AN EXAMINATION OF WINTER SEVERITY IN NEW JERSEY

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ABSTRACT

This study develops a method of assessing winter severity in New Jersey through the use of an index integrating various factors of winter weather. This index is based on the summation of the effects of these factors relative to extreme values of each weighted subjectively according to their relative economic, physiological and psychological importance. Theoretical limits of index values are 0 and 100 with a standard deviation of 20. Applied to data values ranged from 98.907 to 7.289.

This index can be used throughout New Jersey and in areas with a similar wintertime climate. Relative winter severity between different areas can be explored. By applying this index to various locations, studies of the sociological effects caused by winter severity can be undertaken.

The methods of examining winter severity in this study could be extended to the development of winter severity indices for other areas and may find application in the examination of extreme weather in other seasons.

INTRODUCTION

Recent studies have examined trends and patterns of winter severity in New Jersey. Rubinfeld and Shulman (3) developed a Winter Severity Index for central New Jersey utilizing the meteorological records of New Brunswick. This index is based on several parameters of winter weather weighted subjectively according to their relative economic, physiological and psychological importance. A non-significant general negative trend in winter severity was noted by the authors in the period from the winter of 1897/1898 to the winter of 1974/1975.

This study was updated by Shulman (4) for the winters of 1975/1976 through 1979/1980, and revealed a progressive increase in winter severity through that period.

The present study expands the work done by Rubinfeld and Shulman (3) and Shulman (4) by developing a method by which the severity of winter throughout New Jersey can be examined through the use of a similar index. In this study, an index is developed which used the same parameters to describe the relative severity of a winter compared to a statistically "average" winter for the entire state using meteorological records from 1897/1898 to 1983/1984. This study also updates and corrects the data used in Rubinfeld and Shulman (3).

Previous studies have examined winter severity through the use of various aspects of winter weather. Conover (5) examined winter severity using a number of parameters. The index consisted of the sum of the number of days that Houghton's Pond, a lake in the Boston area, was completely frozen over, and the number of days six inches or more snow was on the ground at Blue Hill Observatory. The values for this index were not limited to a particular scale, and relative severity of winters was determined by comparing values to past winters.

Diaz (6) studied the contribution that each winter month, December-February, had on the total winter temperature anomaly for the period from the winter of 1975/1976 through 1981/1982. It was concluded that, by far, January made the greatest contribution toward the very low average winter temperature during this period for much of the United States. Temperature averages were used for each of the 48 contiguous states with departures calculated from the 1895/1981 long term averages.

PROCEDURE

Data Collection

Stations for this study were selected from those currently published in New Jersey Climatological Data (NOAA, 1984). The stations were required to have continuous data including average monthly temperatures for December, January and February, monthly snowfall totals and daily temperature extremes for the October to May period of each winter. All stations used have these data for at least 30 years. The stations fitting this criteria are listed in Table 1, and the distribution of these stations across New Jersey is depicted in Figure 1.

Occasionally, a station's record was incomplete for a particular month. The frequency of missing data ranged from 17.2% for Belleplain in the period from 1922/1923 to the present to no missing data at the Atlantic City Weather Service Office station from 1906/1907 to the present. To compensate for this, data was substituted from stations that were climatologically similar to the station with the missing data. Substitute stations were based on proximity and similarity in climate between the stations.

A homogeneity test, discussed in Brooks (7), was conducted for several stations and their primary substitutes. The test involves taking a period of ten years where both stations have average monthly temperature data determining the average temperatures. Differences between the station's and the substitute's deviations from this mean was found. The fraction of the sum of the squared differences to the sum of the original station's deviations yields a value which determines the homogeneity between the stations. If this value exceeds 0.64, these stations are not homogeneous and this substitute improper (7). All station pairs tested yielded values below 0.27, far below the critical value.

For each station with some missing data, a primary substitute was determined. If this station was also missing that data, it was substituted from a secondary station determined in the same way, and so on until all data for the original station was replaced. The stations and their substitutes appear in Table 1.

