The Drought Severity Index and the recollection of drought by agriculturalists in the Palliser Triangle, southwestern Manitoba

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Abstract: Agricultural drought occurs when soil moisture levels fall below normal and crops experience moisture deficiency stress. This results in reduced crop yields for grain farmers and reduced hay production and poor pasture land conditions for cattle ranchers. Nine significant drought periods occurred within the Palliser Triangle area of south-western Manitoba between 1955 and 1988. These droughts were identified using the Palmer Drought Severity Index and characterised using Thornthwaite's Climatological Water Balance. The drought periods are ranked according to the lowest Palmer Drought Severity Index values and the total moisture deficit experienced during each drought. The particularly severe droughts in 1961, 1980 and 1984 had a considerable impact on rural household incomes within the study region. Generally the recollection of drought periods by the respondents to a questionnaire survey coincides with the drought ranking based on physical evidence. The well remembered severe droughts of 1961 and 1980 are ranked numbers three and one respectively. The low ranked 1988 drought however, was well remembered also, as it was the most recent drought event.

Introduction

Agricultural drought occurs when soil moisture levels fall below normal and crops experience moisture deficiency stress (Environment Canada 1989). This results in reduced crop yields for grain farmers and reduced hay production and poor pasture land conditions for cattle ranchers.

South-western Manitoba has experienced drought conditions on several occasions since 1950. The particularly severe droughts in 1961, 1980, and 1984 had a significant impact on the agriculture

and rural household incomes within the region. Consequently, agriculturalists in this region can be expected to have considerable experience and related knowledge of drought and drought conditions in south-western Manitoba.

Objectives

This study intends to identify the drought periods that have occurred in south-western Manitoba over the past 30 years and to rank these droughts with respect to a duration-severity index. The study also will attempt to determine the ability of agriculturalists within the region to recall significant drought periods.

Study Area

The study area for this research covers 2238 km^2 and consists of Edward, Arthur, and Brenda municipalities in the extreme southwest corner of Manitoba (Figure 1). All the municipalities border on the United States and the municipality of Edward borders on the province of Saskatchewan.

Within the study area, Pierson has an Atmospheric Environment Services (A.E.S.) climatological data station and relevant calculations used in this paper are based on data collected at this site.

The three municipalities were selected as the study area because they are located on the eastern edge of the Palliser Triangle. The Palliser Triangle has been set aside by the Geological Survey of Canada as one of three special research regions for the study of global climatic change. The climatic record at Pierson, Manitoba shows evidence of several severe drought periods and provides 47 years of continuous climatic data for analysis. The Palliser Triangle is also an area in south-western Manitoba of marginal agriculture, containing both farming and ranching, thus making it ideal for studying the perception and recollection of agricultural drought.

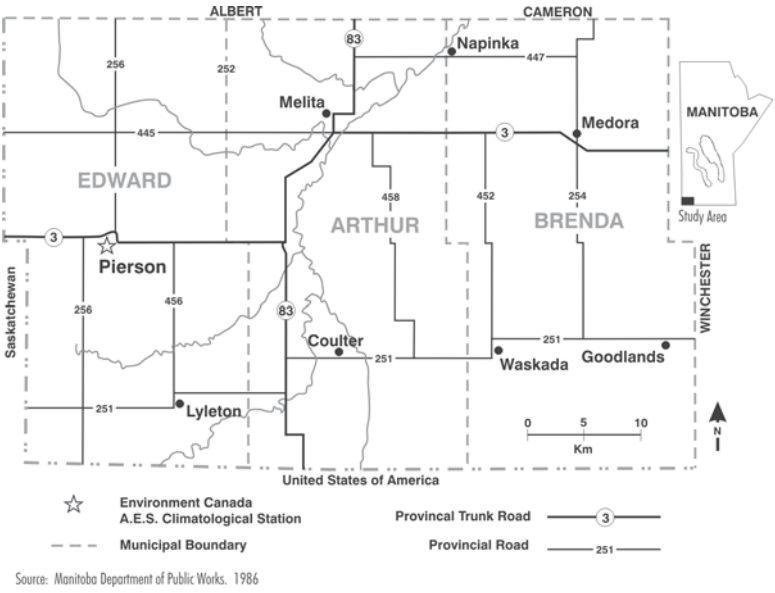

Figure 1: *Location of study area.*

Theoretical Considerations

The Palmer Drought Severity Index

W. Palmer (1965) based his study of drought on the relationships among actual water balance supply and demand parameters and their respective values that are 'climatically appropriate for existing conditions.' Precipitation (P) and plant available moisture held in the soil represent the supply variables, while evapotranspiration (ET) is considered to be the demand generated by the system. A hydrological accounting procedure, similar to Thornthwaite's Climatological Water Balance, was used to plot the distribution of water inputs, outputs, and soil storage amounts over time.

