THE UNIVERSITY OF ALBERTA

RAINFALL MEASUREMENT SOUTH OF EDMONTON, ALBERTA - A COMPARISON OF TWO NETWORK DENSITY SCALES

by

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ABSTRACT

The accuracy of rainfall measurement in the Whitemud Creek basin south of Edmonton is investigated. This area is a designated research b... in under the International Hydrologic Decade program in Canada. It is representative of the Parkland portion of the Prairie region.

Total basin precipitation for various periods were calculated from the established network of rain gauges by means of the Thiessen polygon method. It was compared with results obtained in the same manner for a "dense" network.

Because of the higher gauging ratio, the "dense" network is considered to give a better representation of total basin precipitation. The value calculated from the established network is expressed as a percentage of the total obtained from the "dense" network. For those precipitation events which resulted in more than 0.5 in. of rain, the established network measured from 66% to 147% of the more representative amount.

Total summer precipitation (May to September, 1972) for the two networks is also calculated. The "dense" network rainfall is shown to have been 104% of the established network total. The differences between the two networks is shown to have decreased with increasing total rainfall and also over a longer time period.

Spatial variability is also shown to be of importance when total summer precipitation is considered. The average difference in total precipitation is shown to be 8% at 3 mi from a reference point.

This increased to 17% at about 12 mi. Extreme precipitation gradients of 0.24 and 0.30 in. per mi are shown. A gradient in excess of 1 in. per mi is considered to indicate some fault in guage exposure.

In the summer of 1972 there appeared to be a spacing of about 11.5 mi between preferred storm tracks in this part of Alberta. It also seems that some topographic control of precipitation amounts exists in the study basin. This is hinted at by results from gauges in that portion of the basin where relief is greatest. There is little to indicate the sign of the difference other than short-range radar photographs.

The study has implications for water-balance studies, crop development, groundwater recharge, soil-moisture recharge and runoff calculations.

PREFACE

This study was suggested by Professor Arleigh Laycock whose desire it was to obtain more detailed knowledge of total precipitation amounts in the Whitemud Creek Basin south of Edmonton. The study provides additional input to a data pool for this basin which is part of the Canadian contribution to the International Hydrologic Decade (1965-1974). This basin has been designated as study project No. IWB-RB-28 (Inventory and Water Balance, Representative Basin No. 28). Travel expenses were therefore covered from research funds provided Dr. Laycock by the National Research Council.

I would like to thank Mr. C. Thompson and Mr. D. Currie of the Atmospheric Environment Service, Environment Canada, for allowing me to use the Curtiss Wright weather radar set installed at Edmonton International Airport. My thanks also go to the staff of the AES briefing office who were so tolerant of my presence during the two summers of field work and who refreshed my memory on the use of the radar set.

I would like to thank Prof R.W. Longley and Dr. A.H. Laycock for their untiring efforts in reading, correcting and suggesting improvements to this work. The refinement of content and form is due solely to their assistance while any errors which remain are attributable to the author.

Finally, I would like to thank my fellow students who helped cheer me when my spirits were low, and especially my wife who was so patient yet so persuasive and without whom the work would never have been completed.

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Introduction

The West begins where the average annual rainfall drops below twenty inches. When you reach the line which marks that drop - for convenience, the one hundredth meridian - you have reached the West.

Bernard DeVoto
in The Plundered Province
Harper's Magazine,
Aug., 1934

GENERAL

The desire to know more about anything and everything has led man to pursue many trails into unknown or partly known territory. Even within areas which were thought to be known, man, by walking more slowly and by observing more closely, has mapped and extended the knowledge of things and patterns of things which were previously unknown or imperfectly understood.

Similarly as the number of scientific investigations has multiplied, the scale of investigation has generally decreased. Studies in many fields have increasingly come to include, and in many cases emphasize, meso-and microscale problems. This is certainly true in the case of studies of natural resources. Our use of these resources will in large part determine whether man continues to survive on this planet or perishes.

Before any rational plan for the optimal use of a resource can be predicated, it is imperative to know in what amount the resource exists. Many resources exist in finite amounts and are non-renewable. That is to say, they are no longer being created or are not coming into existence fast enough to be considered as part of the earth's storehouse from which we might draw. Other resources, however, are termed renewable, that is, they are constantly replenished, usually by the recycling of various elemental substances.

In this category we find water. Water is used, discarded and re-used. No matter what use we make of it, the continuous action of the hydrologic cycle will cleanse and return it to us. Though amounts may vary from place to place and though time, an approximate world balance will be maintained in both dimensions.

This thesis is a study of only one aspect of the relationship between atmospheric processes and the earth's surface. It is a study of the spatial distribution of precipitation over the Whitemud Creek Basin south of Edmonton, Alberta. An attempt is made to determine the representativeness of the established rainfall observing network in the area by use of a dense raingauge network and weather radar observations within the basin.

DESCRIPTION OF THE STUDY BASIN

The basin was selected as an International Hydrologic Decade (IHD) Research Basin, representative of the Parkland region of the Interior Plains of Canada. It is transitional between the northern Boreal Forest and the Prairie Grasslands. The basin has been eroded into relatively flat lacustrine plain. The North Saskatchewan River and the lower parts of its tributaries, such as Whitemud Creek, have cut channels up to 200 feet in depth.

The basin is oriented in a north-south direction and extends southward from the junction of the Blackmud and Whitemud creeks at 23rd Avenue, Edmonton, about one-quarter mile west of 119 Street to a point about one mile north of Pipestone Creek (Fig. 1). The total length of the study area is 27 miles while at its widest point it is 13 miles west to east. The total area is approximately 150 square miles (Rains, 1969 gives 150.25 sq mi while Erxleben, 1972 gives 142 sq mi) and maximum relief within the basin is 535 ft (Rains, 1969).

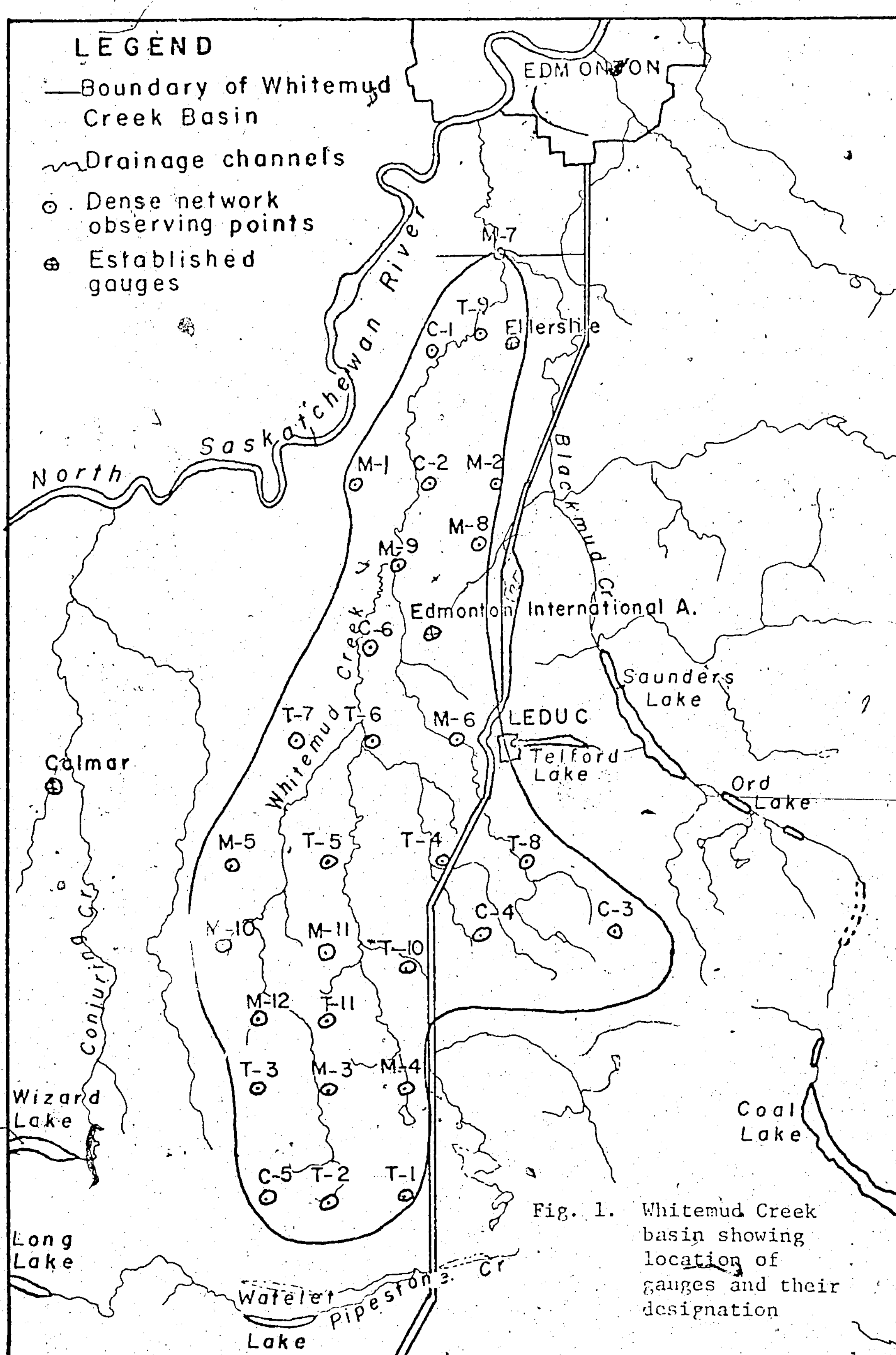


Fig. 1. Whitemud Creek basin showing location of gauges and their designation

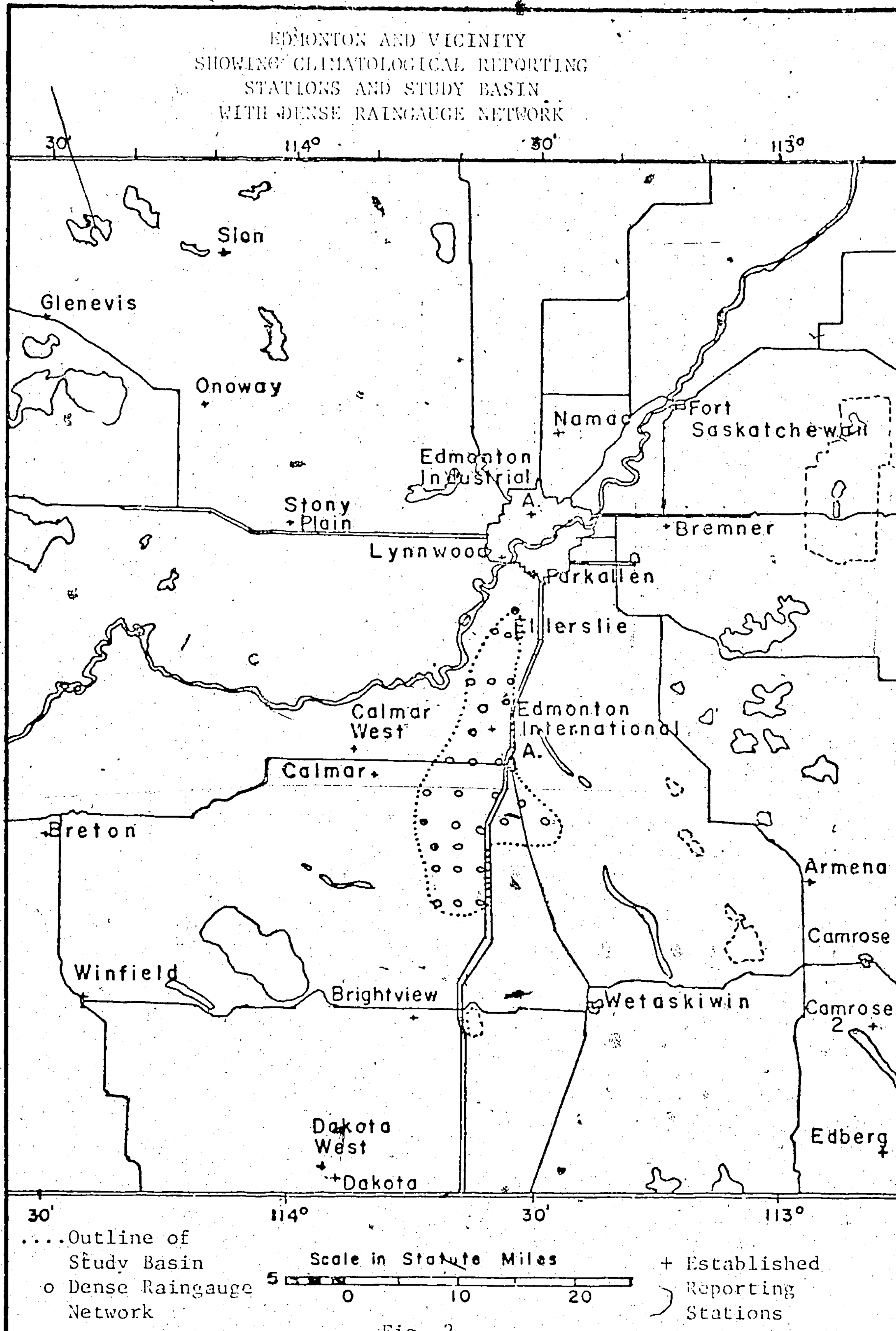

EDMONTON AND VICINITY
SHOWING CLIMATOLOGICAL REPORTING
STATIONS AND STUDY BASIN
WITH DENSE RAINGAUGE NETWORK
30'
114°
30'
113°
Sion
Glenevis
Onoway
Namao
Fort Saskatchewan
Edmonton Industrial A.
Stony Plain
Lynnwood
Bremner
Parkallen
Ellerslie
Calmar West
Edmonton International A.
Calmar
Breton
Armena
Camrose
Winfield
Brightview
Wetaskiwin
Camrose 2
Dakota West
Dakota
Edberg
30'
114°
30'
113°
....Outline of Study Basin
o Dense Raingauge Network
Scale in Statute Miles
5
0
10
20
+ Established Reporting Stations

Fig. 2

The northern half of the basin is mantled by fluvial sand over lacustrine materials originating in the former Lake Edmonton while approximately the southern half consists of fluvial sands over glacial till (Bowser et al., 1962). These different parent materials are superimposed upon the Edmonton Formation, a bedrock composed mainly of weak shale and sandstone deposited in a marine environment. Two different soil orders have evolved on these underlying surfaces, chernozem in the north and solonetz in the south. The vegetation pattern somewhat reflects this difference with more extensive wooded areas in the southern half of the basin. Whitemud Creek has cut a valley approximately one hundred feet deep at the northern end of the basin. The extensive north-south grassland in the study area is bordered to the east by an extensive wooded area. Laycock (personal communication) has suggested that this may be due to greater precipitation and lower potential evapotranspiration over the higher moraine to the east than over the slightly lower plain to the west of the basin. This would be in opposition to the pattern which emerges from the thirty-year normals of precipitation data in this area. Nothing more should be said here concerning this because no precipitation measuring points exist in the higher terrain to test the above hypothesis.

Bowser et al (1962) describe the region as part of a broad tension belt between the semi-arid prairie to the southeast and the sub-humid poplar association to the north west. Moss (1955) suggests that periodic burning of the prairie may account for the less extensive tree cover.

PATTERNS AND SOURCES OF PRECIPITATION IN CENTRAL ALBERTA

The study area is situated 200 to 250 miles east of the continental divide. Because the area is situated in the belt of prevailing westerlies, the highland area upwind creates a rain-shadow but one with surprising variations in total amounts. Muttit (1961) points to results which show up to five times as much precipitation in some parts of the province as in others. He cites physiographic features as the main cause of this variation. Dickison (1968) found no significant variation in the precipitation amounts recorded at different elevations across a river valley at right angles to the prevailing flow of air (over a range of 350 feet), for a location in New Brunswick. Within Alberta, however, Muttit notes that hills as low as 500 feet seem to have a great influence on the amount of precipitation which falls at a point.

Of the moisture which is precipitated over the study area, some first crosses the cordillera, and a small proportion moves north-ward from the Gulf of Mexico. A much larger proportion is moisture evaporated from the many shallow lakes and ponds of Central Alberta and transpired from the extensive forest cover of the foothills region and the belt of forest which separates the Peace River region from the farming area to the south. This northeastward extension of forest corresponds closely with a similar extension in the isohyets for various periods of precipitation analysis.

The gross patterns which are being discussed above are shown in the Atlas of Alberta, Atlas of Climatic Maps, The Climate of the Prairie Provinces, and in other publications. In regard to the study area and its surroundings (Fig. 2) the map of annual average precipitation (Fig. 3a) suggests a west-east moist tongue south of Edmonton including the area of interest. Precipitation for the May to September period (Fig. 3b) has a slight suggestion of this tongue.

Slight differences occur between the maps presented in different publications. For instance, in The Climate of the Prairie Provinces, Fig. 47 shows the 20-inch isohyet of annual precipitation to have a slightly more pronounced "bulge" toward Edmonton. Fig. 46 of the same publication deals with average rainfall for the period May to September. (These figures are reproduced here as Figs 3a and 3b respectively). It reveals a much lower precipitation gradient than does the Growing Season Precipitation map from The Atlas of Alberta which is based on precipitation records from April to August.

Annual and Growing Season variability are lower in the study area than elsewhere in the province with the exception of the forested belt north of Edmonton (Figs 3c and 3d). The area of minimum variability actually covers a large portion of Central Alberta north of Edmonton, but includes an extension southward west of the city and then eastward across the study area. Maps of average monthly precipitation for May, June and July similarly show an eastward extension of higher precipitation values through the Edmonton

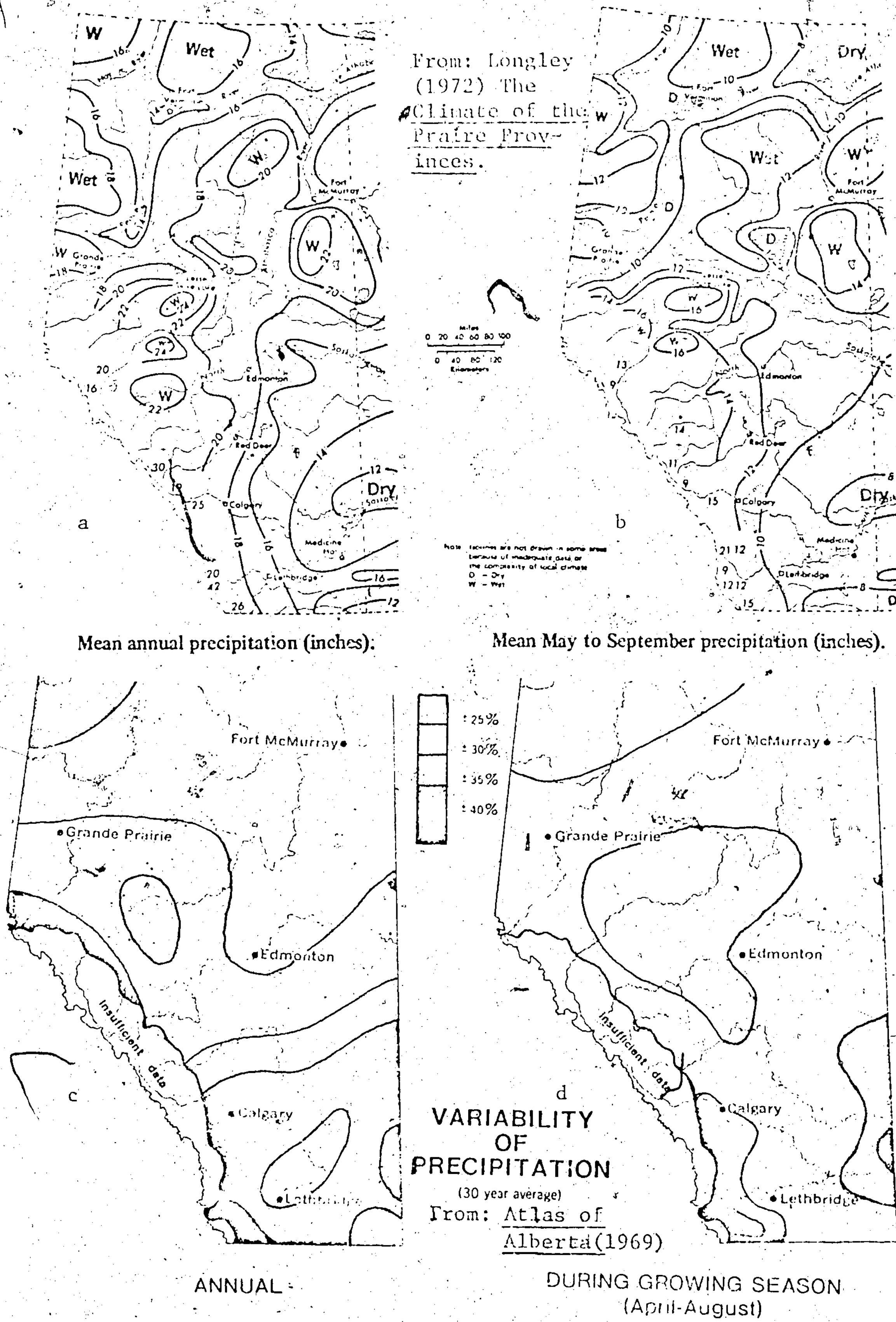
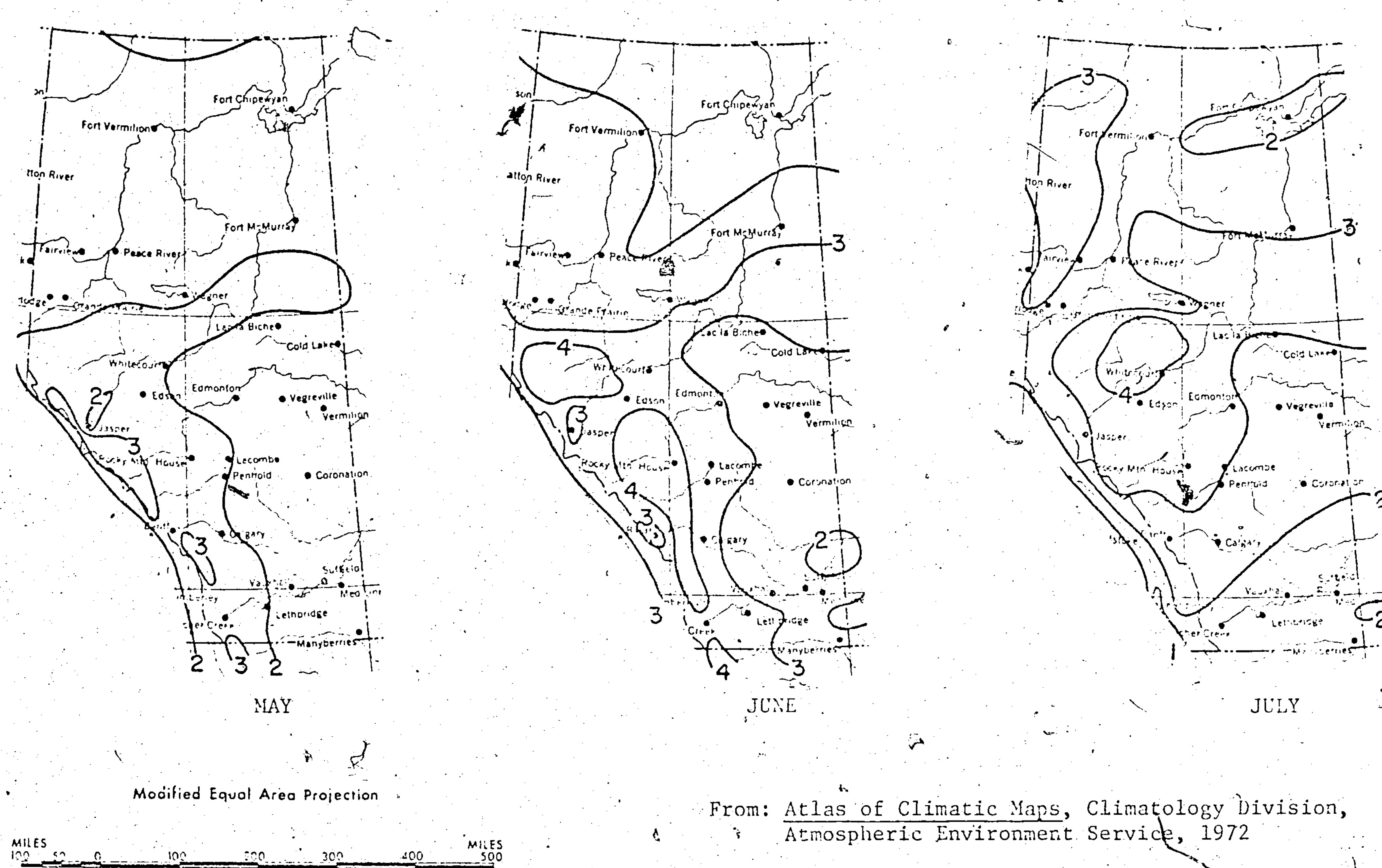


Fig. 3. Annual and seasonal precipitation and variability of precipitation

Fig. 4 Mean rainfall for the months of May, June and July



From: Atlas of Climatic Maps, Climatology Division, Atmospheric Environment Service, 1972 area, though the extent to which they cover the Whitemud Creek Basin varies (Fig. 4). The scale of the maps does not permit more than rough interpretation. Statements made here should therefore be accepted with caution.

