow has been melted and current precipitation is less than potential evapotranspiration by the end of July (See Waterton, Figure 11c) thus streamflow from all areas is low in late summer, fall and winter.

(2) Grinnell Creek (Figure 12b) - Grinnell Creek rises in and obtains a large part of its volume from Grinnell Glacier which rests on the dividing range. The melting of ice and snow provides the greater part of the high and dependable streamflow. Most of the snow adjacent to the glacier has melted by late July and glacial ice and snow melt and cold front precipitation provide the bulk of the flow for the remainder of the season. If the glacier was not present it is probable that annual yield would be much the same but the streamflow would be more concentrated in the months of May, June and July.

(3) Willow Creek (Figure 12c) - The flow of Willow Creek is similar to that of many southern streams that rise in the front range and have most of their tributaries in the foothills and plains areas. The yield is relatively small and is subject to major variations from one season to the next in most years (see Lyndon, Figure 10f). This yield is marginal and most of the basin contributes little or no flow for most of the year. The Willow Creek basin above Nolan (a plus b - 1010 square miles) includes relatively more plains and less foothills area than the basin above Claresholm (a - 462 square miles). The more marginal and variable nature of plains streamflow is indicated. Surpluses are available from large areas in late spring or early summer in some years (e.g., early June 1953) and major floods occur. These are generally of very short duration and the flow for most of the year is quite small.

The peak flow normally occurs in June of high water years, May of normal and most low water years, and in April of some very low water years. Streamflow after early June is generally low.

(4) Crowsnest River (Figure 12d) - This basin is one of relatively low elevation in back range and intermountain areas. Its water yield is low and streamflow is early for such areas because of the relatively low precipitation, high evapotranspiration and early snow-melting period.

(5) Elbow River (Figure 13a) - The Elbow River is measured at two stations: (a) at Bragg Creek (a in graphs) where flow is of intermountain front range and inner foothill origin and (b) at Glenmore Dam near Calgary (a plus b in graphs) where additional flow from outer foothills and plains margin areas is included.

The marginal and variable flow of the lower basin is received largely from snow melt waters and above normal spring rains in April and May. Detention storage capacities are relatively high in this portion of the basin and minor flow is available from storage in later months when evapotranspiration accounts for most of the precipitation.

The upper basin has relatively large areas of bare rock and runoff is rapid. Streamflow is obtained from the melting of snow in May, June and July and to a lesser degree from current rainfall. The storage of water from one year to the next would appear to be small and the net change of storage carry-over from one year to the next might very largely be ignored (Appendix A p.3).

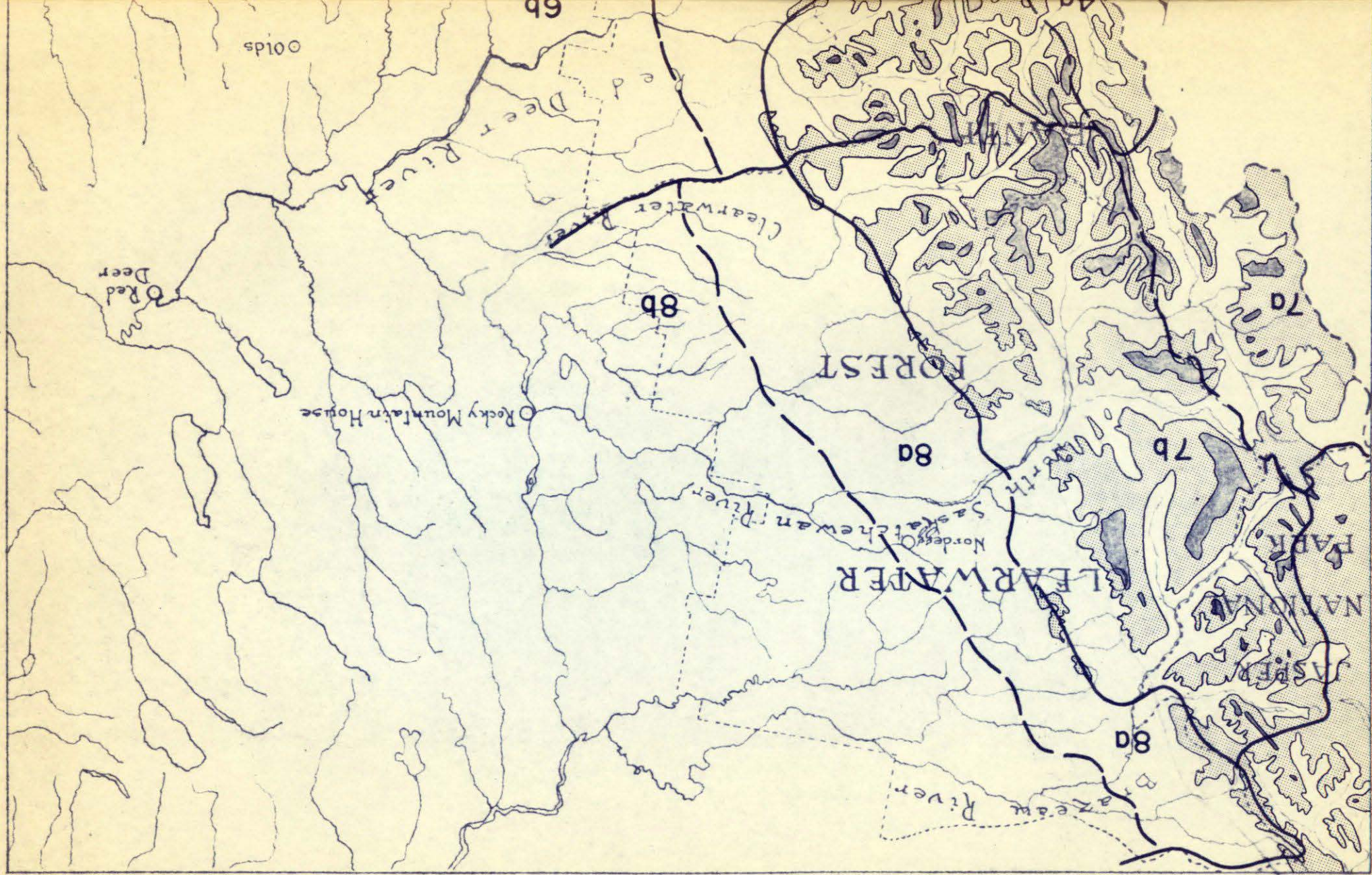
(6) Bow River (Figure 13b) - The Bow River at Banff receives its flow primarily from snowmelt in late spring and summer. The period of snowmelt may vary slightly from one year to the next and summer rainfall may cause lesser variations. The yield is consistently high and dependable.

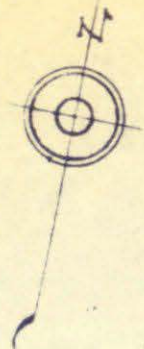
(7) Clearwater River (Figure 13c) - The Clearwater River at Rocky Mountain House receives its flow from intermountain, front range and foothill sources. Snowmelt in the more elevated areas produces a peak of flow in May, June and July. Heavy rains may enlarge this peak or cause a secondary one (as in August - September 1954). These rains are relatively more important in the foothill than in the intermountain areas as is indicated by the regime of Prairie Creek.

(8) Mistaya River (Figure 13d) - Mistaya River has a relatively high level basin in the northern back range portion of the region. Most of its flow is derived from snowmelt and the effects of elevation and latitude are indicated by the late peak of flow.



APPENDIX EHYPOTHETICAL FLOW CURVES - REGION 3

The graph "Hypothetical Flow Curves" (Figure 14f) indicates the possible effects of different vegetative covers upon streamflow regimen of a front range - foothills-- plains margin stream. The solid line (a) shows the flow regime from a burned over or overgrazed watershed (a partially smoothed curve of the flow of Willow Creek in 1953 is used). The dotted line (b) shows the hypothetical flow regime that might be present if vegetative growth were at a maximum for the climate. The dash line curve (c) is approximately the shape of demand curves of irrigation areas to the south-east that might partially be served from this source. In comparison with curve (a), curve (b) indicates (1) delayed and less peaked snow melting, (2) better infiltration and storage of melt, (2) better infiltration and storage of melt and rain water, and (3) slightly reduced yields associated with increases in transpiration. It has less damaging floods, greater flow in late summer, fall and winter, and probably better water quality. It only partially meets the requirements of irrigation but artificial storage measures would not be handicapped by excessive silt and flood damage.



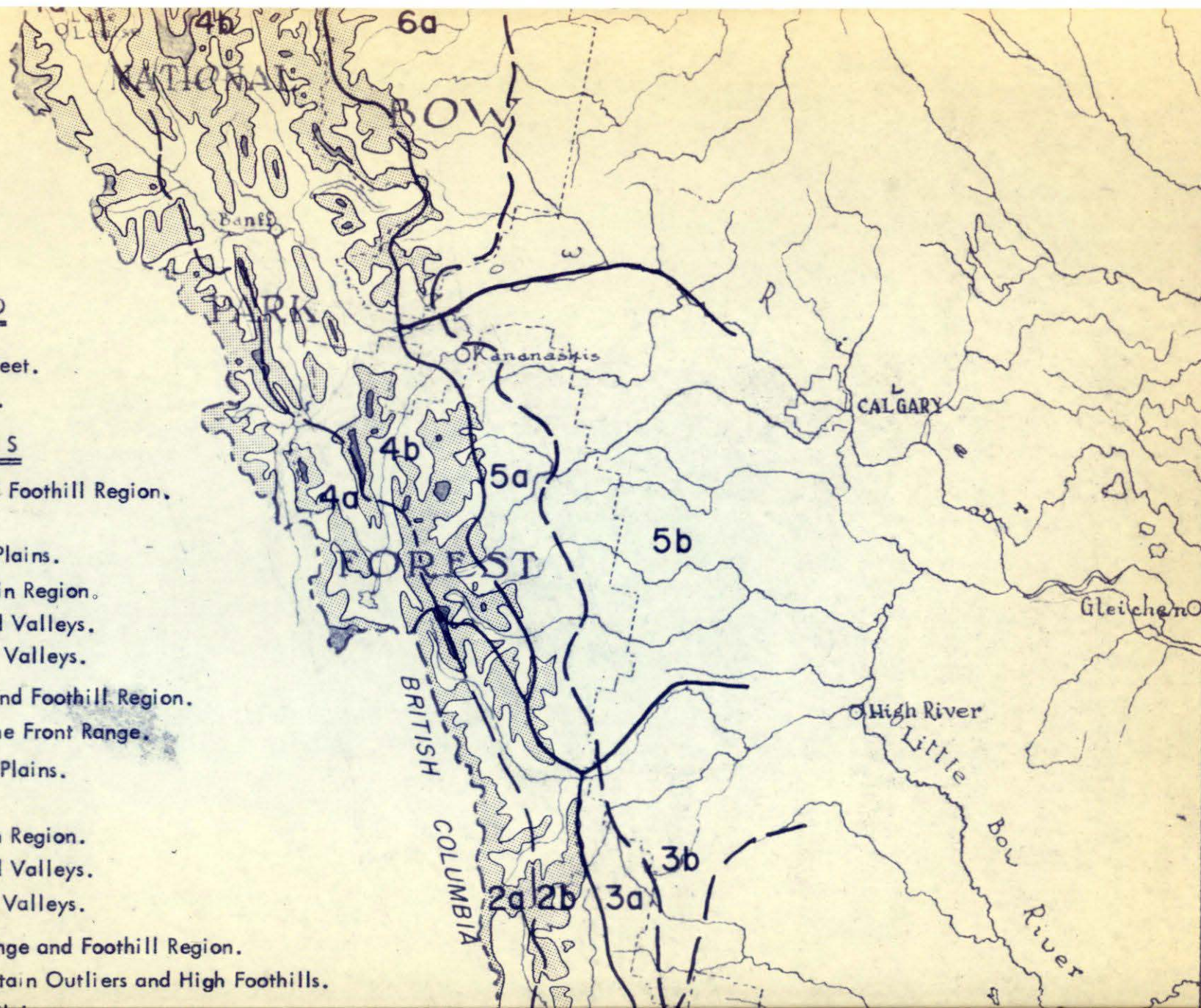


LEGEND

-  7,000 to 9,000 Feet.
 Over 9,000 Feet.

REGIONS

1. Southern Mountain and Foothill Region.
(a) Mountain Ranges.
(b) Low Foothills and Plains.
2. Southern Inter-Mountain Region.
(a) Western Ranges and Valleys.
(b) Eastern Ranges and Valleys.
3. Southern Front Range and Foothill Region.
(a) Eastern Slope of the Front Range.
(b) Low Foothills and Plains.
(c) Porcupine Hills.
4. Central Inter-Mountain Region.
(a) Western Ranges and Valleys.
(b) Eastern Ranges and Valleys.
5. South Central Front Range and Foothill Region.
(a) Front Range, Mountain Outliers and High Foothills.
(b) Low Foothills and Plains.



(b) Low Foothills and Plains.

6. North Central Front Range and Foothill Region.

(a) Front Range and High Foothills.

(b) Low Foothills and Plains.

7. Northern Inter-Mountain Region.

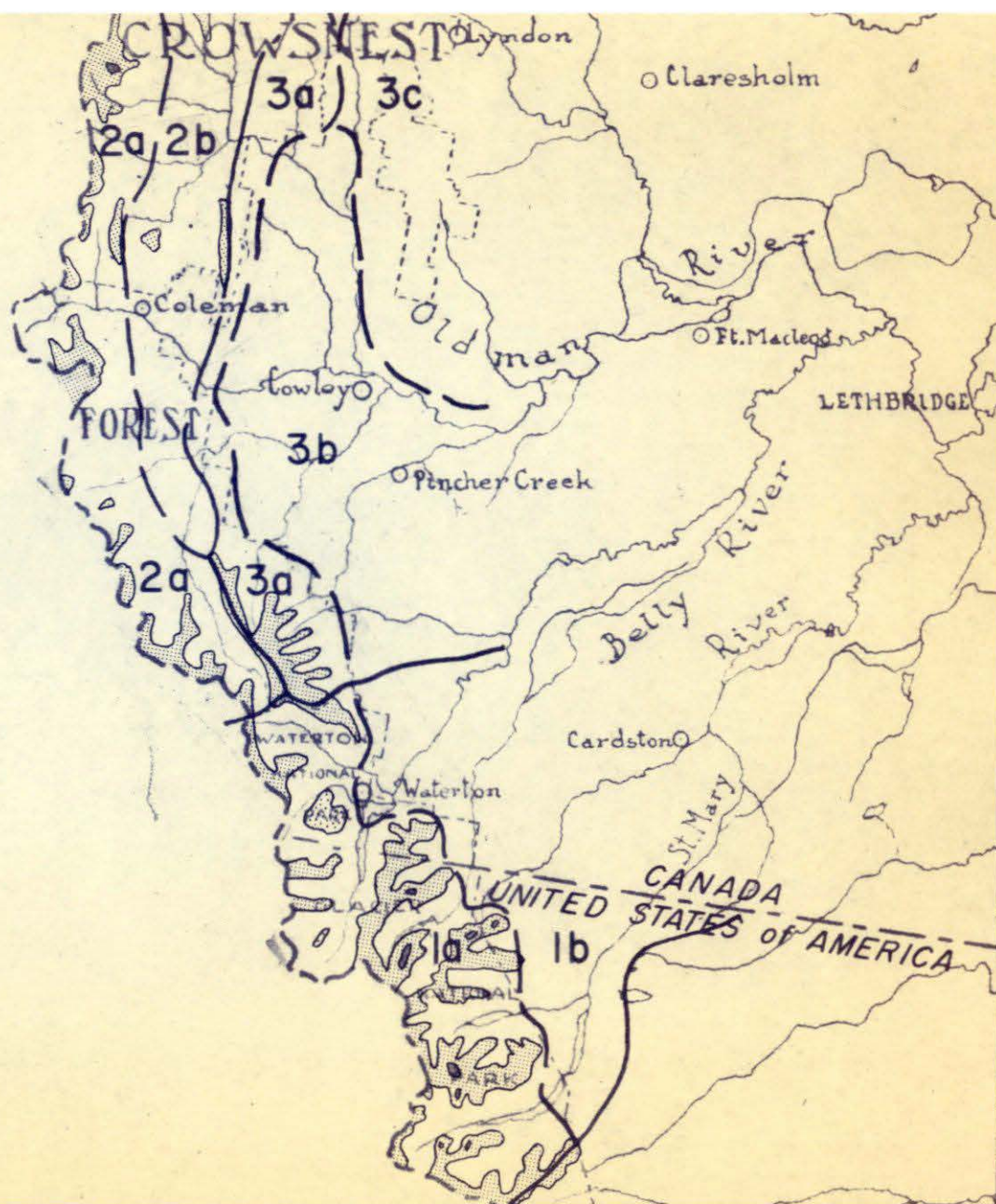
(a) Western Ranges and Valleys.

(b) Eastern Ranges and Valleys.

8. Northern Front Range and Foothill Region.

(a) Front Range, Mountain Outliers and High Foothills

(b) Low Foothills and Plains.



PRAIRIE PROVINCES WATER BOARD

PRECIPITATION AND WATER YIELD REGIONS

Scale:- 1" = 16 Miles

Date:- Aug. 1955

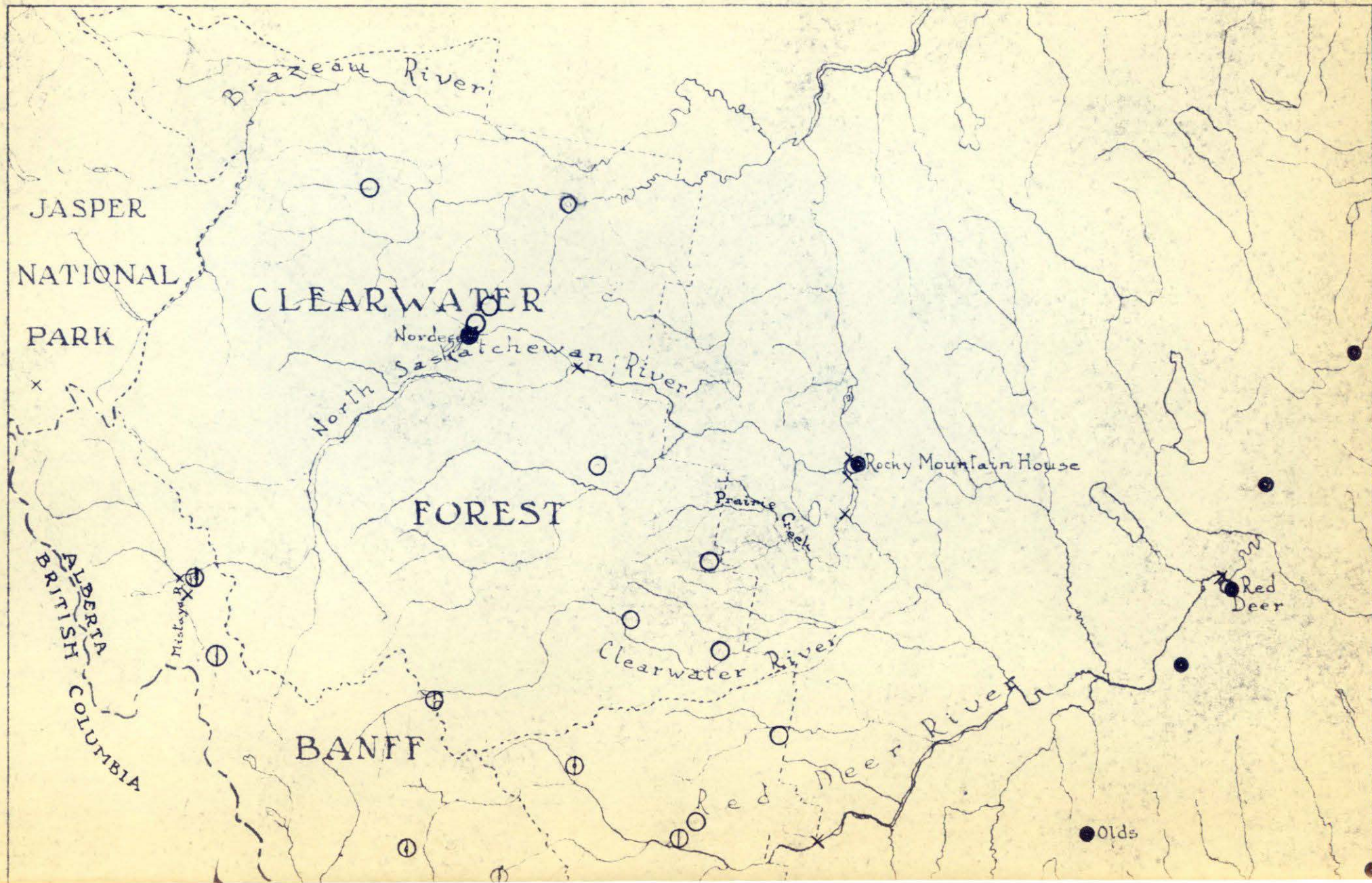
Sheet

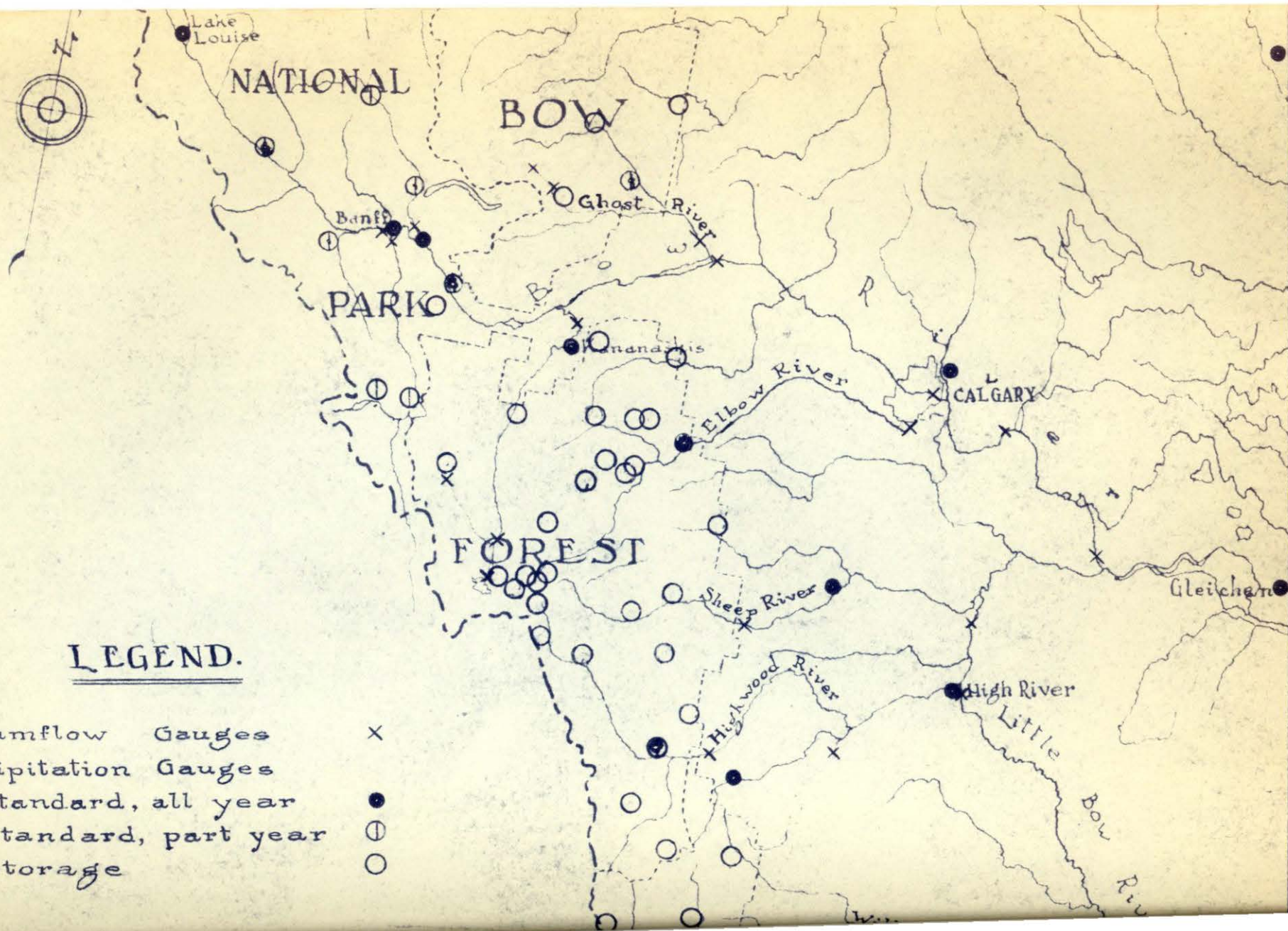
Prepared by A.H.L.