Palmer employs Thornthwaite's (1948) formula for calculating monthly potential evapotranspiration (PE):

$$Daily\ PE = ADJ*1.6\ (10\ T/I)^{A}$$

Unlike Thornthwaite's model however, Palmer's water balance parameters also include estimates of the potential for soil moisture loss (L), recharge (R), and runoff (RO).

Palmer's term "climatically appropriate for existing conditions (CAFEC)," is defined as the product of the ratio of the average of each water balance variable to the respective normal potential value, and the actual potential value. That is:

$$CAFEC\ ET = [Normal\ ET / Normal\ PE] \times Actual\ PE$$

Climatically appropriate for existing conditions precipitation (CAFEC P) represents "the amount of precipitation that would have maintained the water resources of the area at a level appropriate for the established economic activity of the area" (Palmer 1965) and is calculated as a residual in water balance equation:

$$CAFEC\ P = CAFEC\ ET + CAFEC\ R + CAFEC\ RO - CAFEC\ L$$

Palmer argues that the differences between actual precipitation values and the CAFEC precipitation estimates ($D = P_i$ - CAFEC P_i) for each month (i) provide meaningful measures of the moisture departures from normal. Palmer's monthly moisture anomaly index (Z) is the product of the monthly moisture departure from normal (D) and the climatic characteristic (K). The Palmer Drought Severity Index is based on this monthly moisture anomaly index. That is:

$$PDSI\ for\ the\ month\ (i)\ equals\ 0.897\ PDSI_{i} - 1.0 + K_i D_i/3$$

The climatic characteristic (K) is derived from the average moisture departures during the driest spell of the particular period of interest. Thus, the K value is a weighting factor, representing averages for some undefined characteristics of the climate during dry periods (Palmer 1965). The average K value for southern Manitoba is 2.05.

Palmer developed a five point ordinal/nominal scale for describing the various stages of drought severity (Table 1). These values define the lower limit of each class boundary (Palmer 1965).

Table 1: *Stages of Drought Severity*

-0.5 = incipient drought
-1.0 = mild drought
-2.0 = moderate drought
-3.0 = severe drought
-4.0 = extreme drought

Source: Palmer 1965

The Survey Instrument

The data required for studying farmers' recollection of drought were obtained through a questionnaire survey. The questionnaire addressed several aspects of farmers' perception and adjustment to the drought hazard and dealt with various dimensions of the rural inhabitants in south-western Manitoba. A specific section of the survey (four) focused on the recollection of drought periods and severity through 1955 - 1989.

Of the 485 rural inhabitants within the study area, 394 were farmers. A sample size of 164 potential respondents was determined using the Multi Stage Probability Sampling Procedure outlined by Dixon and Leach (1978). In total, 78 questionnaires were returned with four of them being returned incomplete. The final response rate was 45.1% (i.e. 74 out of a total of 164).

Results

The Droughts

Palmer Drought Severity Index (PDSI) values acquired from Environment Canada were used to determine the date and duration of the droughts, which occurred in the study area since 1955. Over the 33 year time frame, the monthly PDSI value indicates that the study area experienced nine significant droughts (Figure 2). PDSI

