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REVIEW OF THE SOCIETAL, ENVIRONMENTAL, AND LEGAL ASPECTS OF PRECIPITATION MODIFICATION IN ILLINOIS

by

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INTRODUCTION

For more than 25 years Water Survey scientists have been investigating the meteorological and climatological aspects of weather modification in Illinois (Changnon, 1977). The theme of this research has been to develop means of evaluation of operational programs, and simultaneously to develop the skills to design, conduct, and evaluate an experimental program that would define, in a scientifically and socially acceptable manner, a capability of precipitation modification in the Midwest. Great attention has been given to the modification of both rain and hail.

A constant companion of this meteorologically-focused research has been attention to the question, "Is weather modification worthwhile?"

Survey scientists in 1965 began economic studies of the impact of weather. These were followed in 1968 by studies of the economic impacts of potential modified weather, both rain and hail, in Illinois. As the economic results began to show the positive attributes of changing summer weather, in particular to agriculture, a series of other impact-related research was launched in 1970-1971. These were limited studies conducted in parallel (Changnon, 1973). They addressed attitudes towards weather modification (social acceptance), the environmental impacts of altered weather, and the legal-institutional issues. These were pioneering efforts, particularly for the Midwest, and were soon broadened into other impact studies. One outgrowth of Water Survey interests in the broader aspects of weather modification was the direction and performance of a major technology assessment of hail suppression and associated rain modification (Changnon et al, 1977). Extensive Survey studies of inadvertent weather modification produced by cities (St. Louis and Chicago) also dealt with the issue of impacts to society (Changnon, 1970).

This report attempts to set forth selected, but key results, from Water Survey studies dealing with the impacts of planned weather modification. The initial section of the report deals with the importance of weather in Illinois, primarily to agriculture. This particular effort is examined because Water Survey scientists pioneered in this type of research in Illinois, and because subsequent studies which rest on the techniques developed have shown that capability to modify precipitation in Illinois (in any season) has the greatest impact on agriculture with lesser impacts on the water resources and energy production.

The second major section of the report deals with the economic aspects of weather modification. Economic aspects defined herein are broad to include agricultural production and its implied financial benefits. The third major section of the report deals with the results of a public attitude sampling study performed in central Illinois by sociologists. The fourth section deals with selected environmental impacts of weather modification. Studies of weather influences on game animals are featured, along with results of studies of silver existing in Illinois rainfall and streams. Extensive studies of water resources impacts of successful weather modification on water resources are also presented. The final section of this report deals with the legal issues and specifically the development of a model state law regulating the performance of weather modification in Illinois.

The approach to this report had been to choose selected results, primarily graphs and tables, to present key findings and ideas. The results are referenced to allow the reader to find additional results.

IMPORTANCE OF WEATHER TO ILLINOIS AGRICULTURE

Farmer Estimates of Weather Effects

A summary of the 1954-1963 crop-loss data due to various forms of weather, generally classed as severe, is presented in Table 1 (Changnon, 1975). It is based on a survey conducted in 1963 of about 500 farmers in the 5-state Corn Belt (Brown, 1967). The total average losses to corn yields due to weather vary from 28 to 38% and those to soybeans vary from 32 to 38%. Drought ranks first in losses in all three subdivisions of the Corn Belt and for both corn and soybeans. Excessive moisture and wind damages also rank high, producing a greater average yield loss, than hail. Hail losses to soybeans rank relatively higher than hail losses to corn, and hail is less important in producing loss in the eastern area of the Corn Belt than in the western part. Clearly, the impact of altered rainfall on crop production, as perceived by the farmers, is quite great and is much greater than that due to temperature extremes. Alterations in moisture (too dry or too wet) account for nearly 50% of the losses of corn crops in all three areas and from 40 to 50% of the soybean losses.

Impacts Revealed in Weather-Yield Regressions

Another way to inspect the impact of weather and climate on agricultural production is through the use of historical yield and climatic data (Changnon, 1966). Regression equations involving monthly and seasonal weather data coupled with crop district and state yield data were used to derive experessions of technology and thus to measure the impact of individual and collective weather variables on corn and soybean yields. This multiple regression technique was

Table 1. Annual Estimated Crop Yield Losses Due to Various Weather Conditions in the Five-State Corn Belt Area.

	Average Annual (Bu/Acre)					
	Western Corn Belt (Nebraska, Western Iowa)		Central Corn Belt (Eastern Iowa, Illinois)		Eastern Corn Belt (Indiana, Ohio)	
	Corn	Beans	Corn	Beans	Corn	Beans
Hail	3.50	2.36	1.88	1.38	1.25	0.88.
Wind	3.67	1.01	.3.88	0.94	3.79	1.19
Drought	7.30	2.67	5.40	2.72	8.74	3.67
Excessive moisture	2.71	1.60	4.88	2.59	6.94	2.83
Excessive heat	3.53	0.85	2.27	1.12	2.99	1.70
Excessive coolness	0.30	0.33	1.47	0.37	1.51	0.73
Freeze or frost	1.10	0.57	0.94	0.38	1.43	0.42
Total loss	22.11	9.39	20.72	9.50	26.65	11.42
Total as percent of total yield	38	32	28	31	36	38

Table 2. Average Annual Property and Crop Losses in Illinois Due to Severe Local Storms, 1950-1957.