Theoretical Development

The index parameters were subjectively based on an economic standpoint and had to be directly derivable from data readily available. The parameters used were the same and were given the same weights as those used in Rubinfeld and Shulman (3) and Shulman (4).

Snowfall and average winter temperature were deemed the most important parameters. Business losses, such as closings or delays in services can be fairly large during heavy snowfall. Each year, numerous deaths are attributed to icy and snow-covered roads in New Jersey, underscoring the importance of snowfall in winter severity. The persistence of snow on the ground is similarly important and may be estimated by the number of days during the winter season in which the maximum temperature remains below freezing and was also selected as a parameter for winter severity.

The average temperature for December through February is another important feature of winter severity and, in part, determines seasonal fuel use. The number of days of extremely cold temperatures, defined as the number of days with minimum temperatures below $0^{\circ}F$, is also included as a parameter in the winter severity index since it too relates to fuel consumption.

The relative weighting of each of these indicators of winter severity is the same as that used in Rubinfeld and Shulman (3). Since total snowfall was taken as a major indicator and snow persistence a minor qualifier, total snowfall accounts for 40% of the index while peristence accounts for 10%. Similarly, winter average temperature accounts for 40% and number of days of extreme cold account for 10% of the total index. Thus, in theory, the final index value can range between 0 and 100.

This index is designed such that the extreme value of each parameter observed over the period of record would maximize or minimize the value of the index. For example, the most snowfall for any year at the 25 stations was 95.0" at Charlottesburg in 1961. Therefore, the snowfall parameter is given a value of 40 for Charlottesburg in that winter season. This will then be added to the values of the other parameters. Similarly, if a station had no snow for a given year, the snowfall component of the index will contribute 0 to the total index value. Table 2 shows the extreme values of each index parameter for the 25 stations used. Since the extreme values for each parameter do not occur at any one particular station, no station can actually have a total index of 0 or 100.

Each parameter was derived separately and their sum is the final index value. The snowfall parameter was designed to give a value of 40 for a seasonal snowfall of 95.0". A value of 0 would be assigned if no snowfall occurred. Therefore, the formula for this parameter is

$$S_i = \frac{40}{95.0} = 0.4211\, S_o \qquad (1)$$

where S_i is the index contribution for the snowfall parameter and S_o is the snowfall reported for that season.

Similarly, for the extreme temperature parameter, a year with 24 days with minimum temperatures below zero gave a parameter value of 10, while no days below zero contributed zero to the final index. The extreme temperature parameter, therefore, is

$$Z_i = \frac{10}{24} = 0.4167 Z_o \qquad (2)$$

where Z_i is the index contribution for the extreme temperature parameter and Z_o is the number of days with minimum temperatures below zero.

The snowfall persistence parameter was designed to give values between 0 and 10 for days with maximum temperatures below $32^{\circ}F$ ranging from 63 days to zero days for the entire winter. This factor is

$$F_i = \frac{10}{63} = 0.1587\ F \qquad (3)$$

where F_i is the index contribution for the average temperature parameter and F_o is the number of days with maximum temperatures below 32.

As noted in Table 2, the mean winter temperature extremes ranged from $19.13^{\circ}F$ to $42.70^{\circ}F$, and contributes 40 and 0 to the final index, respectively. This parameter is

$$T_i = -1.6971 T_o + 72.465 \qquad (4)$$

where T_i and T_o are the same as defined above.

The total initial index is the sum of each of the parameter index values. The final index formula is

$$I = 0.4167\ Z_o + 0.1587\ F_o + 0.4211\ S_o - 1.6971\ T_o + 72.465 \qquad (5)$$

where I is the total index value and all other variables are the same as previously defined.

This index was calculated for all stations for each year of available data. The frequency distribution of index values is shown in Figure 2.

The mean for this initial index is 34.69 with a standard deviation of 14.08. A positive skew, evident in the histogram, is due to the fact that the frequency diagrams of the input data were also positively skewed.