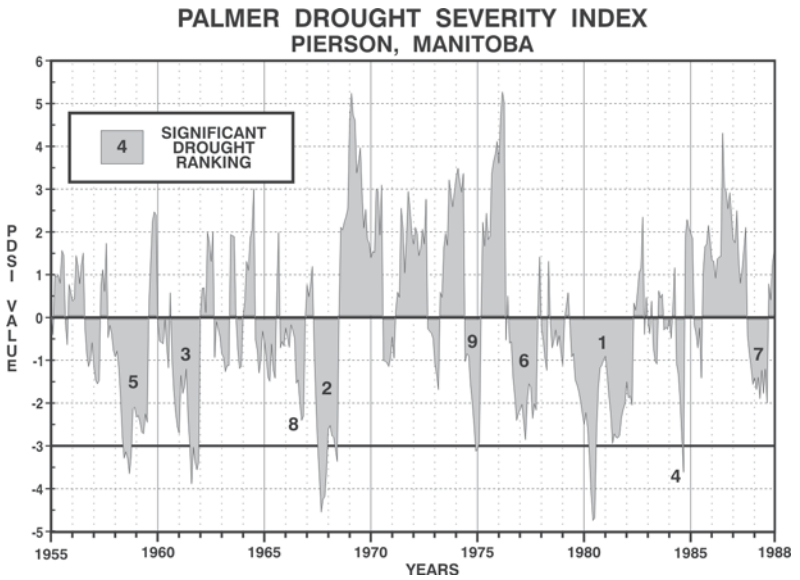

Figure 2: *Palmer drought severity index for Pierson, Manitoba.*

values of -2.0 (moderate drought) or less were considered significant in this study.

The first drought period began in September of 1957 and lasted until August 1959 for a duration of 23 months, and is here termed the 1958 Drought (Figure 2). There appears to have been sufficient moisture for crop growth during the four month antecedent period (May, June, July, and August of 1957) as PDSI values were greater than zero. Thus, the 1958 Drought began at the end of the 1957 growing season. During a period of one year, drought-like conditions continued to deteriorate to a minimum index value of -3.65 (Table 1), the most severe value recorded during the drought. This drought is classified as a "severe drought" on the Palmer scale (Palmer 1965). The summer of 1958 was especially dry with PDSI values of -2.77, -3.29, -3.14, and -3.29 being experienced during May, June, July, and August respectively. There was a four month period of moderate relief following September 1958 and by December of that year, the PDSI value had risen to -2.10. PDSI values began however, to decrease once again and by May 1959, had declined to -2.71, the recorded second minima in the 1958

Drought period (Table 1). By April 1959, drought conditions gradually ameliorated and the August PDSI achieved a positive value of 0.31, indicating the end to this 23 month drought period.

The 1961 Drought began in September 1960 and lasted until January 1962, for a duration of 16 months (Figure 2). PDSI values dropped sharply in the first few months of the drought to -2.71, which marked the first of three minima recorded during the drought duration (Table 1). The following five months recorded fluctuating PDSI values throughout a period of moderate drought relief. June 1961 marked the beginning of a second sharp decline in the PDSI to -3.88 by August 1961, a value that represented the most severe month during the 1961 Drought period (Table 1). Following this minimum there was a second very short (one month) period of drought relief, indicated by an increase in the PDSI value to -1.21. After this relief period, PDSI values declined to -3.56, the third minima of the drought (Table 1). Both periods of drought relief occurred during the non-growing seasons of 1960 and 1961. A PDSI value of -1.21 (May) was recorded at the beginning of the 1961 growing season and this PDSI value had decreased to -3.88 by August 1961. The 1961 Drought ended as suddenly as it started as evidenced by PDSI values of -3.38 in December 1961, followed by 0.14 in January 1962 (Figure 2).

There was a three year, ten month period between significant droughts during the early 1960s with the third drought beginning in October 1965. The conditions prior to the beginning of this drought are similar to those prior to the beginning of the 1961 Drought. There was a one year period were the PDSI values were less than 0 but greater than –2, signifying incipient and mild drought. This period was separated from the significant drought period by two months of relatively moist conditions (Figure 2).

Unlike the 1961 Drought, the 1966 Drought did not begin with a sudden decrease in PDSI values. The PDSI values fluctuated within the incipient drought stage for nine months before the conditions became moderate and only then did PDSI values slowly decrease from -0.31 to -1.46 over the growing season (Figure 2). It was not until September 1966 that the drought, having reached a PDSI value of -2.02 was recognised as a moderate drought. Four months later, the drought ended. October 1966 recorded the lowest PDSI value

of -2.40 (Table 1). The 1966 Drought ended suddenly in January 1967, two months after the most severe minima. The 1966 Drought lasted a total of 15 months with twelve of these months experiencing PDSI values above -2.0. In terms of PDSI values and duration, this drought, ranked eighth (Table 1), was the second least severe of the nine droughts experienced within the study area over the 33 year period (Table 1).

