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Climatology of Hailstorms in Utah--The Hail Suppression Potential by Cloud Seeding

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CLIMATOLOGY OF HAILSTORMS IN UTAH–THE HAIL SUPPRESSION POTENTIAL BY CLOUD SEEDING

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1.0 INTRODUCTION

The hail damage sustained by residents varies greatly as their vocation and location. In addition hail damage variability has been observed to occur both in time, as from one year to the next, and in proximity, as from one field of corn to another. This variability makes it necessary, at times, to speak of average hail damage over a number of years and a given area.

A most interesting approach to evaluating hail climatology and hail suppression programs is to predict for a given day the relative probability of hail formation by using atmospheric measurements and fairly sophisticated models of precipitation physics.

A model is a set of mathematical equations which express an understanding of the physical system. Models of cumulus formation and development have proven to be important tools for use in two basic modes. The use of such models in a forecast mode was demonstrated in a study of Florida cumuli (Simpson et al., 1971) during which operational days were selected according to the predicted seeded growth. The second use of cumulus models has been in the evaluation mode to interpret the effects of seeding. Several workers (Simpson et al., 1965; Weinstein and Davis, 1968) have shown the utility of such a procedure. In adapting a procedure for hail suppression evaluation it is important to determine what parameters are measured in practice which are theoretically related to the formation of ice (hail) in cumulus clouds and to concentrate modeling efforts accordingly. Hirsch (1971) has discussed the verification of such operational models and reported that the following correlations of predicted to observed values were produced for the model utilized in his study: maximum vertical velocity (0.61); maximum radar reflectivity (0.78); cloud top height (0.82).

One aspect of the National Hail Research Experiment involves modeling to examine the feasibility of various hail suppression techniques and identifying the seeding methods which are appropriate to various environmental conditions (Bull. AMS, 1976).

Such useful tools could be applied to the present study if data were available for areas of interest in the state. Detailed measurements are not taken with sufficient spatial resolution to make this feasible, however, and in general few other measures of hail damage are available. The data available are for the National Weather Service (NWS) first order weather stations and aside from these data it takes a special effort or intent to gather insight into the nature of hail climatology.

An accurate assessment of hail occurrence and intensity would be obtained by maintaining a network of hail measuring instruments. Each instrument maintained in the network would cost a minimum of $5 (Towery et al., 1976) and the time required to obtain relevant hail statistics would be greater than a few years.

Crop insurance records have sometimes proven valuable in determining damage from hail. Crop insurance programs have covered only certain crops and thereby an analysis is difficult in areas where the covered crops represent a small fraction of agricultural production.

In view of this discussion it was decided to generate a hail damage data base from informal observers throughout the state. A discussion of the methodology used to accomplish the data collection and analysis is described further in the following section. Also included in later sections is a limited analysis of the NWS data available.

2.0 SURVEY FOR HAIL DAMAGE

The objectives of the survey were to determine hail damage within Utah. Specific outcomes of the analysis were to include the distribution of hail damage in the state, the frequency of occurrence of hail damage of a certain level, and the probability of occurrence of damaging hail.

The survey methdology follows basically the steps suggested by Cochran (1953) for planning and executing a survey.

2.1 The Population to be Sampled

A list of residents engaged in agricultural and ranching operations was obtained for each of the counties in the state, from the Utah State University Extension Service.[1] About 3 in each 10 individuals were randomly selected from such lists providing a total sample of about 2000 questionnaires. Because no formal arrangements had been made with the residents chosen, all data used were obtained from residents who chose to share their records and memory and therefore the term informal observers is used. Calculations suggest that 3.3 percent of Utah's agriculturally oriented residents participated in the survey.

An example of the questionnaire sent to each resident is shown in Figure 1. The crops listed for hail damage estimates were in agreement with the crops listed in the 1974 Census of Agriculture, thus insuring a value for crop yield as well as crop damage in each county.[2]

2.2 The Sampling Unit

The county unit was chosen for sampling because it seems to be the appropriate size for displaying variations of hail damage within the state. Both the 1974 Agricultural Census and USU Extension Service operate within the county unit and counties have been the unit in Utah which decides as an organization to join or not join state weather modification efforts.

Each of the 29 counties was sampled as a separate unit, and the returned questionnaires were also analyzed by separate county units.

3.0 ANALYSIS OF THE DAMAGE

As completed questionnaires were received the information gained was recorded by a data technician and then digitized for analysis using the computer.

3.1 Determination of Crop Damage

The information requested on each questionnaire includes the number of years which the observations cover. This was considered important in determining an average damage to a specific crop by treating estimates over long periods as more meaningful. In the analysis this was accomplished by a weighting process the effect of which can be seen by the following simplication.