Drawn by K.B. Jarvis

HYD-C-54

FIG. I





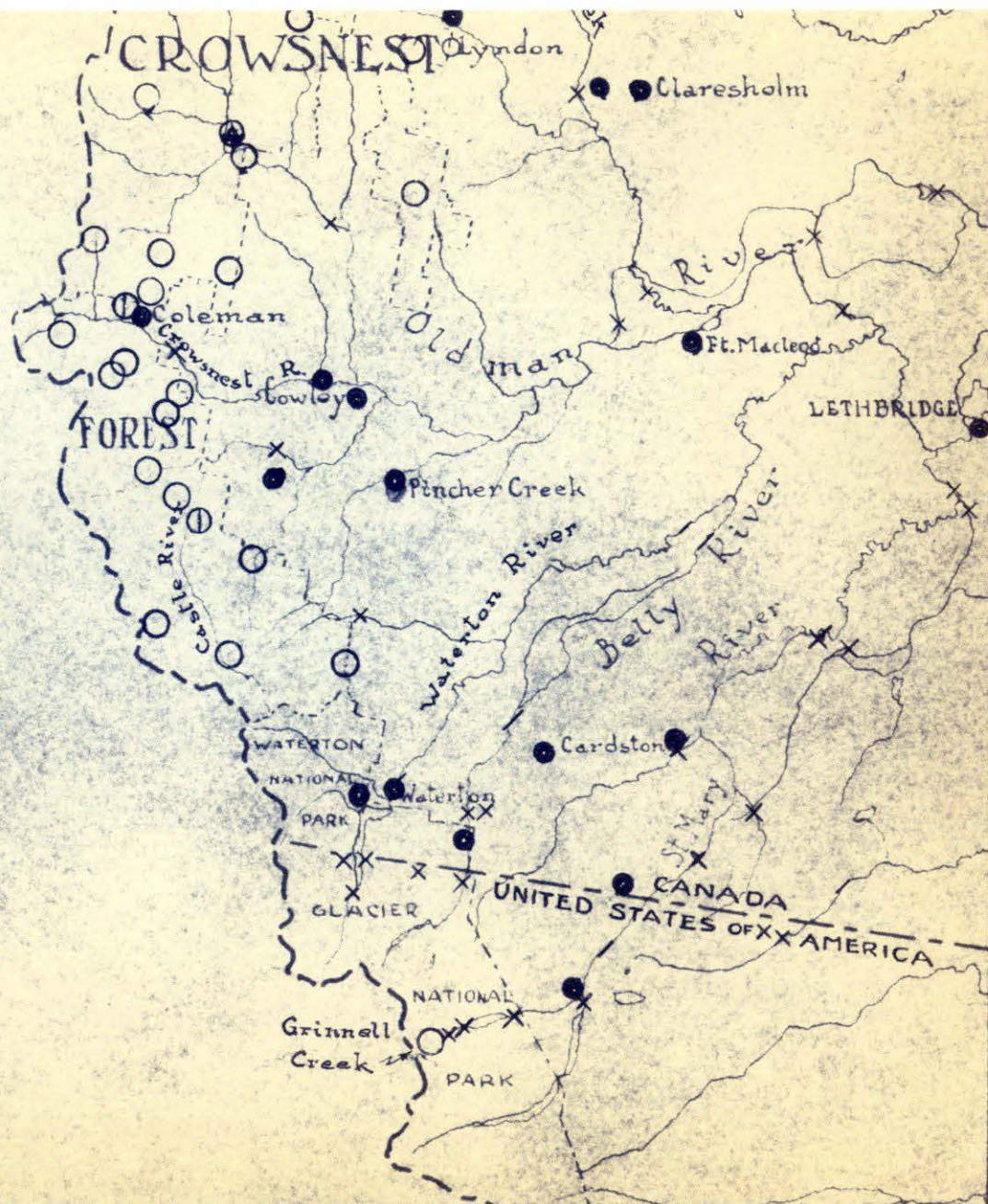
PRAIRIE PROVINCES WATER BOARD.

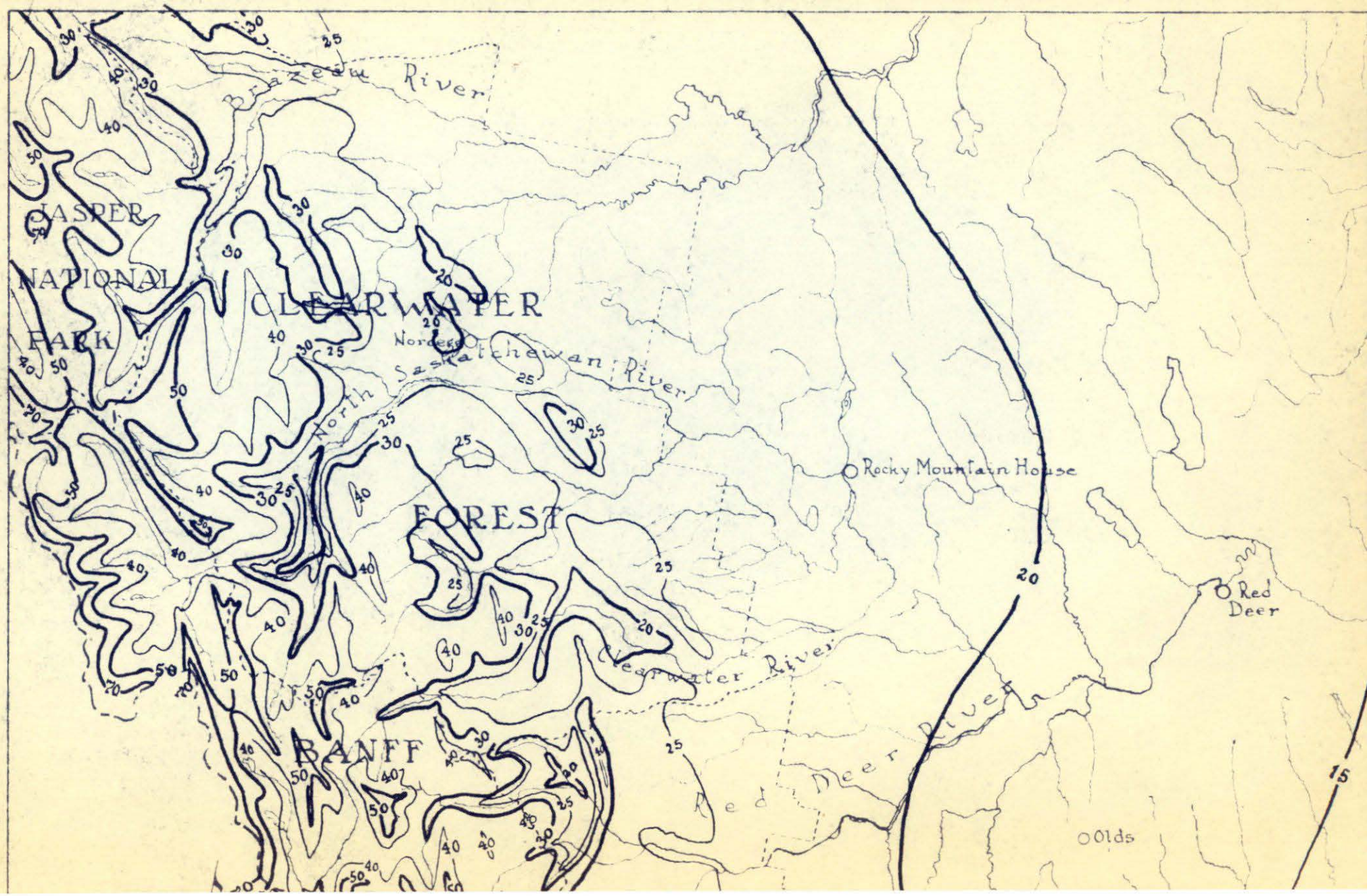
**PRECIPITATION AND
STREAMFLOW STATIONS
1954**

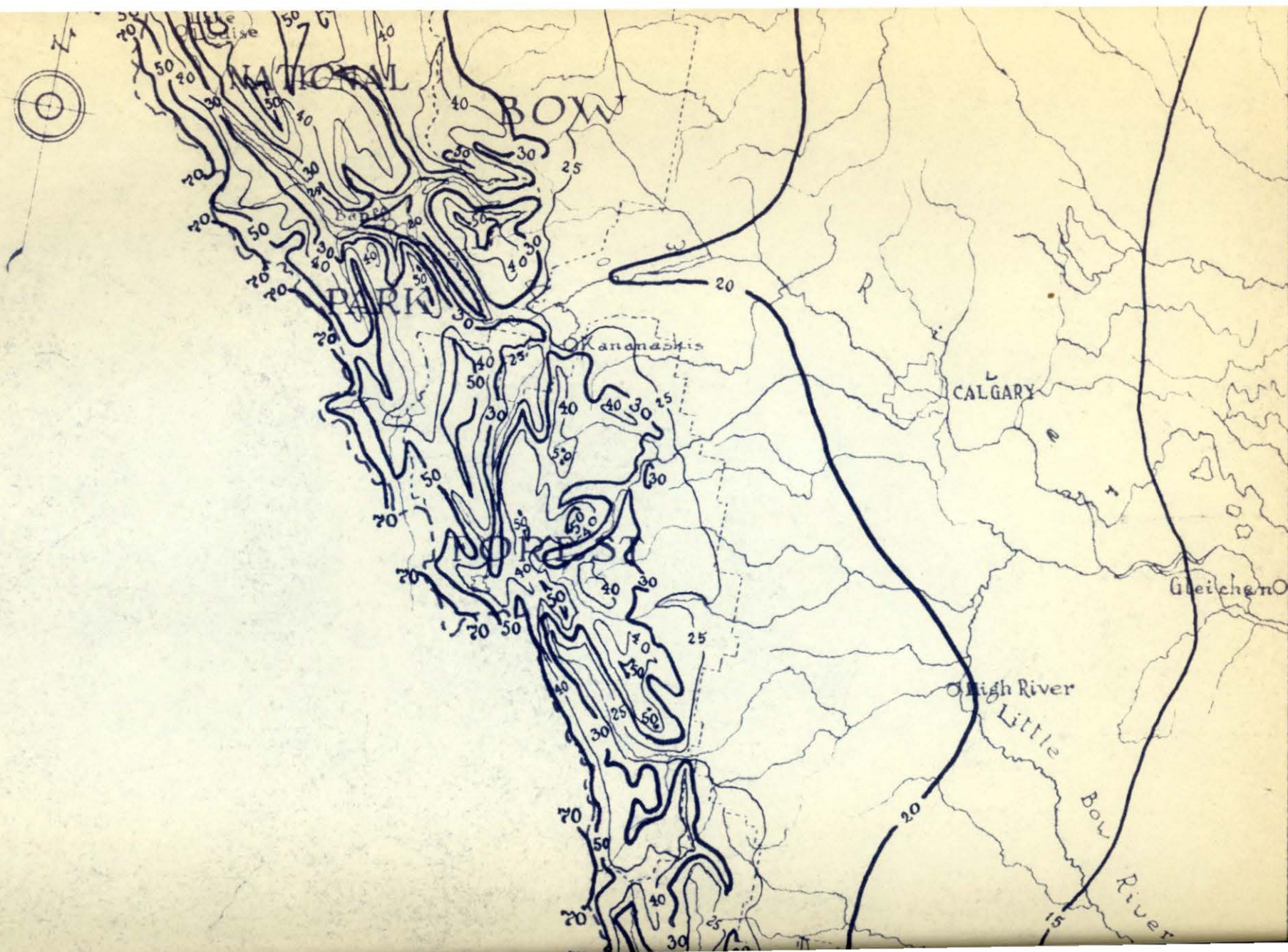
SCALE 1" = 16 MILES DATE AUGUST 1955 SHEET

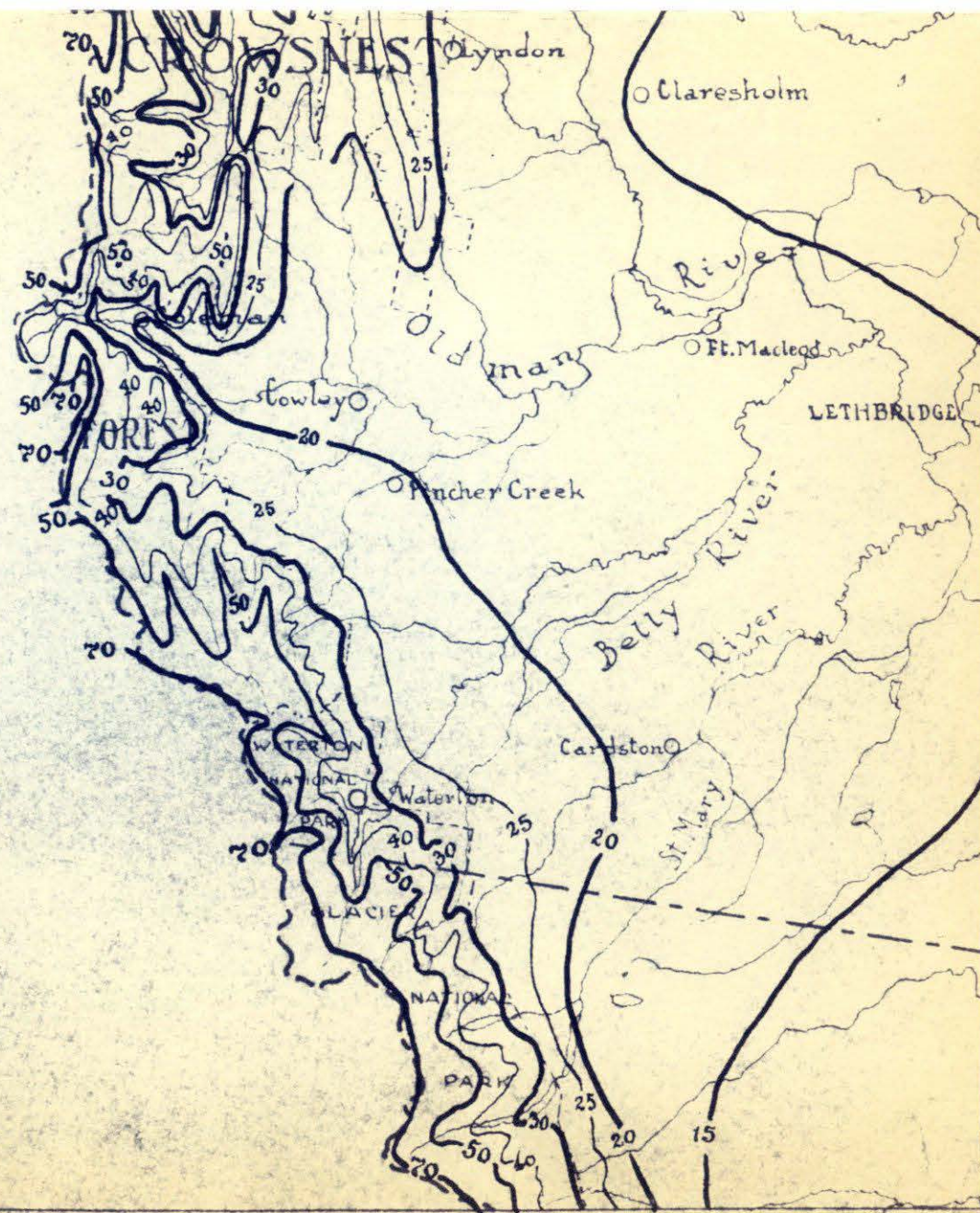
PREPARED BY A.H.L.
DRAWN BY W.M.D.

PLAN
HYD-C-55 FIG-2









PRAIRIE PROVINCES WATER BOARD

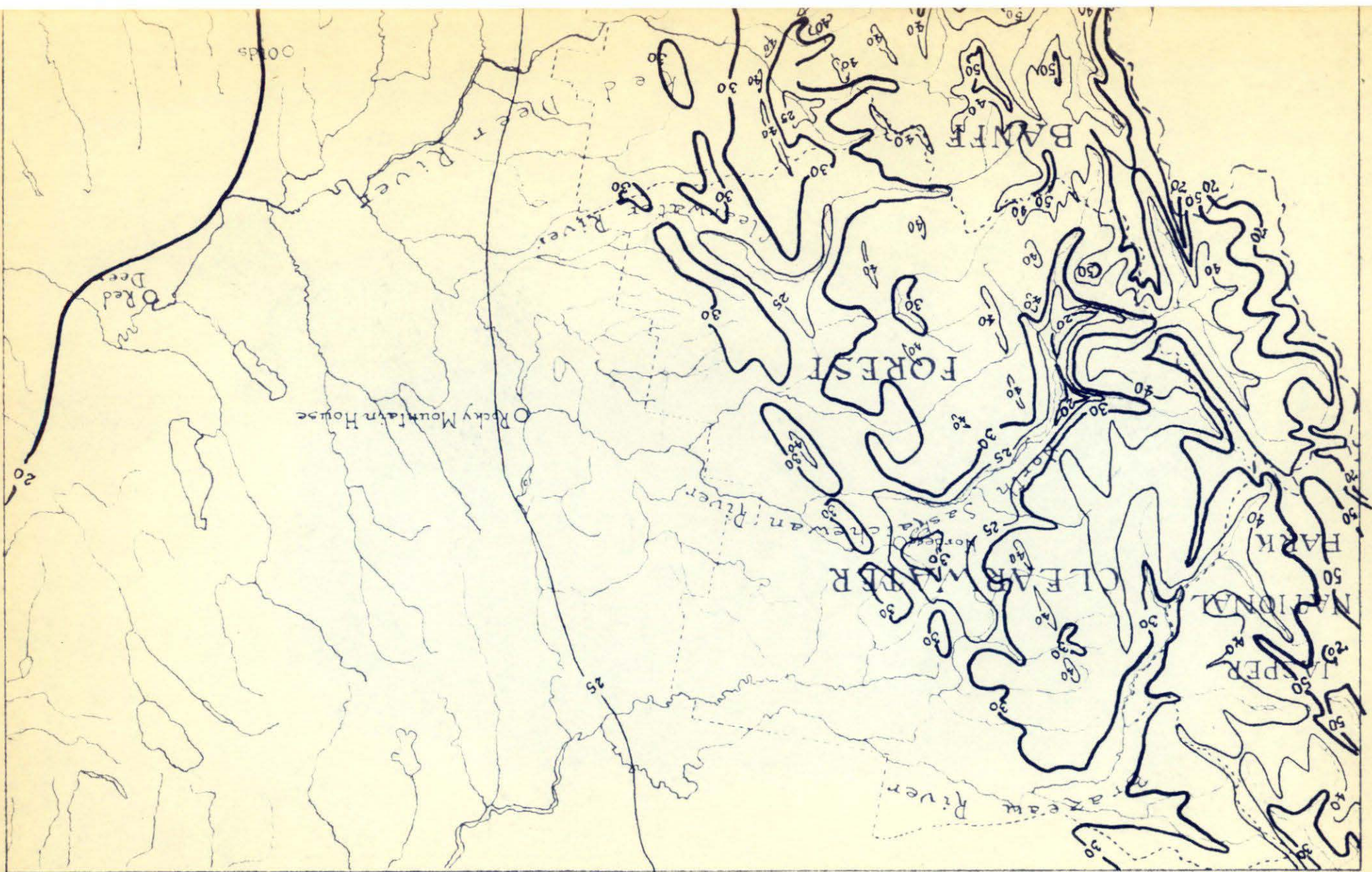
ANNUAL PRECIPITATION 1921~1950

SCALE 1" = 16 MILES DATE AUGUST 1955 SHEET

PREPARED BY A.H.L.

DRAWN BY W.M.D.