A four month period, in which PDSI values were greater than zero, marked the end of the 1966 Drought. This four month period of moist conditions represents the antecedent moisture conditions for the 1967 Drought.

The 1967 Drought began in May 1967 when PDSI values were -0.73. By the end of the growing season (September) values had dropped to -4.54 (Figure 2). PDSI values remained below -4.0 for three months before a period of moderate relief began. According to the Palmer classification, the 1967 Drought was considered "extreme". In fact, the -4.54 value was the third lowest monthly index value recorded in the study area over the 33 year period of record (Table 1).

There was some alleviation in February 1968 when PDSI values of -2.53 were recorded (moderate drought). Conditions experienced during this period of minor relief however, were more severe than the drought conditions experienced during the entire 1966 Drought. PDSI values began to decline again to a minimum of -3.36 in June 1968, the last month of the drought. The 1967 Drought ended when June PDSI values of -3.36 rose sharply to 0.02 by July 1967.

The 1974 Drought (Figure 2) did not begin until five years and eleven months after the 1967 Drought ended. Of these 71 months, only 14 had PDSI values less than zero indicating that the moisture conditions during this period were well above normal.

The 1974 drought began in June 1974 and lasted for only nine months until March 1975. June 1974 recorded a PDSI value of -1.03 and from this mark the index increased to -0.85 and -0.89 for July and August respectively (Figure 2). It was not until after the growing season that PDSI values began to fall reaching the minima during the drought of -3.12 in December 1974 and -3.09 in January 1975 (Table 1). These index values indicate that the drought was classified as "severe" according to Palmer (1965). This drought

however, generally began after the growing season of 1974 and ended before the growing season of 1975 thus, the 1974 Drought may also be classified as a winter drought. Since winter drought is considered to be less significant to the agriculturalists of the region, the 1974 Drought is ranked ninth in the Drought Severity Table (1). February 1975 was the final month of the drought recording PDSI values at -2.92, while the index value in March was a positive 0.06.

The sixth significant drought experienced in the study area over the 33 year period lasted for 16 months; from July 1976 to November 1977 (Table 1). The 1977 Drought (Figure 2) began after a period of moist conditions experienced in late 1975 and early 1976. May 1977 recorded a negative PDSI value but in June 1977 the PDSI value was again positive, delaying the start of the drought until July 1976.

PDSI values dropped over the first nine months of the drought and by April 1977 the drought severity index value was -2.86. There was a small period of relief during the winter of 1976-77 when index values rose up to -2.03 before decreasing to the lowest minima of -2.86 (Table 1). A second and larger period of relief occurred during the first half of the growing season when PDSI values of -1.55 were recorded in June 1977. The index values then began to decrease over the second half of the growing season to a minimum -2.36 in August 1977 (Table 1). The drought ended quite suddenly when the October PDSI value of -2.16 rose to 0.18 in November 1977.

The drought of 1980 (Figure 2) was the longest, and most severe drought experienced in the region over the 33 year period (Table 1). The drought began 18 months after the end of the 1977 Drought. During this 18 month duration, 13 months experienced PDSI values of less than zero. This indicates that the antecedent period for this drought was relatively dry with only short periods of precipitation.

Conditions slowly deteriorated over the first 13 months of the drought, achieving the lowest PDSI value of -4.74 in June 1980, which, according to Palmer, classifies the 1980 Drought as an "extreme" drought (Table 1). This value was also the lowest index value experienced over the study area during the 33 year record (Table 1). A six month period of moderate drought relief began

immediately following this low point. This relief period occurred over the winter months of 1980-81 and PDSI values of greater than -1.0 were experienced in December 1980 and January 1981.

The 1980 Drought continued into 1981 recording PDSI values of -2.94 in May with the index values remaining below -2.70 for the remainder of the growing season. Another four month period of relief began in September 1981 and lasted until January 1982 (PDSI value of -1.51). The 1980 Drought ended in May of 1982 after 36 consecutive months of PDSI values less than zero.