In an attempt to adjust the index so that it was normally distributed with a mean of 50 and a standard deviation of 20 with a range from 0 to 100, a transformation equation was developed. A standard deviation of 20 was selected since it allowed less than 2.5 percent of the winter severity index to take values over 100 or below 0. These results would be comparable to those of Rubinfeld and Shulman (3) and Shulman (4).

To effectively change the index to meet these specifications, a truncated logistic curve transformation (equation (8)) was used. This method, described by Johnson and Kotz (8), uses the percentile of each index value to transform the index. The percentile curve for the initial index is given in Figure 3. This curve was fit by the general percentile curve formula

$$P = \frac{1}{1 + \exp(-B\,Z)} \qquad (6)$$

where P is the percentile of index value i, Z is the Z-Score of index value i (equation (7)), and B is a constant relating this general curve formula to the actual percentile curve. The value of B was set to $\frac{\pi}{\sqrt{3}}$ to approximate the percentile curve shown in Figure 3.

Z was calculated for each value by the formula

$$Z = \frac{(I - \mu)}{\sigma} \qquad (7)$$

where Z is the Z-Score of index value i, I is the original index value, μ is the mean of the original index, and σ is the standard deviation of the original index.

Winter severity appears to be a function of continentality and latitude with lower index values along the coast and in the south and higher values in the northern and western parts of the state. The proximity of the ocean contributes to higher average winter temperatures along the coast and lower snowfall amounts. The noticably lower index values in Jersey City and Newark probably reflect urban related effects of higher average temperatures and lower snowfall amounts. More severe winters occur in the northwestern part of the state and result from lower temperatures and more persistent snowfall common at higher elevations. Not only are average temperatures lower, but extreme cold spells last longer in these regions. The year to year variability of the index along the coast and in the metropolitan northeastern sections is considerably lower than elsewhere in the state, while the interior and northern sections of the state have a more continental climate, with more variability in winter severity.

A station's average index value and standard deviation should be considered when examining the severity of an individual winter. For example, an index value of 50, the state average, would be a very severe winter at Cape May, nearly two standard deviations above the average.

Two severe winter seasons are examined. The winter of 1917/1918, Figure 6, shows that index values ranged from slightly over 98 in the northern sections to just under 60 in Belleplain. Cape May does not have continuous records to this year, and is omitted. These values are similar to the more recent severe winter, that of 1960/1961, Figure 7. Index values in the southern half of the state are higher in 1917/1918 than in 1960/1961, but values in the north are similar. In the latter, a tight index gradient parallel the higher elevations, showing the effect of topography on winter severity. A strong gradient is also evident between Atlantic City and Cape May. This is not only due to the more southerly position of Cape May, but to the effects of the ocean to the east and Delaware Bay to the west.

The general form for a truncated logistic curve with a mean of 50 and a range of from 0 to 100 is

$$I = k \ln \frac{(2(1-C)P + C)}{((2-C) - 2(1-C)P)} + 50 \qquad (8)$$

where I is the final index value, C is a constant which adjusts the standard deviation, P is the percentile of initial index value i, and k is a constant given by the formula

$$k = \frac{50}{\ln((2-C)/C)} \qquad (9)$$

with all variables defined above.

The curve is truncated so that no index value goes above 100 or below 0. Once this is accomplished, the standard deviation is adjusted to 20 by determining an appropriate value for C. A larger value of C yields a larger standard deviation. By trial, it was found that a value of 0.03675 for C gave a standard deviation of 20.003.

Figure 4 illustrates the frequency distribution of the final index. The mean of the final index was 49.63 and the standard deviation was 20.00. The mean does not equal 50 due to the approximation of the percentile curve and this introduces a slight error in the final transformation formula.

DISCUSSION

Index values were plotted for average, relatively severe, and relatively mild winters in New Jersey, and appear in Figures 5 through 9. The state-wide "average" index values for all of the stations is 49.63, and varies from 27.1 at Cape May to 70.9 at Newton. The average values for all 25 stations is listed in Table 3 and isoplethed in Figure 5.