This standard climatological analysis is carried out using reporting stations sponsored by the Atmospheric Environment Service (formerly Meteorological Service of Canada) and in some cases these reports are supplemented by those taken at Alberta Forest Service establishments and those taken by grain elevator companies at some locations. As a result of changes in elevation and other factors, these reports reveal variations in all of the climatic elements from what interpolation would give. Observing standards, inspection procedures, and types of gauge all vary to a greater extent than at AES installations. The results are often filed for future reference and not considered when producing maps because of the complex patterns which result, patterns which would not lend themselves to small scale reproduction (Longley, 1972).

SPATIAL VARIABILITY

Spatial variability is acknowledged on the macroscale everywhere and for many areas. The mesoscale is also acknowledged to have significant variability in the areal distribution of precipitation. At the microscale over relatively homogeneous terrain, both integration and averaging of the precipitation record decreases variability.

It can be demonstrated that as the length of time over which observations are taken is shortened, the variability of recorded amounts increases. Similarly, it can be shown that spatial variability in recorded amounts increases with increasing density of stations in the observing network.

In addition to the determination of the degree of representativeness of the existing climatological network the author will attempt to show that more intensive observation of precipitation patterns can result in refinements of interpolated patterns based on existing observations. They may also add to our understanding of variations in the distribution of precipitation from individual storms. A third benefit will be seen to accrue from the evidence that forty-eight-ounce juice cans can be used with confidence as rain gauges where adequate numbers of "approved" gauges cannot be obtained.

Altogether it is hoped that this work will contribute to a better understanding of one aspect of the water balance pattern in one part of the Province of Alberta and that the techniques used and information gathered may be of use in basin studies elsewhere.

II

Uncertainty in Rainfall Measurement

> For many years I was self-appointed inspector of snow-storms and rain-storms, and I did my duty faithfully.
>
> Henry David Thoreau,
> Walden (1854),
> I, Economy

Spatial Variability of Rainfall: Survey of the Literature

The limited extent of convective storm rainfall is generally recognized. For example, Blair and Fite (1957) give the following description: "Such a storm is normally only a few miles wide, ... The edges of the storm are well marked; the rainfall may be heavy within the path and diminish to nothing within a few hundred feet." Even members of the general public can usually recall some instance of rain falling on one side of the street but not on the other, or of a shower passing in a narrow swath through a field. It is a common experience to pass through wet and dry patches along a highway on a day with shower activity. The degree of variability in space is related directly to the mechanism responsible for the rainfall. Normally the rainfall produced from the ascent of air in the vicinity of a low-pressure area is considered to be quite uniform over a large area. The spatial distribution of rainfall amounts resulting from warm-frontal lift is also deemed to be quite constant. Variability is greater for storms resulting from cold-frontal lift because of the presence of more vigorous ascent and areas of descent. The greatest variability is observed to occur when cumulus and cumulonimbus associated with convective instability produce scattered showers of limited areal extent.

Because the area swept by individual thunderstorms tends to be random, despite some tendency for directional repetition, integration of the rainfall totals from these storms over longer periods of time does smooth out the variability pattern in any given area. However, it must be noted that a single intense storm may result in such a concentration of rainfall in some areas that the anomaly will last through monthly and perhaps even the seasonal or yearly analyses of totals.

McKay (1964) shows a case in the Wilson Creek watershed (8.8 square miles) where one heavy rainfall of over one inch covering an area 1/2 x 3 miles continued to influence the isohyetal pattern of the monthly and four-month charts. Even the isohyetal gradients were similar. When averaged over four Julys however, (the month of occurrence of the heavy storm noted), the effect of this storm in the mapped patterns was lessened and the overall effect of topography and variation in rain gauge exposure was noticeable. McKay (1961) has also shown that, when long-term means over the Canadian Prairies are considered, the mean annual precipitation isohyets rarely show precipitation gradients greater than one inch per one hundred miles.

Such variability from place to place is of interest to the farmer who depends on rainfall for growth of his crops, to the climatologist who seeks complete knowledge of the water balance of the area, and to the hydrologist who wishes to know how much water is available for various uses in the area.

Examples of extreme variability have been given using the established reporting network. Longley (1972) says:

> For the prairie area, the variability of precipitation from place to place or from year to year is of more significance than the variability of temperature. ... (An) example of the variability in a single storm occurred on July 13-14th, 1962. On those two days Hanna reported 5.09 inches, while at Drumheller less than 40 miles away, the precipitation was 0.47 inches.

Huff and Shipp (1968) used a different technique to study variability in four dense gauge networks in Illinois with seven to twelve years of record using a method from Conrad and Pollak (1950) where spatial relative variability is obtained from

$$V = 100(S/M)$$

where V is the relative variability in per cent, M the mean of the sample, and S the average deviation from the mean. The authors calculated V for storm, monthly, seasonal and extended periods. For storms with no measurable precipitation at some gauges in the network, relative variability was recalculated after eliminating zero and trace observations.

Several authors have investigated gradients of rainfall which are associated with variability. The most thorough studies are those of Huff and Schickedanz whose 1972 work shows that in the Midwestern United States, the gradient steepens as the period of rainfall measurement decreases. These authors found an average change of 6% in growing season rainfall in a distance of 3 miles. If the time interval is decreased to a single storm with an average rainfall of 0.5 inch, the average change at 3 mi increases to 30% and rises further to 68% when 1-minute rainfall rate measurements are compared. These authors found that the correlation coefficients were higher in a west-east and a southwest to northeast line across the networks than in any other direction. This can be explained by the direction of prevailing winds aloft which steer individual storms in these directions. This pattern persisted through analysis of storm, monthly, and seasonal correlation values.

It is known that at times the precipitation which occurs between reporting stations may be different from that which one would estimate based on a linear interpolation between the amounts reported at the two stations. If it is suspected that the amount may be significantly different, and if there is some reason to know how much difference there is, then it may be worthwhile placing one or more gauges in the area of interest. If the object of the study is to determine the degree of areal variability of precipitation, then it may be desirable to set up a multi-gauge dense network.

Three networks of this type have been operated for over ten years in Illinois by the Illinois State Water Survey and have yielded valuable information on rainfall gradients, sampling errors in measurement of mean precipitation, and meso-scale spatial variability in precipitation over a portion of the American mid-west (Huff and others: 1967, 1968, 1969, 1970, 1972). Similar studies have been conducted by Ferguson and Storr (1969) in Alberta, Fhanartzis and Kisiel (1972) in Arizona, Hendrick and Comer (1970) in Vermont, and others.

Throughout these studies there runs a continuing concern for the accuracy of measurement of rainfall by gauges. It would seem wise to include here a brief discussion of the problems encountered when measuring rainfall.

PROBLEMS IN THE MEASUREMENT OF PRECIPITATION

It is generally accepted that no rain gauge will be installed closer to a building or trees than two and a half times the height of that obstruction. The main problems can be described under the following headings: (a) Instrument errors and (b) Sampling errors (Ferguson and Storr, 1969).

(a) Instrument errors

During rainfall, errors occur in the amount of precipitation measured as a result of turbulence around the orifice of the gauge. The degree of turbulence is a function of the speed of the wind and the surface over which it flows (roughness). This turbulence normally leads to undercatch and the amount of undercatch increases directly with the size of the unshielded gauge. This error also increases with height above the ground whenever the gauge location is poorly exposed.

Dickinson (1964) used a network of paired gauges in a variety of locations to evaluate the differences in catch of these gauges. MSC standard gauges were installed at all sites. At two sites, MSC standard tipping-bucket gauges were installed. At five sites USWB standard gauges were employed to gather the required information. Five others were paired with Bendix Friez Weighing Recorder gauges. Double mass curves were used to evaluate the results. The author concluded that the results supported the findings of other studies which have shown that "the catch of one gauge type in relation to the catch of another gauge type is dependent upon the station at which the two gauge types are located. However, one cannot say that there is a significant

difference between the catches of the different gauges types."
Assuming that all gauges under-read when there is turbulence but do not over-read under calm conditions, then it will be seen that a systematic error attributable to the instrument has been introduced, one which we do not yet compensate for in most water balance studies. Rodda claims that this error is not significant in water balance calculations because it is masked by errors in the calculation of runoff, evaporation and storage change. Thus, with the exception of some recent studies in the USSR, no extra allowance is made because of the error in measurement.

(b) Sampling errors

By sampling errors, Ferguson and Storr mean those errors introduced by improper siting of a gauge. With unreasonable sheltering from the wind, turbulence is reduced, increasing catch efficiency and increasing inter-gauge variability in rainfall. They also include those errors relating to the density of the observing network. Any point measurement of precipitation can be considered as representative only of a certain small area. How small or large the area is depends on the length of time over which the records have been averaged, the topography of the area and the type of precipitation process sampled. Where convection might be considered important the nature of the ground cover should also be considered as influential.

The representative area is considered large when the underlying surface is flat and precipitation is steady (as with warm-frontal activity or an occluded low). As the record of observations at a site lengthens the representative area of that site becomes larger. The reverse of these situations is also true. It is relatively small for short-period precipitation amounts, areas of marked relief (we might postulate 500 feet on the basis of other studies), and for showery precipitation. Urban effects, lakes, forested areas, grasslands or plowed fields may all act to influence the distribution of rainfall. Therefore, they may be considered to alter the variability and hence the representative area of rain gauges.

To achieve a given level of accuracy in the estimation of areal precipitation, the network density required will vary with those factors outlined above. It therefore changes as the nature of precipitation changes with the seasons.

REQUIRED GAUGE - NETWORK DENSITY

Few authors have risked statements on required gauge-network densities but two who have done so were in some agreement. Huff and Schickendanz (1972) point to the different requirements for different types of rainfall. They state, "Other factors being equal, air mass storms require the greatest sampling density among synoptic types to maintain a given error level." Because this storm type is confined to the summer season, the above authors note that the May to September ampling density requirements are two to three times those of the remainder f the year. To obtain an average of ninety per cent explained variance for all storms combined, these authors calculated that a gauge spacing of two miles was needed in the warm season compared to a spacing of six miles for the cold season. For air mass storms alone, this level of accuracy demanded spacing of one mile while rain caused by the passage of a centre of low pressure could be gauged adequately with spacing of eight to ten miles. These calculations were made from data obtained for two dense rain-gauge networks operated by the Illinois State Water Survey.

"Holtan et al (1962) considered both areal distribution and site exposure requirements for areas with a continental type of climate, where heavy precipitation often occurs as a result of thunderstorms." (Corbett, 1967). They suggested the following densities were necessary for studies in agricultural watersheds.

TABLE I

Number of Rainfall Stations Required

Size of Drainage Area (Acres)	Gauging Ratio mi ^{2}/gauge	Minimum number of Stations
0-30	.05	1
30-100	.08	2
100-200	.10	3
200-500	.16	1 per 100 acres
500-2500	.4	1 per 250 acres
2500-5000	1	1 per sq. mi.
over 5000	3	1 per 3 sq. mi.

Huff and Schickedanz note that the sampling error of individual storms increases with increasing areal mean precipitation and decreases with increasing sampling density and with increasing storm duration. They noted quite large differences in the sampling errors associated with storms which otherwise seemed to have similar characteristics. From these results it would seem, according to the authors, that it would be difficult to predict the sampling error for specific storms with a given sampling density. They also state that some of the factors which influence the sampling error cannot be readily expressed mathematically. In this case the sampling error was defined as the difference between the best estimate of the true mean, obtained from the maximum density of rain gauges on each network and the sample mean rainfall calculated from the gauge amounts for a given gauge density (Huff, 1970).

Remaining Problems

Huff (1970) found that when he broke the data into two five-year periods and compared these, that there was considerable difference in the magnitude of the storm sampling errors for the May to September period. This illustrates the problems and dangers when working with data associated with natural phenomena. Such phenomena tend to have a degree of persistence and may not be counted on to produce the effects which the research student may wish to study. They may also fail to produce similar results if a second test is run at another time.

The author recalls a conversation with a friend who operated a General Store in a tiny community near North Battleford, Saskatchewan, for about forty years. He told of one five-year period in which all the rain storms seemed to pass to the northwest of North Battleford thus providing farmers in that area with higher wheat yields than south and east of the city. During the following five years the situation was reversed and those south and east of North Battleford received consistently higher rainfalls and wheat yields.

III

Instrumentation and Observation

Establishment and Maintenance of the Whitemud Creek Basin Dense Rain-Gauge Network

> We may achieve climate,
> but weather is thrust
> upon us.
>
> O. Henry
> "A Fog in Santone"
> in Rolling Stones, 1913

USE OF WEATHER RADAR

The variability of precipitation through space has been discussed. It is now time to look at the particular network which was established for this study.

It was necessary to establish the density of gauging to be used because as discussed in the previous chapter, the error of estimate of areal precipitation over a given region is a function of network density as well as of the accumulation period. In the planning stage of the study, the author decided to explore the possibility of using weather radar as a way to study the precipitation patterns in the study area. This information was to be integrated with that obtained from a dense rain-gauge network. Because the author had seven years experience with weather radar as an employee of the Canadian Meteorological Service and had received training on the type of set installed at Edmonton International Airport, permission was received for its use.

There are distinct benefits to be gained from the use of radar pictures in combination with the dense network. Gauges alone are misleading when estimating areal totals of showery precipitation and the density of gauges required to obtain highly accurate estimates of areal precipitation is at times prohibitive. As Battan (1959) suggests, at the very least, qualitative radar observations used in conjunction with rain gauge measurements make it possible to draw isohyets more accurately. Conversely, as Rodda (1969) points out, though radar may be employed to determine the areal distribution of rainfall, quantitative results can usually be obtained only from comparison with records obtained from rain gauges.

PLANNING AND ESTABLISHMENT OF THE NETWORK

Planning for the network began in February, 1971. It was the wish of Professor A. Laycock to obtain the fullest possible knowledge of precipitation in the study basin. Practical considerations included accessibility, permission of land owners or county officials to install gauges at particular locations, and length of time required to make a circuit of the gauges. The latter was considered important because the author wished to have all gauges emptied early in the day before evaporation began. As the summer progressed and the problem of servicing the gauges at an early hour on the morning following a rain day became excessive, .05 to .10 inch of light-weight motor oil was left in each gauge. This had the result of lessening the importance of trip time.

One other consideration which loomed large in the author's mind at the outset was the availability of rain gauges of approved design. Initially, five MSC standard gauges and seven Cassella gauges were available. Preliminary design of the network was based on the principle of sampling most intensively in the zone of ground clutter. Density of the network was to decrease slightly in those portions of the basin farthest from the radar antenna. This research indicated a need for 23 gauges.

Several alternatives for selecting gauge locations were considered.

Random locations and stratified random locations were rejected because of the impracticability of locating gauges in the midst of fields or wooded areas. The gauges had to be located as close to roads as possible but it was not thought wise to leave them exposed to damage by local "cowboys" who shoot at almost anything for target practice and make a regular habit of driving down the drainage ditches. Theft also had to be considered as each gauge was valued at about forty dollars.

If the originally designed network were to be established, eleven more gauges had to be acquired. Discussion with Dr. Laycock brought forward the idea of using 48-ounce juice cans as substitutes. The author wasn't too impressed with the idea at first but after considering other alternatives and what they would require in time and money, decided to try the juice cans.

Very shortly after this decision, ten more MSC standard gauges became available on loan from the Atmospheric Environment Service. These gauges are being gradually replaced at AES stations by a new model and, as surplus equipment, are available for research purposes. The additional gauges were used to increase the number of reporting points to 29, located in such a way that the density of the network was more uniform.

The value of this more uniform distribution of gauges was confirmed by driving the route and observing the radar pictures. The network remained stable from mid-July, 1971 through the summer of 1972. Only one other site appears to be desirable as a gauge location and that is between C-3 and C-4 at the junction of highway 2A. Though results are not included here, a gauge was installed at this site to improve the representation of rainfall distribution in this area.

Gauges were numbered by a letter and number combination. The letters indicate the type of gauge originally installed at a point. M indicates MSC standard, C - Cassela, and T - tin can. Numbers were assigned consecutively as the gauges were installed.

PROTECTION FROM EVAPORATION

The problem of evaporation from gauges has been investigated by various authors. Procedures employed to reduce this loss include such commonly employed design features as funnels to restrict vapour flow, multiple inner containers to reduce evaporating surface and to insulate the catch, and highly reflective containers to reduce absorbed insolation. Hamilton and Andrews (1953) found measured losses of 0.19 inches per day from a USWB standard gauge without funnel or 0.006 inches per day with funnel could be suppressed by using 0.03 inch of oil in the spring. When temperatures rose to 75°F, 0.15 inch oil was required to give sustained protection to the catch. By sustained protection, is meant the suppression of evaporation for periods up to 30 days.

These findings have a bearing on this study in that the juice cans utilized as gauges were highly reflective, but, because they remained uncovered throughout the study, were subject to evaporation losses. No evaporation tests were run on these gauges but, in keeping with Hamilton and Andrew's findings, ASE #5 motor oil was used during May and early June to prevent evaporation whenever early morning readings could not be assured. It was used continuously through the latter half of June and throughout July, August and early September.

Statistical Proof of the Reliability of Juice Cans as Rain Gauges.

Beginning in June, 1971, one gauge location, M-7 was equipped with both a juice can and an MSC standard rain gauge. Readings from both gauges were taken using an MSC standard graduated cylinder. The depth of rainfall was recorded for both of the gauges. Because the same graduate was used to record the depth of fall in both gauges, the amounts collected in the juice can (4.2 inches diameter) were usually greater than for the standard gauge (3.6 inches diameter).

A graph of conversion values could have been constructed based on the comparative areas of the two containers. The areas are 13.9 in.^{2} for the can and 10.2 in.^{2} for the standard gauge. Thus the can should catch 136% of the "official" catch. Not wishing to trust to theory however, the author recorded readings from the paired gauges without alteration until, at the end of the 1971 season, a graph of the catch of the two gauges at M-7 was prepared and a regression line was fitted by eye to the data. This line was drawn in such a way that the slope of the line b=1.30, and the intersection with the Y axis was at approximately 0.02 inch. This line can be seen in Fig. 4. All readings from cans for that summer were then converted to equivalent MSC standard gauge readings.

In setting up for the summer of 1972, it was decided that this comparison should be continued as a check against the accuracy of the conversion graph. The comparison was made in an urban setting with

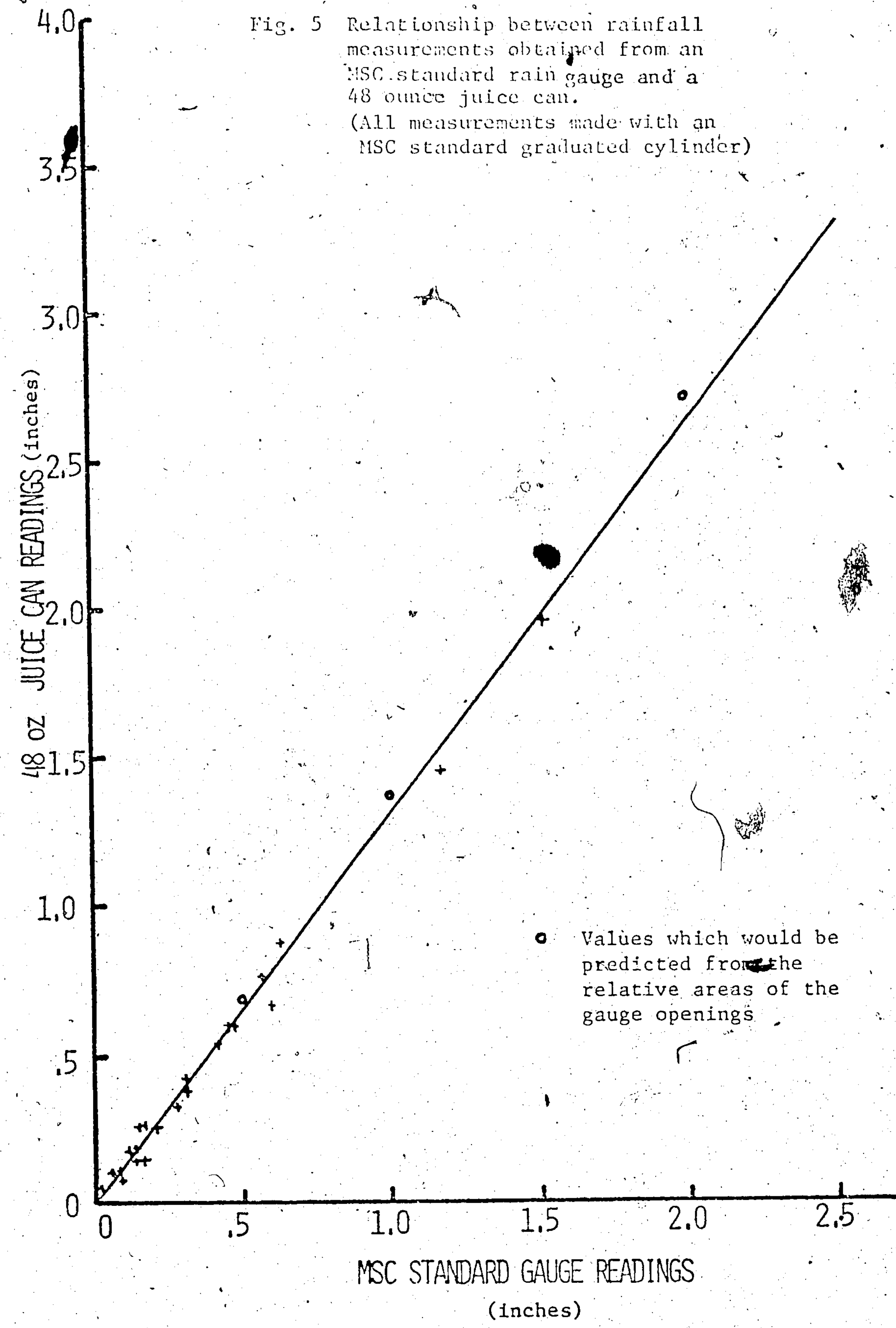


Fig. 5 Relationship between rainfall measurements obtained from an MSC standard rain gauge and a 48 ounce juice can. (All measurements made with an MSC standard graduated cylinder)

different boundary layer problems although roughness was probably not much greater on the average. This comparison was thought to be quite necessary because only tin cans were available to instrument the basin for a second summer.