Suppose farmer A has lived at his location for 20 years and reports the average hail damage to his corn crop as 10 percent and farmer B has been farming at his location for 1 year and reports 100 percent of his corn crop was lost to hail damage. This information would be combined by considering the 20 year estimate as 20 times more important than the 1 year estimate

$$\frac{(20)\ (10)\ +\ (1)\ (100)}{20\ +\ 1} = 14.3$$

and the result would be 14.3 percent for the area. Of course this example is simplified with respect to the number of observations (N) making up the estimated average ($\bar{E}$), the extremes of the individual estimates involved (E_i), and the large differences in residence times (n_i). It does illustrate how an estimate over a longer period of time is treated with respect to observations over a shorter period of time and can be stated more generally as:

$$\bar{E} = \frac{\sum_{i=1}^{N} n_i E_i}{\sum_{i=1}^{N} n_i} \quad \ldots\ldots\ldots\ldots \quad (1)$$

The crop damage figure for each county was determined by this method for both the average year and the worst year. A measure of the reliability of the survey will involve how the average year relates to the worst year and will be discussed further in a later section.

3.2 Determination of Crop Yield

County wide crop production was obtained from the 1974 Agriculture Census (U.S. Department of Commerce, 1974). The selection includes 14 crops which were considered representative of Utah and are listed in Table 1.

3.3 Determination of Crop Value

The mean value of individual crops sold in Utah is listed for various years in Table 1. The assumed crop values applied in this study (listed in Table 2) are simply the average over the years for which information was available.

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[1] Several counties were not served by the Extension Service, in which case a list was obtained from the appropriate County Tax Assessor.

[2] This was identified as an important element of the study through conversations with members of the Division of Water Resources.

HAIL QUESTIONNAIRE

1. Please estimate the percent hail damage to each item below. Be sure to place 0% where appropriate and leave blank the items which do not apply to your situation.

Average Year	Worst Year	
________%	________%	corn or sorghum (milo)
________	________	wheat, oats or barley
________	________	soy beans or dry beans
________	________	wild hay or alfalfa hay
________	________	potatoes
________	________	truck garden vegetables or melons
________	________	orchards
________	________	sugar beets
________	________	other, specify ____________
________	________	____________

2. On the average I have observed hail at or near my location every ______ years.

3. I have observed damaging hail at or near my location every ______ years.

4. The above observations cover ______ years.

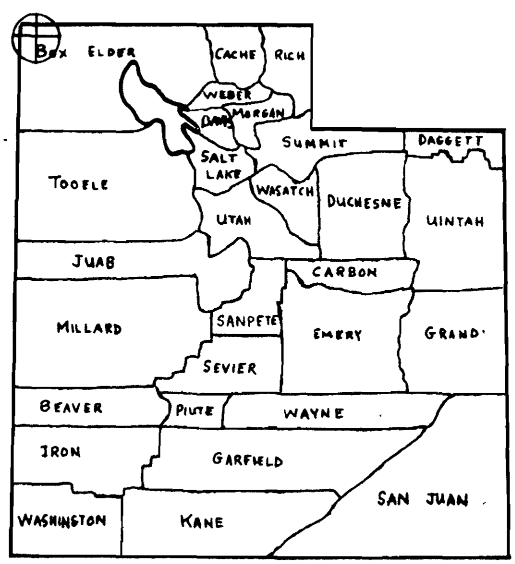
5. I feel I have fared (better, worse, no different) than residents in nearby communities when it comes to hail damage.

6. I feel I have fared (better, worse, no different) than residents in other parts of the state when it comes to hail damage.

7. The months for which you feel hail causes you damage, leave blank if none.

   1. April 2. May 3. June 4. July 5. August 6. September 7. October

8. Please place the symbol ⊕ on the map to identify the location relating to questions 2, 3, and 4 above. An example is given for a resident who lives in the northwest corner of Box Elder County.



9. The nearest city (as the crow flies)

   a. City ______________________

   b. Direction ______________________

   c. Miles ______________________

Figure 1. The hail questionnaire sent to residents of the 29 Utah counties.

3.4 Hail Damage by Counties

Each county was analyzed for hail damage and the results are displayed in Tables 3 through 31. In Table 3, for instance, reading from left to right, the total silage production is 1,527 tons at a value of \$13.30/ton. This yields \$20,309.10, the value of silage produced in Beaver County. The survey indicated an average hail damage ($\bar{F}$) of 9.15 percent or \$1,858.07 worth of hail damage to silage in the average year. Adding the crop value column shows \$2.47 million worth of crops for Beaver using the assumed values and adding the crop damage column shows an average hail damage figure of \$93,487. The corresponding numbers for other counties can be found in the tables and in Figure 2. A composite of hail damage is given in Figure 3 which displays the relationship between a hypothetical reduction in hail damage and the corresponding savings in crop values for the entire state. As can be seen, a hypothetical reduction in hail damage of 10 percent results in a savings of about 474 thousand dollars per year. Obviously a program may not be desirable across the entire state which leads us to interpret the savings on a county by county basis. The hail damage as determined for each county showed Box Elder County incurs the greatest average damage in dollars and Daggett County receives the least average damage. The remaining counties were ranked according to the average damage in the county with Utah County being second, Millard County third and so on. The result of this ranking can be seen most clearly in Figure 4 where the x-axis ranks the counties according to dollar damage and in particular from high dollar damage to low, reading from left to right. The y-axis represents the total percentage of hail damage for all counties up to and including the ranked county being considered. By reading this figure for rank 3 one can find 48 percent of the hail damage occurs in only 3 counties. Over 80 percent of the hail damage occurs in only 12 counties. If one displays these 12 counties on the state map a geographical grouping becomes possible. In the north the 4 counties of Box Elder, Cache, Rich, and Weber form one group. A second logical group is formed by Salt Lake and Utah Counties and the third group is made up of Millard, Sanpete, and Sevier Counties. Of these 12 counties only Iron, Duchesne, and San Juan are not part of a group. However, the grouped counties represent about 72 percent of the total and the three nongrouped counties represent only about 12 percent of the data.