The very mild winter of 1931/1932 and a more recent mild winter of 1972/1973 are shown in figures 8 and 9, respectively. The ocean's effects on winter severity are evident in these years. In 1931/1932, values of less than 10 occur in the southern half of coastal New Jersey while in

1972/1973, values of less than 15 occur along the southern New Jersey coast. The highest values of the index only exceed 35 in the northwestern hills of the state while most of the state has values below 20 in figure 9.

The 1972/1973 winter has higher values overall, with a much larger gradient of values in the northern third of the state. Index values ranged from 14.7 at the Atlantic City Weather Service Office to 51.4 in Sussex. This winter was exceptional for its lack of snow.

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FOOTNOTES AND REFERENCES

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Station Number	City	Number of Years	Substituting Stations	Percent Missing
1	New Brunswick	86	Plainfield	1.1%
2	Atlantic City WSO	78	(None)	0.0%
3	Newark	49	Jersey City	14.9%
4	Sussex	81	Newton,Charlottesburg,Boonton	11.6%
5	Pemberton	54	Indian Mills	1.4%
6	Belleplain	62	Atlantic City WSO	17.2%
7	Plainfield	82	Somerville,Cranford	2.7%
8	Cape May	43	Belleplain,Atlantic City WSO	8.5%
9	Long Branch	70	Freehold,Sandy Hook,Asbury Park	3.4%
10	Lambertville	82	Hightstown,Flemington	6.4%
11	Morris Plains	39	Boonton,Long Valley	0.2%
12	Boonton	70	Little Falls,Morris Plains, Charlottesburg	16.8%
13	Charlottesburg	82	Newton,Sussex,Boonton	2.7%
14	Newton	83	Sussex,Charlottesburg,Boonton	6.3%
15	Canoe Brook	37	Morris Plains	3.3%
16	Long Valley	54	Morris Plains,Newton	9.2%
17	Jersey City	74	Newark	15.0%
18	Little Falls	70	Morris Plains,Boonton, Somerville,New Brunswick	3.6%
19	Hightstown	85	Freehold,New Brunswick	7.6%
20	Flemington	81	Somerville,Lambertville	0.7%
21	Somerville	82	Plainfield	7.1%
22	Freehold	53	Hightstown	9.8%
23	Belvidere	82	Allentown, Pa.,Stroudsberg,Pa., Flemington	5.8%
24	Trenton	85	Hightstown	1.9%
25	Indian Mills	78	Hammonton,Moorestown	0.9%

Table 1. Stations corresponding to each identifying station number in Figure 1 with the number of years of data used. The percentage of missing data and substitute stations are listed.

Parameter	Most Severe	Station	Year	Least Severe	Station	Year
Total Snowfall	95.0	Charlottesburg	1961	0.0	Cape May	**
Dec.-Feb average temp	19.13	Charlottesburg	1918	42.70	Atlantic City	1932
Days below 32 F	63	Newton	1904	0	*	**
Days below 0 F	24	Charlottesburg	1918	0	*	**

* more than one station has this value
** more than one year has this value

Table 2. Extreme values of parameters including total snowfall (inches), December to February average temperature (^{O}F), number of days with maximum temperature below 32^{O}F, and number of days with minimum temperature below 0^{O}F.