Precipitation measurements were obtained using an MSC standard graduate. To ensure comparability of the measurements between the tin cans of the "dense" network and the gauges of the established network, Fig 5 was used to convert the original readings to equivalent MSC standard gauge values. These are referred to as "corrected" readings. Constant checking of the results of the paired samples during the second summer proved to the author's satisfaction that the graph used for converting the amounts caught by the cans to "official" amounts was satisfactory.

Analysis of these paired samples was carried out during the winter of 1972-73 using the data from the two summers and two locations. The analysis was carried out twice, once using 27 uncorrected juice can readings and once more using 46 corrected measurements. The output of these two analyses follow as Table II.

Uncorrected data from the tin cans were used to test a null hypothesis that the amounts recorded from the paired samples would not differ significantly. From this analysis the earlier conclusion regarding the conversion values was confirmed. The slope is shown to be 1.30 and the Y intercept is zero. The latter differs only slightly from the estimated value 0.02. From the Students 't' test, a value of 2.87 was obtained with 25 degrees of freedom (N=27, D.F.= N-2). This compares with a value of 2.79 which could be attributed to chance at the 0.01 probability level. This is larger than that which could be attributed to chance. The null hypothesis must be rejected therefore.

Theoretical conversion values based on the relative areas of the gauge openings have been plotted on Fig 4. The closeness of fit gradually deteriorates as rainfall amount increases. This is to be expected because heavier rainfalls are normally associated with higher wind speeds and therefore must be related to greater turbulence resulting in larger errors from undercatch.

Moving to the corrected values we have a very different story as a test of 46 pairs of observations produced a 't' value of 0.001 against a tabular value of 2.70 at the 0.01 level of probability. Thus the difference between the population samples is negligible. This is further shown by a regression slope of 1.008. In this analysis, the standard error of the mean is only 0.031, Pearson's correlation coefficient is 1.00 and the 95% confidence limits of the mean difference are from 0.000 to 0.001, beyond the measurement accuracy of the observer. Both instumental and human errors are potentially much greater.

The Radar Photographs

Due to pressures of work and other considerations, a constant radar watch was not kept. Nor could arrangements be made to have the weather briefer on duty at the International Airport contact the author when cells began to show on the radar. It was necessary therefore to keep a visual lookout towards the south and west for any situation that appeared likely to be worthy of study. This did not prove too satisfactory even when combined with phone calls to the weather briefing office and so a number of situations were not photographed while all others were picked up only after rain was falling in the study basin.

Elevation of the antenna to 2.5° to eliminate ground clutter and

TABLE II

Paired Rain Gauge Data Analysis.

Component		Juice Cans	
		Uncorrected	Corrected
Number in the sample (pairs)	N	27	46
Mean of MSC standard gauge measurements	$\bar{X}$	0.30	0.29
Mean of Juice Can Measurements	$\bar{Y}$	0.38	0.28
Correlation Coefficient (Pearson's)	r	0.99	1.00
Variance of the sample	s_x^2	14.21	0.08
Standard Deviation of the sample	s_x	0.38	0.29
Slope of the regression line of Y on X	b	1.30	1.01
The Y intercept of the regression line of Y on X	a	-0.02	0.00
Degrees of Freedom	D.F.	25	44
't' test for significance	t	2.87	0.001

reduction of the range to 60 or 30 miles were the major departures from normal operating procedures of the radar operators. The results have been preserved for ten events during the summer of 1972 and for five events in 1971.

Of these, not all were felt to be worthy of detailed analysis and inclusion here, but two events have been analysed for 1971 to illustrate use of radar photographs in drawing isopleths (Figs. 6 and 7). These illustrate the low level of reliability which can be placed on this particular radar set for interpretation of rainfall amounts. It can guide the placement of the zero-value isopleth only and in the case of a number of cells crossing an area may aid in placement of higher value lines, though with no great level of confidence.

Fig. 6. Storm of July 1, 1971
Progress of radar echoes between 1820 and 2135 MST.
Isohyetal analysis based on rain gauges but adjusted to radar echoes.

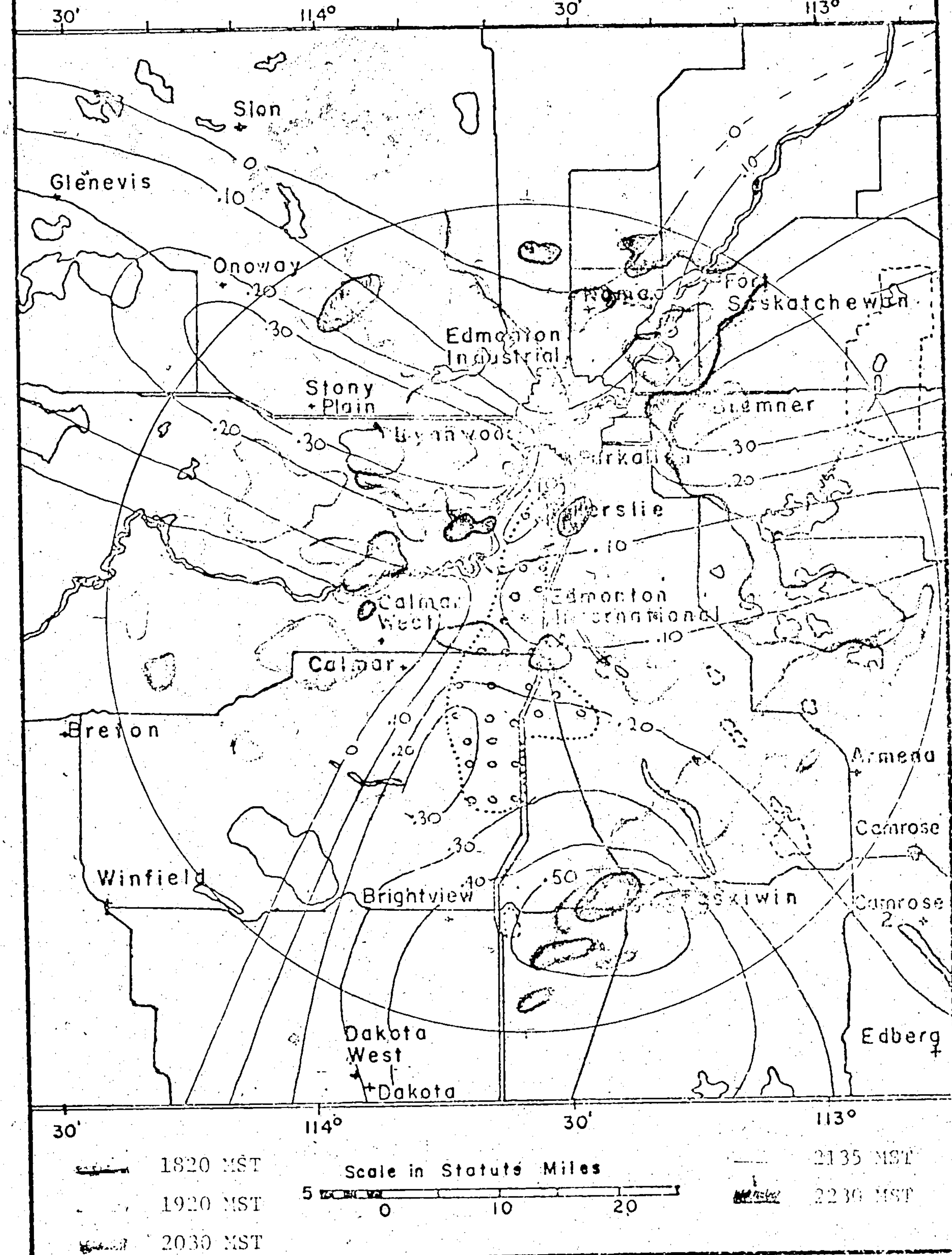
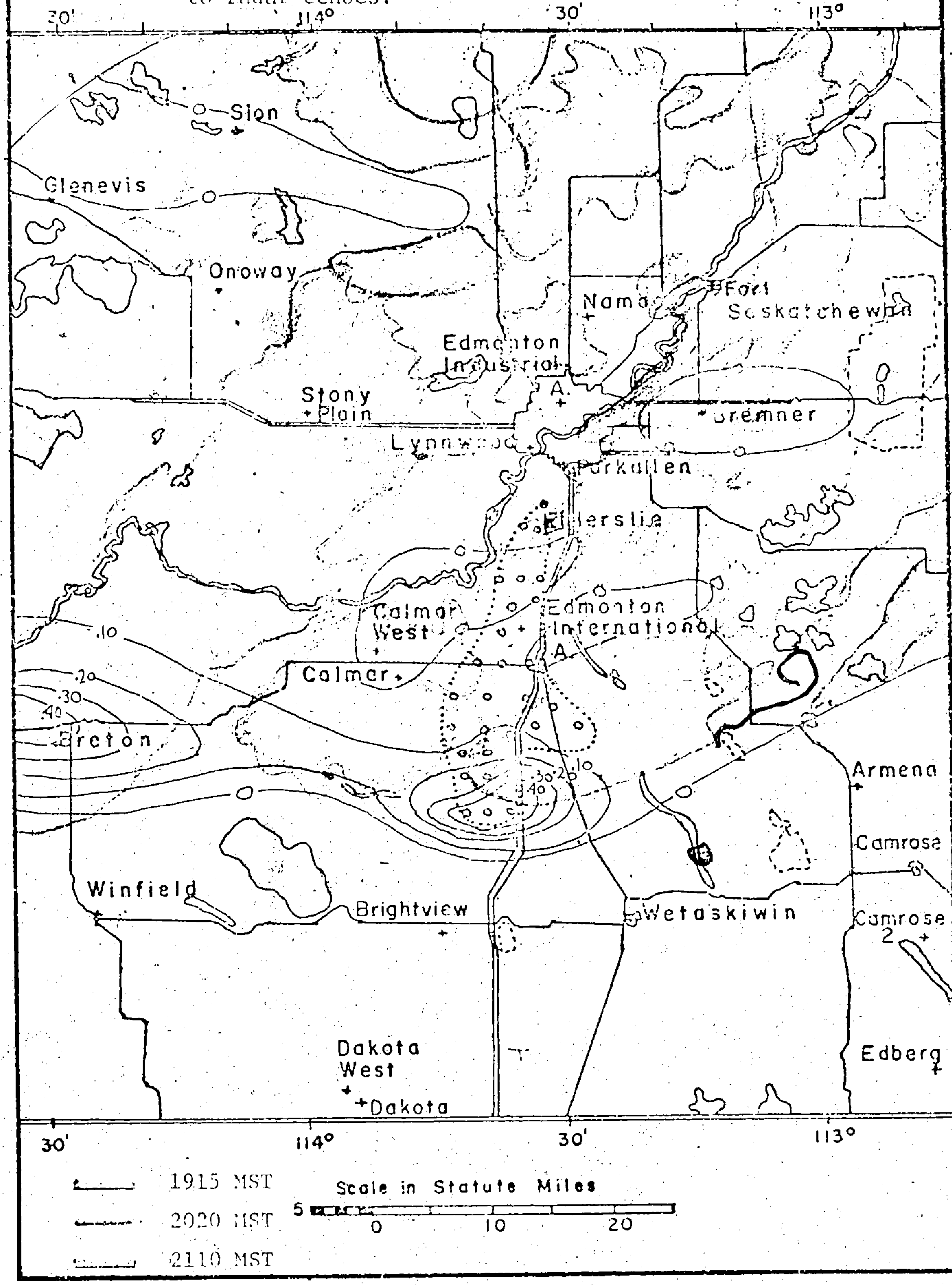


Fig. 7. Storm of August 7, 1971.
Progress of radar echoes between 1915 and 2110 MST.
Isohyetal analysis based on rain gauges but adjusted to radar echoes.



IV

Data Analysis

> It is quite possible that high hills will affect thunderstorm paths, but it is an open question whether small hills and valleys can do so. At Nottingham there exists the belief that storms tend to follow the valley of the River Trent.
>
> Arnold E. Tinn, *This Weather of Ours*, 1946

GENERAL

Rainfall data were obtained from the 29 gauges of the Whitemud Creek "dense" rain-gauge network on the morning following most rain days. Occasionally it was not possible to take readings then and so, in a number of instances, more than one rain day was represented by a set of readings.

Data for the two established stations, Edmonton International Airport and Ellerslie were obtained from the Monthly Record, a publication of the Atmospheric Environment Service.

Data were also obtained from this source for 19 other points, including 17 climatological reporting stations and 2 first order stations. A further supplementary station was operated by the author at his home in the Parkallen Community in south-central Edmonton. This installation comprised part of the validation experiment for the use of tin cans. A list of these stations appears in Table III with the accompanying rainfall totals. Reference will again be made to this table. Total figures are lacking for two of the climatological stations. Armena ceased operation at the end of August, 1972, while Oliver began operation mid-way through May of that year. A further station which appears in the list, Bremner, ceased operation at the end of May, 1972. The loss of Armena and Bremner is regrettable as these two stations represent the only climatological record over a wide area east of Edmonton.

Analysis of the data acquired will proceed from a discussion of the pattern resulting from total precipitation during the summer season to that involving weekly totals. The errors in total precipitation calculations will then be discussed and, finally, the average cell size as detected by both radar and rain gauge observations will be reviewed.

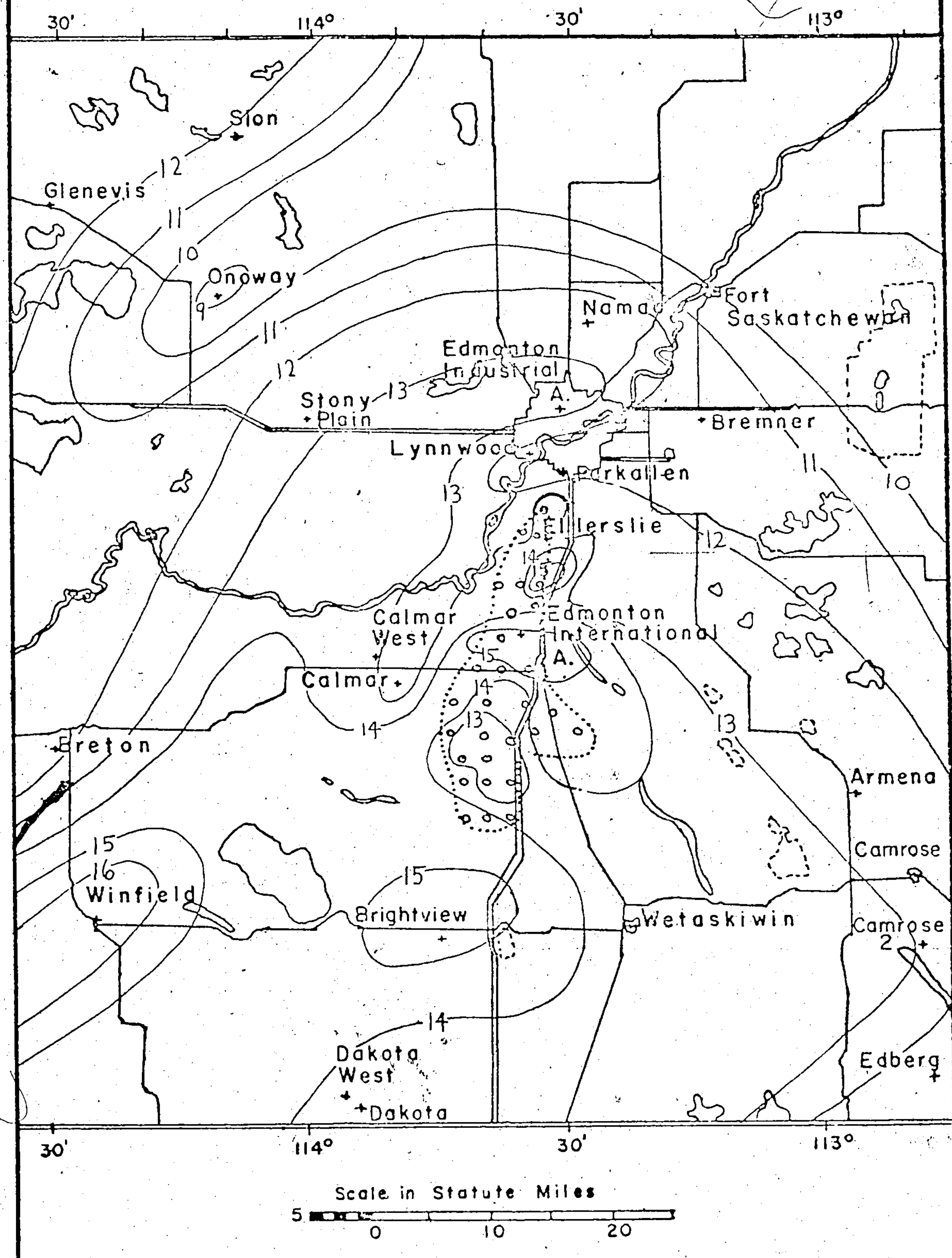
Pattern of Total Precipitation, May 1 to September 30, 1972

In this study all measurements for various time periods were related to the records obtained at Edmonton International Airport. This station will be referred to as the base station. The climatological record at this station represents a series of observations by trained observers maintaining a constant day-by-day record with rainfall read every six hours. It should therefore have the most reliable series of observations in the basin. Nearby, Edmonton Industrial Airport and Edmonton Namao Airport are similarly staffed and with a similar observing schedule. With these exceptions, it should be the most reliable reference point for the area encompassed by the base map of Edmonton and vicinity (e.g. Fig 8a).

In Figs 8a and 8b, numerous relatively wet and dry centres can be distinguished using the 'dense' network in conjunction with the established network and an isohye interval of one inch. Within the basin wet centres occurred at M-2 (see Figs 8a and 8b) and in the central part of the study basin. This area with 15 to 16 in. of precipitation included the base station, C-6 and M-6.

Total precipitation at the base station was higher than that recorded at all but two points within the basin and two points external to it (Table III). The two stations within the basin, C-6 (105%) and M-6 (101%), were adjacent to the airport on the west and south

Fig. 8a. Total Precipitation May to September, 1972.
Isohyetal interval - 1 inch



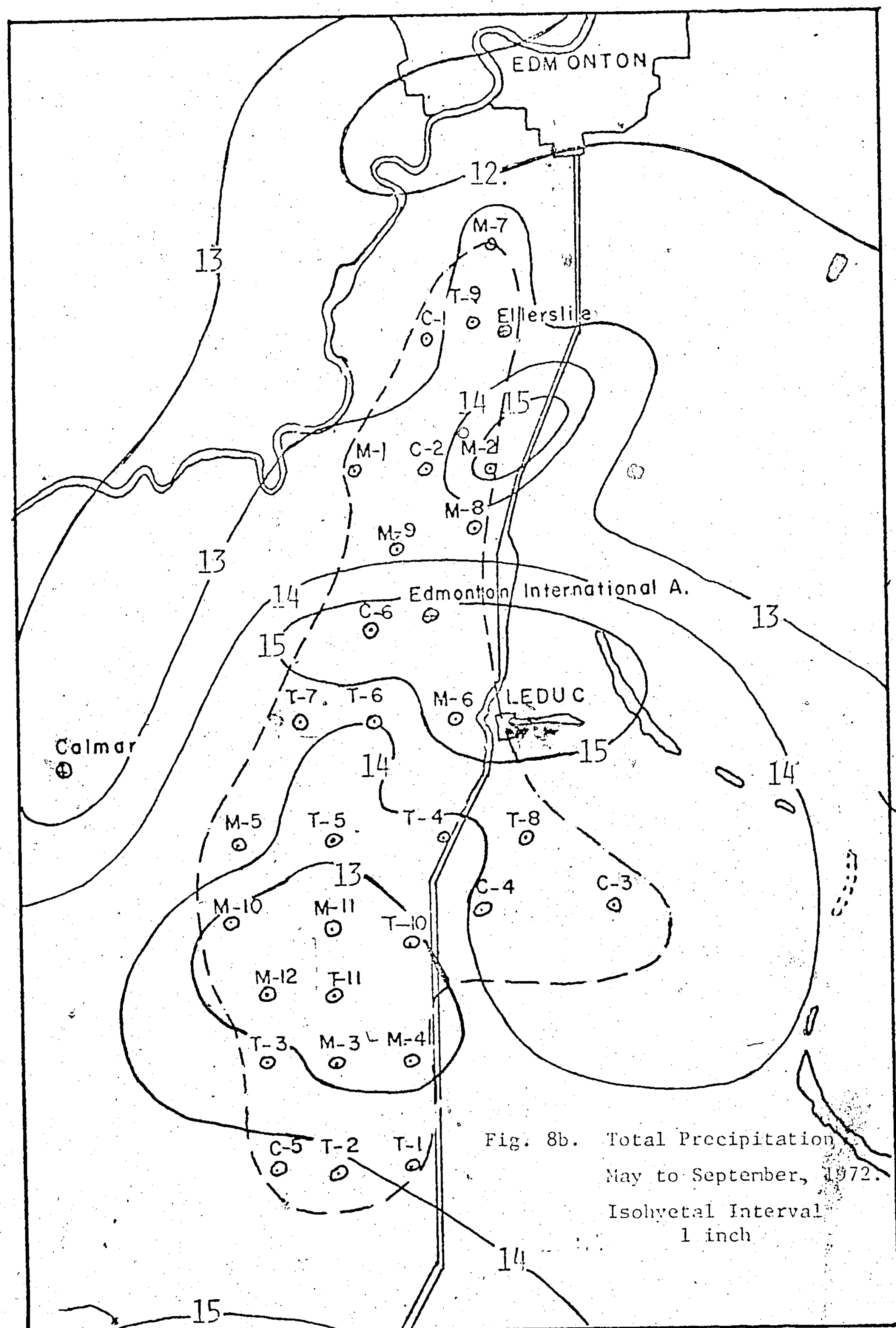


Fig. 8b. Total Precipitation May to September, 1972. Isohyetal Interval 1 inch

sides respectively. One of the external points was Brightview (100%), 26 mi south of the base station and 9 mi south of the southern boundary of the basin. The other was Winfield (108%) 43 mi southwest of the base station.

Drier conditions prevailed over the southern third of the basin and in a north-south band just beyond the western and northern limits of the basin. Total rainfall amounts in the area to the west were 12 to 14 in. while to the north, an east-west area with less than 12 in. of precipitation can be seen on the map.

Over the entire area included in Fig 8a, the driest spot was Onoway, west-northwest of the city, where only 8.92 in. of precipitation fell. This was 59% of the value recorded at Edmonton International Airport, 37 mi distant, and 67% of the amount received at the Industrial Airport, 29 mi away. Fort Saskatchewan, which received 10.00 in. of precipitation, registered 77% of the amount received at the Industrial Airport, 16 mi southwest, and only 66% of that reported at the base station, 32 mi away.

Within the study basin, the greatest departures from the base station amounts occurred at M-11, M-10, M-12 and T-10, some 10 mi south; and at C-1, 8 mi to the north. These were matched by Calmar, 11 mi southwest of the base station. The total rainfall at each of these five points was 82 to 83% of that reported at the base station (Table III). The amount reported from Brightview, 26 mi south, was almost identical to that reported from the base station while Winfield reported 8% more than the base value at a point 43 mi southwest.

Onoway recorded the greatest negative departure in total precipitation with 41% less than the base value. Within the dry area immediately north of the basin, large departures in total precipitation were recorded at both Lynnwood and Parkallen. The climatological station (Lynnwood) reported 78% of the base value, a change in total precipitation of 22% in 14 mi. The supplementary station in Parkallen received 26% less precipitation than the base station, 13 mi distant.