From Figure 4 the difference between the cumulative percentage value indicated for a particular county and the value for the county immediately to the left represents the total percentage contribution to Utah's Hail Damage for that county. For example, for Cache County one finds the value of 54 percent and for Millard County the value is 48 percent. The difference of 6 percent is the contribution from Cache County to the total state hail damage. The respective contributions for each county are the numbers given in parentheses in Figure 4.

The usefulness of Figures 3 and 4 may be seen by stating a hypothetical problem. Suppose that one wishes to determine what amount of funding would be appropriate for a three county summer hail reduction program involving Box Elder, Cache, and Rich Counties under the assumption that a 10 percent reduction in hail damage will be achieved. From Figure 4 the contribution to the state's hail damage from Box Elder County is 22.3 percent while Cache County is 6.0 percent and Rich County is 2.1 percent. This gives a total of 30.4 percent of the state's hail damage for the three counties. A state-wide reduction of 10 percent in hail damage would save \$474,000 as shown in Figure 3. The state-wide number must be reduced to reflect the counties involved and this is accomplished by merely multiplying by 0.304. This multiplication yields approximately \$144,000 and represents the maximum funding which would be justifiable in obtaining a 10 percent reduction in hail damage in the three counties at present prices.

It is worth noting that a 15 percent reduction or a 20 percent reduction in hail damage can be obtained from the above example by multiplying the result with 1.5 and 2.0 respectively which extends the usefulness of Figure 3 to numbers beyond those which are plotted.

3.5 Frequency of Hail Damage Occurrence

A limited amount of data is published by the National Weather Service in the Storm Summary section of Climatological Data. The estimated damage level for each state is published in monthly issues. The data were obtained for the period 1959-1973 and the months May through September.

The data were reduced and curves were fit to describe the recurrence intervals for each state as indicated in Figure 5. A linear curve fitting scheme was used. As indicated by the curves Utah incurs a million dollars damage in one month once every 11 years and one hundred thousand dollars damage in one month once every 4 years. As can be readily seen Colorado and Idaho have higher hail damage frequencies in comparison. Due to the limited amount of data the accuracy is about ± 5 years at the 10 year recurrence interval. Of course the shorter recurrence intervals have higher absolute accuracy.