#	Station	Average	Standard Deviation	1917-1918	1960-1961	1931-1932	1972-1973
1	New Brunswick	47.0	16.6	80.3	77.3	13.1	26.0
2	Atlantic City WSO	30.4	13.7	60.8	63.6	7.6	14.7
3	Newark	44.3	15.2	*	80.9	*	18.6
4	Sussex	68.5	20.0	97.1	98.6	32.1	51.4
5	Pemberton	36.6	14.6	*	65.0	10.3	18.9
6	Belleplain	30.1	13.6	*	63.6	7.3	15.3
7	Plainfield	50.6	17.1	86.8	83.6	15.4	25.0
8	Cape May	27.1	10.9	*	41.5	*	15.3
9	Long Branch	41.2	16.0	79.8	65.5	14.2	19.2
10	Lambertville	46.9	16.3	86.6	87.8	16.2	22.1
11	Morris Plains	60.2	17.8	*	95.9	*	23.8
12	Boonton	57.5	17.5	91.8	92.7	18.4	33.9
13	Charlottesburg	67.6	17.2	98.4	98.9	28.6	51.3
14	Newton	70.9	16.6	97.4	98.8	35.3	49.0
15	Canoe Brook	58.3	17.4	*	97.8	*	35.0
16	Long Valley	63.4	17.7	*	94.6	35.3	41.2
17	Jersey City	44.8	17.0	78.2	85.8	12.7	20.2
18	Little Falls	50.5	16.3	87.2	84.7	16.1	30.1
19	Hightstown	45.7	16.3	80.9	73.7	8.9	21.6
20	Flemington	53.7	18.5	85.5	97.4	14.2	31.0
21	Somerville	50.7	16.6	83.2	82.0	14.7	32.3
22	Freehold	43.8	16.4	*	68.6	10.6	23.7
23	Belvidere	58.5	18.3	90.2	92.3	20.4	32.9
24	Trenton	41.4	14.6	74.6	67.5	12.0	20.8
25	Indian Mills	40.4	14.6	75.8	71.9	10.8	19.6

* station does not have continuous winter data back to this year

Table 3. The average index value and standard deviation for each station. Index values calculated for years isoplethed in Figures 6 to 9.

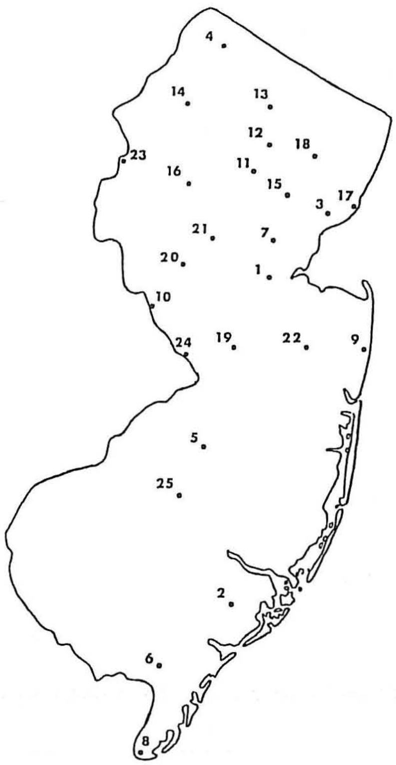

Figure 1. Distribution of Stations. Corresponding cities for each number are listed in Table 1.