The last two values may alternately be expressed as precipitation gradients of .24 in. per mi and .30 in. per mi respectively. These seem to be identical with values calculated for Fort Saskatchewan to Namao and Onoway to Stony Plain for the same time period. No attempt was made to calculate all of the interstation precipitation gradients for this study. The extreme case appears to be that between M-2 and M-8 just to the north of the airport. Total precipitation seems to have produced a gradient slightly in excess of one in. per mile. For total season precipitation, this appears to be an extreme value for reasonably uniform terrain.

<u>Percentage of Rainfall (May to September, 1972) at the Base Station Compared to Distance From That Point</u>

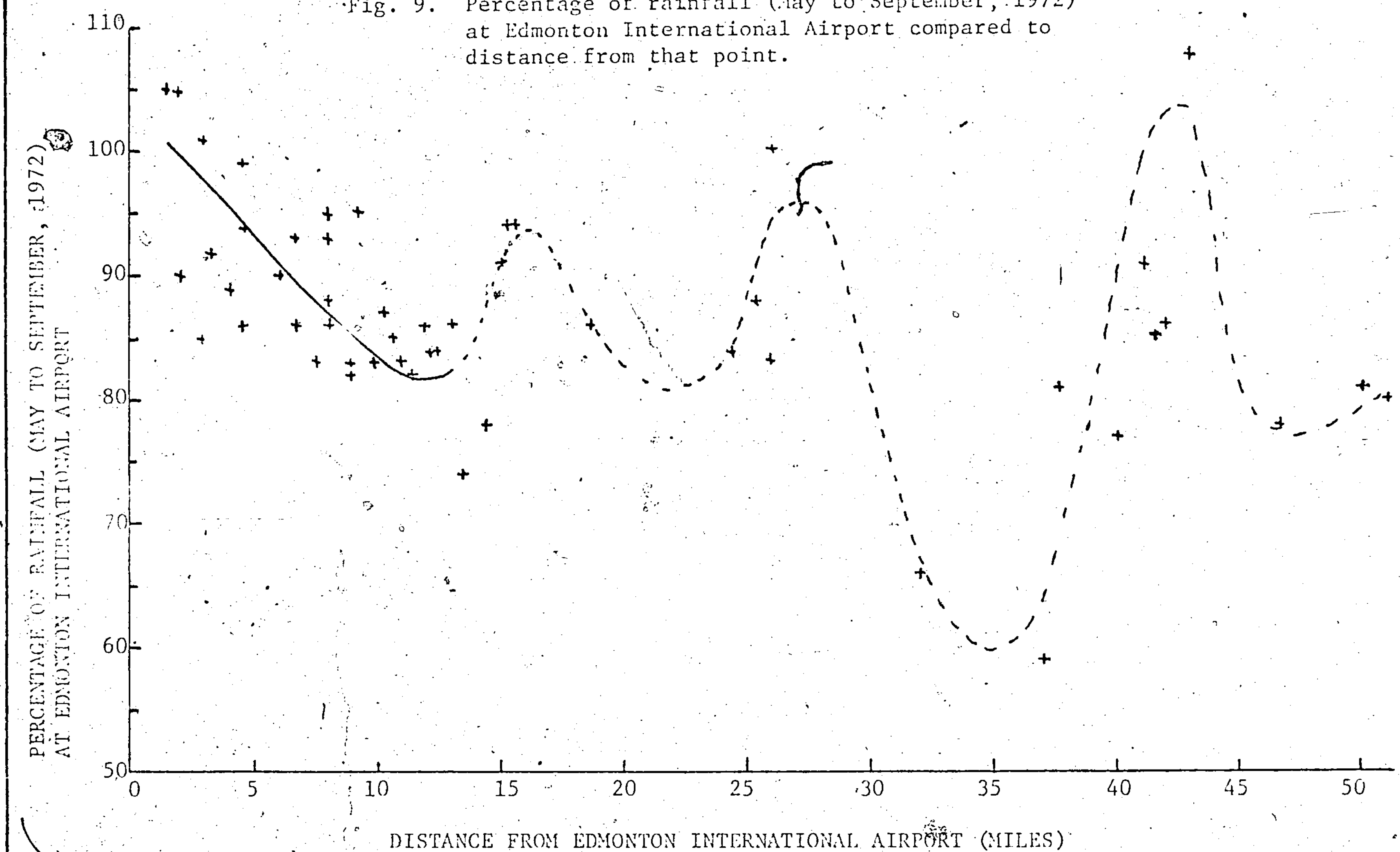
Fig 9 graphically portrays the contents of Table III. The rainfall at each reporting point is expressed as a percentage of the base value. It is compared to the distance between the base station and each of the other reporting points. At a distance of 3 mi, the average change in total precipitation was 8%. At about 12 mi, the average change in total season precipitation increases to 17%. In this year the rain decreased with distance from the base station but

TABLE III

Rainfall Amounts (May to September, 1972), Expressed as a Percentage of the Base Value, and Distance From the Base Station (miles)

Station	Amount	Per cent	Distance	Station	Amount	Per cent	Distance
Edmonton Int.	15.22	100	0	T-3	13.16	86	12.9
M-7	13.30	87	10.2	T-1	13.91	91	15.0
Ellerslie	13.15	86	8.0	T-2	14.35	94	15.2
T-9	[illegible].45	88	8.0	C-5	14.38	94	15.5
C-1	[illegible]61	83	7.5	Ed. Ind. A.	13.14	86	18.6
M-1	[illegible].20	86	4.5	Ed. Namao	12.65	83	25.8
M-2	15.11	99	4.5	Lynnwood	11.87	78	14.3
C-2	13.59	89	4.0	Stony Plain	12.79	84	24.3
M-8	13.02	85	2.8	Calmar West	13.10	86	11.8
M-9	13.71	90	2.0	Calmar	12.63	83	10.8
C-6	15.99	105	1.8	Brightview	15.24	100	26.0
M-6	15.45	101	2.9	Wetaskiwin	13.43	88	25.3
T-6	14.04	92	3.2	Camrose	12.36	81	37.7
T-7	14.25	94	4.6	Camrose 2	12.99	85	41.5
T-8	14.20	93	6.6	Parkallen	11.32	74	13.4
T-4	13.77	90	6.0	Winfield	16.46	108	42.7
T-5	13.10	86	6.6	Dakota	13.15	86	42.0
M-5	14.40	95	8.0	Dakota West	13.83	91	41.1
C-3	14.41	95	9.2	Breton	11.68	77	40.0
C-4	14.08	93	8.0	Glenevis	12.14	80	51.0
T-10	12.54	82	8.9	Onoway	8.92	59	37.0
M-11	12.59	83	8.9	Sion	11.87	78	46.7
M-10	12.65	83	9.9	Ft. Sask.	10.00	66	32.0
T-11	12.97	85	10.6	Edberg	12.32	81	49.7
M-12	12.57	83	11.3				
M-4	12.78	84	12.1				
M-3	12.80	84	12.4				

Fig. 9. Percentage of rainfall (May to September, 1972) at Edmonton International Airport compared to distance from that point.



the author realizes that in other years the change will be positive. The magnitude of change might also differ. In some years the average change could be suppressed by a combination of positive and negative amounts. If all changes are considered to be positive, the magnitude will probably remain near the above values. Corroboration of this statement may be found in the work of Huff and Schickedanz (1972) who have found an average decrease in growing season rainfall of 6% at a distance of 3 miles from a reference point.

When a curvilinear regression line was fitted by eye to the data plotted in Fig 9, peaks and valleys appeared. The valleys all reached low points near multiples of 11.5 mi. This may be a result of the average spacing between preferred storm tracks during this summer. Attempts to find a directional bias have failed, probably because of the limited area under study and the sparseness of the reporting network beyond the Whitemud Creek basin. The problem may be considered as a possible avenue for further research using data from the Alberta Hail Studies volunteer reporting network.

Patterns of Weekly Total Precipitation Over the Whitemud Creek Basin

This discussion must be quite limited in nature because space limitations do not permit a full description of the 14 maps included here. The precipitation values were analysed at 0.1 - inch intervals (Figs 10a to 10o) except for those cases in which precipitation gradients were so great that a 0.2-inch interval was utilized to separate the isohyets. Dashed lines have occasionally been used to indicate the placement of an intermediate isohyet within a closed wet or dry