There was only a two year period following the drought of 1980 until the next drought occurred in 1984. The 1984 Drought (Figure 2) lasted for five months making it the shortest drought to occur within the study region over the 33 year period (Table 1).

After a period of fluctuating moisture conditions following the 1980 Drought, the 1984 Drought began in May when the PDSI value reached -1.07. The PDSI values continued to decline rather sharply over the next five months to a value of -3.61 in September (Table 1). This classifies the drought of 1984 as "severe" on the Palmer scale. The 1984 Drought was a serious drought to the local farmers in that it was a summer drought occurring over the length of the growing season. The 1984 Drought ended quickly, with the minimum PDSI value of -3.61 occurring in September and an index value of 1.90 occurring in October.

The period between the 1984 and 1988 drought was a time where sufficient moisture was available for plant use leading to adequate crop yields for the farmers. The drought of 1988 (Figure 2) began in September 1987 following this long period of moist ground conditions and adequate precipitation.

The 1988 Drought differs from that of the 1984 Drought in that the drought conditions fluctuated monthly over the duration of the drought progressing to the lowest value rather than the sharp drop from the beginning of the drought which occurred in 1984 (Figure 2). In fact, it was not until August 1988, the final month of the drought, that the PDSI values actually achieved -2.0, a "moderate" drought on the Palmer (1965) scale. September 1988 recorded a PDSI value of 0.78 indicating the end of this 12 month drought.

Table 2: *Recent droughts in the Palliser Triangle, south-western Manitoba.*

DROUGHT I.D. YEAR	DROUGHT BEGINS	DROUGHT ENDS	DURATION (Months)	NUMBER of MINIMA	MINIMA INDEX VALUES	SUBJECTIVE RANKING
1958	09/1957	08/1958	23	2	-3.29 -3.65	5
1961	09/1960	01/1962	16	3	-2.71 -3.88 -3.56	3
1966	10/1965	01/1967	15	1	-2.40	8
1967	05/1967	06/1968	13	2	-4.54 -3.36	2
1974	06/1974	03/1975	9	1	-3.12	9
1977	07/1976	11/1977	16	2	-2.86 -2.36	6
1980	05/1979	05/1982	36	2	-4.74 -2.94	1
1984	05/1984	10/1984	5	1	-3.61	4
1988	08/1987	08/1988	12	1	-2.00	7

Ranking The Droughts

Table 2 illustrates the ranking of the droughts based on the minimum PDSI value during the growing season and the duration of the drought. Two droughts are classified as extreme, four droughts are considered severe and the remaining three droughts fall into Palmer's (1965) 'moderate drought' classification.

The 1980 drought was the longest and most severe drought recorded during the 33 year time frame and is ranked number 1. The thirteen month 1967 drought receives the second ranking based on the second lowest PDSI minima of -4.54. The severe drought of 1961, although slightly longer in duration, received the third ranking based on the third lowest PDSI value of -3.88. The relatively short (5 month) and severe (minimum PDSI = -3.61) 1984 drought received a higher ranking (4) than the 23 month 1958 drought due to the fact that the 1984 drought persisted through the five month growing season from May until September. The fifth ranked 1958 drought recorded only a slightly lower monthly index value of -3.65. The 1974 drought occurred during the winter

"hibernal" season and although classified as "severe" received the ninth and lowest ranking.

The 1966, 1977, and 1988 droughts all registered minimum PDSI values less than -2.00 but greater than -3.00. The 1977 drought is ranked sixth based on a minimum monthly PDSI value of -2.86. The shorter (12 month) 1988 drought was ranked ahead of the 15 month duration 1966 drought on the basis that the 1966 minimum occurred during September and October, where as the 1988 drought achieved its minimum index value at the end of July.

Recollection of Droughts by Agriculturalists

The Palmer Drought Severity Index permits the drought researcher to precisely establish the beginning, duration and conclusion of a drought; farmers however, do not clearly delimit droughts (Taylor, Stewart and Downton 1988). For this reason the droughts identified in this study have been assigned the year designation associated with the lowest Palmer Drought Severity Index value.