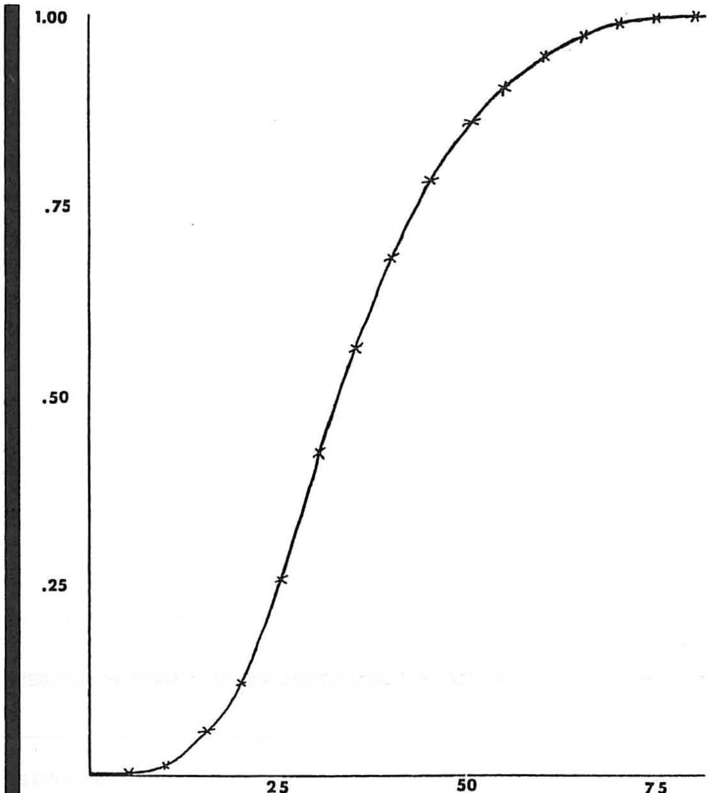

Figure 3. Percentile curve for the initial index distribution.

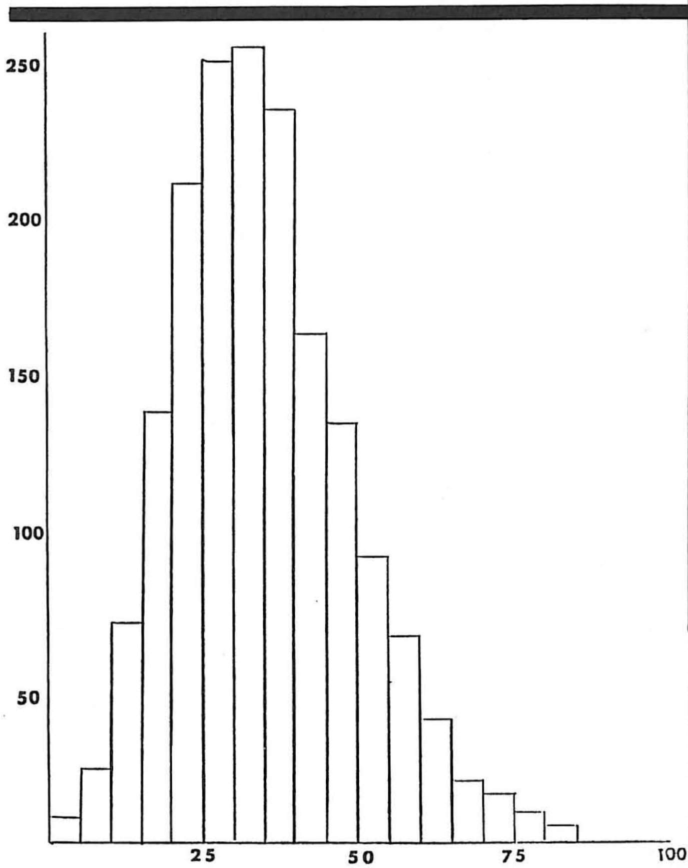

Figure 2. Frequency distribution of initial index values using equation (5).