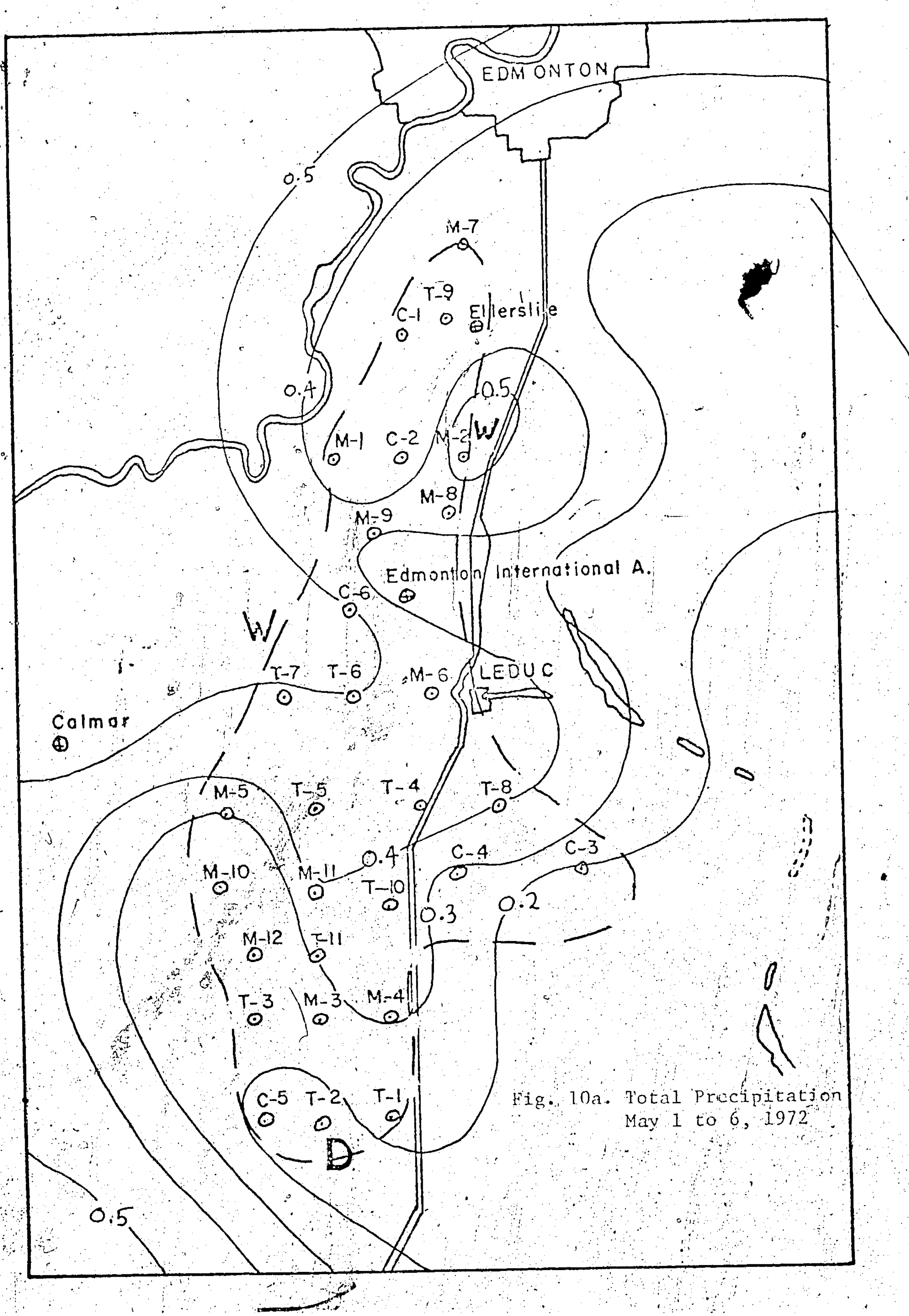


Fig. 10a. Total Precipitation
May 1 to 6, 1972

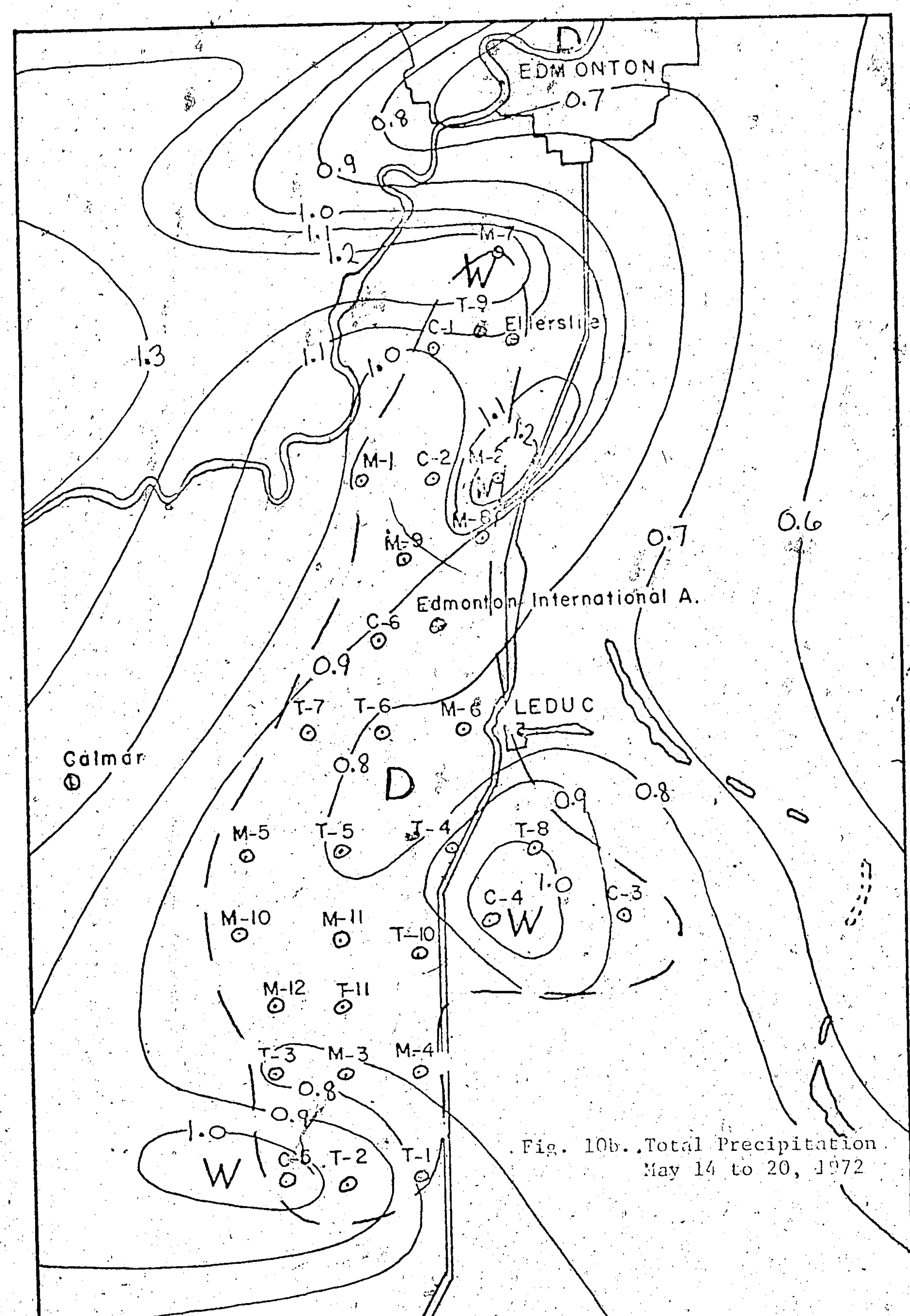


Fig. 10b. Total Precipitation May 14 to 20, 1972

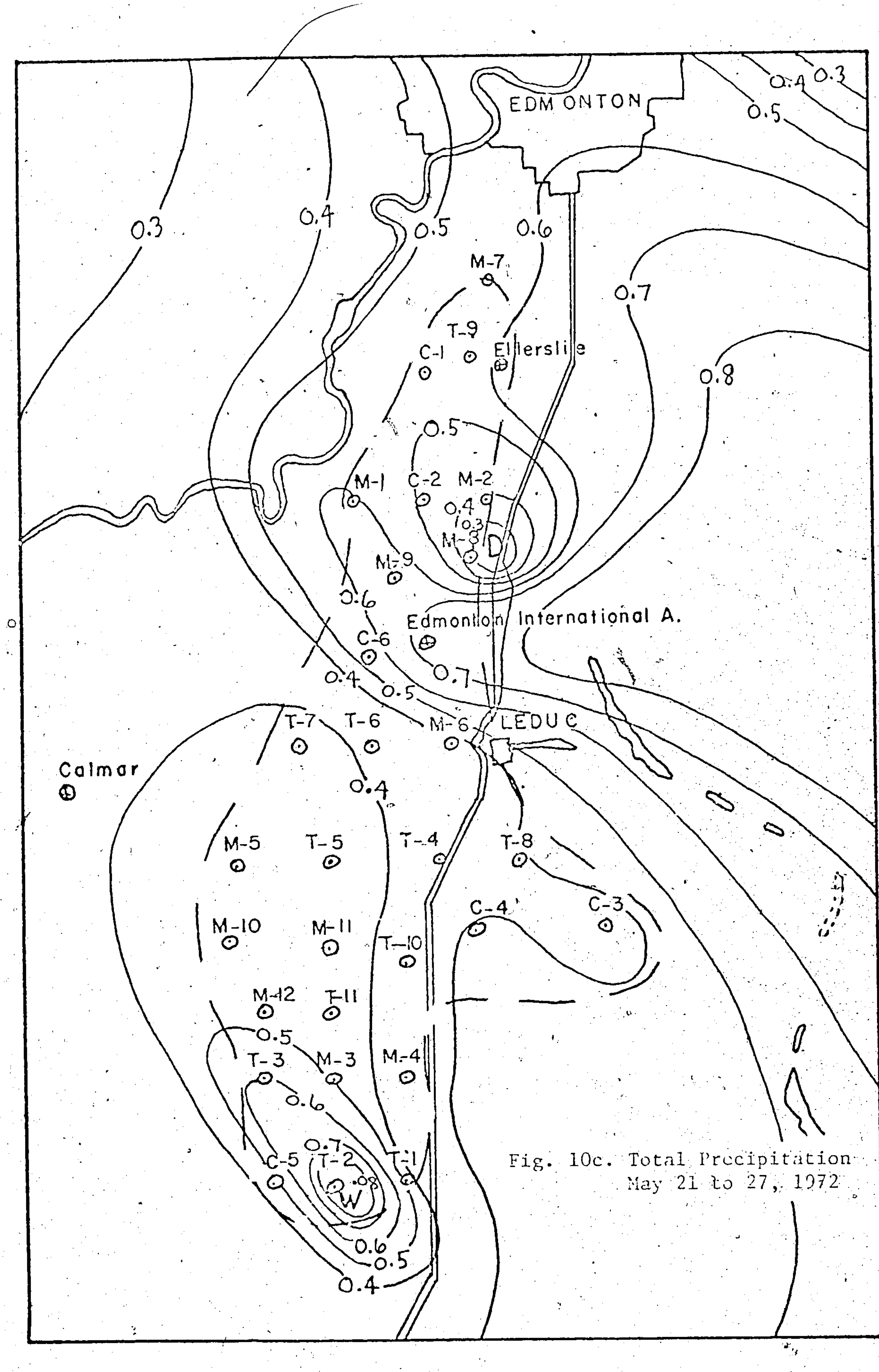


Fig. 10c. Total Precipitation
May 21 to 27, 1972

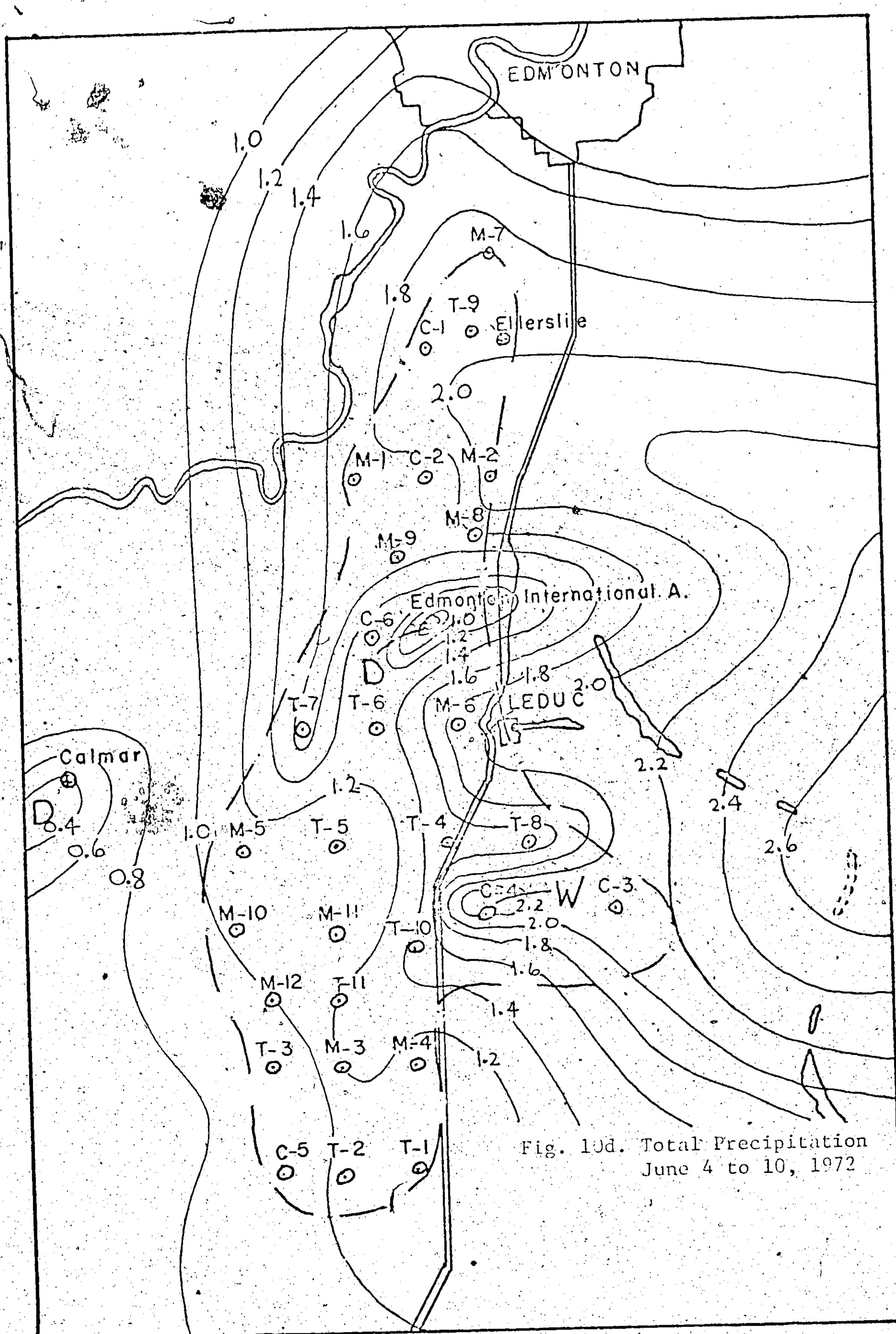


Fig. 10d. Total Precipitation
June 4 to 10, 1972

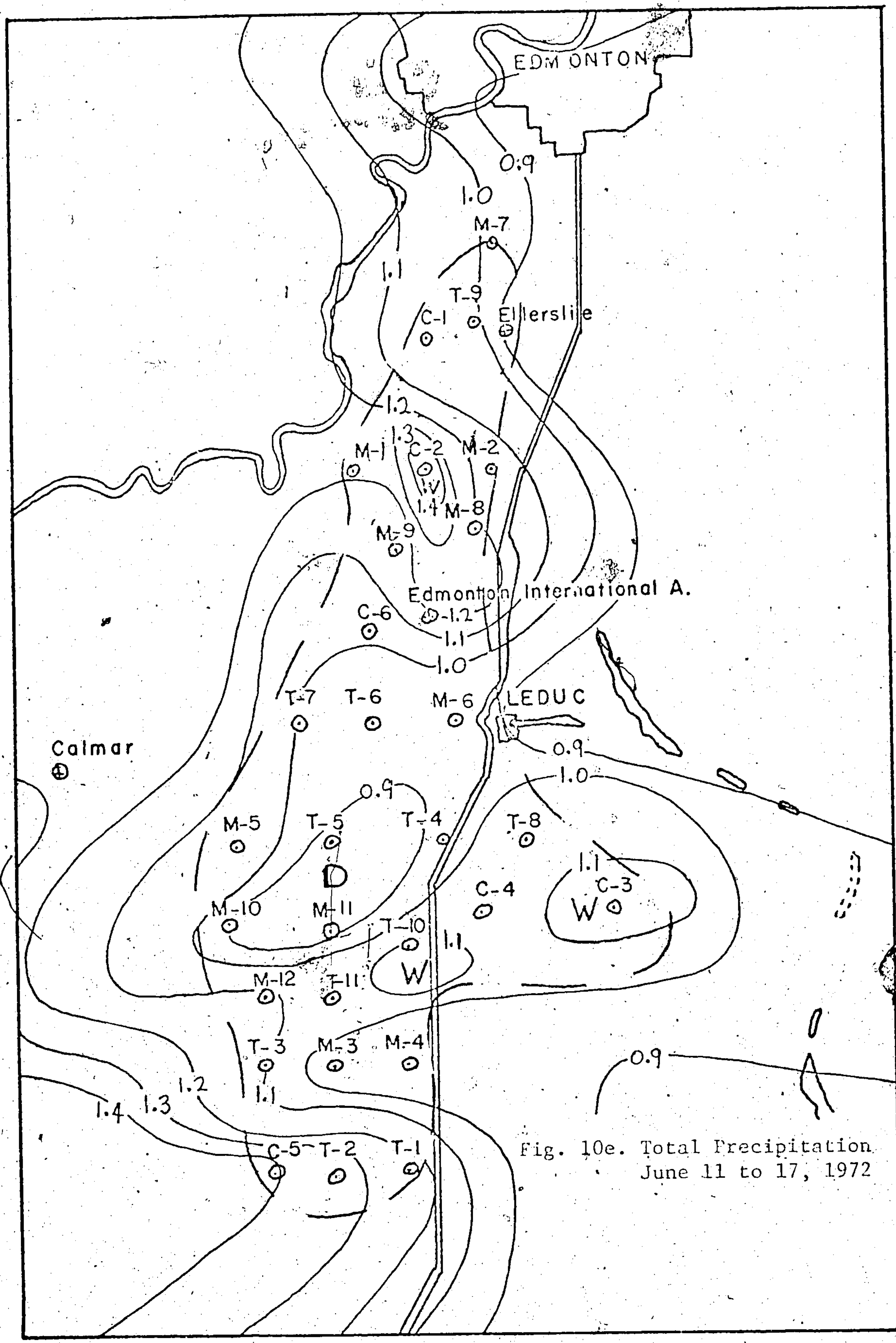


Fig. 10e. Total Precipitation
June 11 to 17, 1972

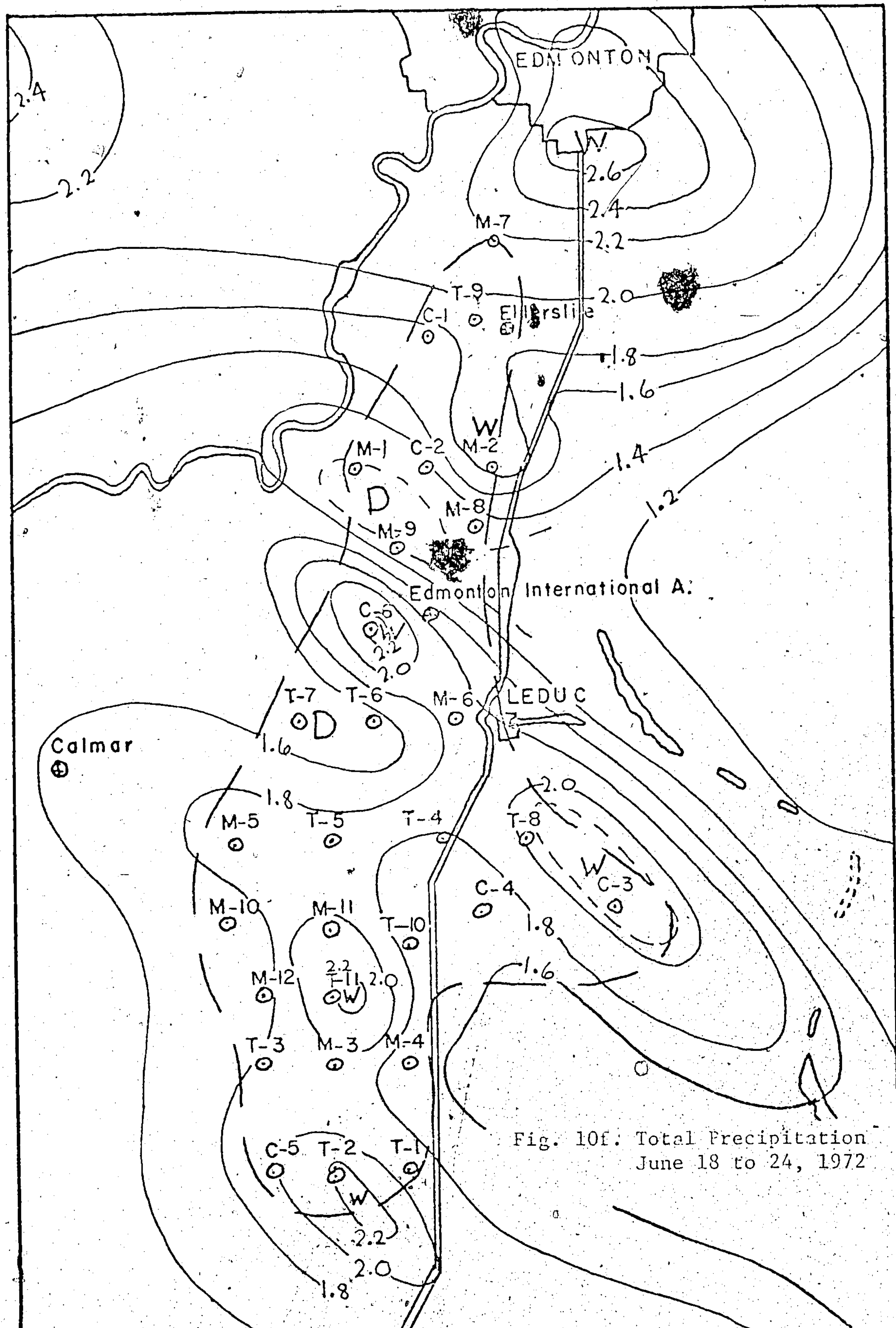


Fig. 10f. Total Precipitation
June 18 to 24, 1972

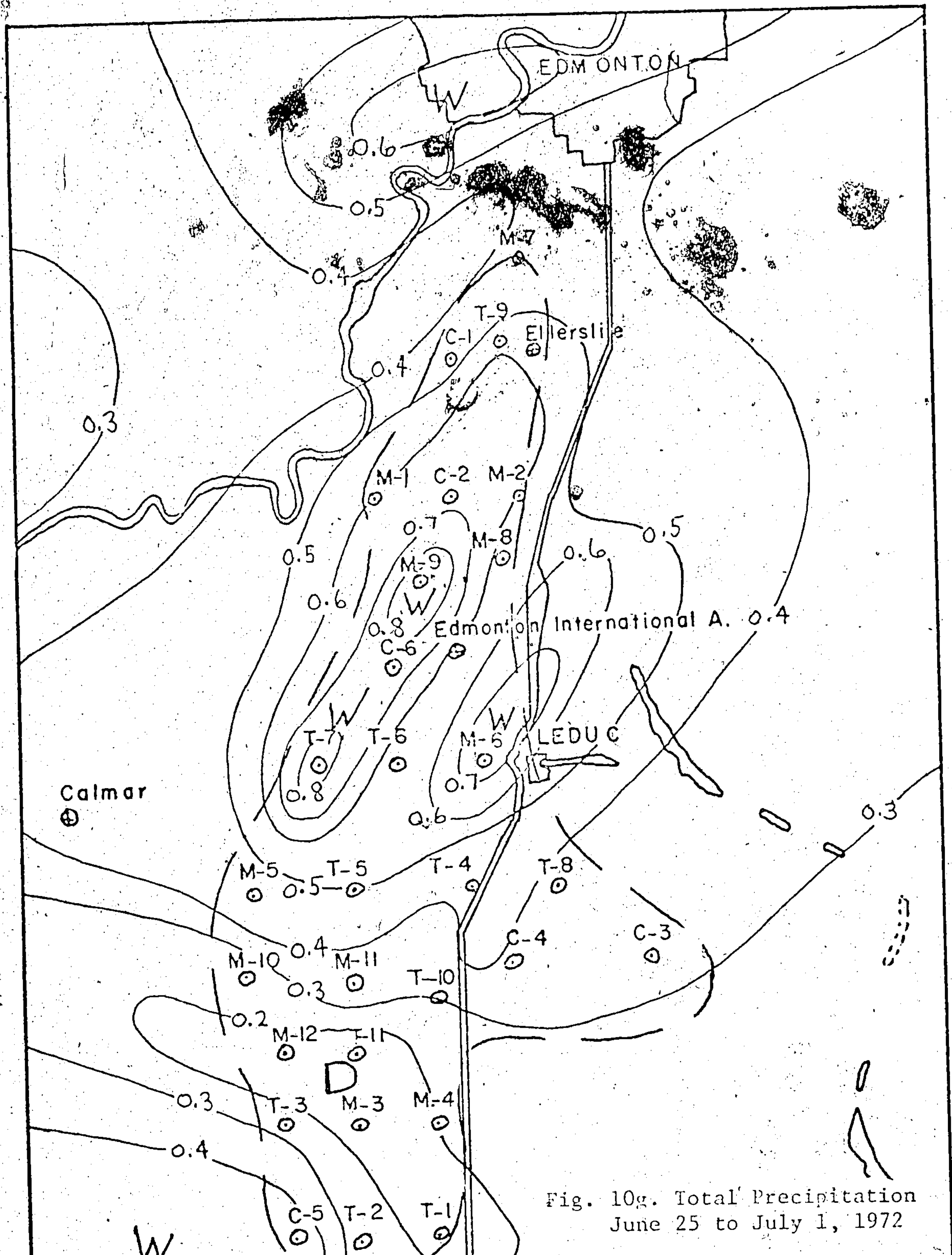


Fig. 10g. Total Precipitation
June 25 to July 1, 1972

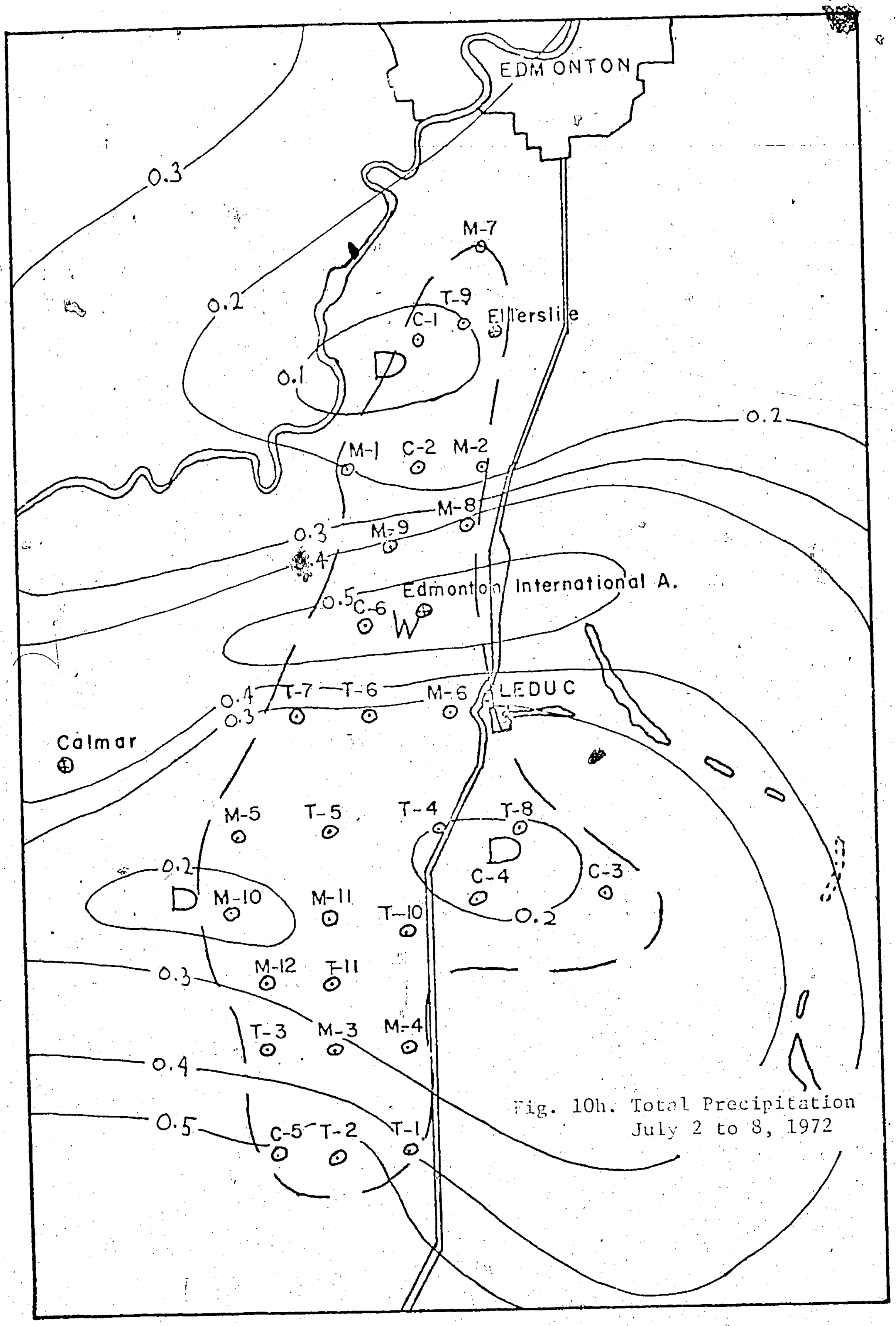


Fig. 10h. Total Precipitation July 2 to 8, 1972

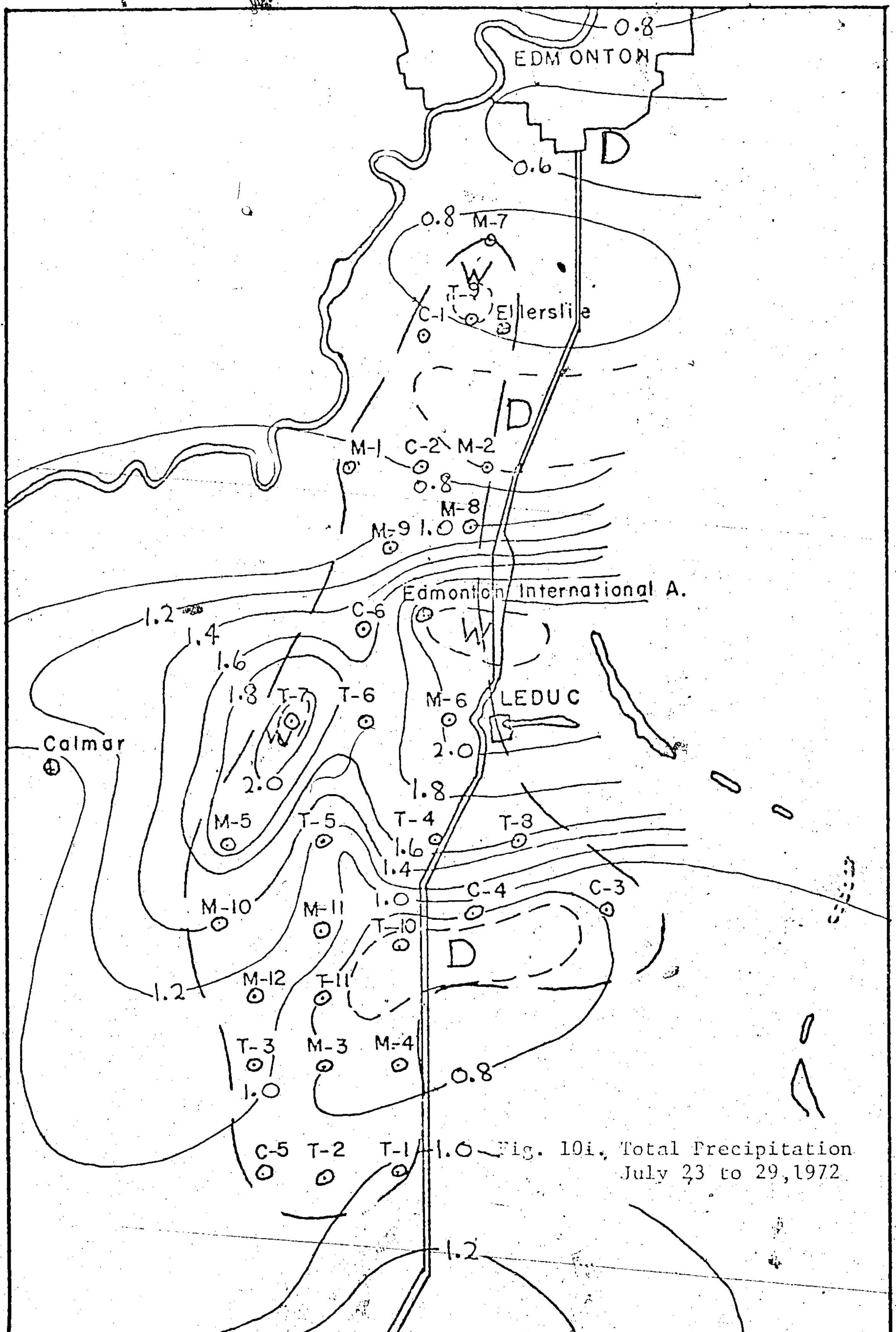


Fig. 10i. Total Precipitation July 23 to 29, 1972

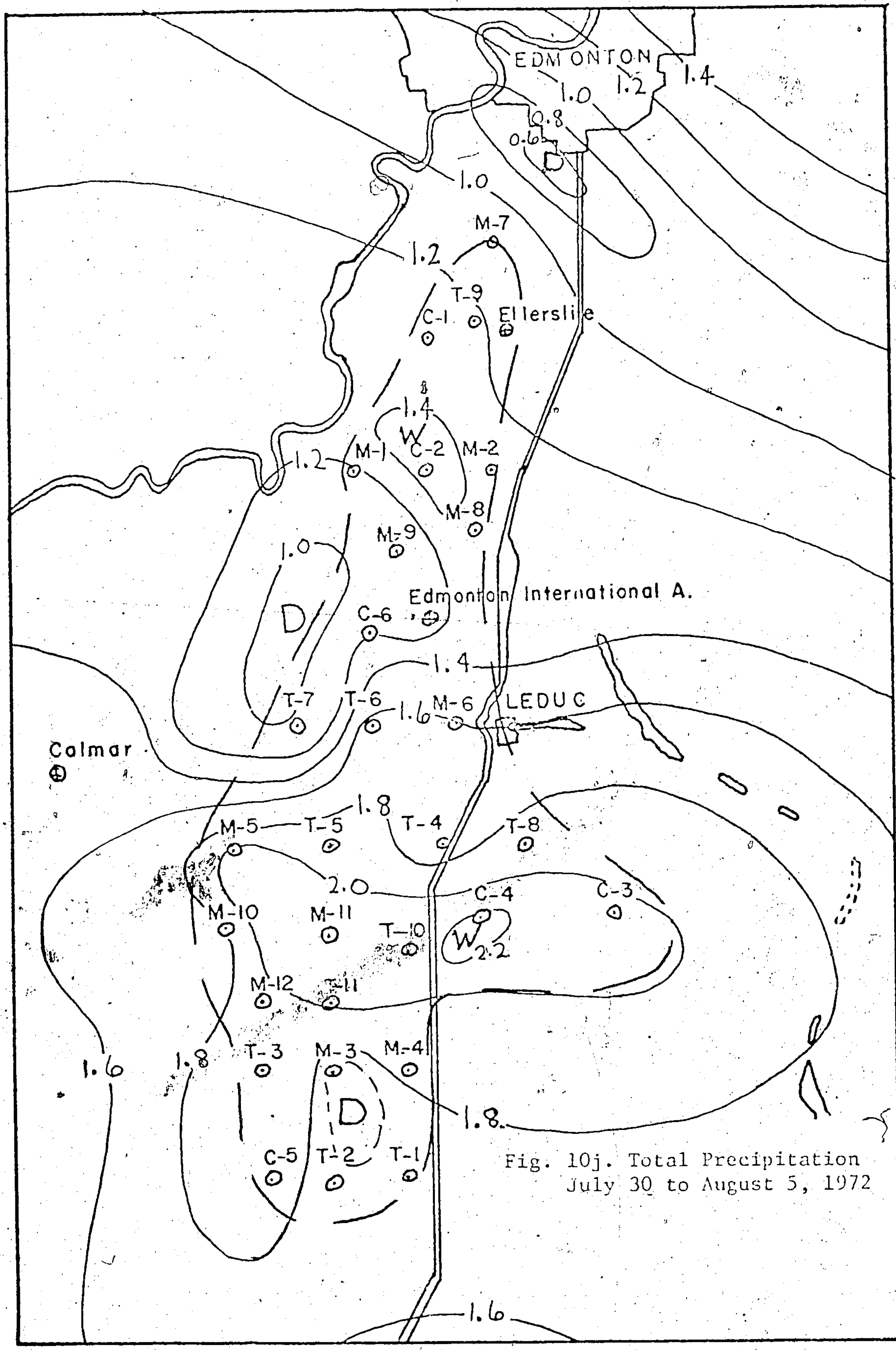


Fig. 10j. Total Precipitation
July 30 to August 5, 1972

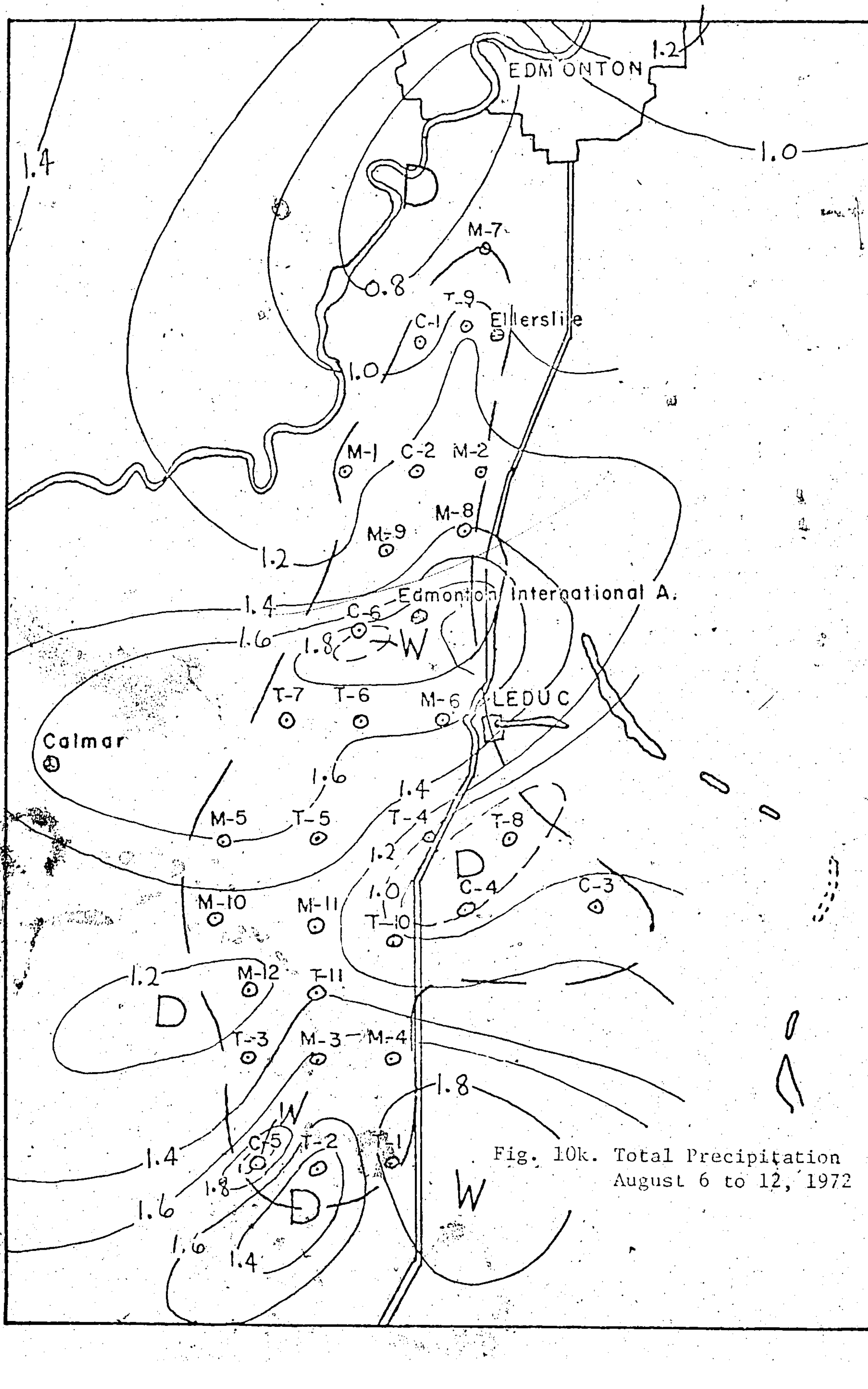


Fig. 10k. Total Precipitation
August 6 to 12, 1972

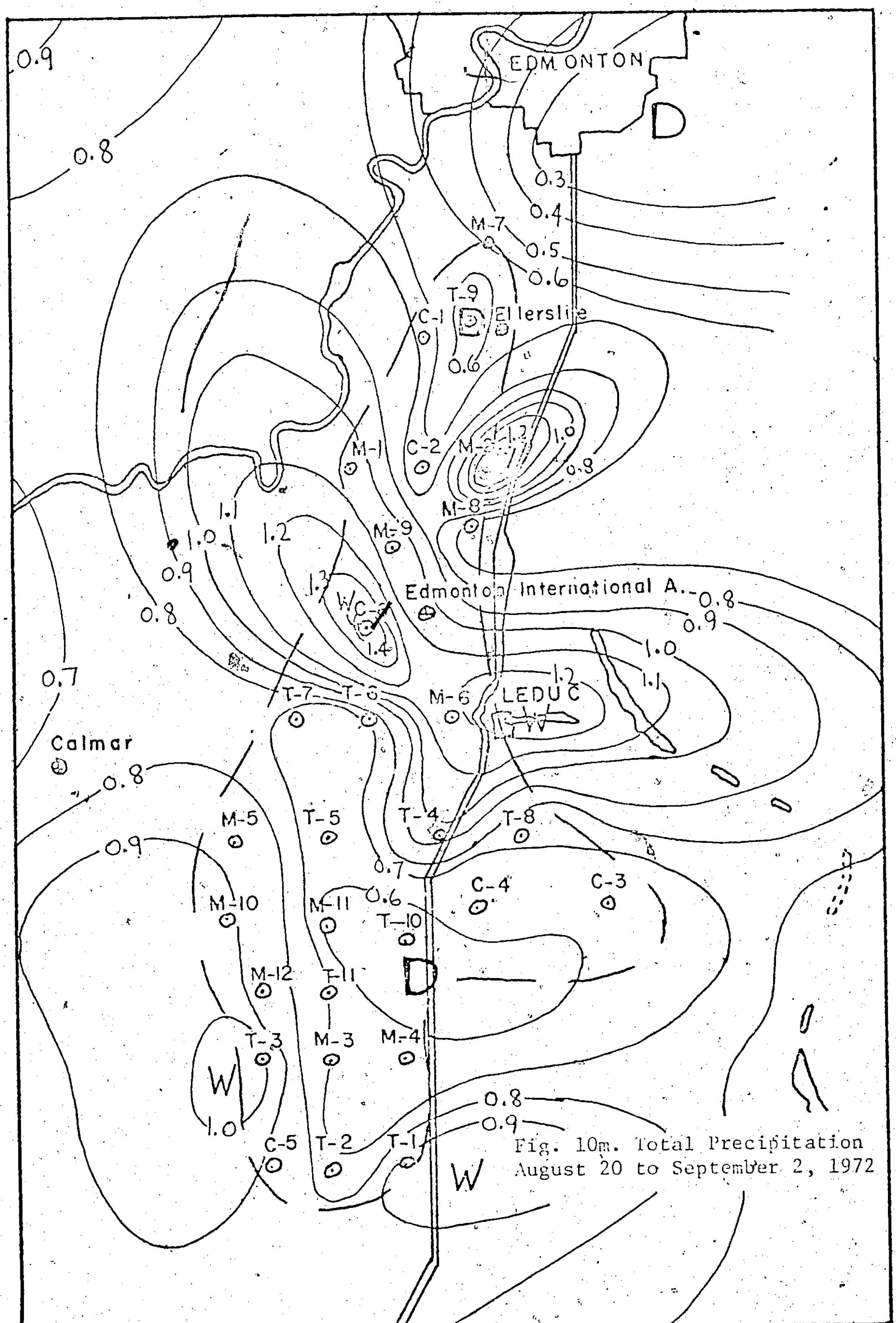


Fig. 10m. Total Precipitation
August 20 to September 2, 1972

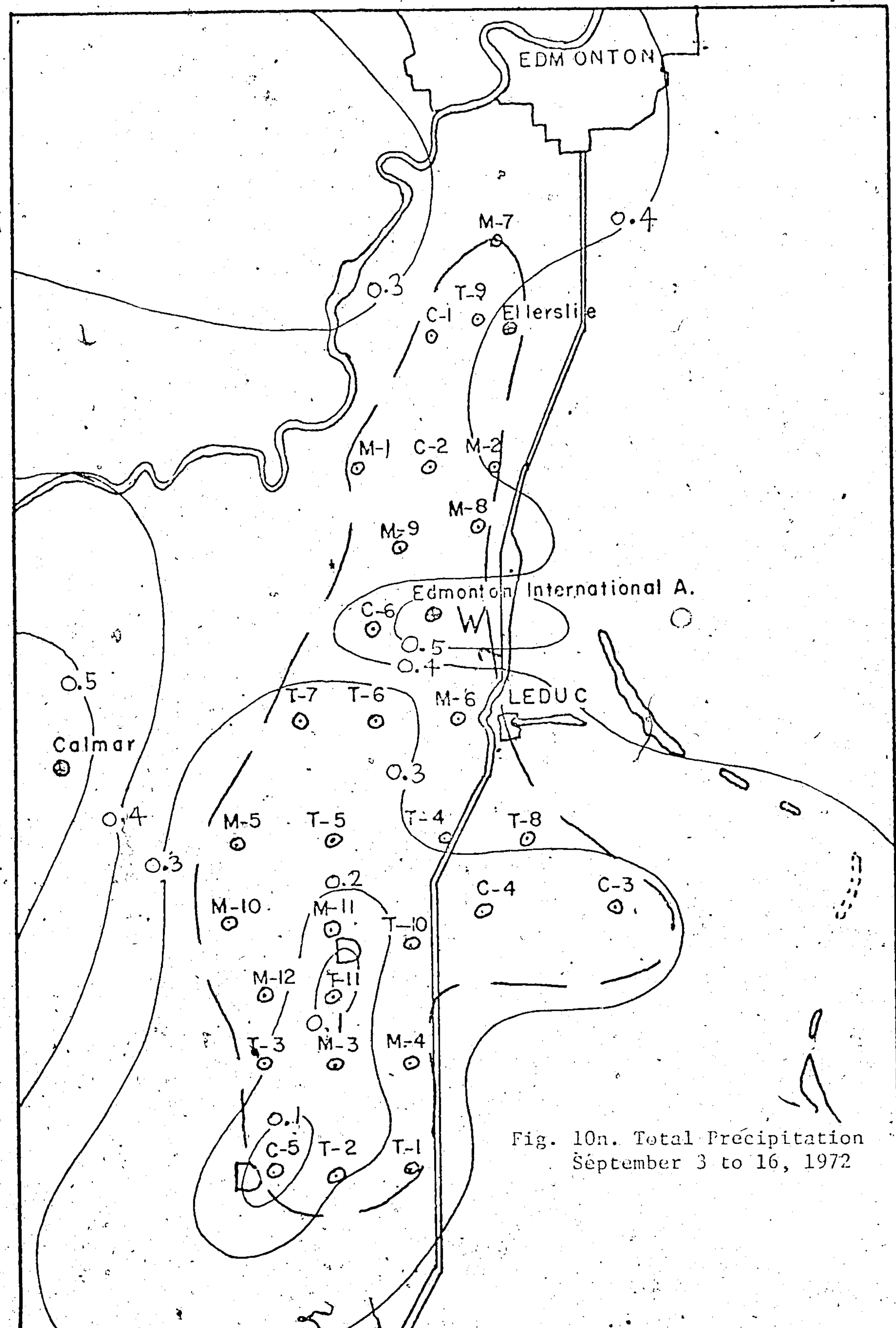


Fig. 10n. Total Precipitation September 3 to 16, 1972

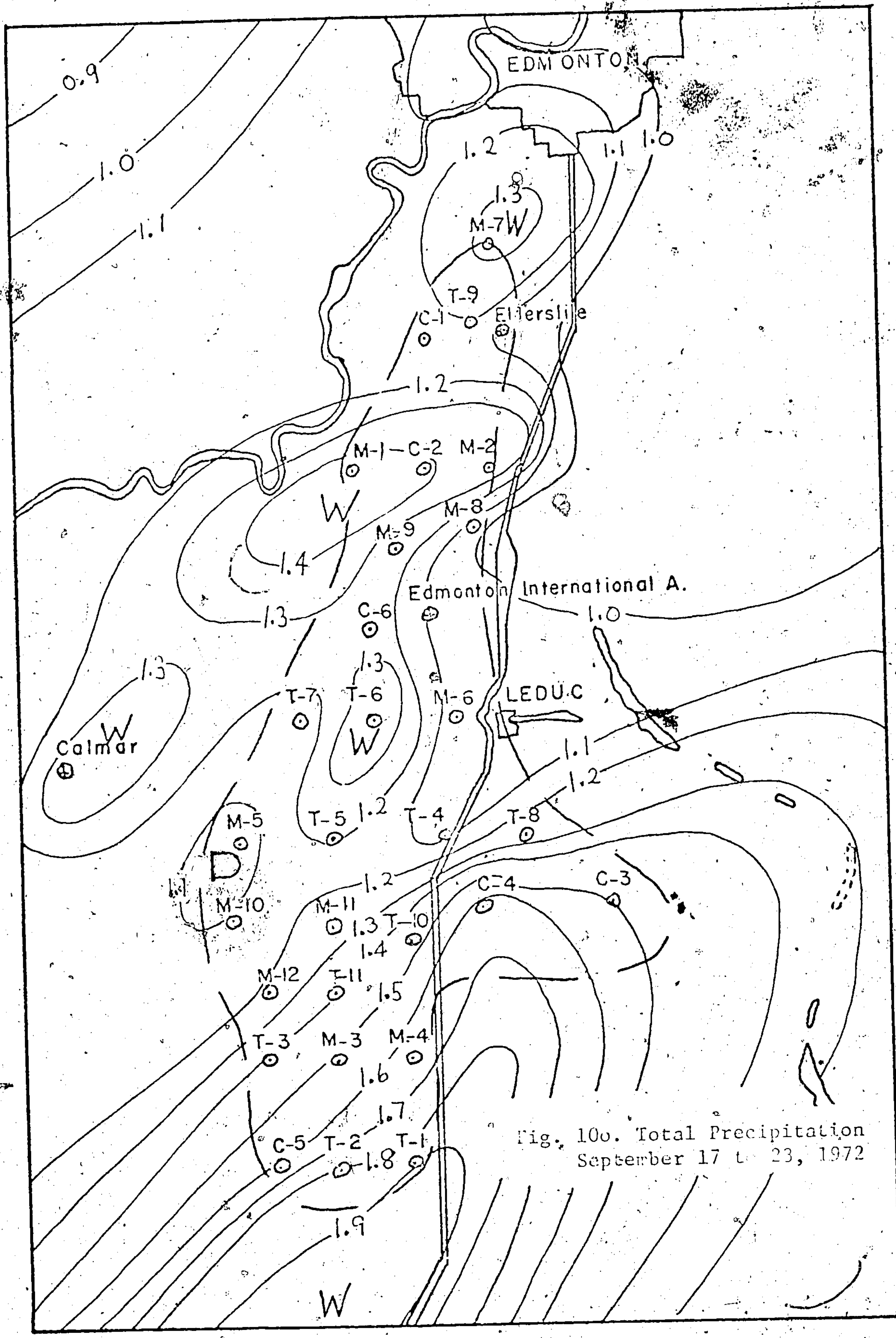


Fig. 10o. Total Precipitation
September 17 to 23, 1972

centre and solid lines have been used [illegible] the map boundaries for the same purpose.

The degree of variability over short distances is highlighted by these maps. Several approaches might be taken in the description of this variability. The author has chosen simply to count the wet and dry centres occurring in or near the basin. This has been done to illustrate the spatial distribution and frequency of wet and dry centres. If one gauge or area were to show a clustering of one or the other occurrence, it could be assumed that either the gauge exposure was poor or, if rainfall amounts supported the evidence, that some truly anomalous wet or dry area had been found.