PLAN
HYD-C-53 FIG.-3





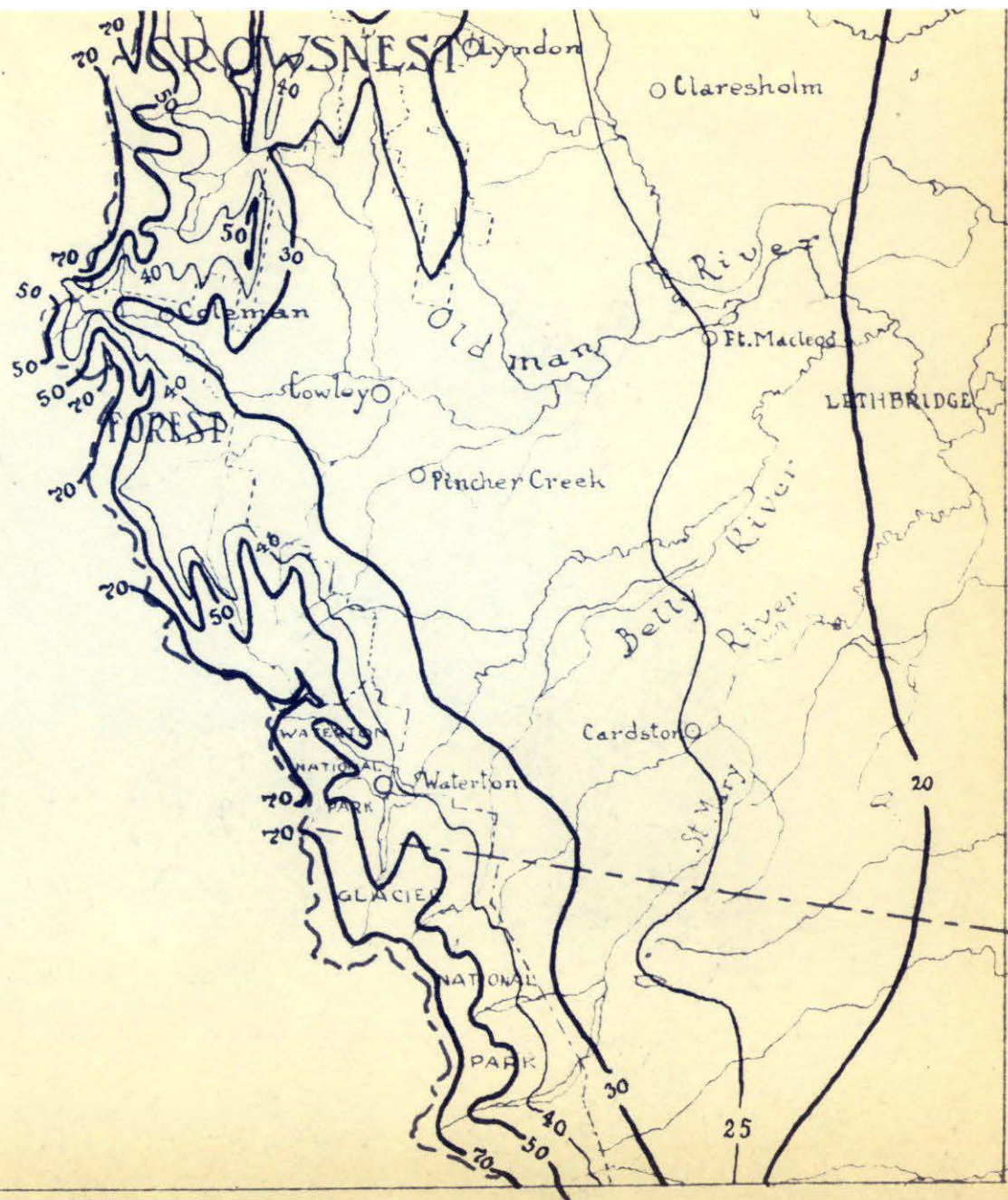
PRAIRIE PROVINCES WATER BOARD

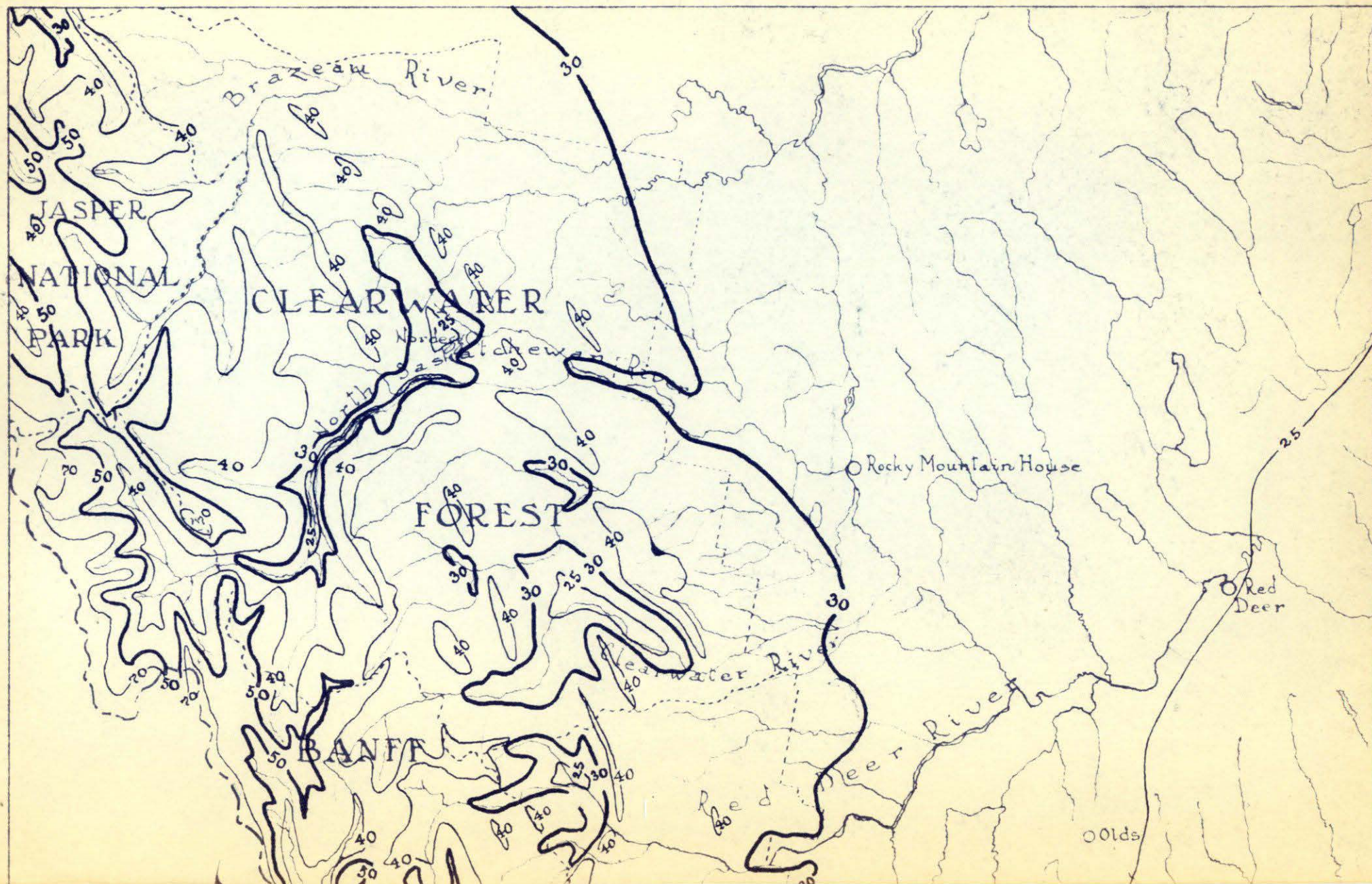
PRECIPITATION 1953

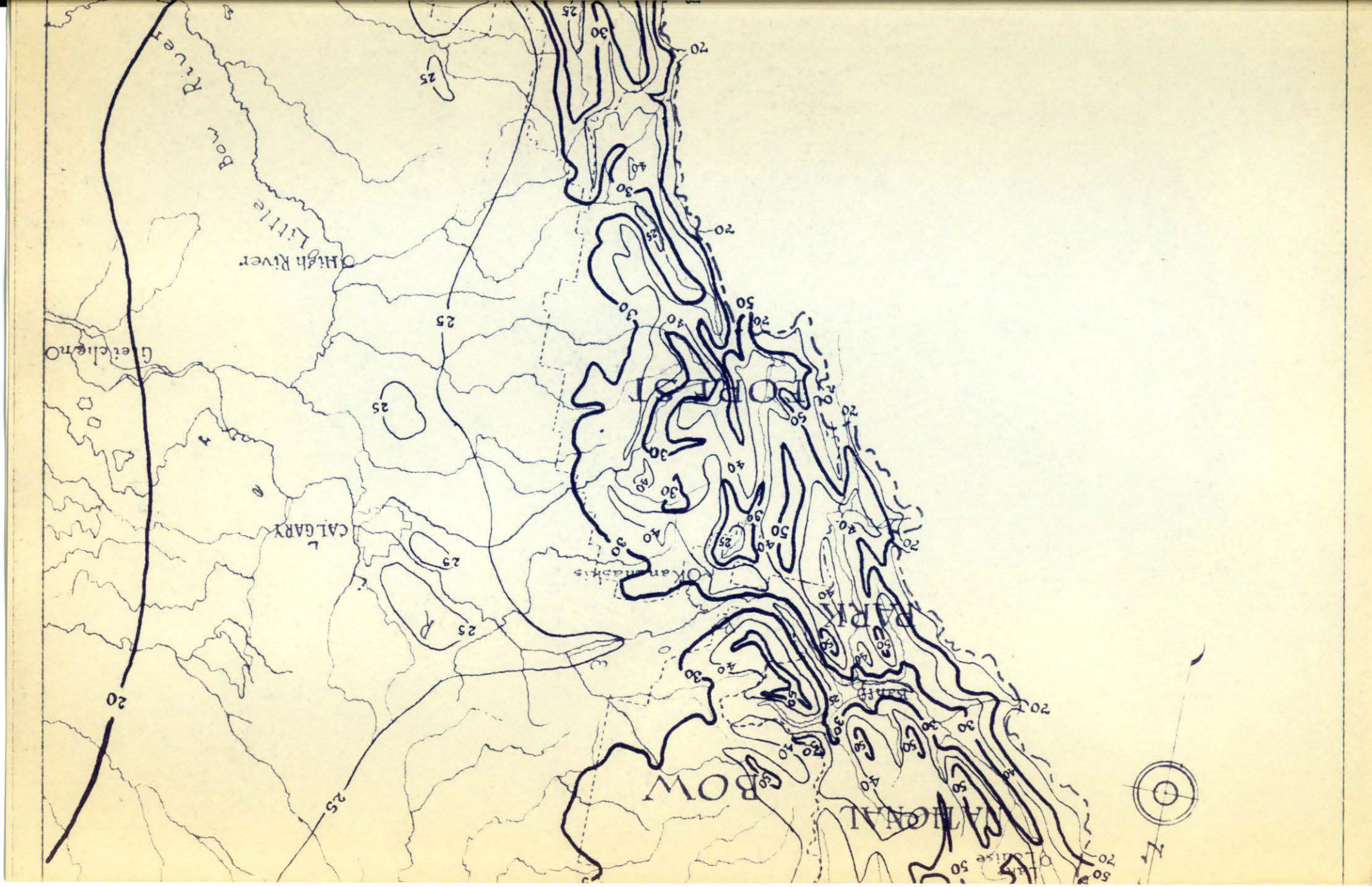
SCALE 1" = 16 MILES DATE AUGUST 1955 SHEET

PREPARED BY A.H.L.
DRAWN BY W.M.D.

PLAN
HYD-C-60 FIG-4







PRAIRIE PROVINCES WATER BOARD

PRECIPITATION 1954

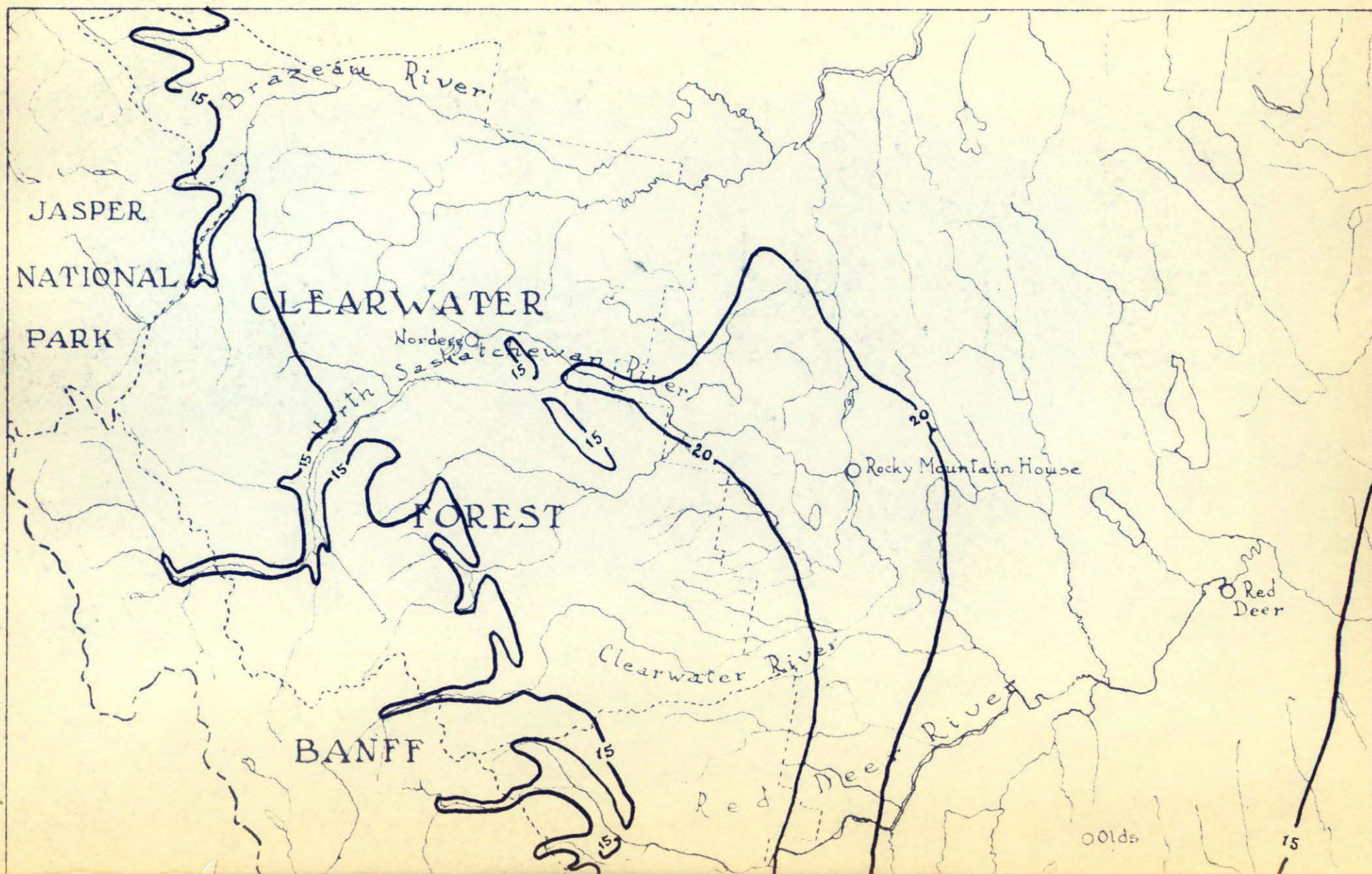
SCALE 1"=16 MILES DATE AUGUST 1955 SHEET

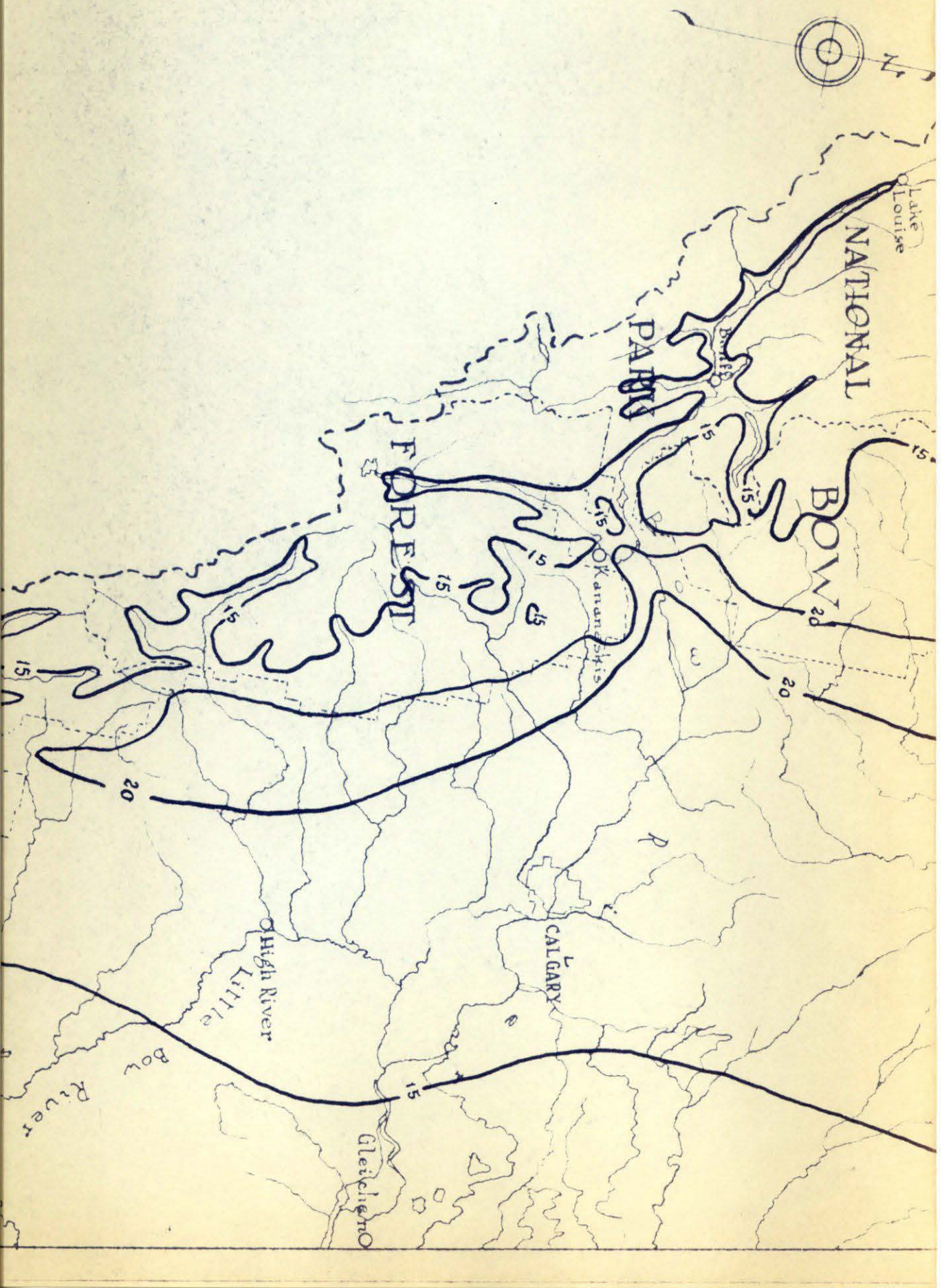
PREPARED BY A.H.L.

DRAWN BY J.M.D.