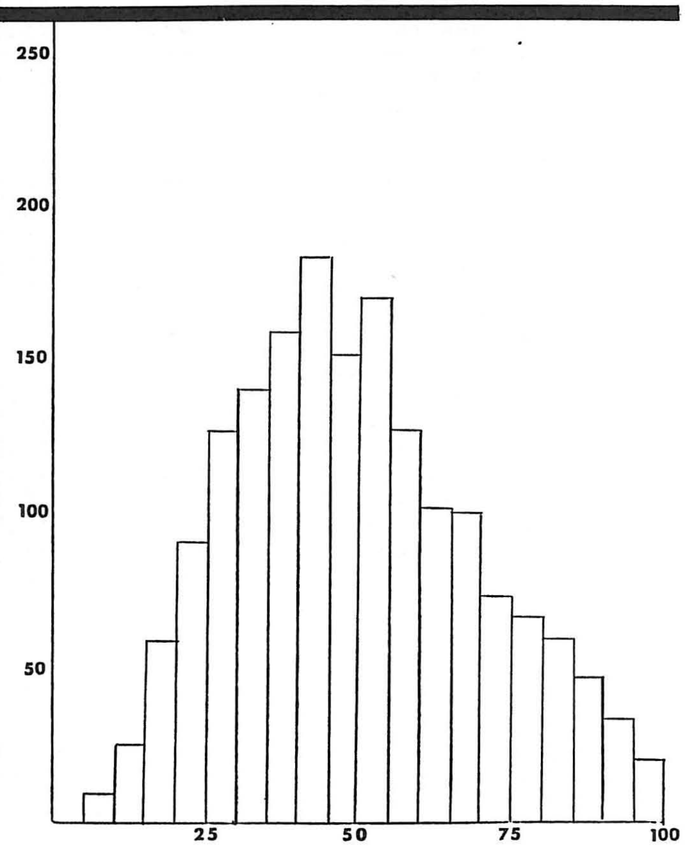

Figure 4. Frequency distribution of final index values after transformation.

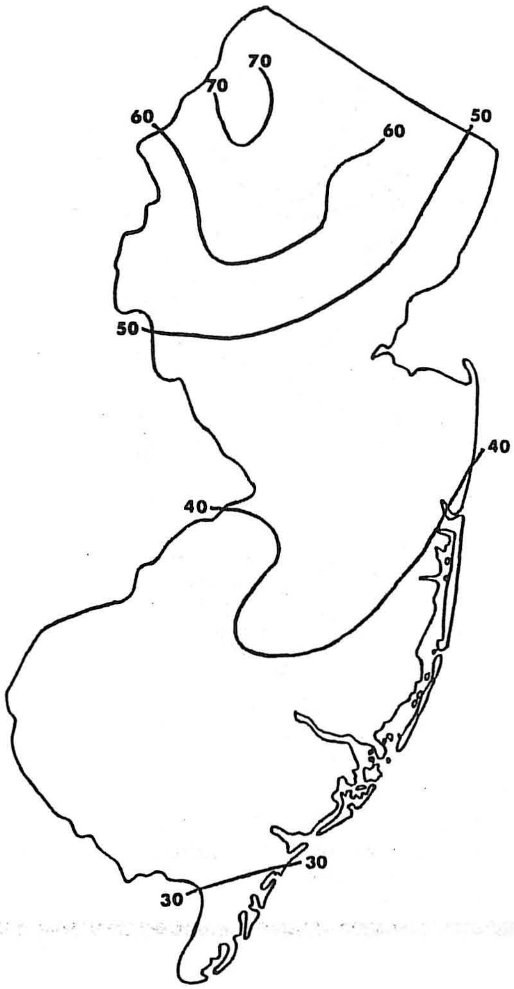

Figure 5. Isopleths of average index values for each station.

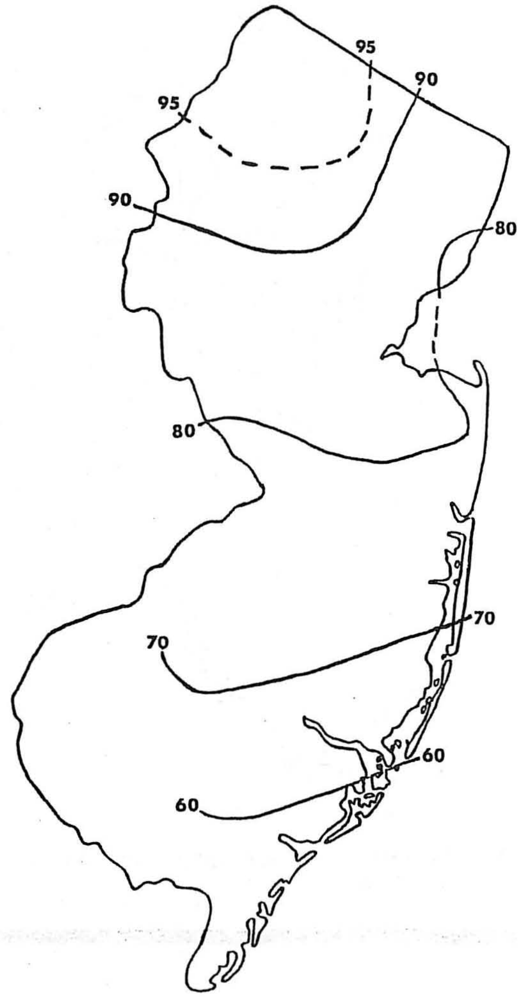

Figure 6. Isopleths of index values for the winter of 1917/1918.