Saarinen (1966) identified a characteristic pattern for drought recognition by the farmers on the Great Plains. Most farmers (more than 50 percent) remembered the most recent drought, regardless of severity, the most severe drought experienced, and the drought of primacy or first drought experienced. Taylor, Stewart and Downton (1988), substantiate Saarinen's 1966 postulate. Taylor *et al.* (1988) point out however, that while many farmers remembered the most recent drought, unlike in the Saarinen study, this number was less than 50 percent of the respondents.

In this study the average age of respondents to the survey questionnaire was 46.3 years with 97.2% of them living within the study area for more than 20 years. The ethnic make up of the respondents is as follows: 68.6% British, 22.5% Belgian, 5.8% Scandinavian, and 1.9% French. Among the respondents, 64.8% have attained a secondary education while 35.1% have a post-secondary education. The majority of the farmers (62.1%) run mixed farming operations, 31.0% operate grain farms, and only 6.7% are employed in a cattle operation. The average farm size is

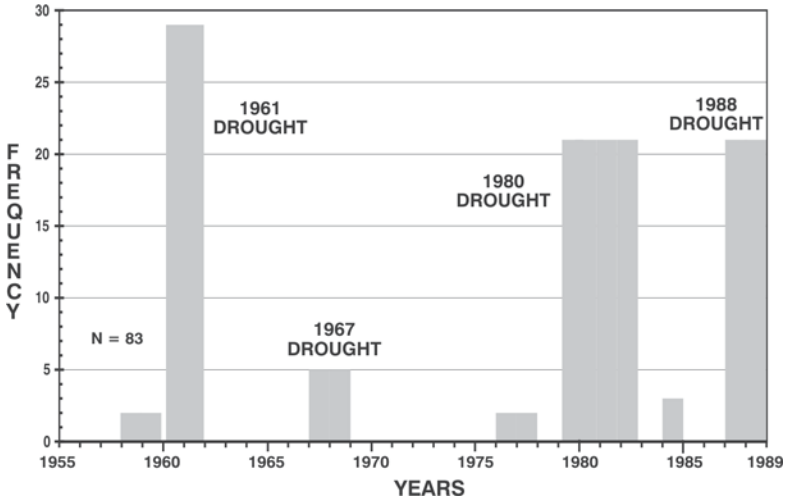

Figure 3: *Drought recollection by experienced agriculturalists.*

1402.5 acres with the majority of the respondents operating farms between 501 - 1500 acres.

The population of respondents to the questionnaire survey was divided into two groups. "Experienced" agriculturalists are operationally defined as farmers born or farming in the area before 1951. These farmers would be at least ten years old in 1961, would have experienced the severe drought of 1960 -1961 and could be expected to remember this severe drought. The "inexperienced" agriculturalists are operationally defined as farmers born or farming in the area after 1951 and are unlikely to remember the severe drought of 1960 - 1961.

The severe drought of 1960 -1961 was remembered by thirty respondents or 40.5 percent of the farmers responding to the questionnaire. Twenty-nine of these farmers are classified as "experienced" and only one farmer born after 1951 was able to recall this drought.

Figure 3 illustrates drought recollection by "experienced" farmers. Fifty-six percent (29 respondents) of the experienced farmers recalled the severe drought of 1961. For most of these older agriculturalists, the 1961 drought was the drought of primacy (Saarinen 1966). The 1980 Drought was well remembered by this

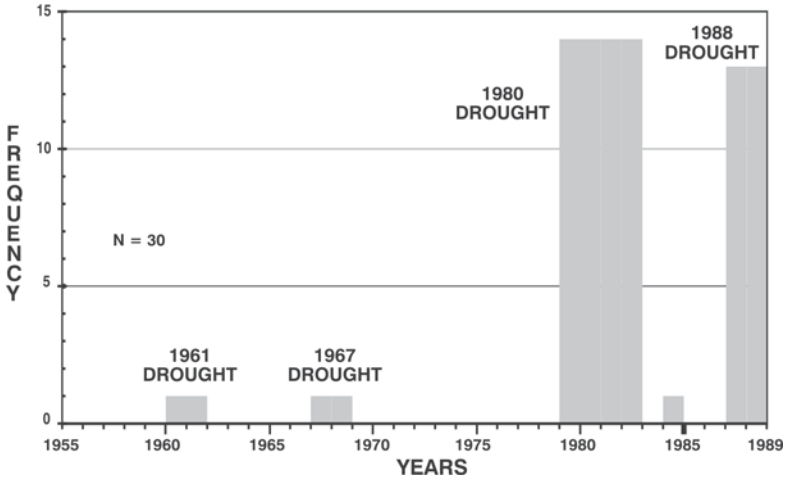

Figure 4: *Drought recollection agriculturalists born after 1951.*

group of agriculturalists because it was both the longest in duration and most extreme drought that occurred within the study area over the 33 year period (Figure 2, Table 1). Although the 1988 Drought was neither long, nor severe, the "experienced" farmers remembered this drought probably because it was the most recent drought event (Figure 2).