PLAN
HYD-C-61 FIG.-5







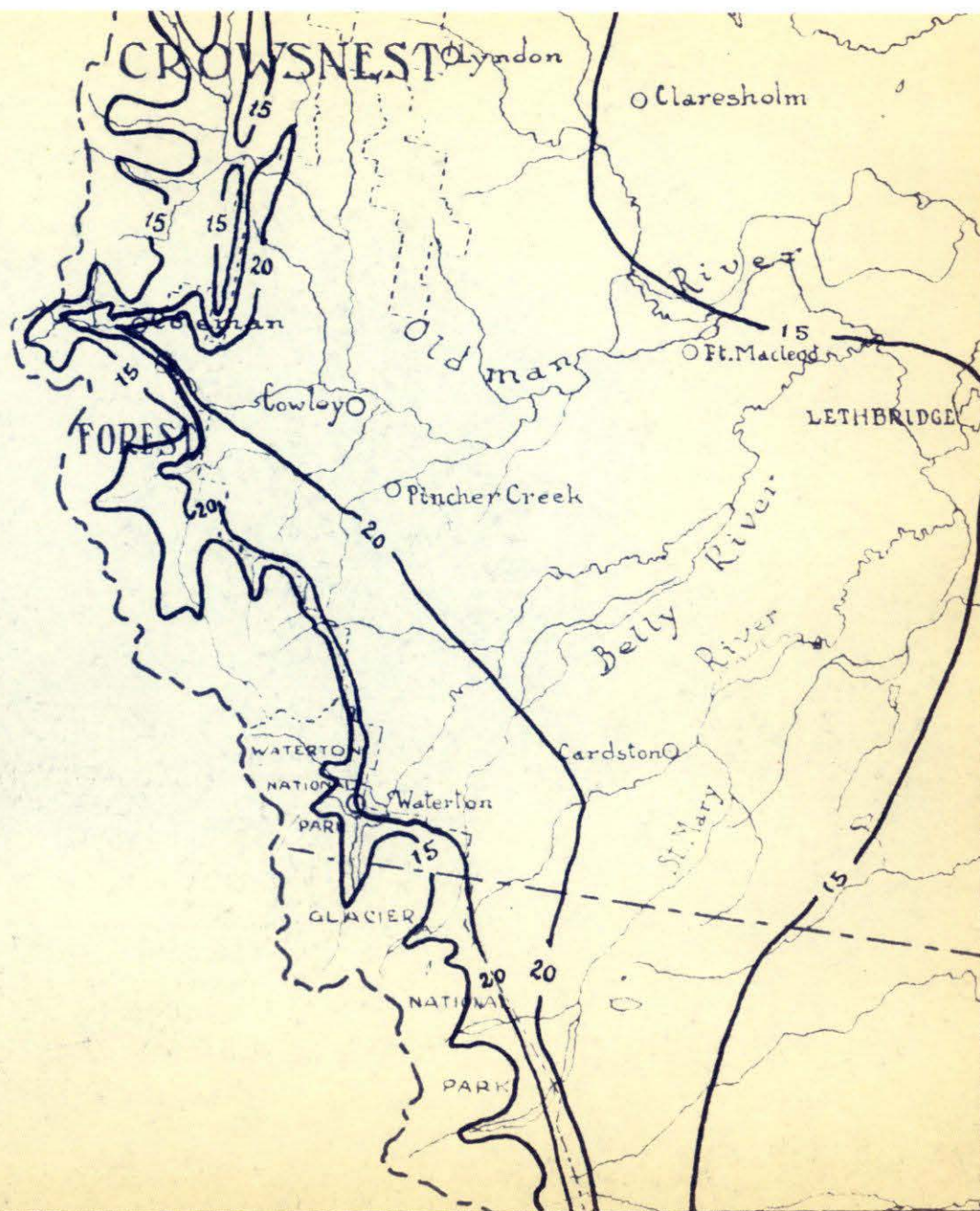
PRAIRIE PROVINCES WATER BOARD

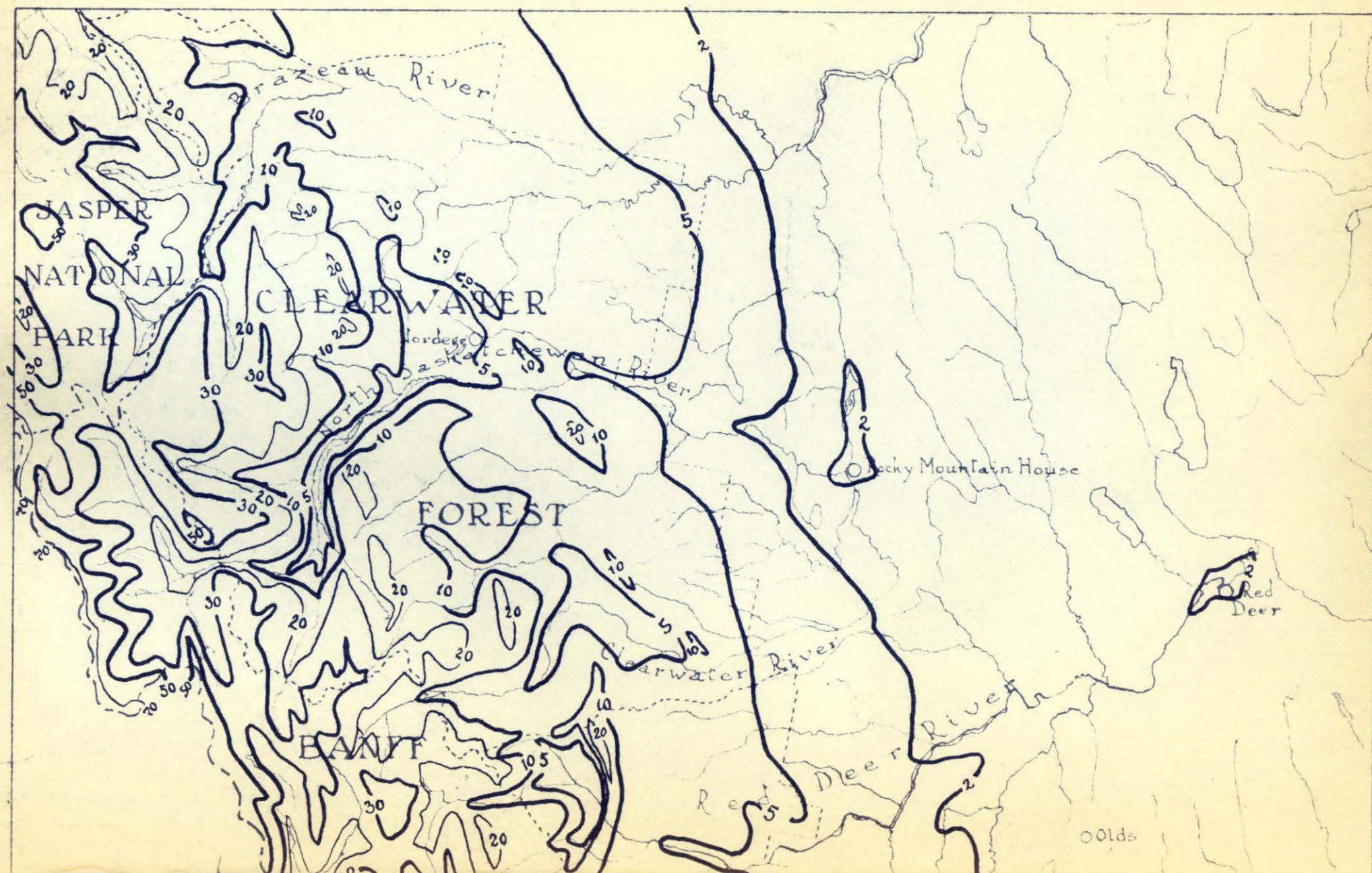
ANNUAL EVAPOTRANSPIRATION

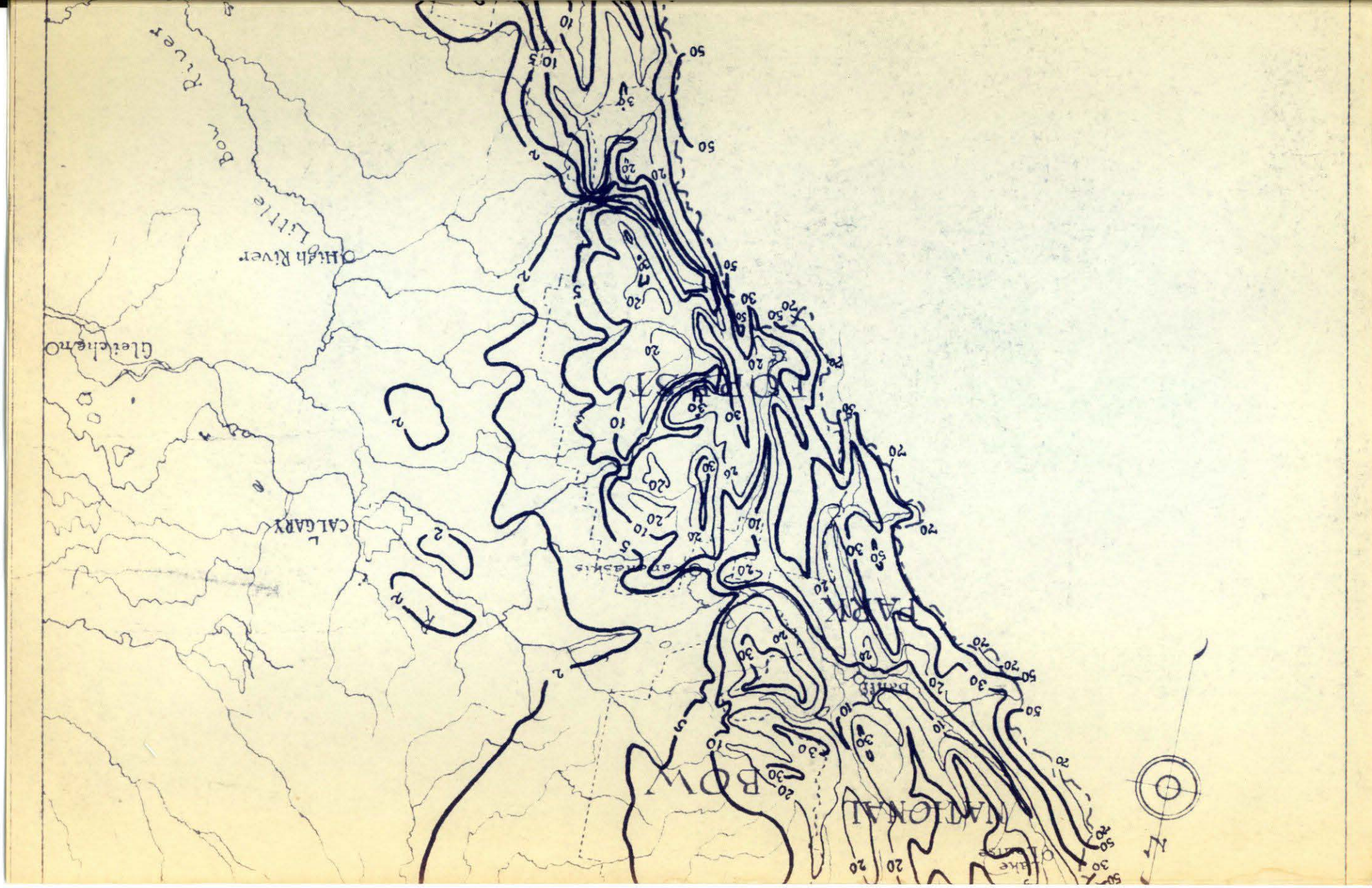
NORMAL 1921 ~ 1950

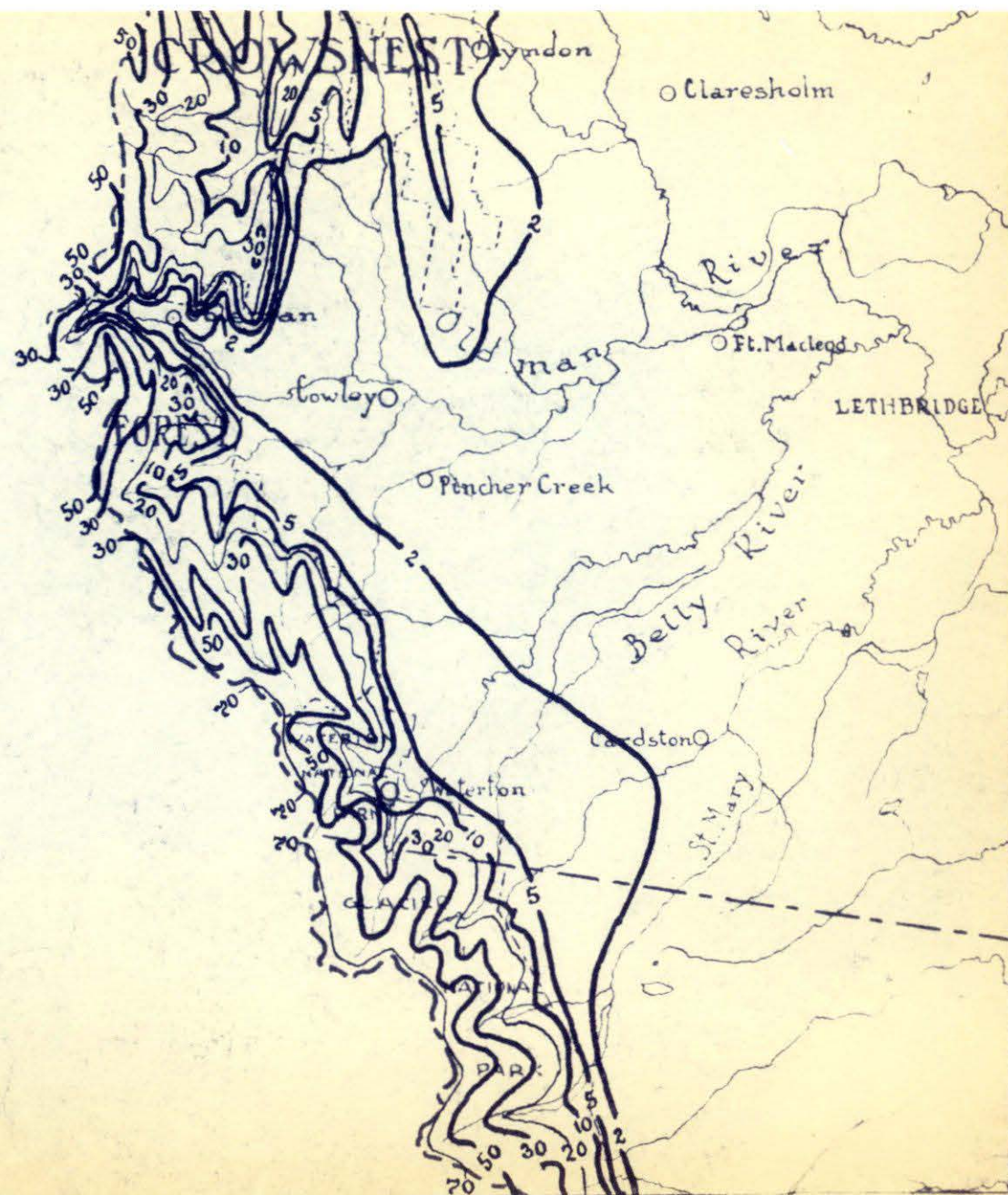
PREPARED BY *A.H.L.*
 DRAWN BY *W.M.B.*

PLAN
 HYD-C-62 FIG.- 6









PRAIRIE PROVINCES WATER BOARD

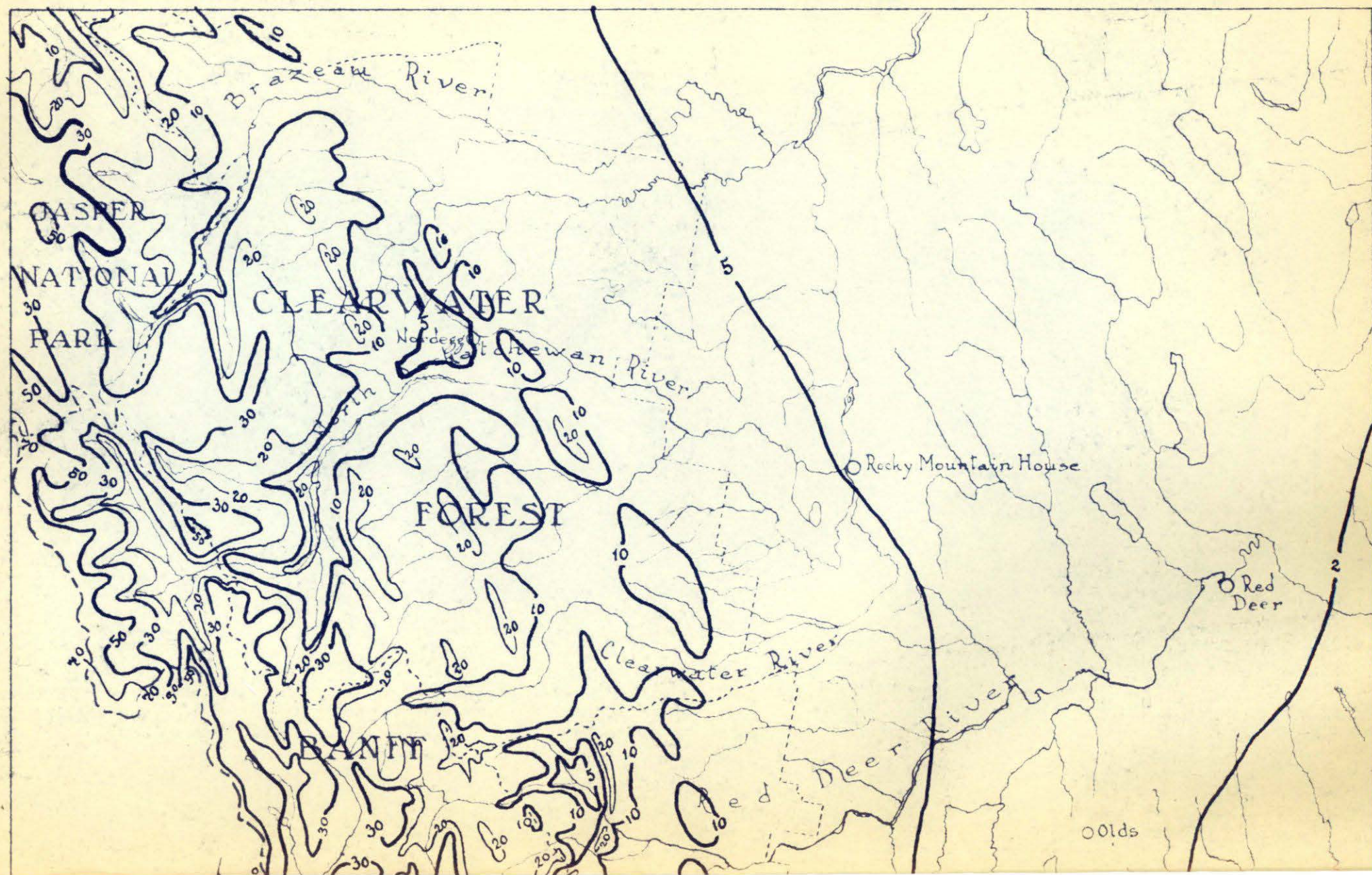
ANNUAL WATER YIELD NORMAL 1920-1950

SCALE 1" = 16 MILES DATE AUGUST 1955 SHEET

PREPARED BY A.H.W.

DRAWN BY G.M.D.

PLAN
HYD-C63 FIG.-7





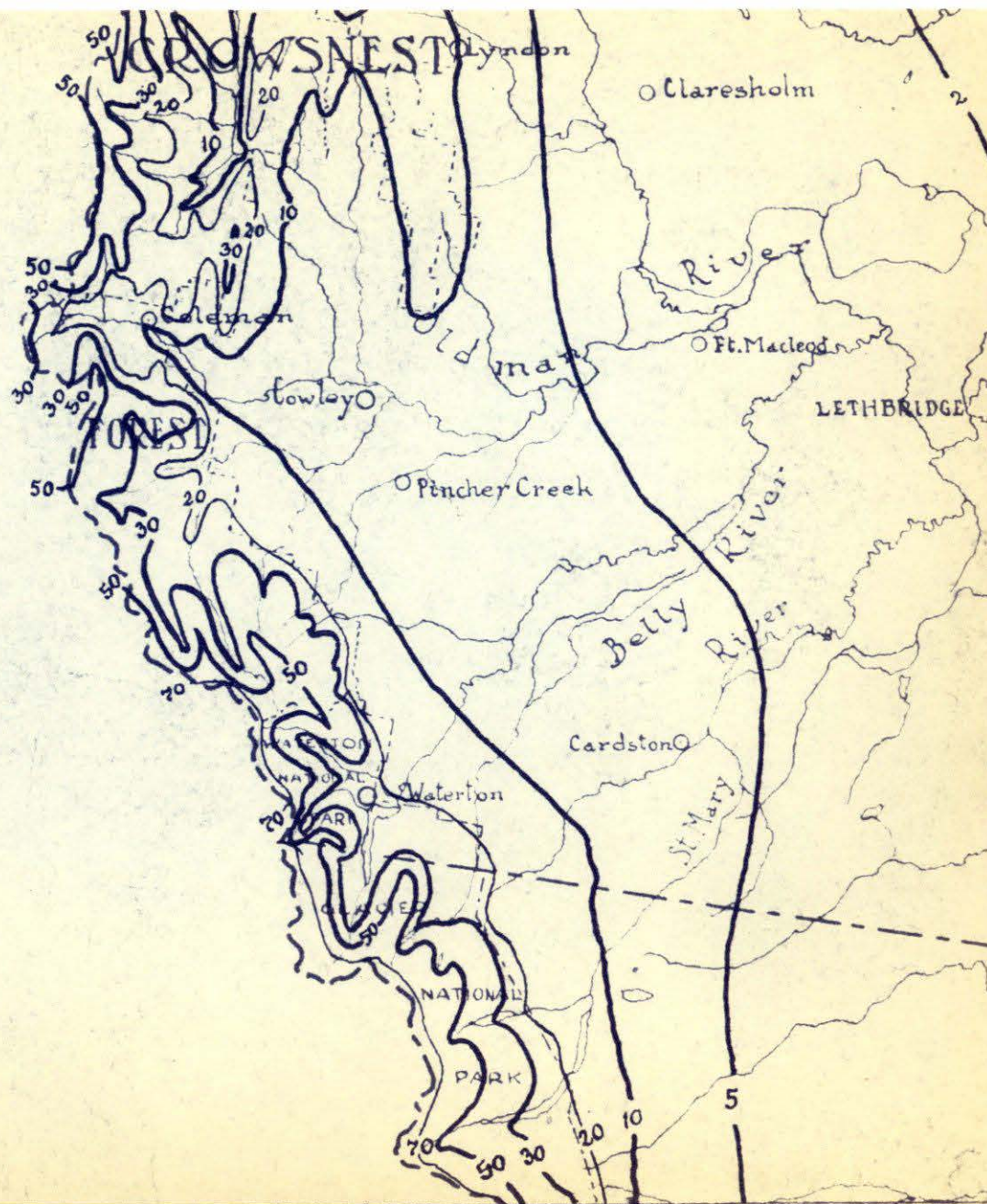
PRAIRIE PROVINCES WATER BOARD

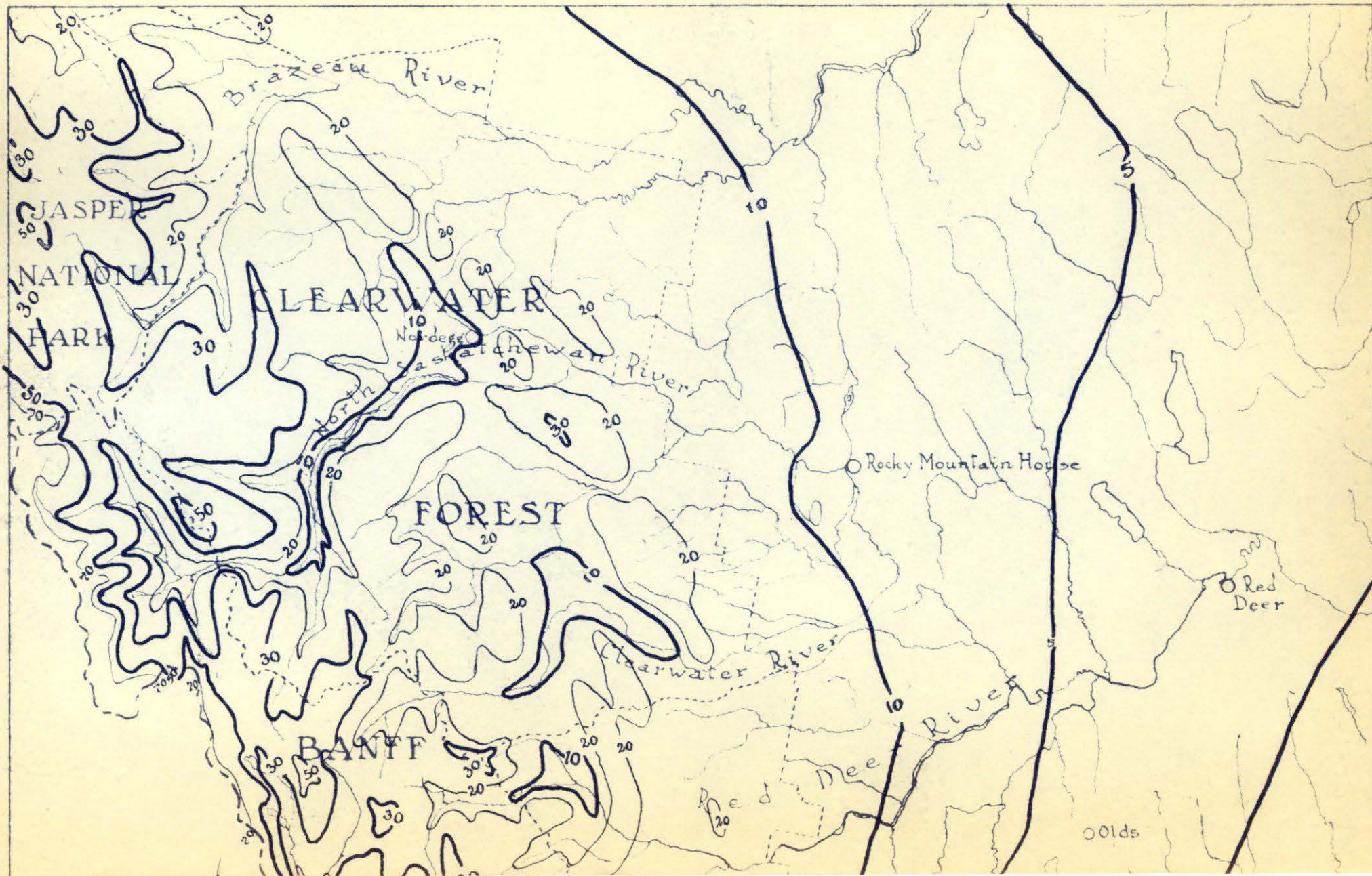
WATER YIELD OCT. 1952 - SEPT. 1953.