The basin was divided into North, Central and South portions by dividing the long axis of the basin evenly into three parts (Figs 13a and 13b). One map was designated for "wet" centres and the other for "dry" centres. A tally mark was placed on the appropriate map corresponding to the location of each centre on the maps of weekly rainfall. The results were then tallied (Table IV).

TABLE IV

Location of Wet and Dry Centres
in the Whitemud Creek Basin, May to September, 1972.
(from weekly precipitation
totals)

	Wet	Dry
North	12	13
Central	14	9
South	16	10

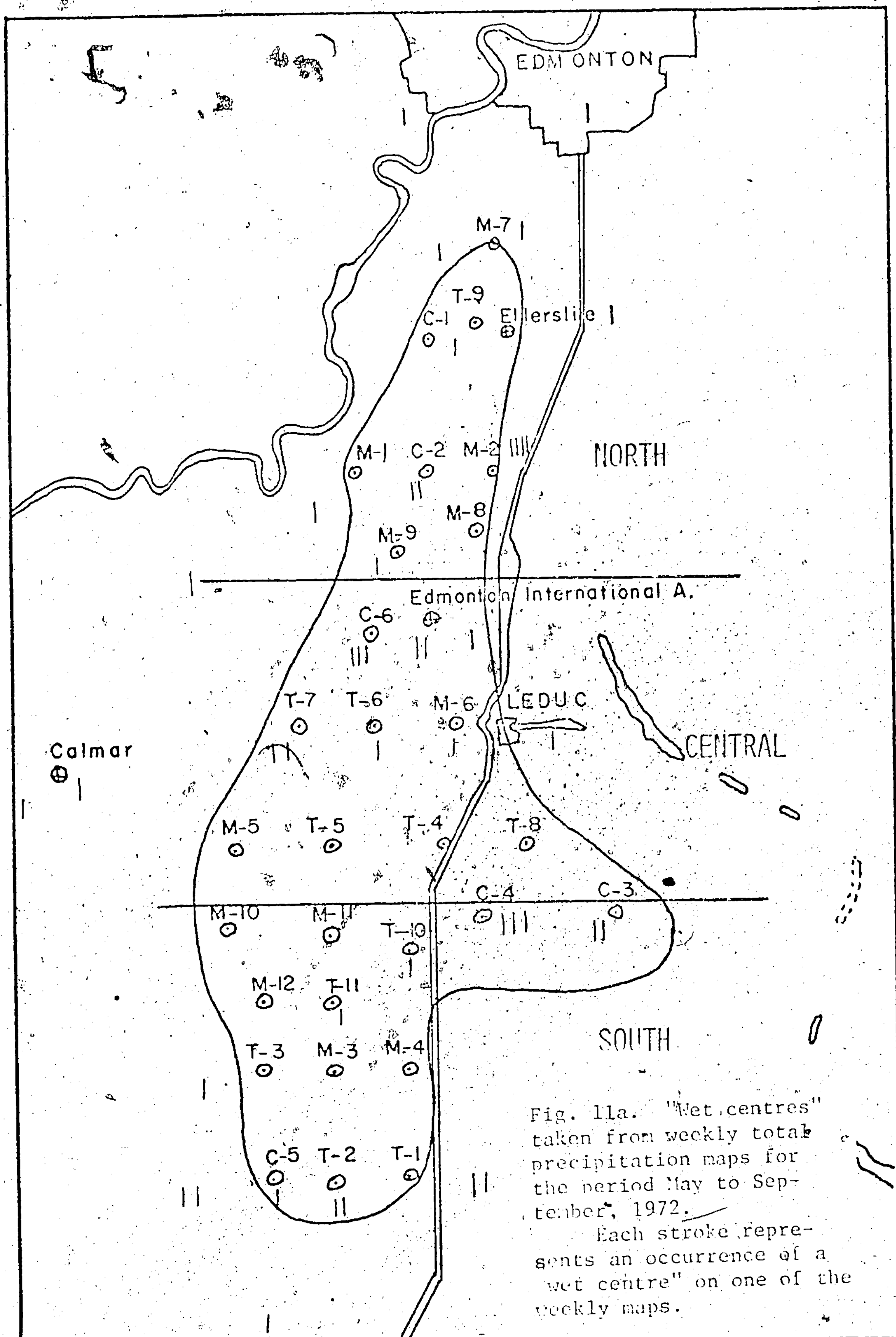


Fig. 11a. "Wet centres" taken from weekly total precipitation maps for the period May to September, 1972.

Each stroke represents an occurrence of a "wet centre" on one of the weekly maps.

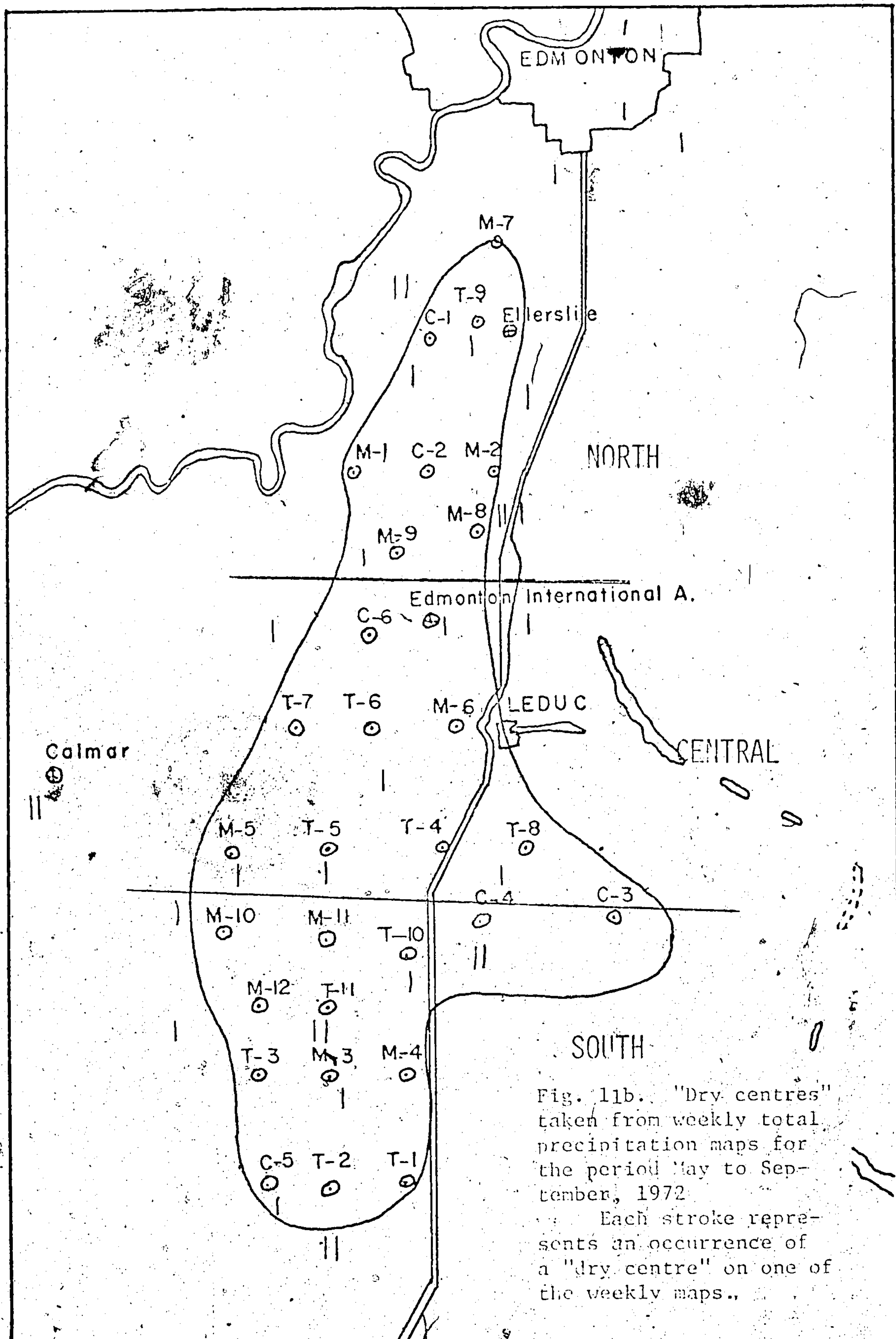


Fig. 11b. "Dry centres" taken from weekly total precipitation maps for the period May to September, 1972.

Each stroke represents an occurrence of a "dry centre" on one of the weekly maps.

The count reveals slightly more cases of wet centres occurring in the South portion of the basin while the least number of dry centres occurred in the Central portion. Fig 8 shows total precipitation for the summer to have been less in the South than in the Central portion. It seems then that the reason the maximum precipitation totals occurred in the Central portion of the basin was a relative consistency in precipitation (an absence of dry centres) combined with a near average number of wet centres in that area.

The highest frequency of occurrence of wet centres was at M-2(4). C-6 and C-4 each recorded 3 maxima. The most frequent location of dry centres by station was at M-8. This places the highest frequency of "wet" next to the highest frequency of "dry". These are the same two stations between which the maximum precipitation gradient was calculated based on the total summer amounts. These facts suggest that either M-2 is too sheltered (resulting in overcatch) or M-8 is too exposed (resulting in undercatch), or both.