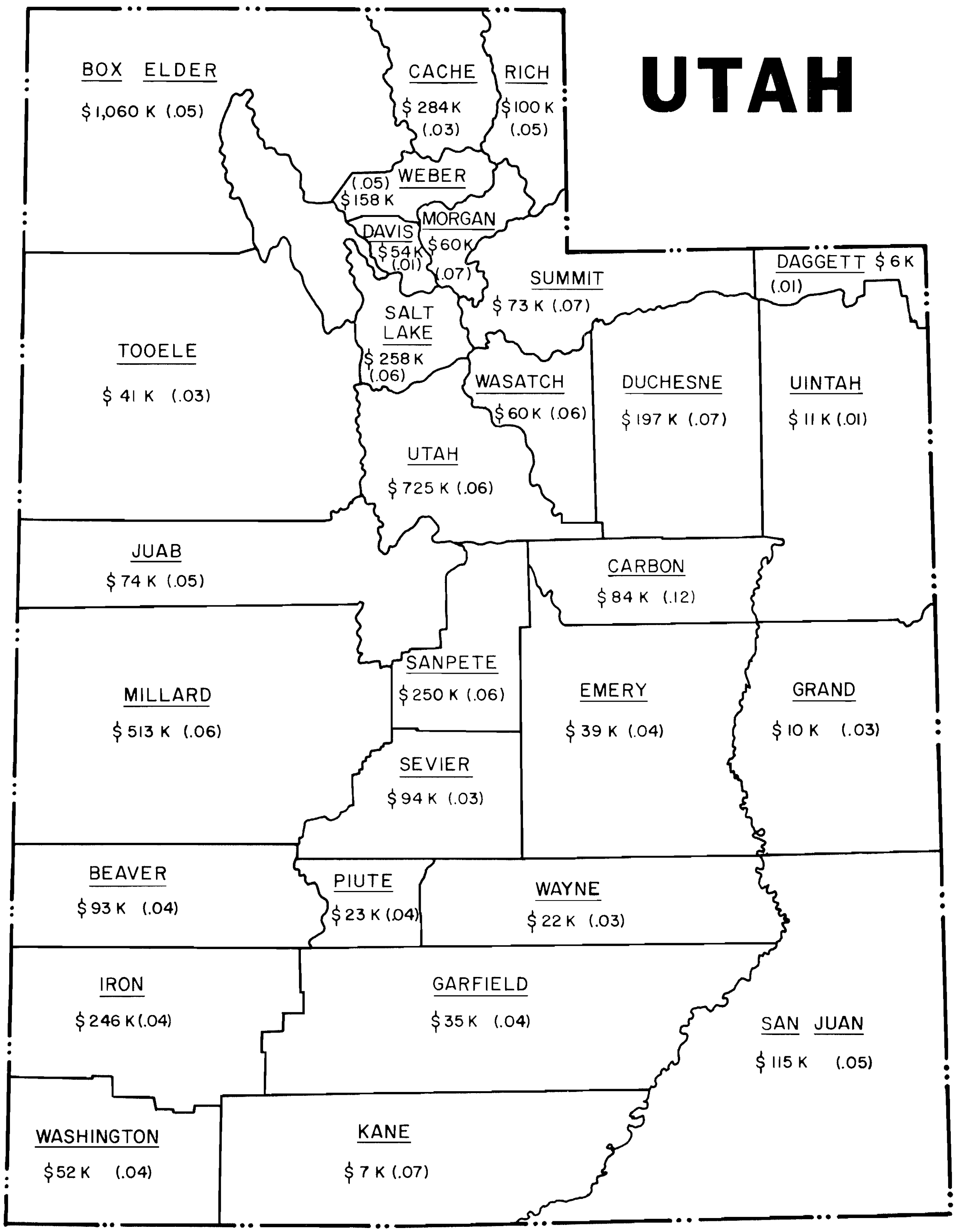


Figure 2. Map depicting hail damage in the 29 Utah counties. Two numbers are shown: the first number represents the hail damage in thousands of dollars while the second number in parentheses is the hail damage as a fraction of total crop values.