SCALE 1" = 16 MILES DATE AUGUST 1955 SHEET

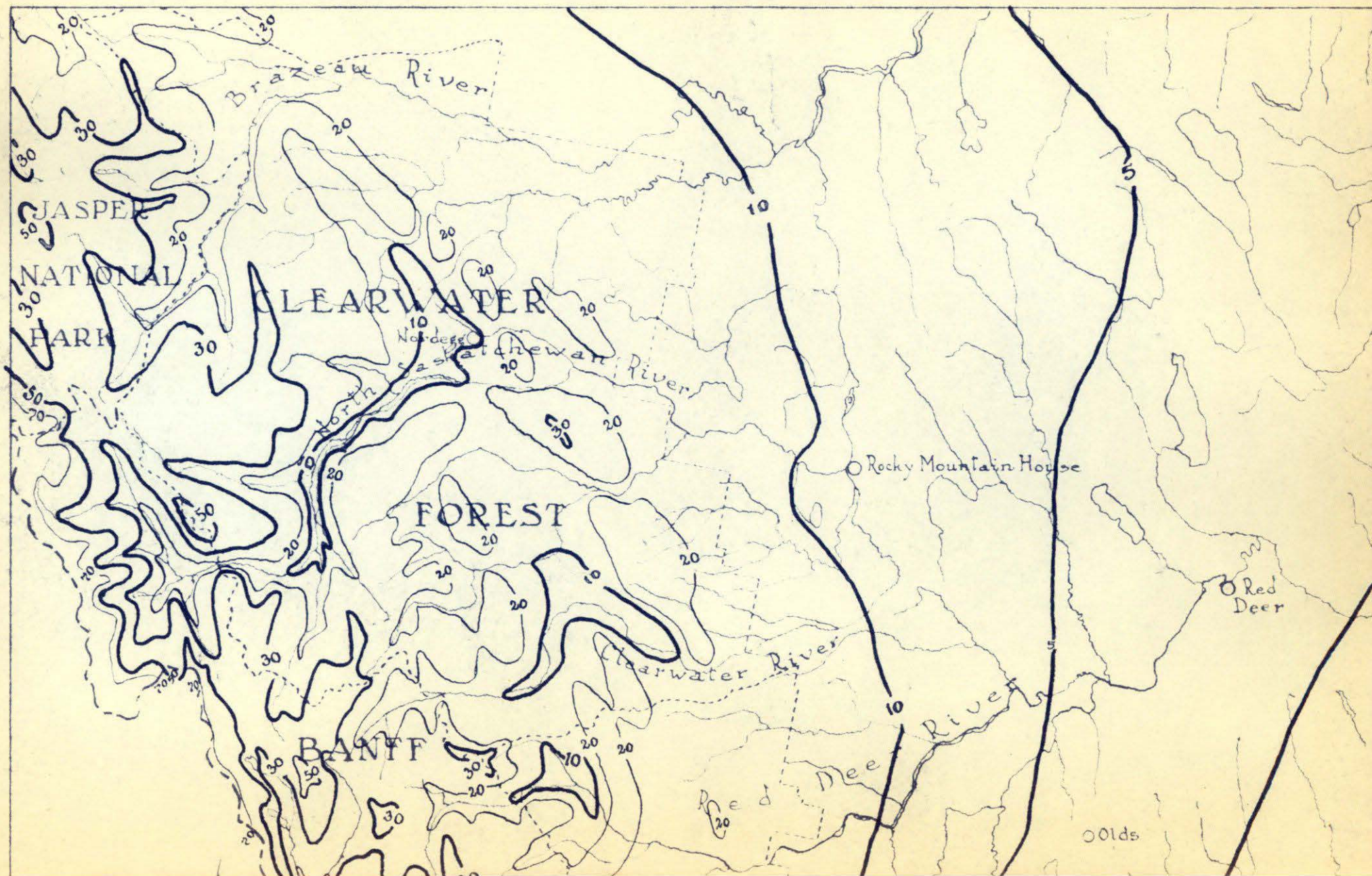
PREPARED BY A.H.L.
DRAWN BY W.M.D.

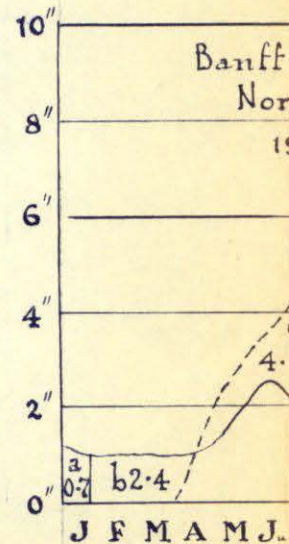
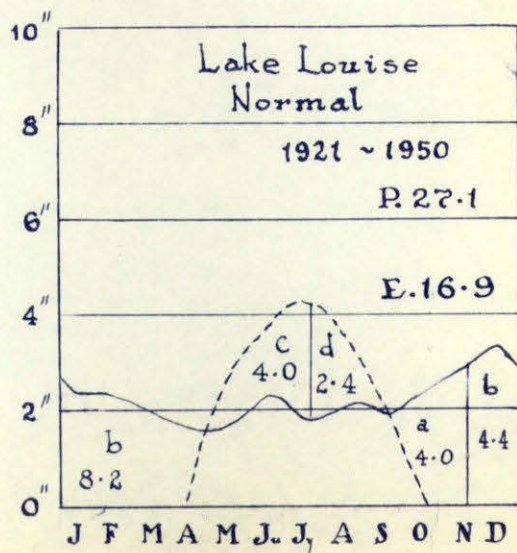
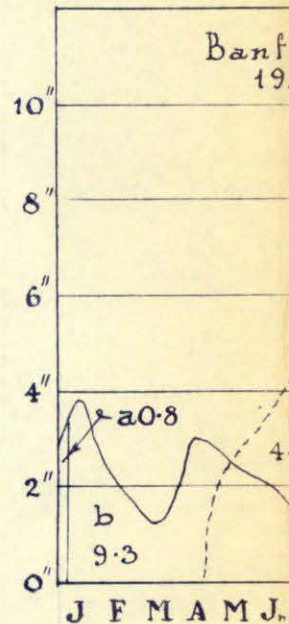
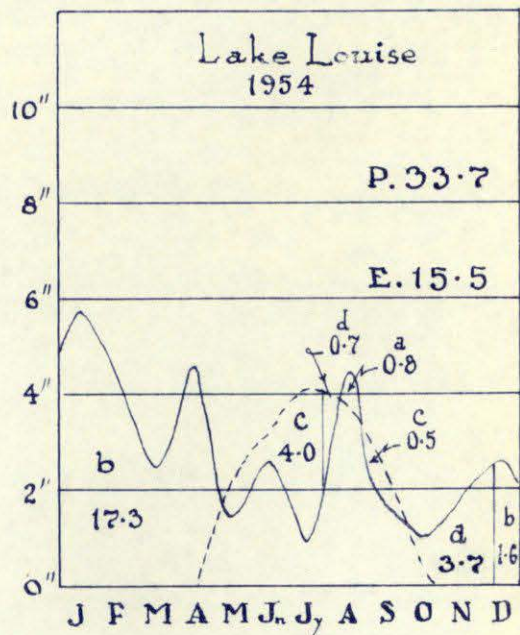
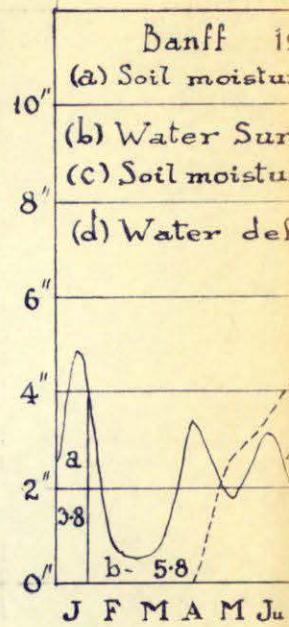
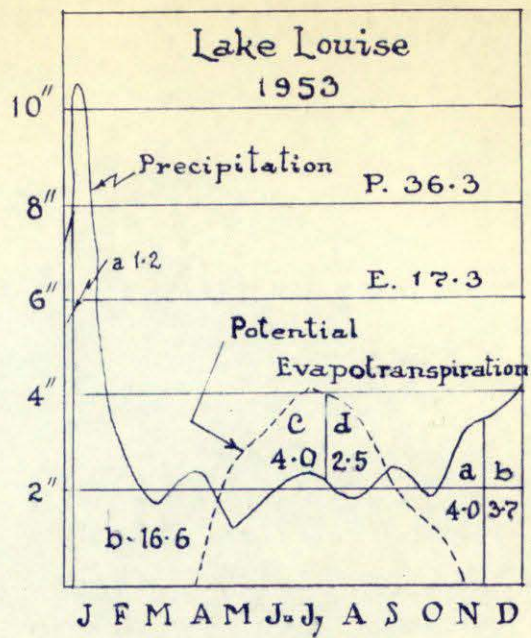
PLAN
HYD-C64 FIG.-8

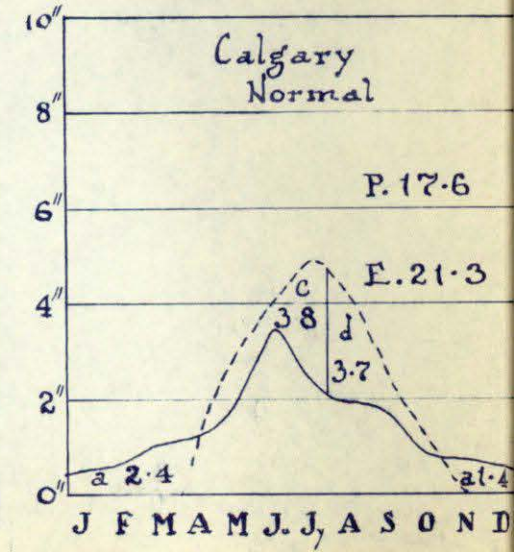
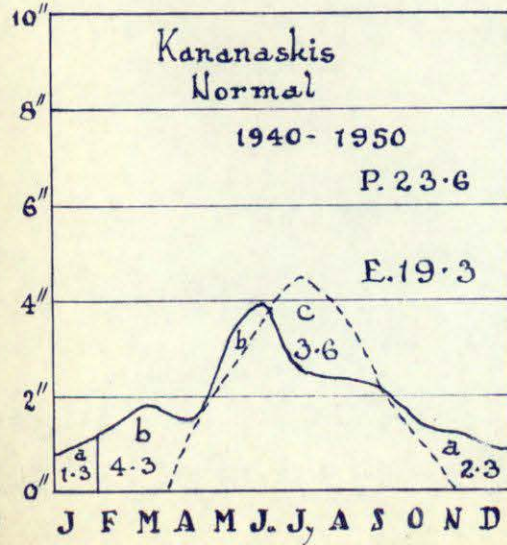
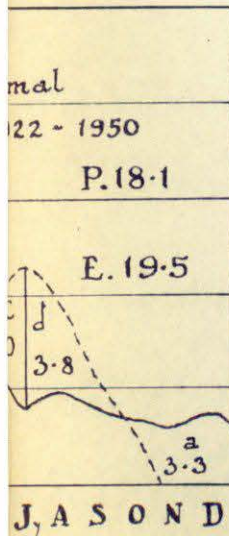
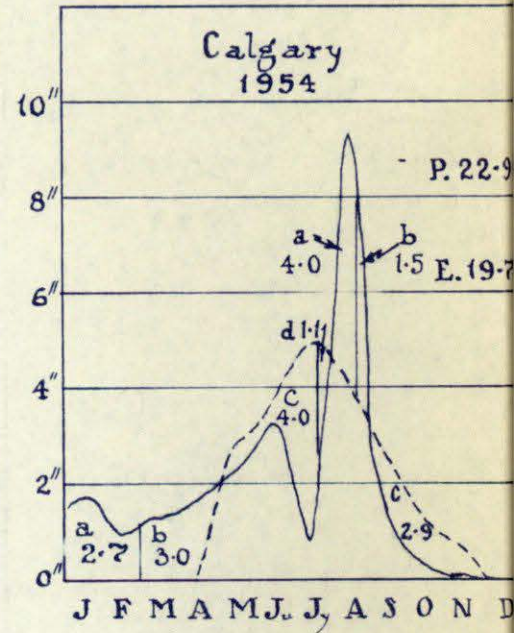
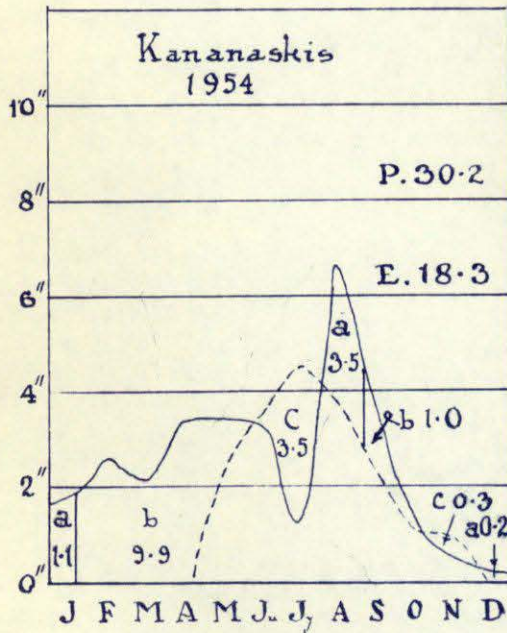
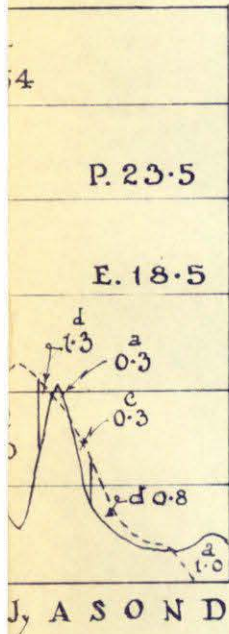
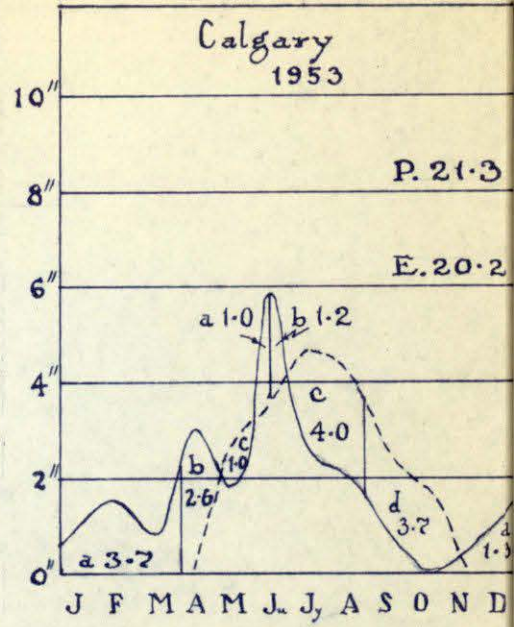
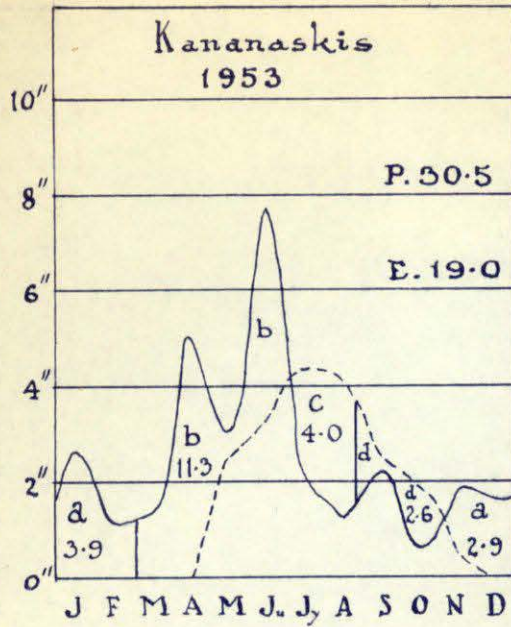
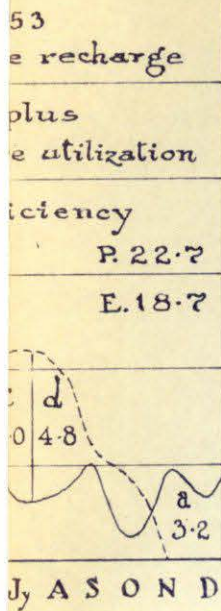


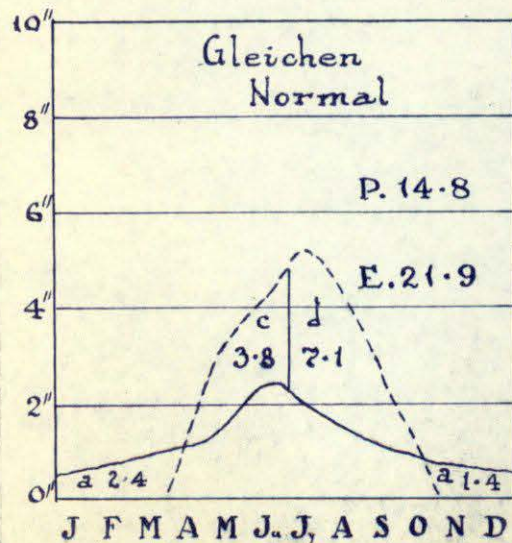
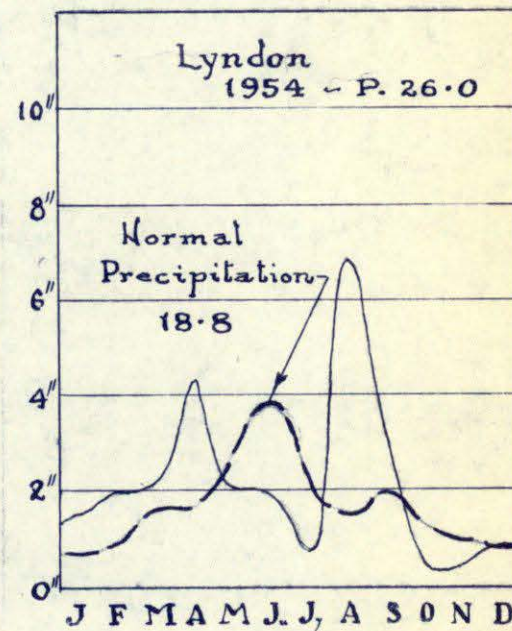
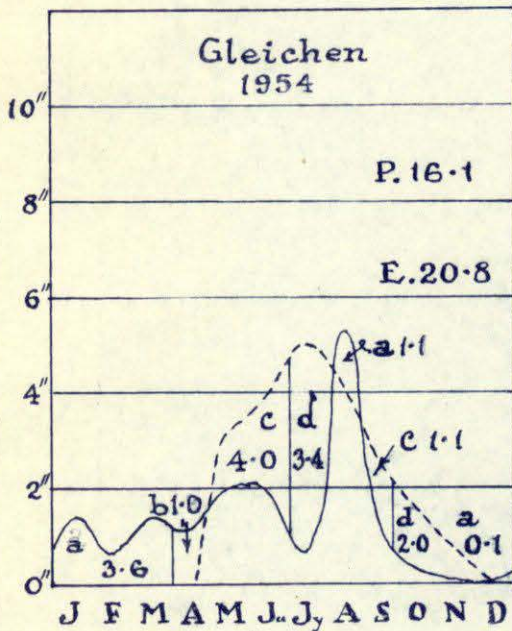
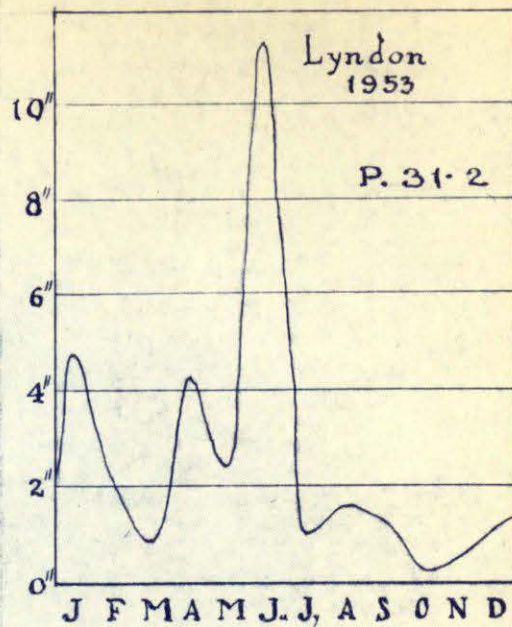
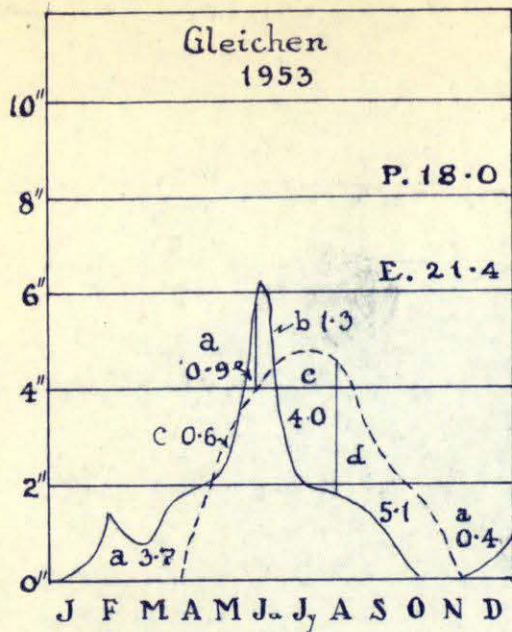








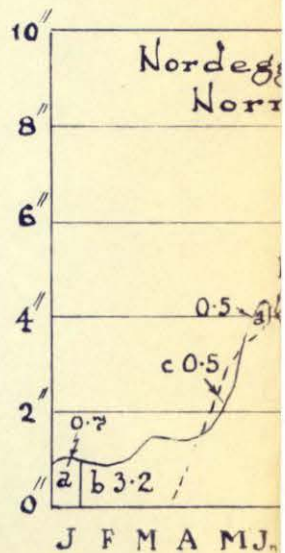
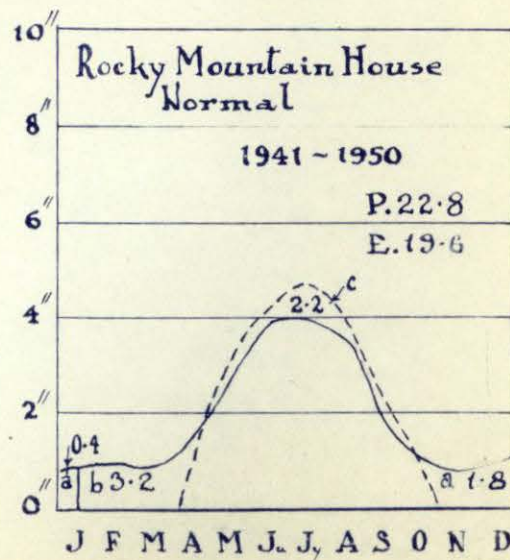
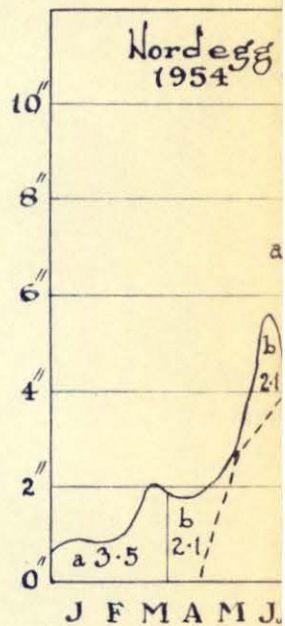
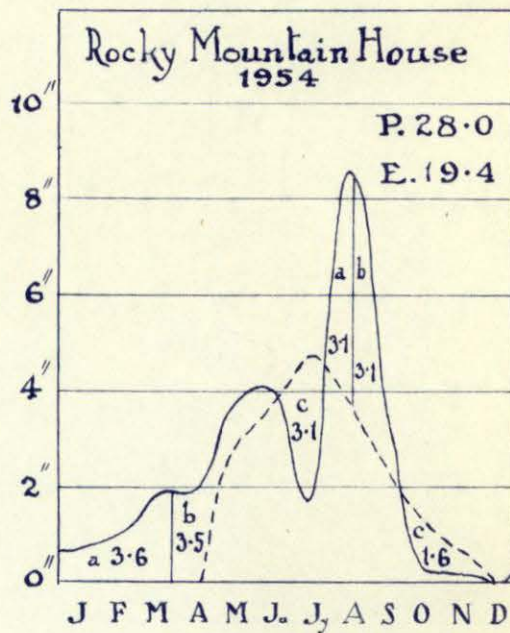
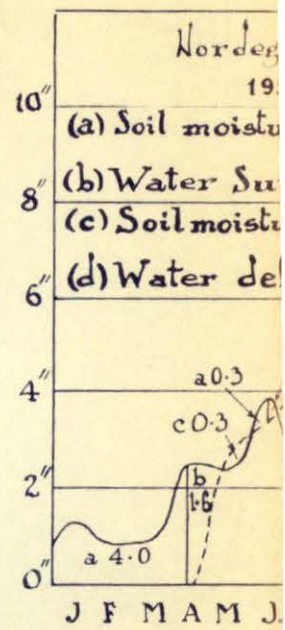
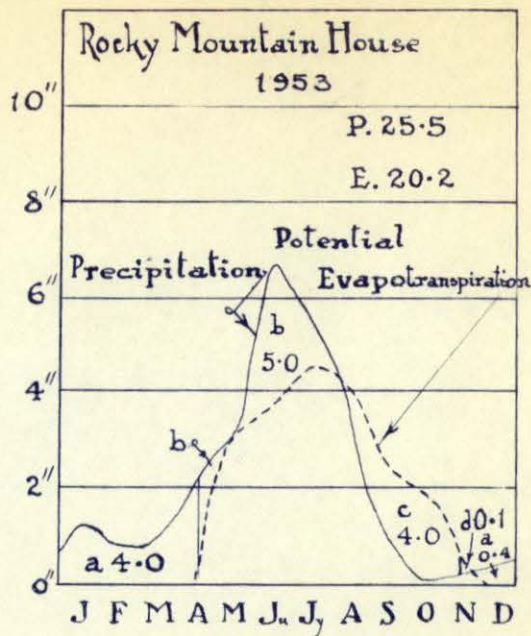