There are some anomalies present in the histogram (Figure 3). The 1967 Drought was more severe over the growing season than the 1961 Drought, yet only five respondents recognised this as being a drought year. Another example involves the short but very severe 1984 drought, which was recognised as a drought year by only three of the "experienced" agriculturalists.

Figure 4 illustrates drought recollection by the agriculturalists born after 1951. Clearly the 1980 drought is well remembered by the "inexperienced" farmers. Perhaps this was the drought of primacy, but this drought also was the drought of greatest duration and severity. The 1988 drought (most recent drought) was equally well remembered.

Figure 5 combines the two sub-populations of agriculturalists, farming or ranching, in the study area. Again, drought recollection in the Palliser Triangle region of south-western Manitoba may be

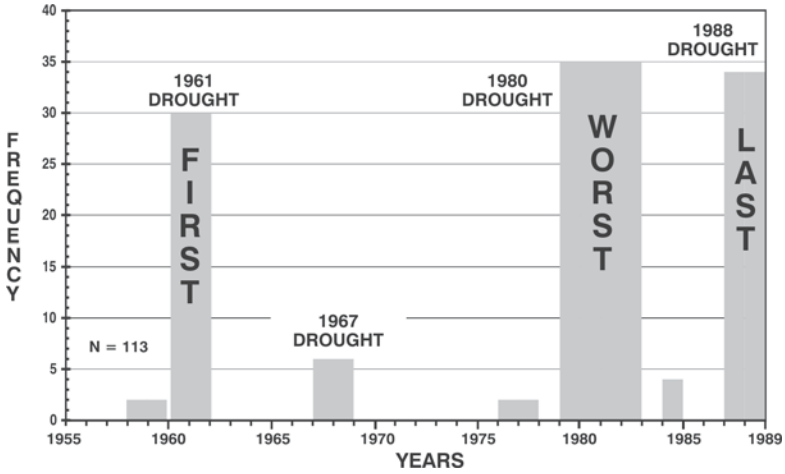

Figure 5: *Drought recollection by agriculturalists farming in southwestern Manitoba.*

patterned as a recollection of the first, worst and most recent droughts.

Conclusions

Nine significant drought periods occurred within the study area between 1955 and 1988 (Figure 2). These droughts where identified using the Drought Severity Index (Palmer, 1965) and ranked subjectively according to duration and the lowest monthly PDSI value experienced during each drought (Table 1).

Generally, the recollection of drought periods by the respondents to the questionnaire survey coincides with this ranking. For example, the well remembered droughts of 1961 and 1980 are ranked numbers three and one respectively.

Fifty-six percent of the older, more experienced, respondents remembered the 1961 drought probably because it was the first severe drought many of these farmers experienced. The 1980 drought was well remembered because it was both the longest and most extreme drought that occurred within the study area over the 33 year period. The 1980 drought was also the first severe drought experienced by 47 percent of the respondents farming after 1970.

The fifth and second ranked droughts (1958 and 1967 respectively) were probably less well remembered because they both occurred too long ago, and because neither was likely to be the first drought most respondents experienced while farming within the study area. Also, the severe 1984 drought was less well remembered because it was preceded by the extreme drought of 1980 and followed by a more recent drought in 1988. The low ranked 1988 Drought (number seven), although neither long, nor severe, is well remembered (46%) by the respondents because it was the most recent drought event. These results are similar to those of Taylor *et al*. (1988). The respondents to the questionnaire survey generally knew when the droughts occurred but had little understanding of the varying degrees of drought severity.

In conclusion, it is suggested that drought recollection, by experienced agriculturalists, is based on the principle of "First, Worst and Last" (Figure 5).

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