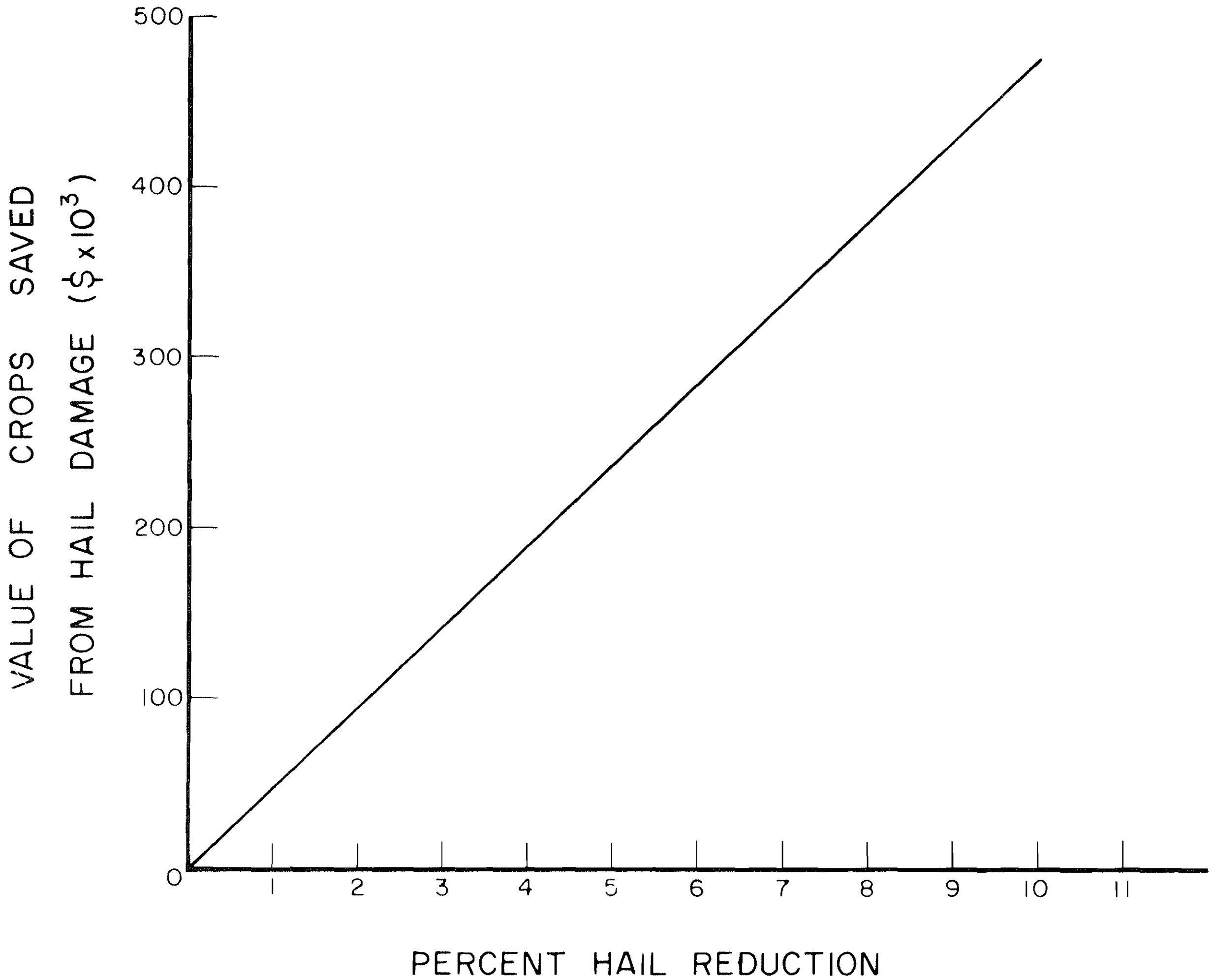


Figure 3. The relationship between a hypothetical hail reduction and the average crop savings over the entire state.

3.6 Timing of Hail Occurrence

Question 7 of the questionnaire was included so that an estimate of the hail occurrence as a function of time of year could be made. The frequency of hail occurrence for each month April through October is displayed in Figure 6. Not surprisingly the summer period in July and August was found to possess the highest rate of occurrence. The type of crop grown by a particular observer seemed to be a controlling factor in his response. Fruit producers included the earliest months, presumably due to the fact that young fruit and blossoms could easily be damaged. The later months were reported by producers of alfalfa seed, a crop which is harvested in September and October. Apparently a light hail can strip the dry seeds from the stem causing considerable damage.

3.7 Reliability of Data

An estimate of the reliability of the information obtained through the survey was made by testing the internal consistency of the various responses involved. This test was basically to check for a linear relationship between the average year and the worst year as reported for each crop on the questionnaire. Although one can deduce situations where a linear relationship should not exist, the test seems to be one of the few checks possible.

The correlations between the average damage and the worst damage as reported on the questionnaires were computed for each county and these correlations are plotted in Figure 7 as a function of

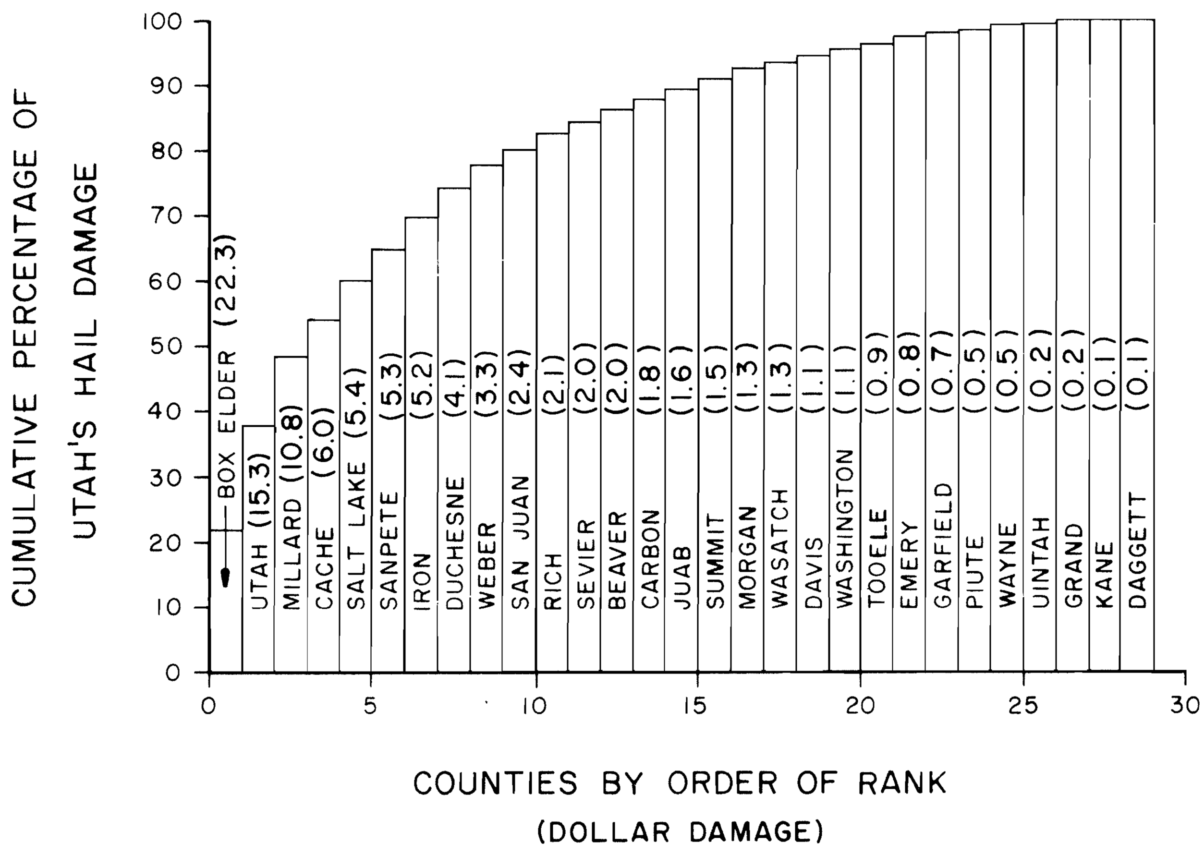


Figure 4. Cumulative hail damage as a function of rank.