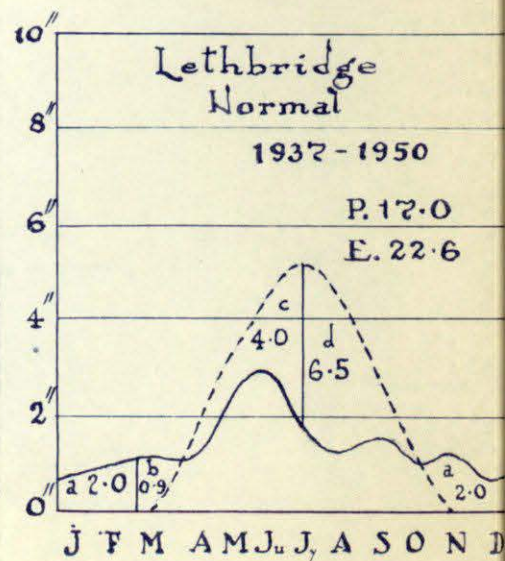
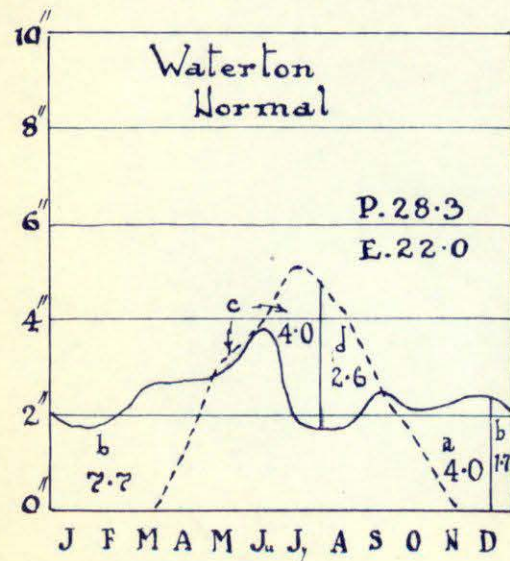
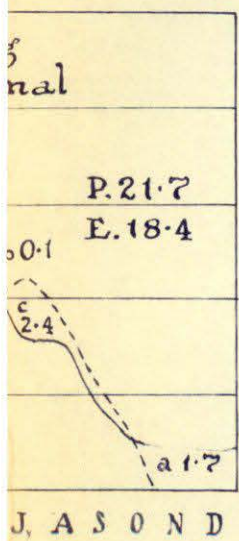
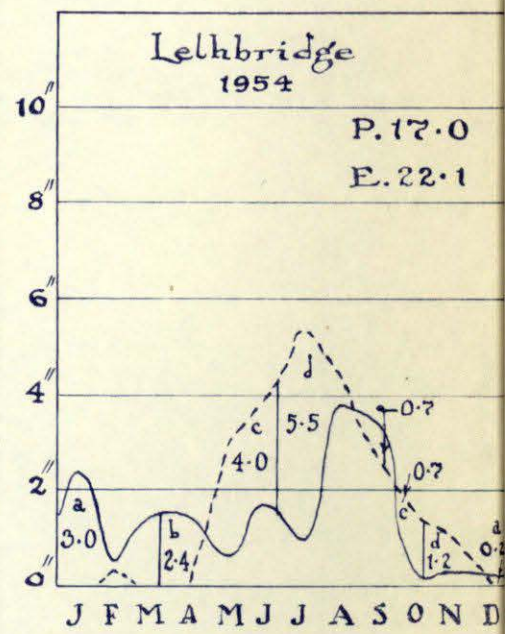
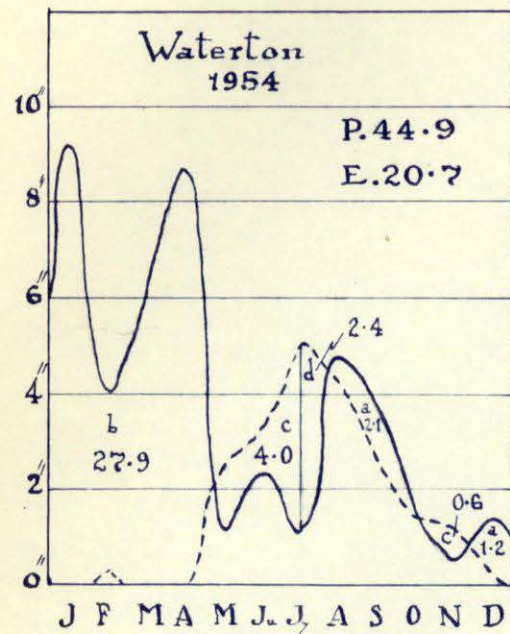
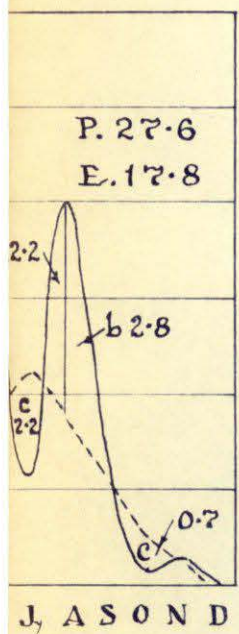
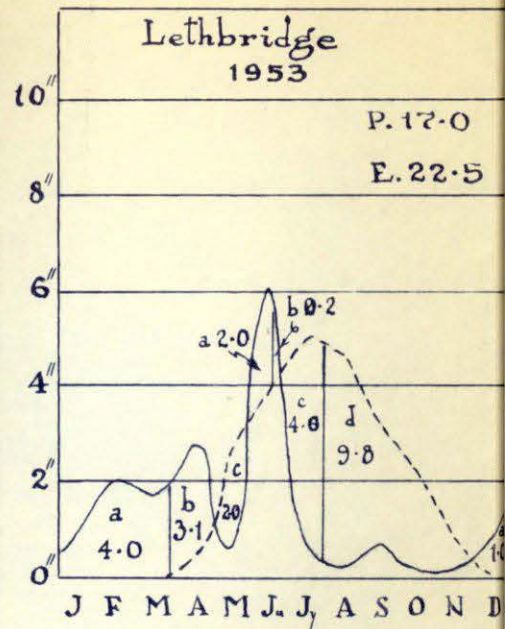
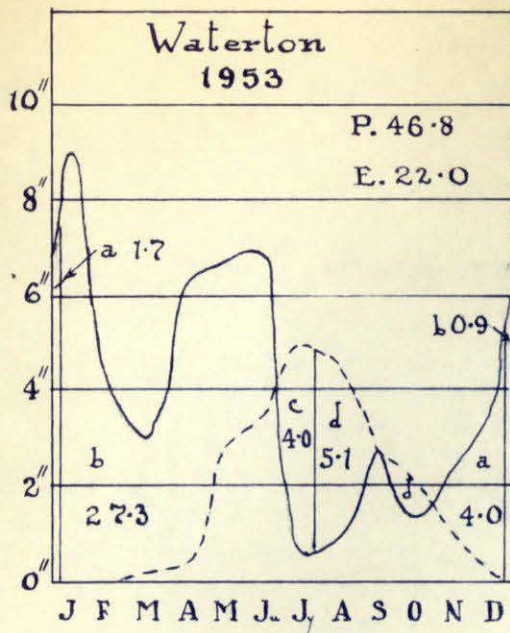
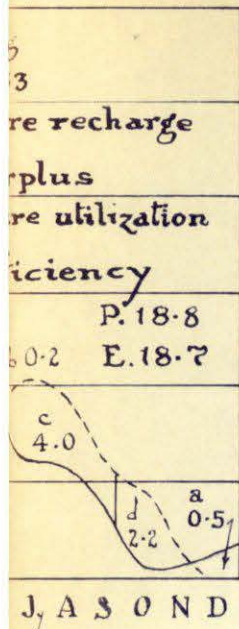


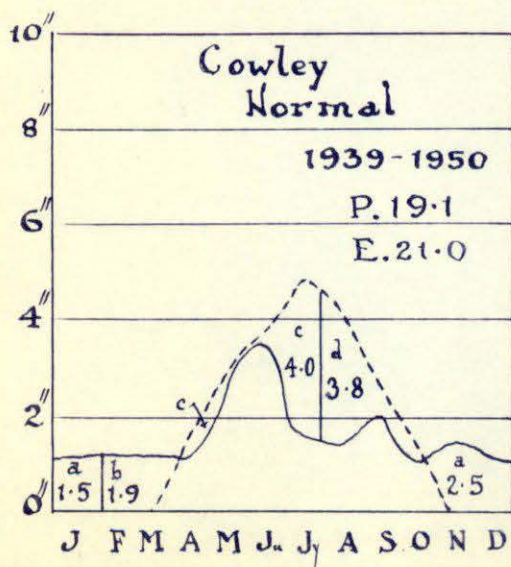
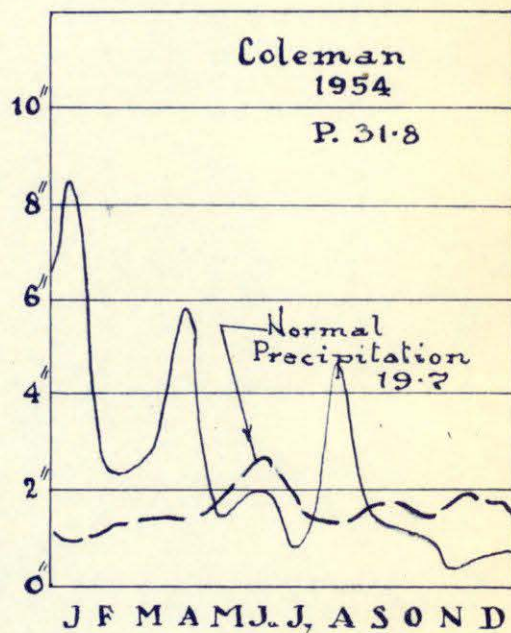
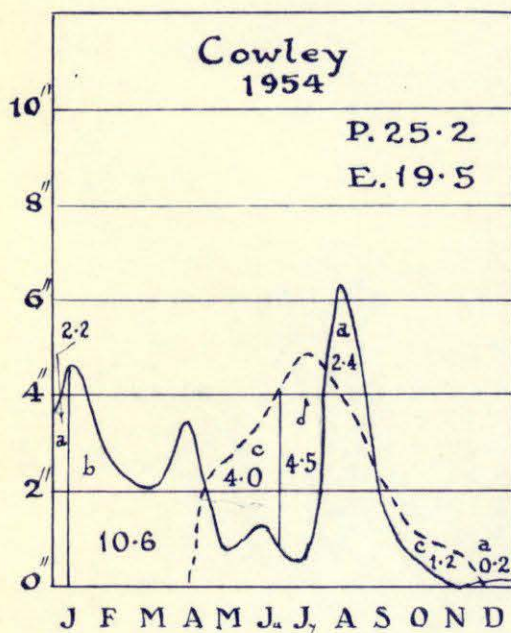
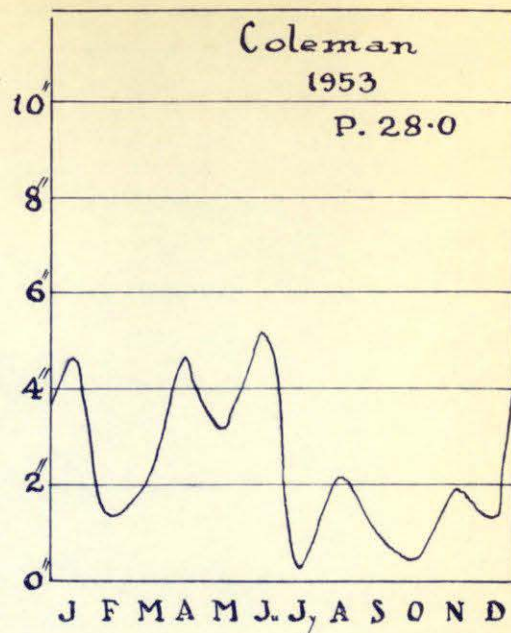
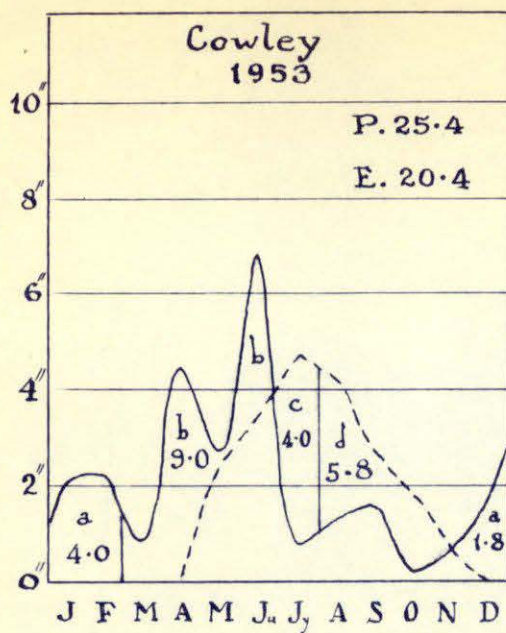
PRAIRIE PROVINCES
WATER BOARD
**PRECIPITATION &
EVAPOTRANSPIRATION
for SELECTED STATIONS
1953, 1954 & NORMAL**

PREPARED BY A.H.L.
DRAWN BY W.M.S.

PLAN
HYD. C. 59 FIG. - 10







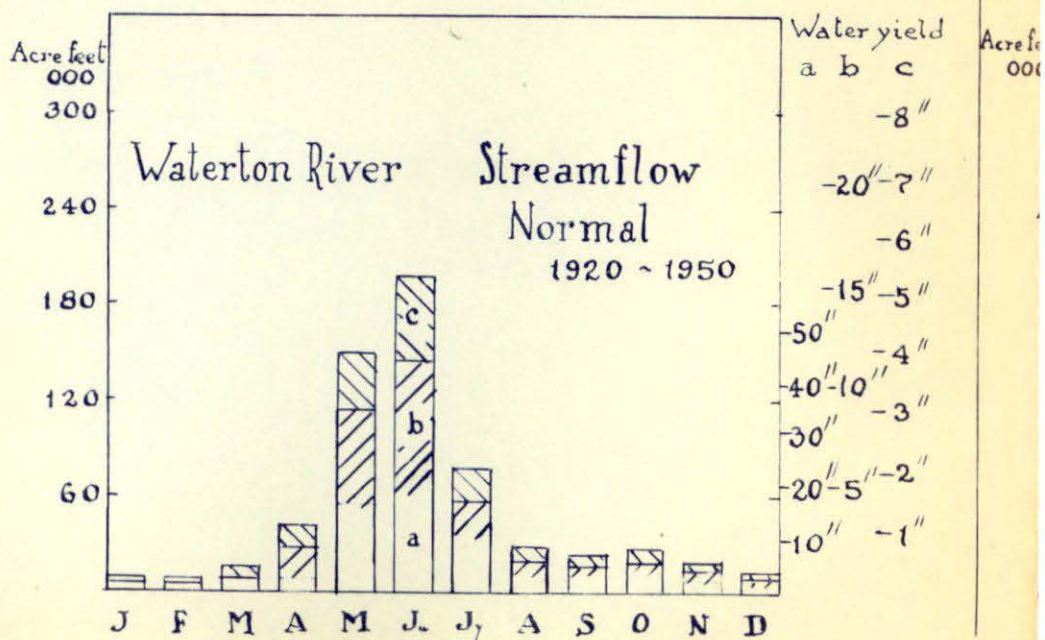
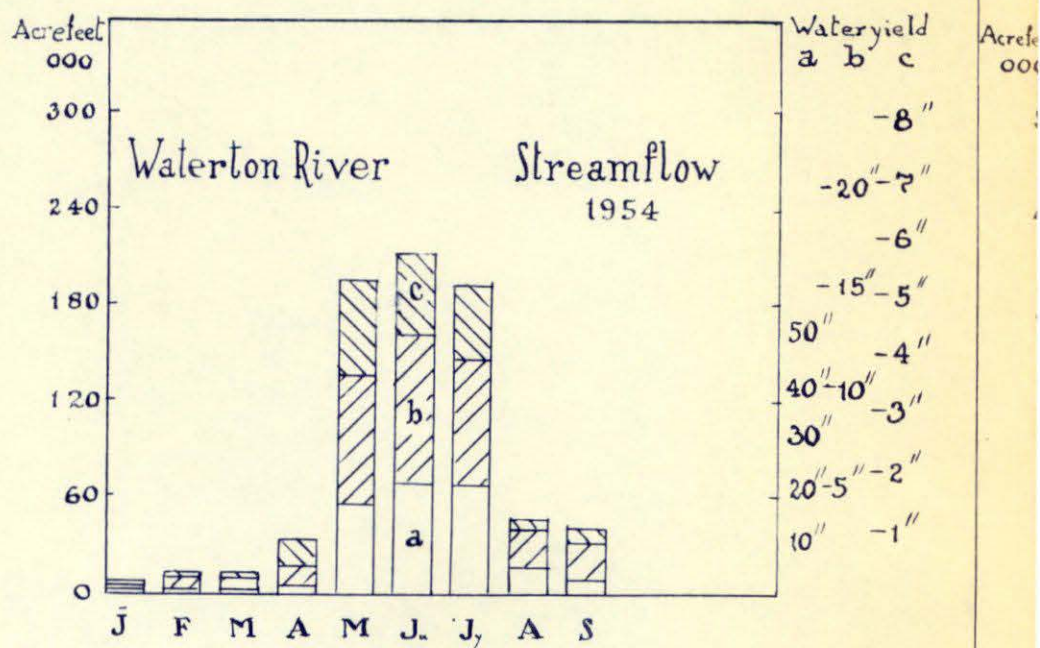
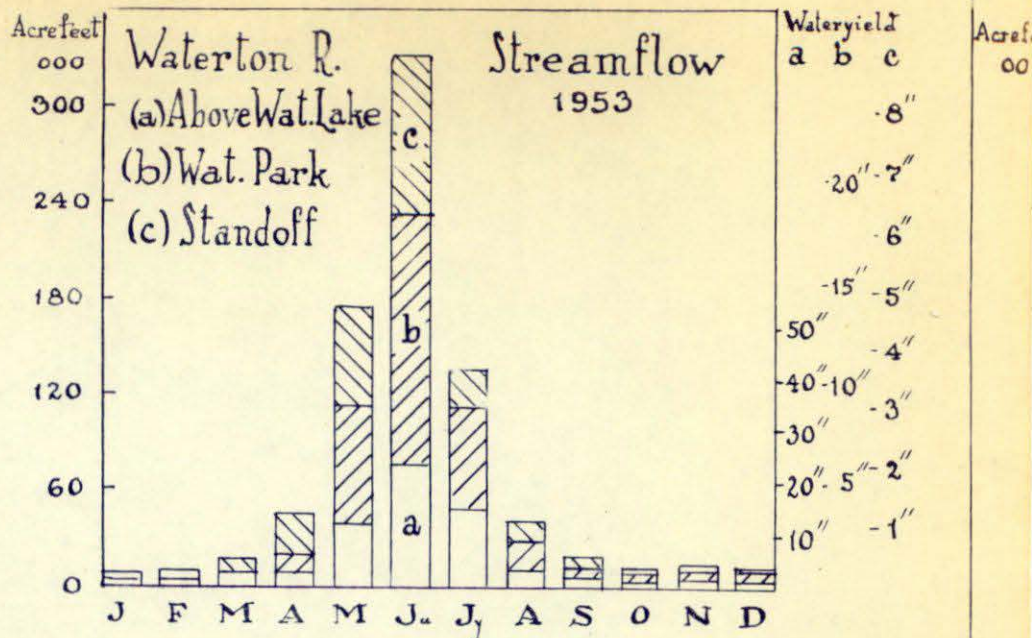
PRAIRIE PROVINCES
WATER BOARD