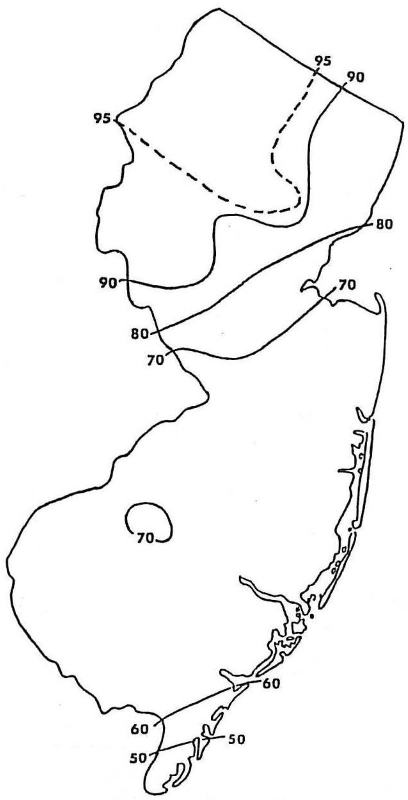

Figure 7. Isopleths of index values for the winter of 1960/1961.

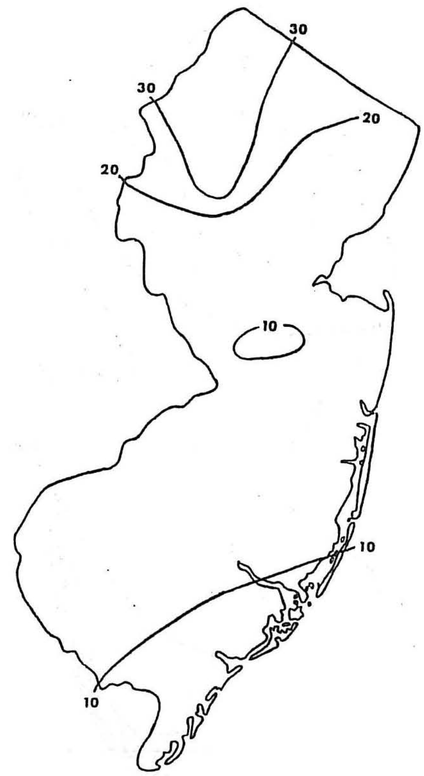

Figure 8. Isopleths of index values for the winter of 1931/1932.

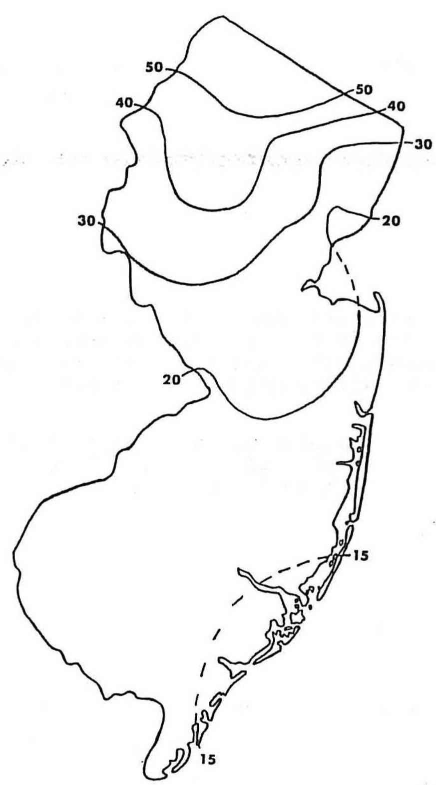

Figure 9. Isopleths of index values for the winter of 1972/1973.