the county's rank in the survey. Only two counties were found to have a very poor linear relationship between the average and worst years. It is possible that the nonlinearity develops because of the nonhomogeneous nature of hail within a county. It is also possible that the nonlinearity develops because of observer estimation failure. Even in the case of Weber and Washington Counties there is not a large gradient of average hail damage to any of the nearest neighboring counties. In summary, the accuracy of the survey cannot be completely determined; however, Figure 7 shows that the average and worst years as estimated by observers have, in most cases, interconsistency.

4.0 CONCLUSIONS AND RECOMMENDATIONS

On the basis of the study performed several conclusions can be drawn:

1. Most of the hail damage occurs in only a few of the 29 counties.

2. The occurrence is more likely in the summer because of the severity of the storms, even though crops may be less susceptible in terms of plant structure.

3. A small percentage of the crops are damaged by spring and fall hail due to the high susceptibility of the crop and not necessarily the severity of the storms.

4. In an average sense the state's hail damage is 4 to 5 percent of the total agricultural crop which is over $4.7 million average damage at 1971-1974 prices.

On the basis of these conclusions several recommendations are made:

1. Counties being considered for state support of their hail modification activities should be ranked in the order depicted by Figure 4, and when limited

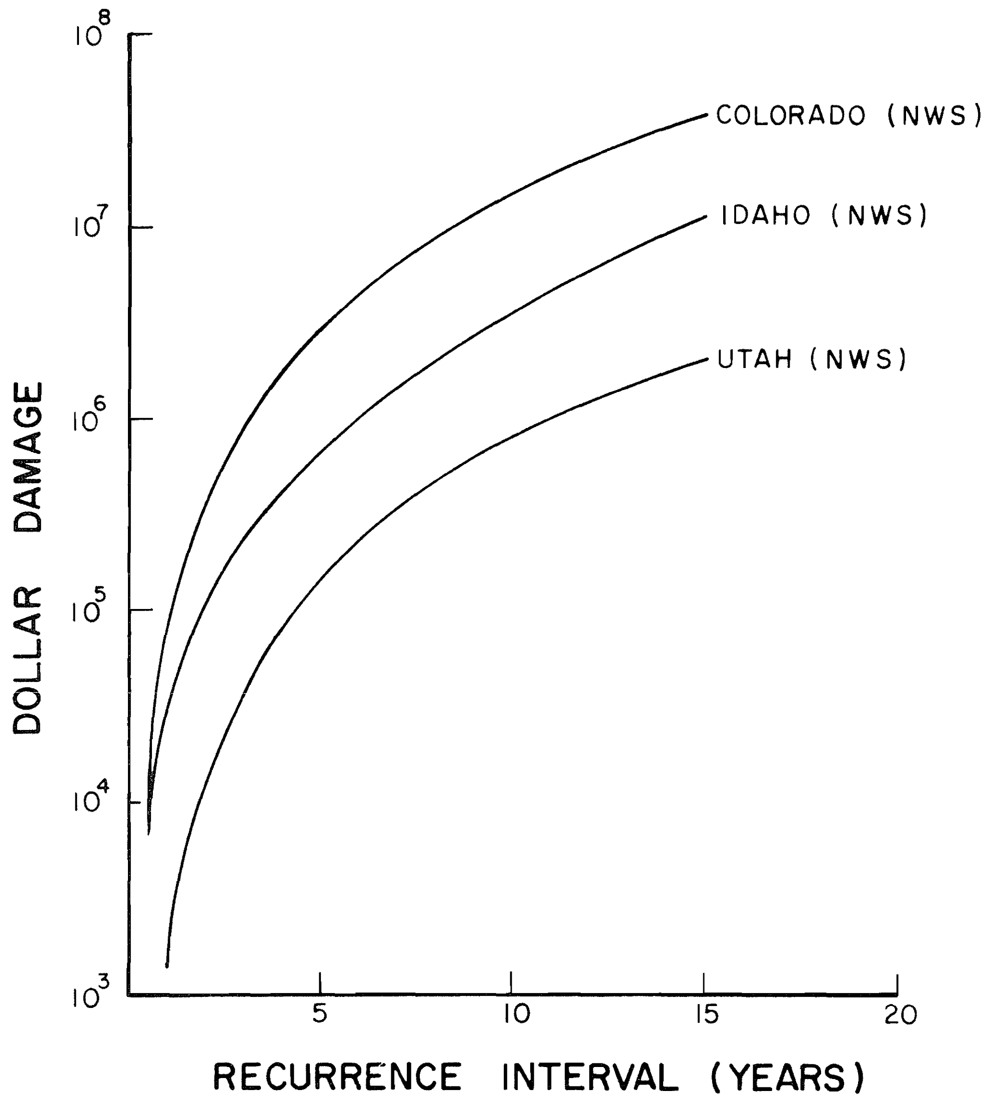


Figure 5. Recurrence intervals for state hail damage as determined from NWS data.

state support is available, the highest dollar damage counties should be considered first in importance for funding purposes.