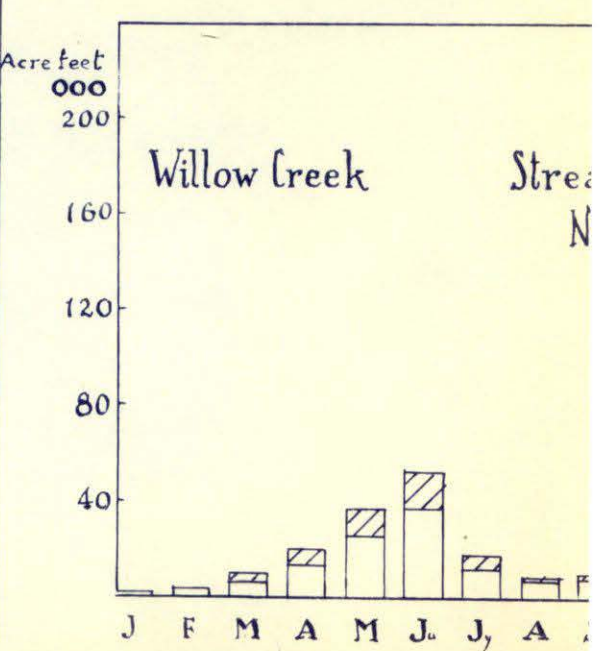
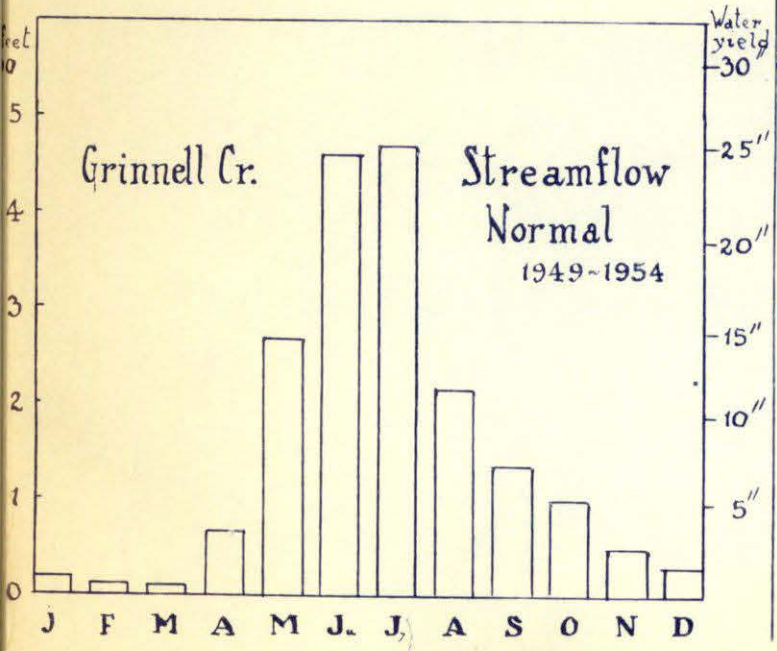
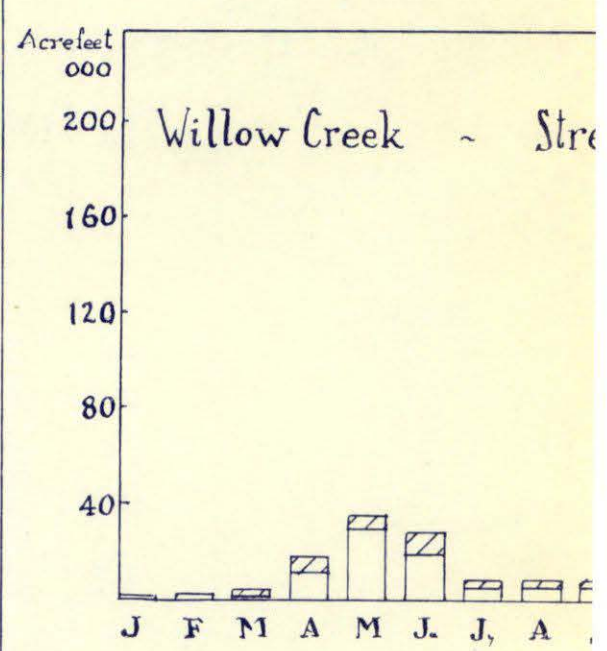
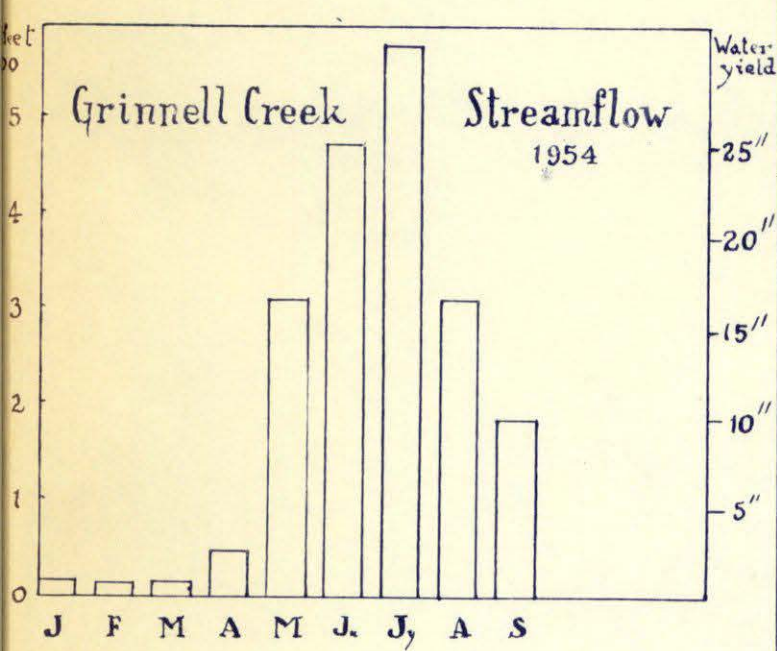
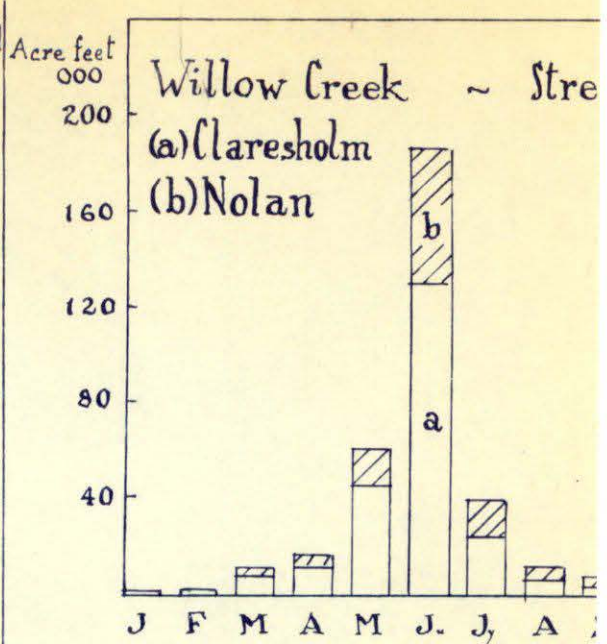
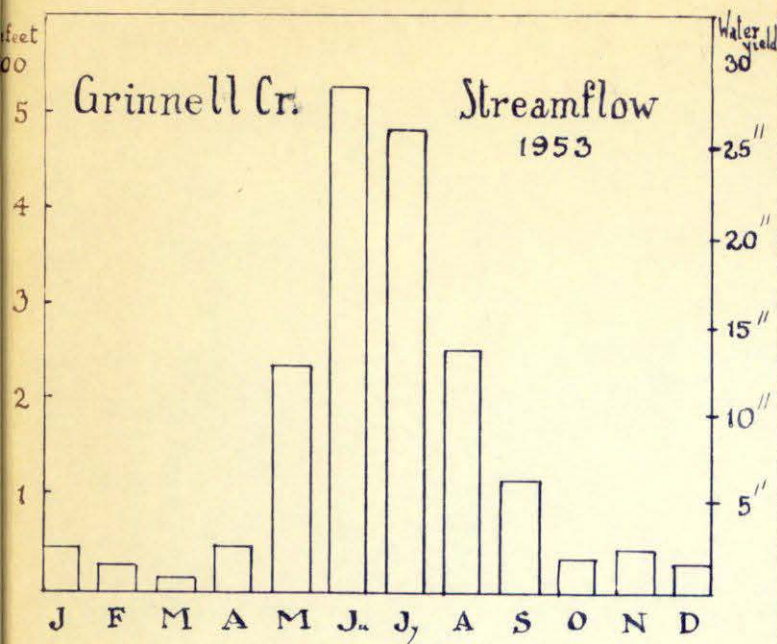
**PRECIPITATION &
EVAPOTRANSPIRATION
for SELECTED STATIONS
1953, 1954 & NORMAL**

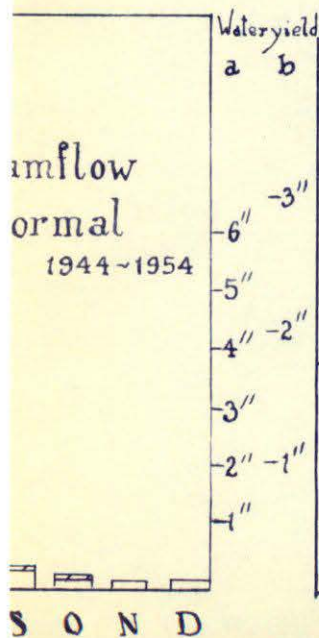
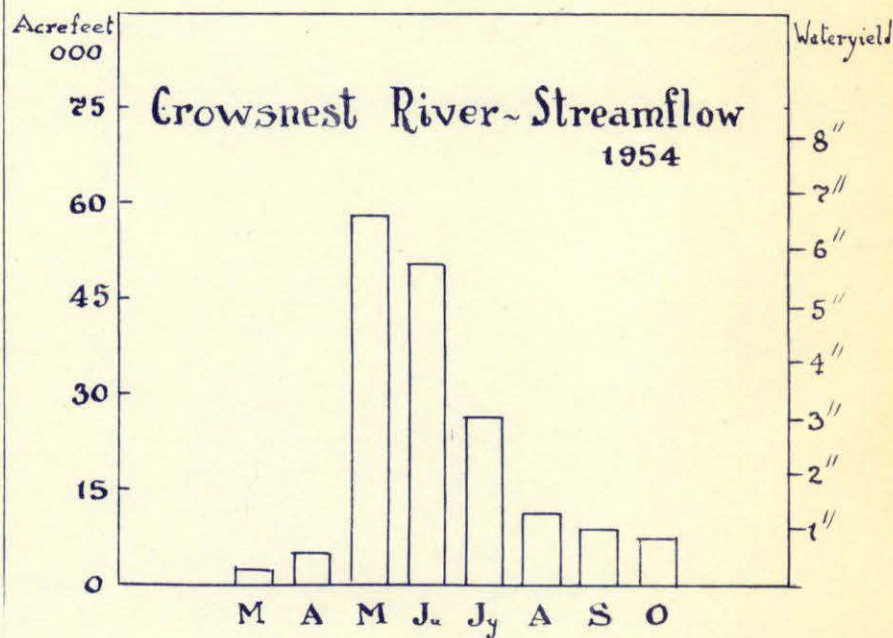
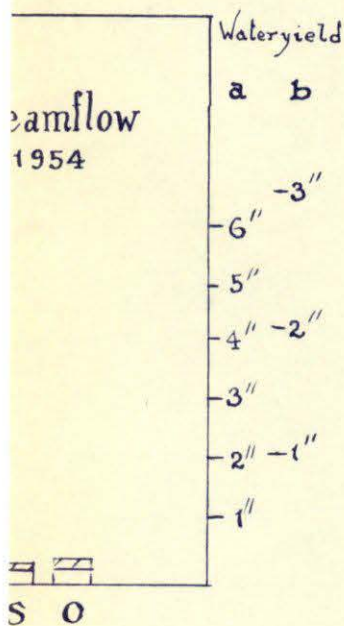
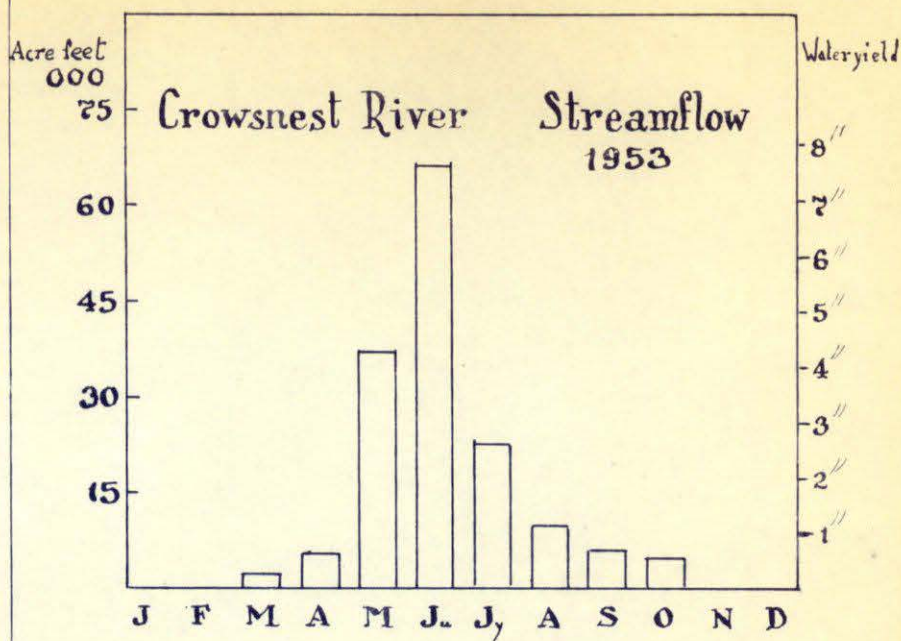
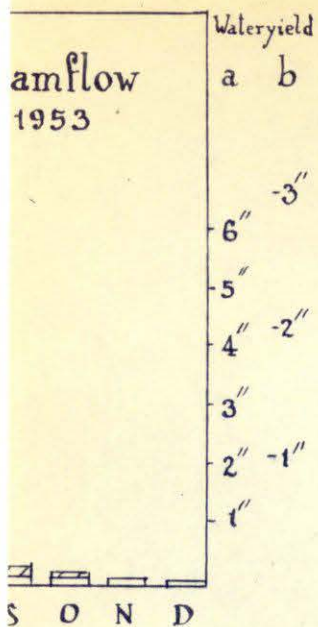
PREPARED BY A.H.W.
DRAWN BY W.M.D.

PLAN
HYD - C - 56

FIG. - 11







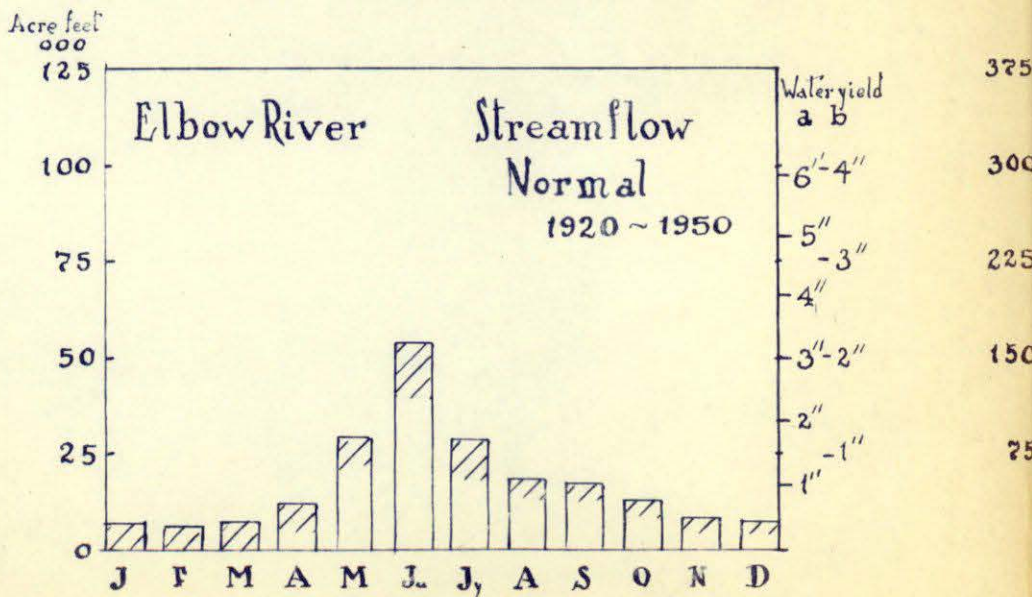
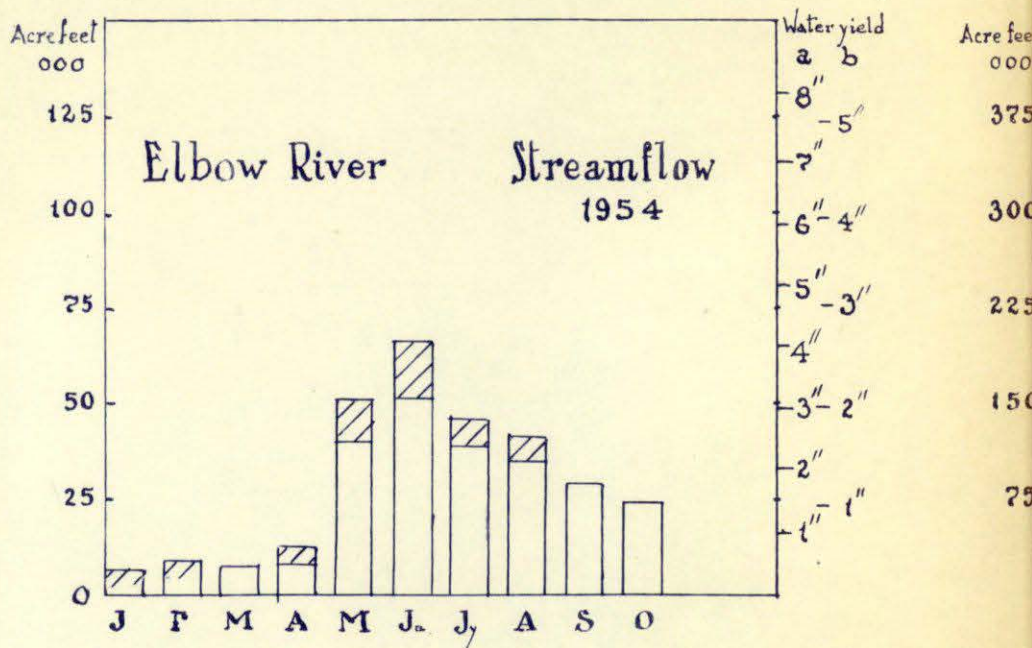
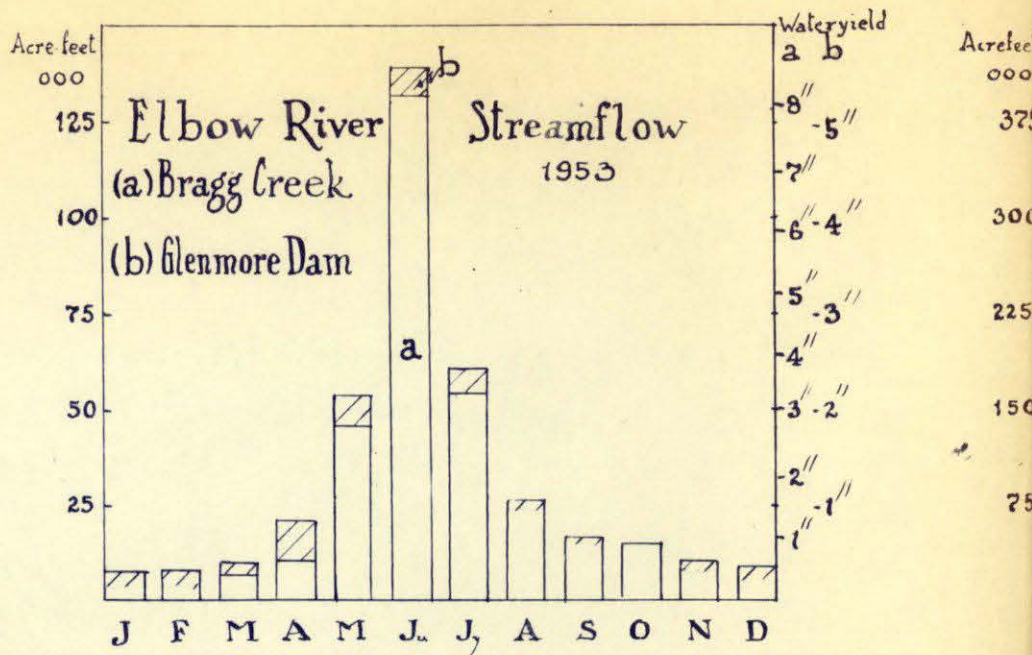
PRAIRIE PROVINCES WATER BOARD

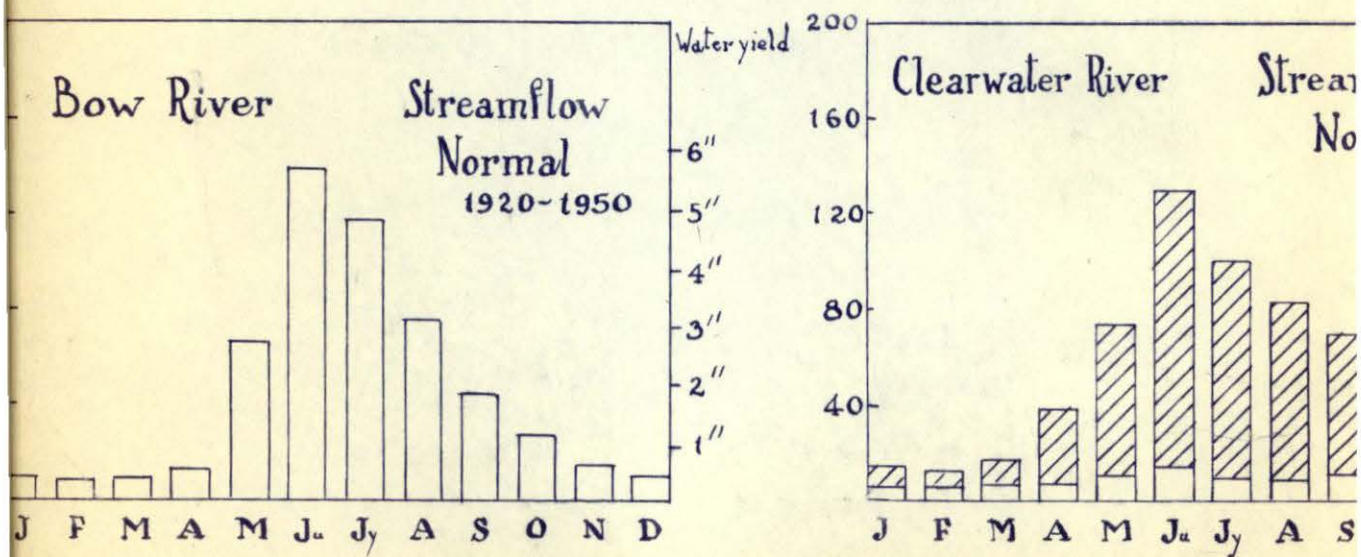
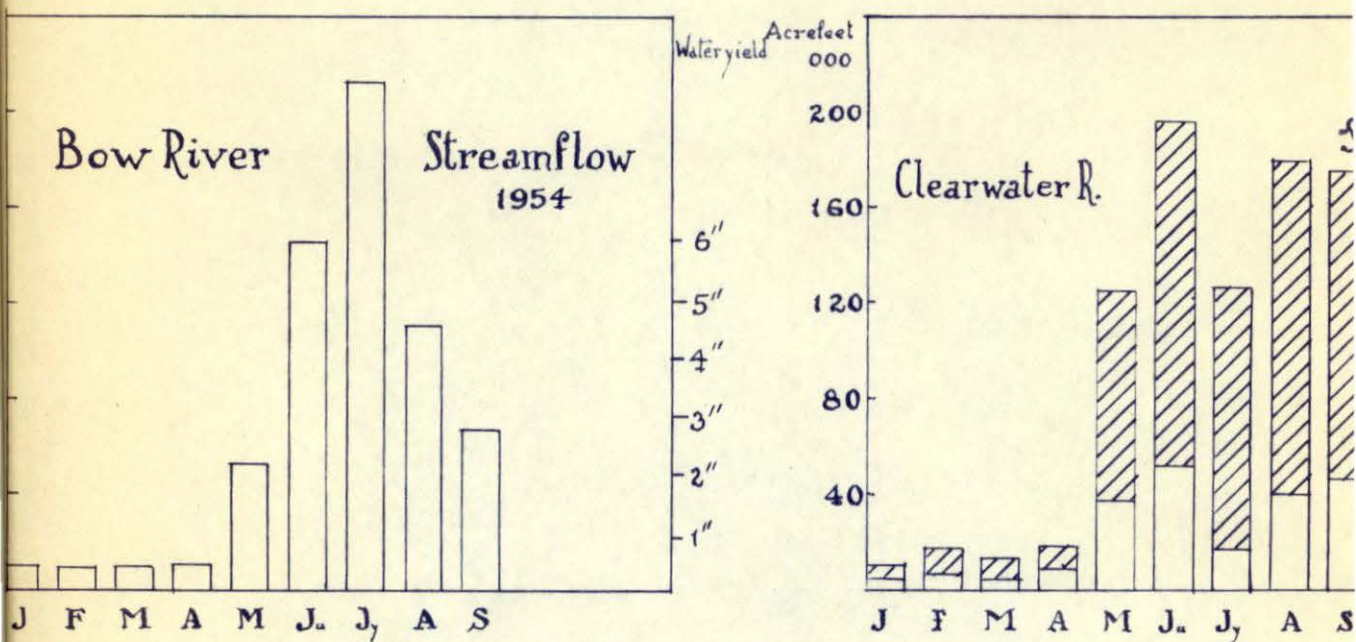
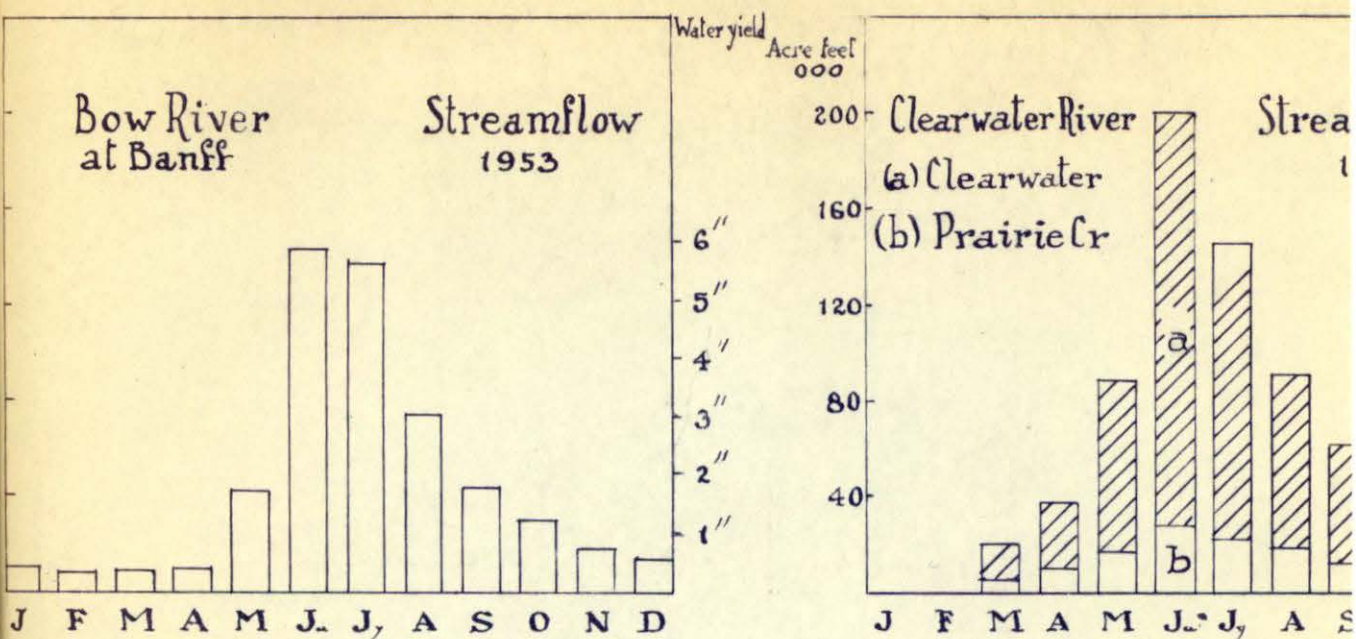
STREAMFLOW SELECTED STATIONS