The highest weekly amounts recorded were 2.1 and 2.2 inches. These occurred during the weeks of June 4 to 10 at C-4; June 18 to 24 at C-3, C-6, T-11 and T-2; July 23 to 29 at Edmonton International Airport and T-7; and July 30 to August 5 at C-4. These results would seem to indicate that the area around C-3 and C-4 with three occurrences would have had the greatest total precipitation for the summer. But three occurrences of dry centres in the same location were sufficient to reduce the total values to 95% and 93% respectively of the base value.

One interesting feature arising from the analysis could not be developed at this stage of the investigation for lack of detailed information. It concerns two stations located in the valley of the Whitemud Creek where the creek has cut to depths of 75 to 125 ft below the surrounding plain. These stations, T-9 and M-7, showed smaller differences from the total summer precipitation measured at the base station than did those stations surrounding them. On 8 of the 17 maps of weekly total precipitation, greater total precipitation was recorded at the valley location T-9 than at Ellerslie to the east or at C-1 to the west. On 6 of these 8 maps, M-7 also received more precipitation than the two stations at higher elevation. Table III shows that total precipitation was also higher at the valley locations. This may have been the result of sheltering by the valley walls, eddying within the valley, or may be a true anomaly in which precipitation is higher in and along the valley than over flat terrain. More detailed investigation of this feature is warranted.

Difference in Precipitation Measurement

The author wished to know if the dense rain-gauge network would reveal large differences in the total depth of precipitation in the study basin. The Thiessen polygon method was used for both the season and shorter periods (More, 1967). This involved drawing the right bisectors of the lines joining all pairs of adjacent gauges. All points within a polygon are closer to the gauge within it than to any other gauge. It is felt that the polygons give the representative area of each gauge within the basin.

The following two maps (Figs 12 and 13) show the polygons

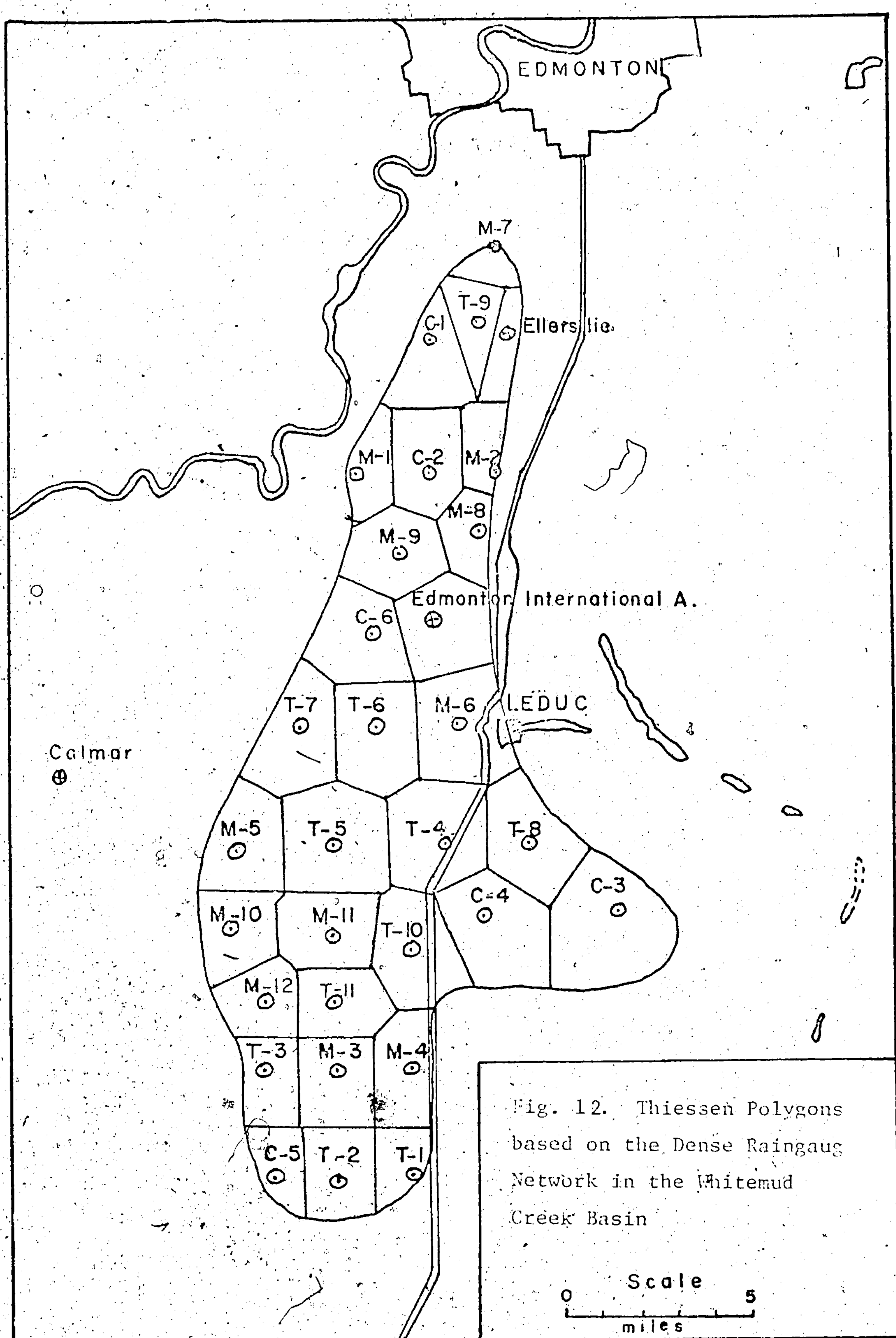


Fig. 12. Thiessen Polygons based on the Dense Raingaug Network in the Whitemud Creek Basin

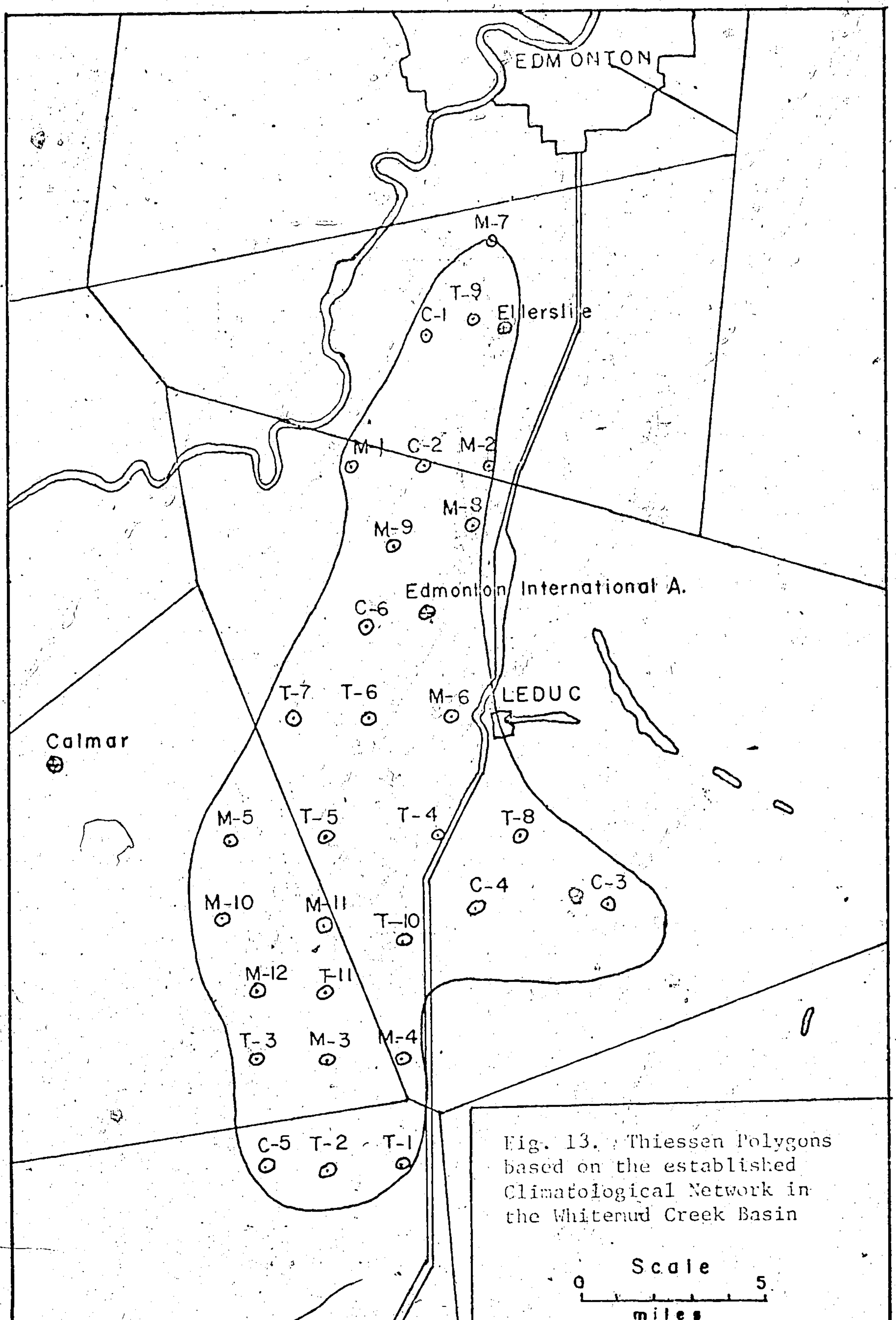


Fig. 13. Thiessen Polygons based on the established Climatological Network in the Whitemud Creek Basin

which resulted from the division of the basin on the basis of the climatological network alone and the established plus supplementary dense-network within the basin. The accompanying table, Table V is a listing of the areas of the polygons and the proportions of the basin (expressed as percentages) which were assigned to each gauge location. These percentages varied from a low of 1.0% to a high of 6.7% for the combined network. In the established climatological network the Edmonton International Airport was representative of 59% of the total area of the basin.

The influence of the higher values reported for summer precipitation at and near the base station shows in the totals calculated, by this method. Based on the climatological network, 14.40 in. of precipitation fell in the Whitemud Creek basin from May to September, 1972. The dense rain-gauge network showed that only 13.80 in. fell during that period. This latter amount represents 96% of the value given by the established network. If we accept the dense-network as giving a "true" reading of the precipitation amount received, then the established network measured 104% of the true value. This implies a high level of reliability for the established network during this particular summer. It must be borne in mind, however, that the base station and its surroundings received somewhat more rainfall than did other parts of the basin. The heavy weighting given to the base station in the calculations based on the climatological network is responsible for this error. Though the magnitude of the difference during the summer of 1972 was very small, it may be only coincidence. It is quite possible that in another year the difference could be much more.

TABLE V

Thiessen Polygon Areas and Percentages of Basi

for the "Dense" and Established Networks

Established Network

Gauge designation	Area of Polygon (sq mi)	Per cent of Basin
Ellerslie	17.0	11.5
Edmonton Int. A.	87.6	59.1
Calmar	32.1	21.7
Brightview	11.5	7.8
Total area	148.2	100

Dense Network

Gauge desig.	Area (sq. mi)	Per cent of Basin	Gauge desig.	Area (sq mi)	Per cent of Basin
M-7	1.3	1.0	T-5	8.3	5.5
C-1	4.1	2.7	T-4	6.8	4.5
T-9	2.6	1.7	T-8	6.6	4.4
Ellerslie	1.6	1.1	M-10	4.3	2.9
M-1	2.9	1.9	M-11	5.2	3.4
C-2	4.9	3.3	T-10	6.4	4.3
M-2	2.1	1.4	M-12	3.9	2.6
M-9	5.0	3.3	T-11	4.3	2.9
M-8	2.5	1.7	T-3	3.7	2.5
C-6	5.6	3.7	M-3	5.2	3.5
Ed. Int. A.	5.5	3.7	M-4	4.4	2.9
T-7	6.0	4.0	C-5	2.8	1.9
T-6	6.0	4.0	T-2	5.2	3.5
M-6	6.8	4.5	T-1	3.0	2.0
M-5	5.4	3.6	C-3	10.0	6.7
			C-4	7.3	4.9
			Totals	149.7	100

The slight discrepancy in the total areas could not be resolved despite many attempts to do so.

Short-term differences in precipitation measurement were revealed by calculating an average value from each network for each event. The maximum number of rain-days represented by a measurement is 7 between July 11 and 22. A rain-day is defined as a day on which .01 in. or more of precipitation was recorded at any station within the boundaries of Fig 2. In this period spotty showers gave a total of .14 in. at the International Airport and .18 in. at Ellerslie. Two of the 5 rain-days in this period at the airport had more than .01 in. while 4 of the 6 rain days at Ellerslie had more than this minimum amount.

Comparison of the amounts recorded was carried out by use of calculated percentages as follows:

$\frac{T_2}{T_1} \times 100$ = per cent of "dense" network precipitation amount accounted for by the established network.

where T_2 is the precipitation in the basin calculated from the established network and T_1 is the amount calculated from the dense network. The period covered, the rainfall amounts calculated, and the percentages are shown in Table VI. The established network amounts total from 6% to 819% ($\frac{.001}{.017}$ x 100 and $\frac{.131}{.016}$ x 100). These extreme values may be virtually meaningless because of the very low recorded measurements for T_1 or T_2. As T_1 0, percentage of "true" rainfall increases without bound while as T_2 0, the percentage of "true" rainfall 0. Most of the calculated values were indicative of more meaningful contrasts.

These values were then order ranked and divided into quartiles (Table VII). In 27 of the 46 events studied, the established network showed greater than 100% of "true" rainfall, and 19 cases showed less

TABLE VI

Percentage of "Dense" Network Rainfall
Recorded at Established Network Stations
Calculated by Means of the Thiessen Polygon Method

Period	Total T_1	Total T_2	$\frac{T_2}{T_1}$X100
1971			
July 29-Aug 2	.007	.001	6
3	.382	.173	45
4-7	.099	.019	19
8-17	.026	.028	108
18-27	.015	.052	347
Aug 28-Sept 3	.215	.178	83
4-6	.068	.061	90
7-10	.062	.107	173
1972			
May 1-3	.112	.109	97
4	.224	.217	97
5-15	.035	.215	614
16	.165	.167	101
17-18	.670	.601	90
19-24	.386	.506	131
25	.047	.107	228
May 26-June 7	.012	.002	17
8	.484	.461	95
9	.076	.140	184
10-11	.947	.649	69
12-13	.037	.169	457
14-16	.612	.414	68
17	.398	.410	103
18-21	.083	.142	171
22	.324	.368	114
23-24	1.404	1.046	75
25-26	.009	.017	190
27-28	.251	.289	115
29	.006	.020	333

Period	Total T_1	Total T_2	$\frac{T_2}{T_1}$X100
Jun 30-Jul 1	.178	.214	120
2-6	.279	.420	150
7-10	.051	.120	235
11-22	.016	.131	819
23-27	1.015	1.496	147
28-29	.191	.165	86
30-31	.423	.314	74
Aug 1-4	1.150	.759	66
5	.061	.060	98
6-9	.378	.462	122
10-11	.963	1.155	120
12-13	.059	.176	298
14-18	.069	.027	39
Aug 19-Sept 1	.806	.846	105
2-11	.283	.463	164
12-18	.140	.260	186
19-23	1.184	1.066	90
24-30	.096	.159	166

TABLE VII

Ranked Percentages of "Dense" Network Rainfall Recorded at Established Network Stations

Rank	Per Cent	T_1	T_2		Rank	Per Cent	T_1	T_2	
1	819	.016	.131		24	108	.026	.028	
2	614	.035	.215	C	25	105	.808	.846	C
3	457	.037	.169		26	103	.398	.410	L
4	347	.015	.052		27	101	.165	.167	
5	333	.006	.020		28	98	.061	.060	
6	298	.059	.176		29	97	.112	.109	
7	235	.051	.120		30	97	.224	.217	L
8	228	.047	.107		31	95	.484	.461	L
9	190	.009	.017		32	90	.068	.061	
10	186	.140	.260	L	33	90	.670	.601	C
11	184	.076	.140		34	90	1.184	1.066	L
12	173	.062	.107		35	86	.191	.165	
13	171	.083	.142		36	83	.215	.178	C
14	166	.096	[illegible]	[illegible]	37	75	1.404	1.046	L
15	164	.283	[illegible]	[illegible]	38	74	.423	.314	L
16	150	.279	.420	[illegible]	39	69	.917	.649	L
17	147	1.015	[illegible]	[illegible]	40	68	.612	.414	C
18	131	.386	[illegible]	[illegible]	41	66	1.150	.759	C
19	122	.378	[illegible]	C	42	45	.382	.173	C
20	120	.963	1.155	L	43	39	.069	.027	
21	120	.178	.214	C	44	19	.099	.019	
22	115	.251	.289	C	45	17	.012	.002	
23	114	.324	.368	L	46	6	.017	.001	

Cases Analysed: By Quartiles

	1st	2nd	3rd	4th
Both networks 0.2 in	0	8	6	5
One network only 0.2 in.	3	1	0	2
Total analysed	3	9	6	7

than 100%. During the summer of 1972, therefore, the established network more frequently led the analyst to overestimate the amount of precipitation falling on the study basin. Most of these cases involved small precipitation amounts. Table VII shows that only 4 cases of more than 0.5 in. of precipitation are included in this category. For those occasions on which the amounts reported by the established network led to underestimates of precipitation, there were 6 cases where more than 0.5 in. was recorded in the study basin. A description of these 10 cases follows:

The 4 cases where $\frac{T_2}{T_1} \times 100 = >100\%$ and total rainfall exceeded 0.5 in. resulted from the following circumstances:

Aug 19 to Sept 1, 1972: $\frac{.846}{.808} \times 100 = 105\%$

A north-south cold front moved eastward through Edmonton about 18 GMT on Aug 22. A few showers were reported visible in the area at Aug 23, 00 GMT. A thunderstorm occurred at the base station between 00 GMT and 06 GMT and another between 11 GMT and 12 GMT of Aug 23. Nothing was reported from surrounding stations. When the records for these two days are combined, the International Airport reported .53 in. of rain, the Industrial Airport - NIL, Brightview - .15 in., Calmar - .35 in., and Ellerslie - .07 in.

On Aug 29 and 30, a complex, nearly stationary low, with centres in the north and extreme south of Alberta, gradually weakened. A cold front from Fort McMurray to Red Deer was gradually forced aloft. Continuous rain with some scattered thundershower activity was general throughout the central portion of the province. Rain ended on the morning of the 30 but cumulus and cumulonimbus produced showers and thunderstorms throughout the study area between Aug 31, 00 GMT and 06 GMT.

Rainfall distribution for this period bore some resemblance to the map of total season precipitation. The largest amounts recorded were for C-6, M-6, and M-2 with 1.20 to 1.46 in. The smallest amounts occurred at M-11 (.51 in.) and T-10 (.53 in.), both within the 13 in. isohyet of total summer precipitation. In fact, within the basin, only M-12 recorded less total precipitation than did these two stations for the entire summer.

Aug 10 to 11, 1972: $\frac{1.155}{.963}$ x 100 = 120%

A low in southeastern B.C. grew more complex with a new centre formed near Medicine Hat. An east-west cold front moved south to Central Alberta giving a thunderstorm at the base station at Aug 11, 06 GMT. A new wave formed in southeastern B.C. and moved to Jasper-Edson by Aug 12, 00 GMT. Rain showers were visible from Edmonton by this time and thunderstorms arrived in the area between 00 GMT and 06 GMT. Showers and virga were observed through 12 GMT at Edmonton.

The greatest rainfall amounts were recorded at the base station and at those stations west and southwest of it, C-6 and T-7. Amounts reported from these 3 stations were 1.45 in., 1.57 in. and 1.44 in. respectively. The least amount of rainfall was recorded from M-7 at the northern extremity of the basin (.57 in.).

May 19 to 24, 1972: $\frac{.506}{.386}$ X 100 = 131%

A cold front passed Edmonton on the morning of May 22 just prior to 12 GMT. Showers and thunderstorms accompanied this front. A second cold front at 18 GMT does not seem to have given any rain.

At 06 GMT of the 24th a cold front from Fort McMurray to Edmonton and Red Deer gave a shower to the last mentioned station. A wave formed on this front near Edmonton by 12 GMT and was producing showers in the area. Thunder was reported at the base station at 18 GMT and rain showers to the northwest and southwest.

Precipitation was greatest at the southern tip of the basin at T-2(.78 in.) and in the central portion where a number of stations, including the base station, reported from .5 to .6 in. of rain.

July 23 to 27, 1972: $\frac{1.496}{1.015}$ X 100 = 147%

During this 5-day period, rain was reported every day. Showers and thundershowers formed along the eastern slopes of the Rocky Mountains during the evening of the 23rd and moved through Edmonton between 11 GMT and 12 GMT of the 24. A weak low formed near Jasper about midnight GMT. Thunderstorms and lightning were reported over much of central Alberta. Edmonton reported a thundershower at 12 GMT the following morning. A wave formed in southern Alberta about this time and spread rain northward to Rocky Mountain House, Red Deer and Vermilion. Thunderstorms were reported west of Edmonton during that evening but did not reach the study area or Red Deer. On the following evening however, heavy cumulus did build to thunderstorm size and both the above observing stations were reporting thunderstorms at 06 GMT of the 27th. A cold front moved eastward from the mountains bringing more showers and thundershowers to Edmonton between July 28, 00 GMT and 06 GMT. Hail was reported at Red Deer from these storms.

Within the basin, rainfall varied from .47 in. at the northern end of the basin to 2.02 in. at the airport. The precipitation amounts show a west-east swath of amounts from 1.38 to 2.02 in. with very strong gradients to north and south.

Circumstances which resulted in the 6 cases where $\frac{T_2}{T_1}$ X 100 = <100% and total rainfall exceeded 0.5 in., were as follows:

<u>May 17 to 18, 1972: $\frac{.601}{.670}$ = 90%</u>

On May 17 at 18 GMT a cold front lay from Wagner to Banff. Rain developed ahead of the cold front from Red Deer southwestward merging with precipitation associated with a low pressure centre near Havre, Montana. This low split into a series of small lows in an inverted [illegible] the Alberta-Saskatchewan border by midnight GMT. Showers were occurring at this time in an east-west band across central Alberta. By May 18, at 06 GMT the cold front had moved to a Fort McMurray-Rocky Mountain House line and rain was falling west of it. The front passed Edmonton about 12 GMT and a narrow band of rain moved through the study area.

This is a good example of the uniform distribution of rainfall normally associated with this synoptic situation.

<u>Sept 19 to 23, 1972: $\frac{1.066}{1.134}$ X 100 = 90%</u>

Precipitation early in the period was the result of upslope conditions. This was followed by over-running from a low which moved through southern Alberta. Upslope again prevailed to the rear of the low. Much of the precipitation was snow. Again, the result was a very uniform distribution of precipitation such as is generally considered typical of the situation.

June 10 to 11, 1972: $\frac{.649}{.917}$ x 100 = 69%

A complex low between Lethbridge and Prince George moved eastward. Precipitation began as drizzle because of upslope conditions. With the passage of the low, thunderstorms moved through the study area about June 10, 12 GMT. This produced very heavy rainfall in some areas with 12 stations of the dense network recording over 1 in. The greatest amount fell at C-4 which received 1.64 in. compared to .75 at the airport. Of the climatological stations, only Ellerslie recorded more than 1 in. for this event.