2. The timing of hail suppression efforts in a given county should be directed toward the appropriate crops as determined by Tables 3-31 and the individual crop growing characteristics.

3. Funding levels should be consistent with Figure 3, as reduced by the number of counties not involved, and as adjusted to present crop values. The present figure indicates that no more than $144,000 could be justified in the three northern counties for a 10 percent hypotehtical reduction (shown on page 4).

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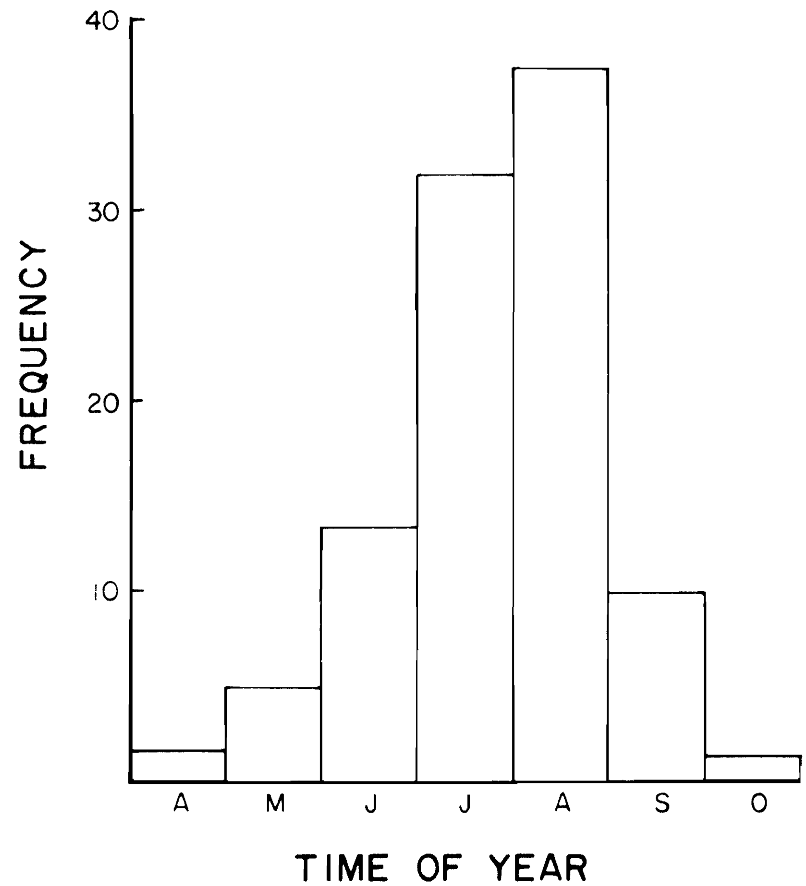

Figure 6. Hail occurrence as a function of time of year.

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Table 28. Crop values and hail losses for Wasatch County.

	CROP	PRODUCTION UNITS[a]	VALUE (IN DOLLARS/UNIT)	CROP VALUE (DOLLARS)	PERCENT DAMAGE	DAMAGE (DOLLARS)
1	CORN	.00000	2.40(/BUSHEL)	.00	.00	.00
2	SILAGE	.37400+03	13.30(/TON)	4974.20	.00	.00
3	SORGHUM	.00000	3.30(/BUSHEL)	.00	.00	.00
4	WHEAT	.16249+05	2.70(/BUSHEL)	43872.30	6.30	2762.33
5	SOY BEANS	.00000	5.00(/BUSHEL)	.00	5.00	.00
6	DRY BEANS	.00000	11.30(/100 WT)	.00	5.00	.00
7	POTATOES	.28000+02	2.80(/100 WT)	78.40	.00	.00
8	VEGETABLES	.00000	700.00(/ACRE)	.00	10.00	.00
9	ORCHARDS	.15000+02	562.00(/ACRE)	8430.00	.00	.00
10	OATS	.95560+04	1.00(/BUSHEL)	9556.00	6.30	601.67
11	BARLEY	.73023+05	1.90(/BUSHEL)	138743.70	6.30	8735.71
12	ALFALFA	.18206+05	37.60(/TON)	684545.59	6.56	44939.63
13	SUGAR BEETS	.00000	34.00(/TON)	.00	.00	.00
14	WILD HAY	.14940+04	32.00(/TON)	47808.00	6.56	3138.54
	TOTALS			938008.19	6.42	60177.89

[a]Entries are shown by two numbers, the first a factor, the second a power of 10.

Table 29. Crop values and hail losses for Washington County.