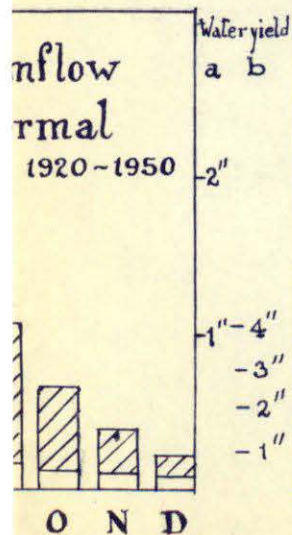
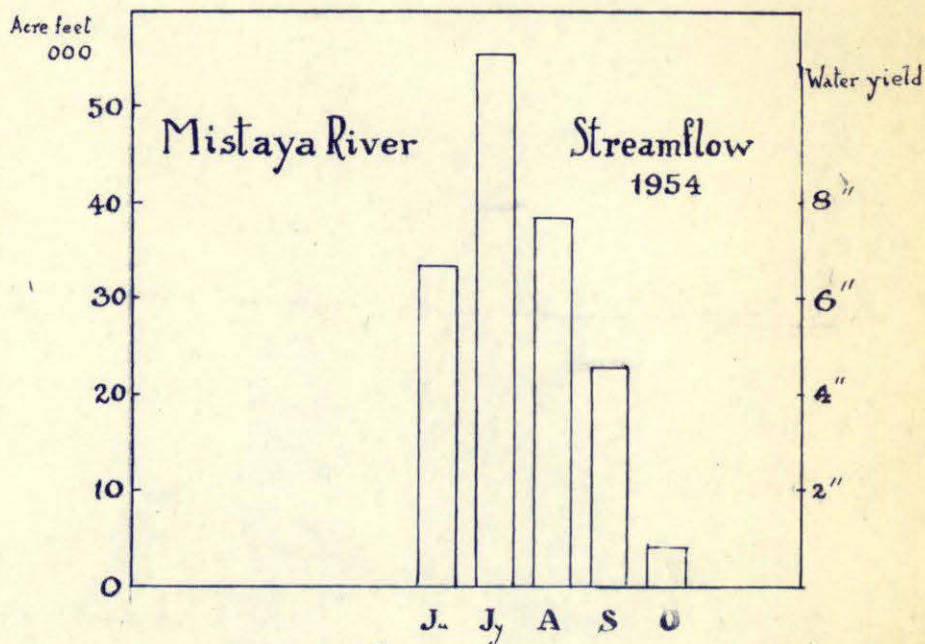
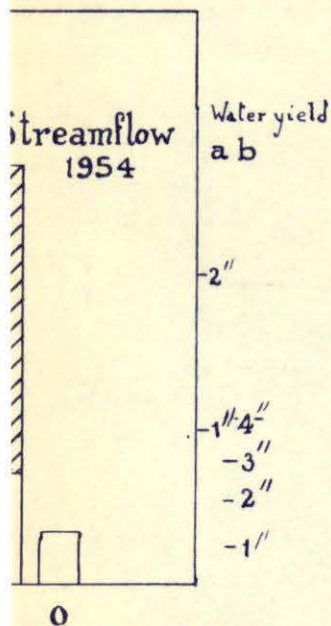
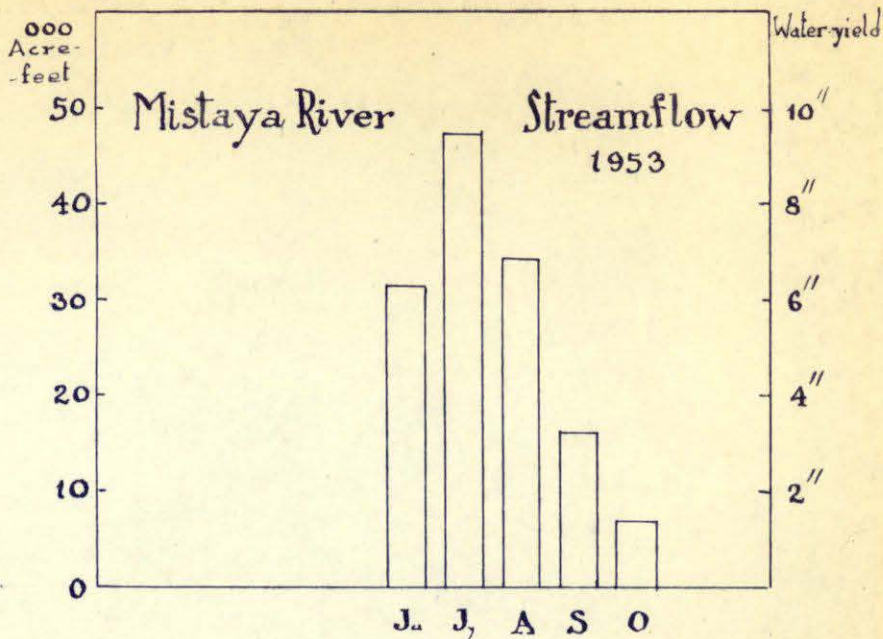
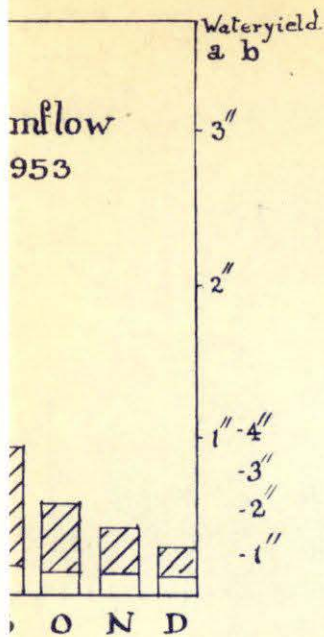
BY MONTHS

1953, 1954 AND NORMAL

PREPARED BY A.H.L.	
DRAWN BY W.M.S.	
	PLAN HYD-C-57 FIG.-12







PRAIRIE PROVINCES WATER BOARD

STREAMFLOW SELECTED STATIONS

BY MONTHS

1953, 1954 AND NORMAL

PREPARED BY A.H.	PLAN HYD-c-58 FIG.-13
DRAWN BY W.M.D.	

Inches

Lake Louise Annual Precipitation

Inches

50"

50"

40"

40"

30"

30"

20"

20"

10"

10"

0

Normal

1935 1936 1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 1952 1953 1954

Normal

20"

10"

1935

Inches

Calgary Annual Precipitation

Acre feet
000

50"

375

40"

300

30"

225

20"

150

10"

75

Normal

1935 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54

Inches

Lyndon
Annual
PrecipitationAcre
feet
000

50"

40"

30"

20"

10"

Normal

1949 50 51 52 53 54

Willow Creek
Streamflow

Water yd

250

200

150

100

50

Normal

1945 46 47 48 49 50 51 52 53 54

10"

9"

8"

7"

6"

5"

4"

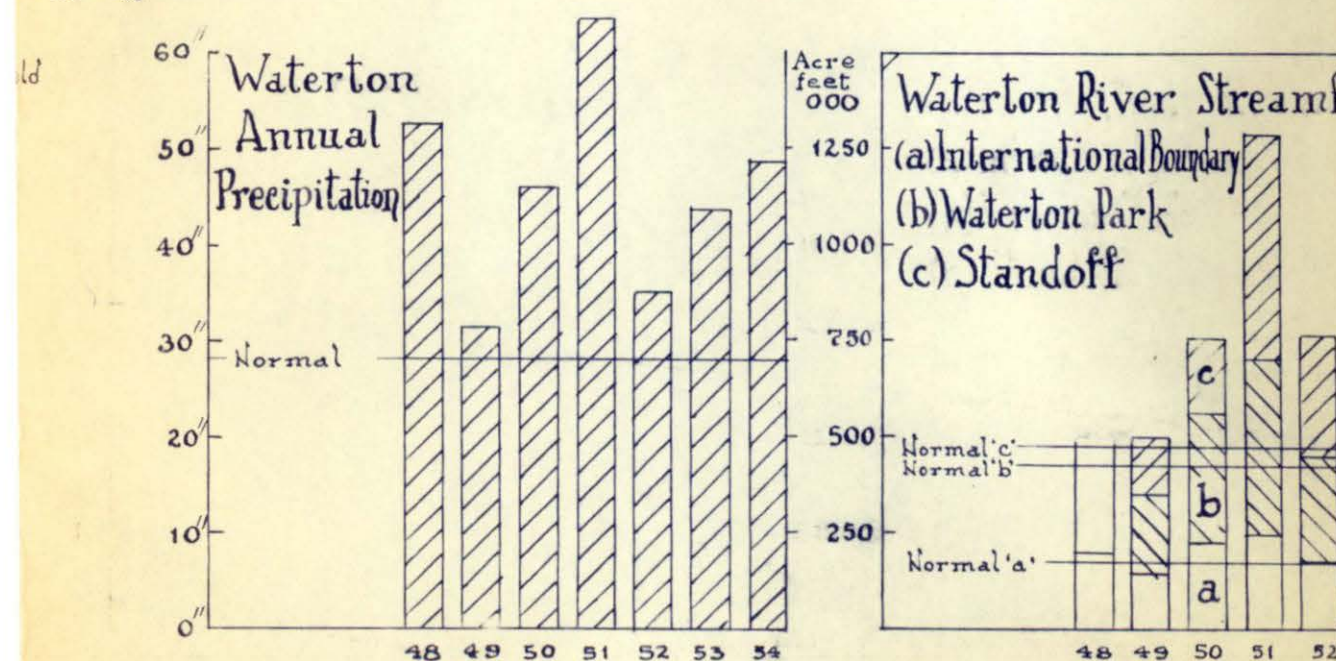
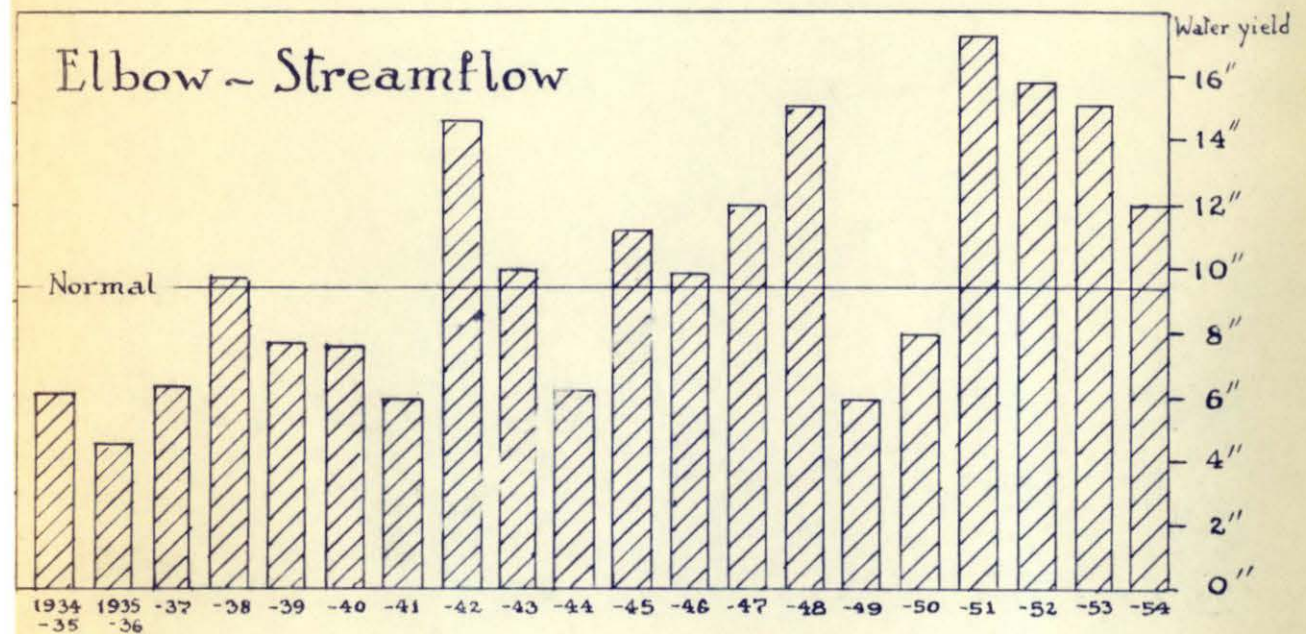
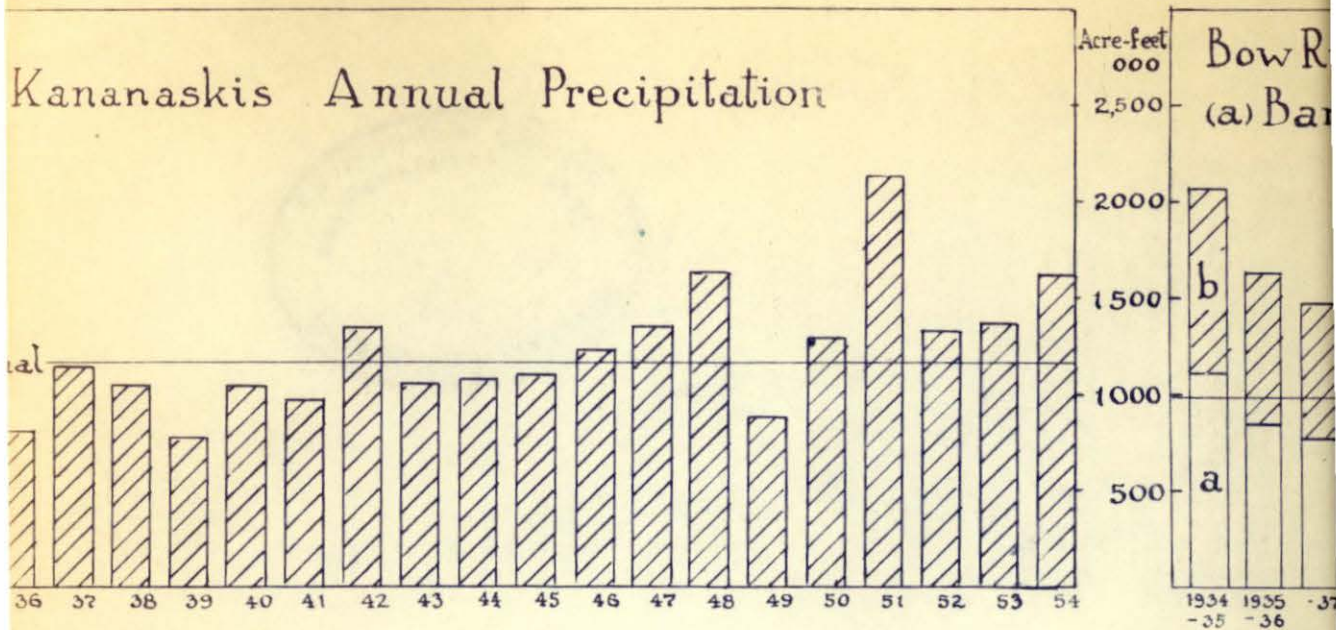
3"

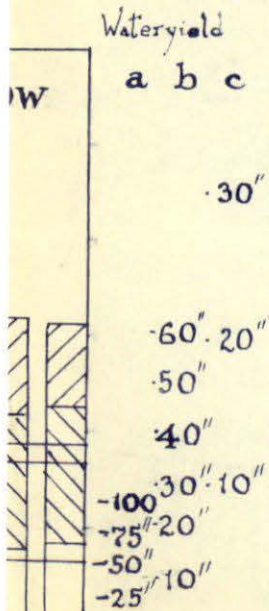
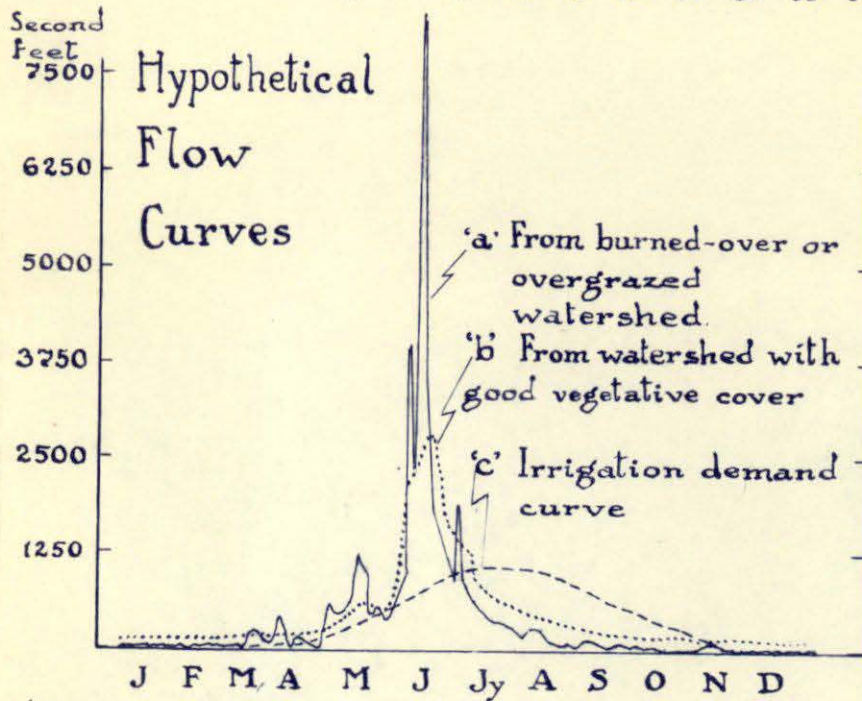
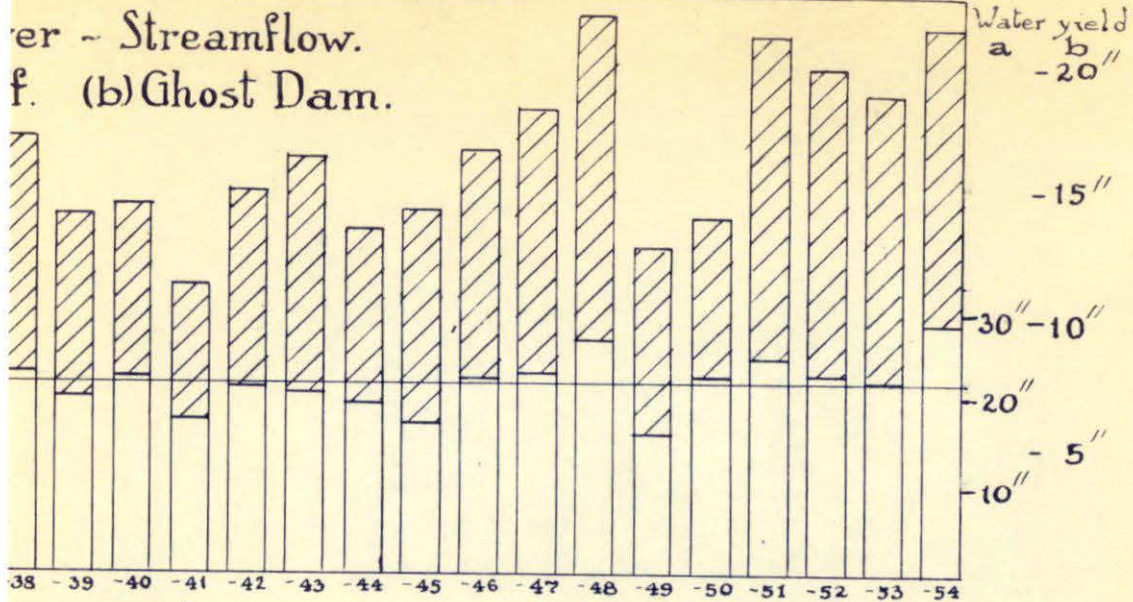
2"

1"

0"

Kananaskis Annual Precipitation





PRAIRIE PROVINCES WATER BOARD

ANNUAL PRECIPITATION
AND
STREAMFLOW
AT
SELECTED STATIONS

PREPARED BY A.H.L.

DRAWN BY W.M.D.

PLAN
HYD. C-67 FIG. 14