June 14 to 16, 1972: $\frac{.414}{.612}$ X 100 = 68%

A low in northeastern B.C. at the start of the period moved eastward. A cold front associated with this low passed Edmonton June 15, 00 GMT. Scattered showers and thundershowers occurred along and near the front and persisted till 12 GMT. Again the area of maximum rainfall occurred south and slightly east of the airport. This time it was C-3 which recorded the maximum, 1.19 in. This was sufficient to flood the ditches in the immediate vicinity. Few other gauges in the area recorded more than .60 in. Ellerslie measured .45 in. and Brightview recorded .55 in. Calmar did not measure any on the 16 but Calmar West recorded .65 in. It would seem impossible for Calmar to have been missed by these showers. This is just one of the problems which face the research student when using such data, however. If, for instance, the .65 in. reported at Calmar West, had also been reported at Calmar, total precipitation for the established network would have been .577 in. and the percentage of the "dense" network rainfall would have been near 94%.

Another problem encountered with this calculation arose because it rained heavily between the time the airport reported its 24 hr amount and the time at which the climatological stations and dense network gauges were read. It was necessary to apportion the total rainfall of the 16 and 17 at the airport between the two days. This was done on the basis of the amounts recorded from the gauges nearest to the base station.

Aug 1 to 4, 1972: $\frac{.759}{1.150}$ X 100 = 66%

Precipitation occurred on the 3 and 4 only. A cold front oriented east-west moved southward to reach Edmonton at Aug 3, 18 GMT. Cumulonimbus was reported in the vicinity during the evening but thunderstorms were not reported until Aug 4, 12 GMT. As the cold front continued to move south to Red Deer, a high pressure area built southeastward to central Saskatchewan. An upper cold front moved eastwards bringing thunderstorms during the night. The base station reported a thunderstorm on Aug 5 at 06 GMT. At the same time, Rocky Mountain House reported a heavy thunderstorm with hail. Precipitation ended by 12 GMT.

Again precipitation was heaviest in the area represented by C-3 and C-4. C-4 received 1.94 in. while 1.73 in. was recorded from C-3. The northern portion of basin, from the airport north, received less than 1 in.

June 23 to 24: $\frac{1.046}{1.404}$ X 100 = 75%

At the beginning of this time period, an extensive low pressure area lay over the northwestern United States and southeastern B.C. It moved eastward to southwestern Saskatchewan by June 24, 12 GMT. Showers occurred throughout the first 24 hrs. Continuous rain was reported at Red Deer and Rocky Mountain House by June 24, 06 GMT. A few scattered cumulonimbus were reported on the northern fringe of the rain area but none from the base station.

According to the weather maps reviewed, a small low moved northwest from Kindersley, Saskatchewan, and became stationary in the vicinity of Edmonton during the second 24 hrs. Rain was continuous but there was no evidence of thundershowers.

With few exceptions, rainfall amounts were in excess of 1 in. The only area which received less than 1 in. was from the airport north and west for a short distance. Though these stations received from .89 in. to .97 in. of rain, the amounts south of the airport ranged from 1.34 in. to 1.97 in.

Division into Quartiles

Division into quartiles also reveals that of the cases showing more than 0.2 in. of rainfall, the bulk came from the 2nd, 3rd and 4th quartiles in almost equal numbers. The only contributions from the 1st quartile were 2 cases where one network only received more than 0.2 in. The total range in percentages of cases where one of the network received over 0.2 in. was from 45% to 614%. All but two of these (those in the 1st quartile) were clustered between 45% and 164%). This may illustrate a decrease in variability with increase in total areal precipitation. It might also indicate a decrease in variability with increasing size of precipitation producing occurrence (i.e. low or frontal system vs airmass thunderstorm).

Analysis of the magnitude of difference was performed for those measured events which produced more than 0.2 in. of precipitation on at least one of the rain gauge networks. This value was arbitrarily chosen so that only the more important amounts and differences might be analysed. An attempt was made to classify the above cases according to synoptic situation. Weather maps were reviewed for each event which met the stated criterion. These maps revealed two major causes of rainfall in Central Alberta during the period studied. Showers and thundershowers accompanying and following cold-frontal or trowal passage accounted for 12 occurrences while 11 other cases resulted from some form of cyclonic circulation or convergence such as low-pressure centre, wave, trough, or upslope with cyclonic curvature of the isobars. Only one occurrence was accepted as airmass thundershower activity, the phenomenon which was to have been the original focus of this study. It may be emphasized that this represents the author's judgement and that a different analyst might attribute the precipitation to somewhat different causes for many of the situations reviewed.

Table VIII is a summary of the results of this analysis. One of the surprising results is that the differences resulting from precipitation associated with the two major synoptic types are similar in magnitude. Precipitation associated with low-pressure areas is generally considered to be much more uniform than the showery precipitation associated with cold-fronts and trowals.

For each synoptic type, positive and negative differences were calculated. This was done in an effort to discover whether, for storms

Differences in Short-term Rainfall Measurement
Associated With Synoptic Pattern Types as Calculated for the Whitemud
Creek Basin for the Period May to September, 1972
(Rainfall 0.2 in. in at Least One of the Networks)

Synoptic Type	Total No. Cases	Average Percentage Dense Network Rainfall	Average Difference (Per cent)	Average Positive Difference No. Cases	Average Positive Difference Inches	Average Positive Difference Per Cent	Average Negative Difference No. Cases	Average Negative Difference Inches	Average Negative Difference Per Cent
Cold-front or Trowal	12	101*	28	7	.10	26*	5	.18	30
Low (including troughs and two cases with warm-fronts in Southern Alberta	11	107	25	5	.10	35	6	.15	17
Airmass Thunderstorms	1	147	47	1	.48	47			
All Cases Analysed	24	101*	27*	13	.10	31*	11	.16	22

*One case with 614% not included in the calculation of the percentage difference.

producing 0.2 in. of precipitation in the basin, the climatological network would more often record more or less precipitation than the "dense" network. It also shows the frequency of each type of difference and its magnitude. It does not show how to predict the direction or magnitude of the difference.

These differences were expressed both as average amounts in inches, and as average percentage departures. In the case of both cold fronts and lows, the value in inches was lower for positive than for negative differences. In percentage terms, the difference is much larger when the sign is positive than when it is negative. Table XIII shows that the differences were quite evenly divided between positive and negative occurrences. It would seem that the chance that difference may be positive or negative is about 50%. This is compatible with the precipitation totals for the summer of 1972 but must be viewed with caution. The occurrence may be coincidental and not a regularly recurring feature of the error determination based on annual summer rainfall.

Size of Storms

Seventy-two radar photographs covering 15 different rain days were analyzed to gain some insight into the size of precipitating cloud elements and to contribute to a further understanding of the differences in precipitation calculations shown earlier in this chapter. Discrete precipitation echo diameters were measured and grouped as follows: less than 5 mi, 5 to 10 mi, 10 to 20 mi, 20 to 30 mi, 30 to 50 mi, 50 to 70 mi, and over 70 mi. Most echoes were of circular or globular form (merging circular echoes) but occasionally lines were encountered. Because these lines sweep an area, the precipitation effect is the same as if the echo were circular. The long axis of the line was therefore taken as the diameter. Table IX is a summary of the analysis.

This analysis can not be treated as more than a preliminary approach to this problem because the size of the sample is quite small. Further, the analysis was not exact in detail because the precipitation elements were often grouped where it seemed that precipitation variability would not be unduly affected by the presence of peripheral cells. These were cases where echo intensity was weak and location was on the upwind or downwind side of the main precipitation element being measured. Where echoes appeared to the right or left of the main element with reference to the direction of movement, these were not included in the size of the main element but were measured independently. This was done because any precipitation measured at the ground from these elements would be independent of the main element. A sufficiently dense rain-gauge network would detect an area of no precipitation between the location of the detached echo and the main body of precipitation. A precipitation echo is a visual display on a Plan Position Indicator scope. It results from energy reflected from water droplets of precipitation size and returned to the antenna of the radar set. Precipitation echoes are equated with storm size or precipitation element size for purposes of this analysis.

The number of elements of different size were counted on each photograph, recorded and summarized for each rain day for which photographs were obtained. The numbers vary greatly not only because some

TABLE IX

Number of Precipitating Cloud Elements Classified by Diameter (mi) as Measured From Radar Photographs

Date 1971	No. of obs	5 Tot/Avg	5-10 Tot/Avg	10-20 Tot/Avg	20-30 Tot/Avg	30-50 Tot/Avg	50-70 Tot/Avg	70 Tot/Avg
June 29	5	25/5	26/5	12/2.5	3/0.6	3/0.6		
July 1	9	33/3.8	25/2.8	6/0.8	6/0.8	44/0.5		
5	3	20/7	2/0.7		3.1	1/0.3		
16	5	35/7	12/2.5	7/1.5				
Aug 7	5		5/1	13/2	4/0.8	1/0.8	1/0.2	1/0.2
1972								
May 3	4	55/14	22/5.5	3/1				
16	2	2/1	3/1.5	3/1.5				
June 11	3	18/6	1/0.3					
27	8	41/5	54/7	30/4	4/0.5			
29	5	24/5	20/4	21/4	4/1			
July 7	1		1/1					
27	5	7/1	11/2	7/1	5/1	6/1	4/0.8	
Aug 9	1		1/1	1/1		1/1		
11	6	16/2.8	22/3.8	13/2	1/0.2	1/0.2		
Sept 17	6	39/6.5	14/2.5	8/1.5		1/0.2		
Tot. Tot Count/Avgs	[illegible]	315/64	219/38.5	124/22.8	30/5.8	18/3.9	5/0.9	1/0.2
Avg of Avgs		4.2	2.6	1.5	0.4	0.3		

rain events produced many more cells than others but also because in some cases many more photographs were taken than in others. This necessitated an averaging of the numbers of cells in each size category for each rain event. It must be kept in mind, however, that at this stage, only relative frequency of occurrence of storms or rain cells of different size was being attempted.

Table IX indicates that the most frequently occurring cells are those of small diameter such as occur during the formative stage of thundershower activity. The average number of precipitation elements per photograph decreased from 4.2 for elements under 5 mi in diameter to .3 for elements between 30 and 50 mi in diameter. The relationship is shown more clearly in Fig. 14. This figure implies that there are a very large number of very small cells or precipitation echoes recorded while discrete precipitation elements over 70 mi in diameter are rare.

It was more difficult to obtain the average size of precipitation elements from the maps of weekly total precipitation and total precipitation for individual rain days. This was so because the progress of a number of cells through the study basin produced rain at all measuring points for almost all cases analysed. Two analyses were performed, one for precipitation totals by week for the summer of 1972, the second for 21 individual rain events selected from the list of those events which produced greater than 0.2 in. of precipitation on at least one of the rain-gauge networks.

In most cases the isohyets enclose elongated precipitation areas, the results of time integration of rainfall amounts. Thus they

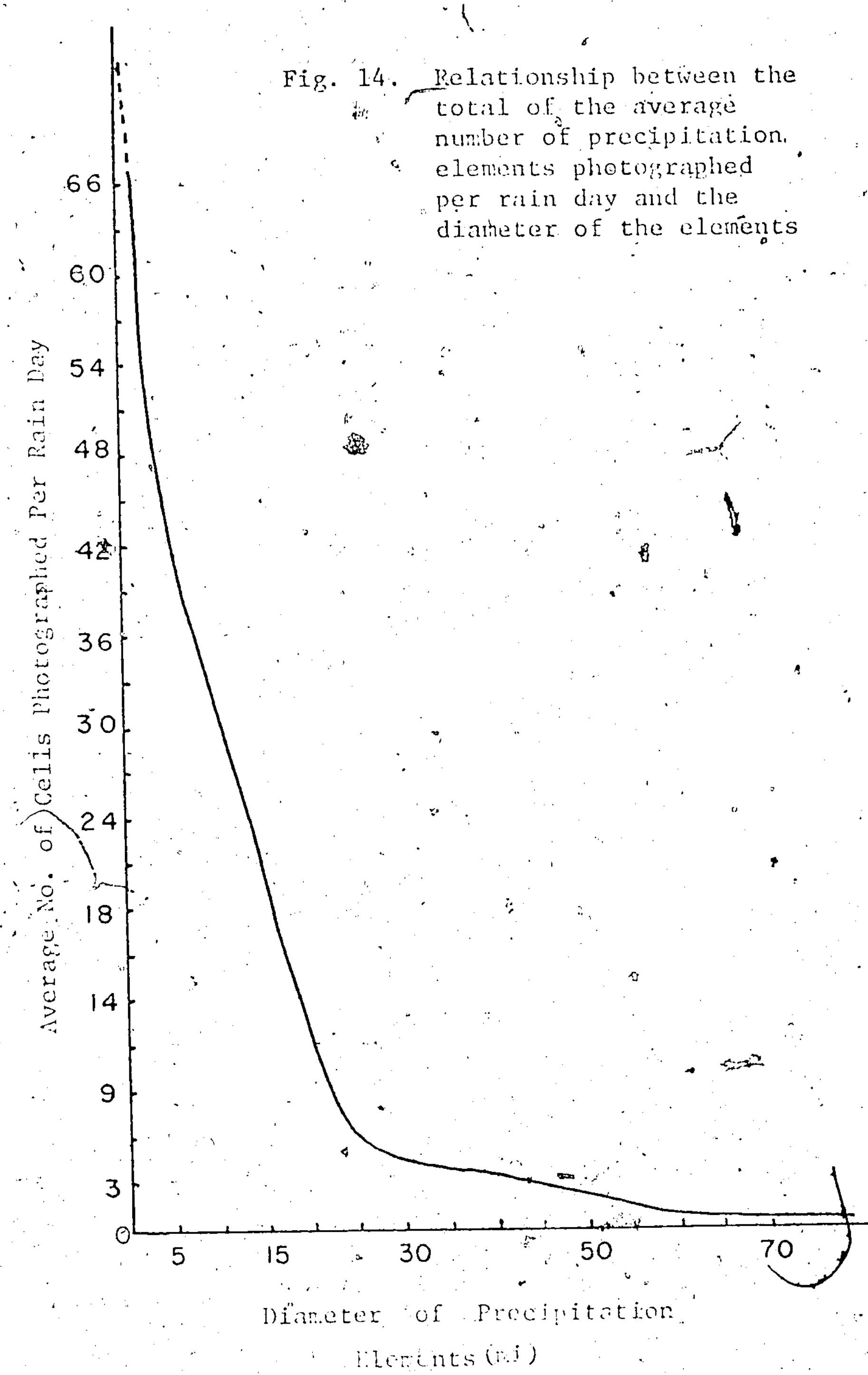


Fig. 14. Relationship between the total of the average number of precipitation elements photographed per rain day and the diameter of the elements

indicate the direction of motion of precipitation elements. If we assume that the cells are mainly circular, it follows that the length of a line normal to the direction of motion may be taken to represent the diameter. Because most of the maps of total rainfall for single events or longer periods lack the "rain-no-rain" patterns of the radar photographs, the length of this line, hence the diameter of the cells, is very uncertain. Arbitrary selection of boundaries based on gradient or isohyet value was therefore used to obtain some approximation of the size of cell contributing to the highest precipitation amounts.

The greatest weaknesses of the method are in the gaps between stations outside the basin and in the subjective interpretation resulting from the use of isohyets. To answer the first weakness, only areas of maximum precipitation within or overlapping the study basin were utilized. The second weakness remains unanswered.

A third weakness in the method was revealed in the analysis of single events in which only cases of greater than 0.2 in. of precipitation on at least one of the gauge networks were analysed. This produced a uniformity in precipitation which tended to mask cell size in many instances and introduced a bias towards larger element size as measured on these maps. Thus Table 11 seems to indicate a majority of cases in which precipitation element diameter is over 30 mi while weekly total maps showed nothing over 20 mi in diameter.

TABLE X

Precipitation Element Size (diameter in mi)
Measured From Maps of Total Precipitation

Period	No of Maps	Diameter				
		5	5-10	10-20	20-30	30
Weekly	17	32	20	4		
Single event	21	4	4	2	1	13

Because of the bias mentioned above the author feels that the results of the single event measurements must be ignored. The agreement between the values taken from the weekly total maps and those from the radar photographs is of a high order. It could be profitable to assume that a reasonable answer has been given to the question "how large is the average storm?" in this part of Alberta.

V

Summary and Conclusions

> Life is the art of drawing sufficient conclusions from insufficient premises.
>
> Samuel Butler
> *Notebooks*, 1912
> "Lord, What Is Man?"

SUMMARY

This study was an attempt to gain as much knowledge as possible in a very limited time, about the spatial distribution of precipitation in the Whitemud Creek Basin, south of Edmonton, Alberta. It gradually evolved into a comparison of rainfall measurement by two raingauge networks of quite different densities. The established network in the area encompassed by Fig 2 has approximately 1 gauge per 240 sq. mi with a wide range in the areas represented by individual gauges.

For this study, a "dense" raingauge network was operated in the Whitemud Creek basin. It consisted of 29 supplementary gauges, 1 climatological station (Ellerslie) and 1 "First order" station, Edmonton International Airport. The last station was used as the base station and all measurements were compared to it when calculating variability. The gauge density in this network was about 1 gauge per 5 sq mi.

The supplementary stations comprising the "dense" network were equipped with 48 oz juice cans as rain gauges. The accuracy and comparability of these units was evaluated and found to be satisfactory.

Differences in rainfall measurement between the two gauge networks was evaluated through the use of the Thiessen polygon method. This involved the calculation of the representative area of each gauge in each network. Two stations (Ellerslie and the base station) were common to both networks. These stations have two different representative areas each, therefore, based on the different spacings within the networks.

CONCLUSIONS

Differences in Rainfall Measurement Between Two Gauge Networks

The Thiessen polygon method was used to measure the difference in rainfall catch by two rain gauge networks of different densities operating in the same river basin. Two stations were common to both networks. The average rain gauge density in the dense network was approximately 1 gauge per 5 sq mi. In the established network, 4 gauges represented the nearly 150 sq mi of the basin. Two of these were located outside the basin. One gauge, that at the base station, represented 59% of the total area under study.

For the summer of 1972, the established network measured 104% of the total precipitation received by the dense network. This result seems to have been caused by the high values reported at the base station. The percentage of the "dense" network precipitation amounts varied from 819% to 6% for measured rainfall events. It may be considered coincidental that the results for the summer total were in such good agreement.

The ranked percentages were divided into quartiles. This revealed that of those events which produced more than 0.2 in. of rainfall, the bulk came from the 2nd, 3rd and 4th quartiles. Of the cases contained within the 1st quartile, one produced 614% of the "dense" network rainfall and one was calculated to be 190%. Both had just sufficient rainfall to be included. The remainder of the cases analysed, those from the other quartiles, were quite tightly clustered between 45% and 164%. This would seem to indicate that as precipitation increases, variability decreases to some extent.

There were 10 events which produced more than 0.5 in. of rain in the study basin. Four of these 10 resulted in more than 100% of the "dense" network rainfall being calculated for the established network.

Twelve of the measured rain events of 1972 were attributed to cold front or trowal passages. Eleven others were considered to be primarily of cyclonic origin and one was attributed solely to surface heating. Precipitation of cyclonic origin and that resulting from warm-frontal lift are considered to be quite uniform. That is, variability is considered to be low. This study has produced differences between the networks that are remarkably similar for both the cold frontal and cyclonic situations.

<u>Total Summer Precipitation</u>

The "dense" network revealed a more complicated pattern of wet and dry centres over the study basin than over the surrounding area. This is in keeping with earlier studies which show that observed variability increases as gauge density increases (Huff and Schickedanz, 1972, and others). Precipitation maxima were observed at M-2, 4.5 mi north of the base station, and over a wider area which included the base station and those stations nearest it on the south and west. Within the basin only these two stations (M-6 and C-6) received more rain than did the base station. Brightview and Winfield, outside the basin, but within the base map area, reported as much as, and more than the base station.

Within the basin, the driest conditions were recorded over the southern third of the basin where totals were less than 13 in. Just west of the western boundary of the study basin, another area of less than 13 in. rainfall has been shown. This is based on the record at Calmar which the author feels contains errors in the daily record of precipitation during the summer of 1972. Specifically, on the following dates, Calmar reported no precipitation, although other stations nearby, including Calmar West, reported more than .10 in.: May 3; May 21; June 8; June 16; June 23; July 24; July 26; Aug 8; Aug 29; Sept 4.

Just north of the study basin, an east-west dry area with less than 12 in. rainfall, is based on readings at the Lynnwood climatological station and at the author's home in Parkallen. These dry areas are also the areas of greatest difference in total seasonal precipitation.

At a distance of 3 mi the average difference in total precipitation was 8%. At about 12 mi this increased to 17% and extreme values of 22% and 26% were calculated at 14 and 13 mi respectively. The first value is quite close to the 6% value at 3 mi calculated by Huff from a longer term record in Illinois.

These differences may be expressed as extreme precipitation gradients. Between the base station and Lynnwood, the gradient is .24 in. per mi. Between the same point and Parkallen, a gradient of .30 in. per mi was calculated. Between M-2 and M-8, just north of the base station, the gradient was calculated to be greater than 1 in. per mi.

A curvilinear regression line was fitted by eye to data relating percentage of base station rainfall to distance from that point. It revealed an oscillation with wave length of about 11.5 mi. This may reflect the average spacing between preferred storm tracks during this summer. This may provide an avenue of further research using data such as the Alberta Hail Studies volunteer network. It may have implications for agriculture, hail insurance, and forest fire forecasting.

Weekly Patterns

Short-term, short-distance variability is highlighted. Despite the fact that total summer precipitation was higher in the central and northern portions of the basin, the greatest number of wet centres on the weekly maps occurred in the southern portion. This oddity is accounted for by the number of occurrences with small total precipitation amounts. The central and northern portions received more high-value wet centres.

Two stations at the north end of the Whitemud Creek basin were located at about 75 ft (T-9) and 125 ft (M-7) below the level of the surrounding plain. These stations frequently recorded greater total weekly precipitation than adjacent stations at higher elevations. This was the case for 6 of the 17 such maps and also for total seasonal amounts. In 2 other weeks T-9 received more rain than the adjacent higher stations but M-7 did not.

This feature should receive more intensive investigation by means of a more dense gauge network in that area. Factor analysis might be employed to discover the influencing variables.

Size of Storms

Radar photographs, and maps of single event and weekly total precipitation were analysed to obtain some idea of average storm size in the study area. The radar photographs reveal a strong tendency for precipitating cloud elements to be less than 5 mi in diameter. The same tendency is obvious in the maps of weekly total precipitation. In both cases, the 5 to 10 mi category contains 66% of the number reported in the first category. In the 10 to 20 mi category, the radar photographs reveal about 58% of the previous group. In this same category, the maps of weekly total precipitation show 20% of the number recorded in the previous column.

Because of the method employed with the weekly maps and the obvious bias in selecting events to be photographed, the results can be accepted as valid only for situations involving thunderstorms.

General

The present rainfall measurement network in the vicinity of Edmonton gave quite an adequate estimate of the total summer season rainfall (May to September) during 1972. For individual rain events however quite large differences were noted. These differences were roughly in the range of ± 30%. This applied to rainfall associated with cold fronts and post cold frontal instability (and trowels), and that resulting from lows. Differences resulting from convective storms could not be assessed because of the lack of an adequate number of cases. Table VI reveals no obvious seasonal bias in the magnitude of the difference although there does seem to be a higher proportion of cases with positive difference during June and July of 1972, than at other times.

Implications of Findings

For storms producing more than 0.2 in. of rain on both networks, differences in calculated totals ranged from -34% to +64%. There is no way of predicting whether the difference will be positive or negative for any given rain event. Error in the precipitation total calculated from the established network for any one event may therefore be as much as 100%. How often this might happen cannot be predicted as yet. Additional data should be gathered to establish the validity of the size of error. With added data and further study, it may become possible to predict the sign and possibly the approximate magnitude of the error. The uniformity of error in measurement of precipitation from both lows and cold fronts (including trowals) should also be validated.

There appear to be significant implications in the above findings for calculation of s[illegible]-term water balance, for calculation of irrigation requirements, crop development, groundwater recharge, soil-moisture recharge, and runoff.

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