	CROP	PRODUCTION UNITS[a]	VALUE (IN DOLLARS/UNIT)	CROP VALUE (DOLLARS)	PERCENT DAMAGE	DAMAGE (DOLLARS)
1	CORN	.96000+03	2.40(/BUSHEL)	2304.00	6.33	145.92
2	SILAGE	.30000+02	13.30(/TON)	399.00	6.33	25.27
3	SORGHUM	.15320+05	3.30(/BUSHEL)	50556.00	6.33	3201.88
4	WHEAT	.18471+05	2.70(/BUSHEL)	49871.70	3.92	1956.51
5	SOY BEANS	.00000	5.00(/BUSHEL)	.00	.00	.00
6	DRY BEANS	.00000	11.30(/100 WT)	.00	.00	.00
7	POTATOES	.17400+05	2.80(/100 WT)	48720.00	1.77	863.61
8	VEGETABLES	.79000+02	700.00(/ACRE)	55300.00	12.95	7163.86
9	ORCHARDS	.30500+03	562.00(/ACRE)	171410.00	7.70	13196.62
10	OATS	.82500+03	1.00(/BUSHEL)	825.00	3.92	32.37
11	BARLEY	.14104+06	1.90(/BUSHEL)	267968.40	3.92	10512.61
12	ALFALFA	.14083+05	37.60(/TON)	529520.80	2.86	15155.90
13	SUGAR BEETS	.00000	34.00(/TON)	.00	1.18	.00
14	WILD HAY	.98000+02	32.00(/TON)	3136.00	2.86	89.76
	TOTALS			1180010.89	4.44	52344.30

[a]Entries are shown by two numbers, the first a factor, the second a power of 10.

Table 30. Crop values and hail losses for Wayne County.

	CROP	PRODUCTION UNITS[a]	VALUE (IN DOLLARS/UNIT)	CROP VALUE (DOLLARS)	PERCENT DAMAGE	DAMAGE (DOLLARS)
1	CORN	.00000	2.40(/BUSHEL)	.00	5.00	.00
2	SILAGE	.53100+03	13.30(/TON)	7062.30	5.00	353.11
3	SORGHUM	.00000	3.30(/BUSHEL)	.00	5.00	.00
4	WHEAT	.22320+04	2.70(/BUSHEL)	6026.40	4.11	247.62
5	SOY BEANS	.00000	5.00(/BUSHEL)	.00	.00	.00
6	DRY BEANS	.00000	11.30(/100 WT)	.00	.00	.00
7	POTATOES	.15457+05	2.80(/100 WT)	43279.60	4.71	2040.32
8	VEGETABLES	.30000+01	700.00(/ACRE)	2100.00	5.00	105.00
9	ORCHARDS	.18000+02	562.00(/ACRE)	10116.00	.00	.00
10	OATS	.95760+04	1.00(/BUSHEL)	9576.00	4.11	393.47
11	BARLEY	.98335+05	1.90(/BUSHEL)	186836.50	4.11	7676.95
12	ALFALFA	.16766+05	37.60(/TON)	630401.59	1.84	11612.66
13	SUGAR BEETS	.00000	34.00(/TON)	.00	.00	.00
14	WILD HAY	.10000+03	32.00(/TON)	3200.00	1.84	58.95
	TOTALS			898598.39	2.50	22488.08

[a]Entries are shown by two numbers, the first a factor, the second a power of 10.

Table 31. Crop values and hail losses for Weber County.

	CROP	PRODUCTION UNITS[a]	VALUE (IN DOLLARS/UNIT)	CROP VALUE (DOLLARS)	PERCENT DAMAGE	DAMAGE (DOLLARS)
1	CORN	.26509+05	2.40(/BUSHEL)	63621.60	1.59	1008.64
2	SILAGE	.54550+04	13.30(/TON)	72551.50	1.59	1150.21
3	SORGHUM	.94000+03	3.30(/BUSHEL)	3102.00	1.59	49.18
4	WHEAT	.11507+06	2.70(/BUSHEL)	310697.10	3.28	10190.86
5	SOY BEANS	.00000	5.00(/BUSHEL)	.00	.00	.00
6	DRY BEANS	.00000	11.30(/100 WT)	.00	.00	.00
7	POTATOES	.20220+05	2.80(/100 WT)	56616.00	1.80	1020.19
8	VEGETABLES	.55100+03	700.00(/ACRE)	385700.00	2.94	11344.12
9	ORCHARDS	.43500+03	562.00(/ACRE)	244470.00	3.81	9303.44
10	OATS	.96730+04	1.00(/BUSHEL)	9673.00	3.28	317.27
11	BARLEY	.12452+06	1.90(/BUSHEL)	236595.60	3.28	7760.34
12	ALFALFA	.30653+05	37.60(/TON)	1152552.80	2.28	26252.59
13	SUGAR BEETS	.27302+05	34.00(/TON)	928268.00	9.66	89625.87
14	WILD HAY	.41300+03	32.00(/TON)	13216.00	2.28	301.03
	TOTALS			3477063.56	4.55	158323.74

[a]Entries are shown by two numbers, the first a factor, the second a power of 10.