	Average loss (thousands of dollars)		
	Property	Crops	Total
Hail	460.9	3,680.0	4,140.9
Winds	3,352.0	386.8	3,738.8
Tornadoes	2,453.6	10.2	2,453.8
Lightning	105.0	3.0	108.0
Heavy rains	2,635.0	1,503.8	4,133.8
Winter storms	1,780.3	0.0	1,780.3
	10,786.8	5,583.8	16,370.6

Table 3. Wet Growing Seasons During 1891-1978 in Central Illinois.

Wet Years	Duration of Period	Number per Decade
1898	1	1891-1900 = 1
1907-1909	3	1901-1910 = 3
1921-1924	4	1911-1920 = 0
1926-1929	4	1921-1930 = 8
1941-1942	2	1931-1940 = 0
1944-1945	2	1941-1950 = 7
1948-1950	3	1951-1960 = 1
1957	1	1961-1970 = 1
1965	1	1971-1978 = 3
1972-1974	3	

applied in Illinois on a county scale to inspect for various weather-crop relations so as to develop state regions where weather, crop yield, and soil interactions were similar (Changnon and Neill, 1967). Certain results from this study reveal the considerable regional variations in weather-yield relations. Figure 1 presents curves for 7 Illinois counties illustrating the different relations of July rainfall to corn yields. Some of the differences are spurious because of over statistical fitting, but they basically illustrate that to maximize corn yields, 5 to 9 inches of rain are needed with the heaviest in counties like Stark which are largely sandy soils. Normally, only 3 inches of rain falls in Illinois in July.

Further results of this Illinois county study (Changnon and Neill, 1967) are presented in Figure 2. The correlation patterns for the two monthly weather variables found to be most important in explaining yields, July rainfall and July temperatures, are presented in Figure 2a and b. Since July rainfall has a curvilinear association with yields, correlation indices were calculated from a quadratic form of the relationship. The July rainfall and temperature patterns are quite similar, showing that they individually explain between 10 and 50% of the corn yield in Illinois. The greatest weather effect is in the southern half of the state where soils are poorest, rain most variable, and temperatures are most often highest. It is important to realize that an inverse relationship exists between July rainfall and temperature, and thus the individual correlations for the two values are partially interrelated.

The iso-coefficient pattern based on county multiple regressions of all weather variables with corn yields is shown in Figure 2c. Coefficients range from 0.65 in northern Illinois to 0.92 in several southern counties; thus, indicating that the weather variables together explained between 40 and 80% of the variations in Illinois corn yields during the 1931-1965 period.

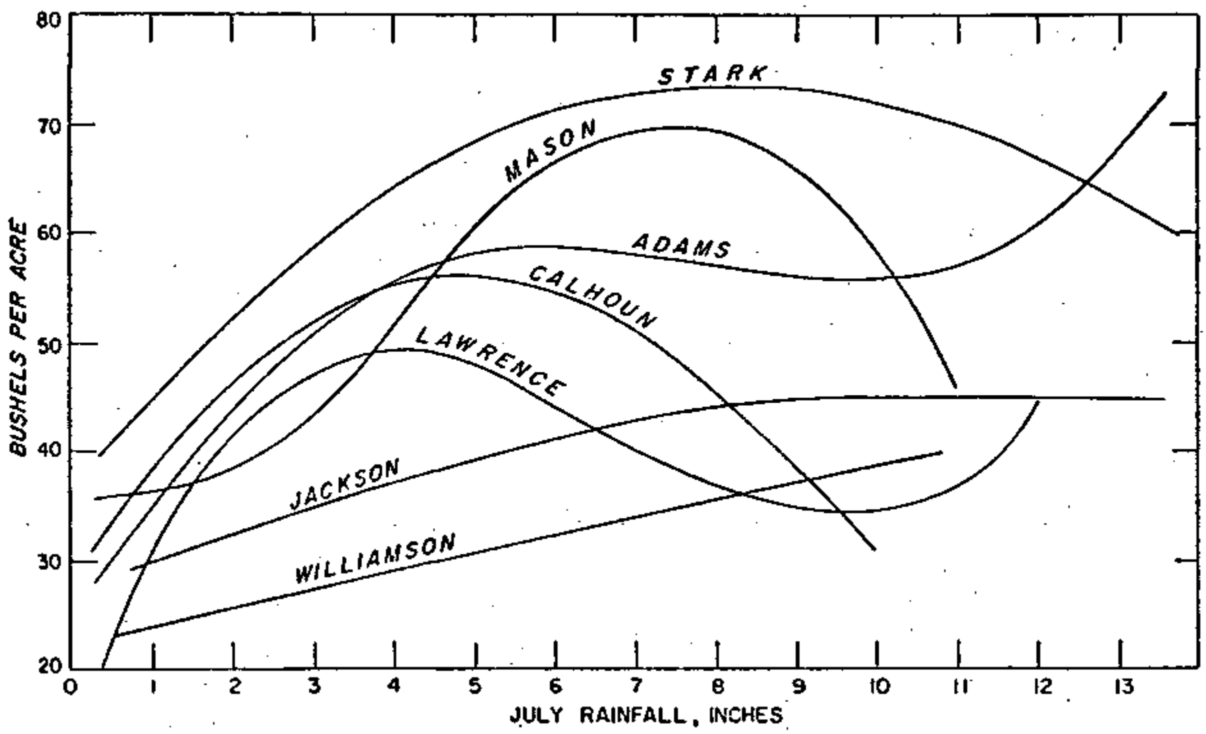

Figure 1. Seven Types of Best-Fit Curves for Corn Yields and July Rainfall Illustrated by Selected Counties in Illinois.

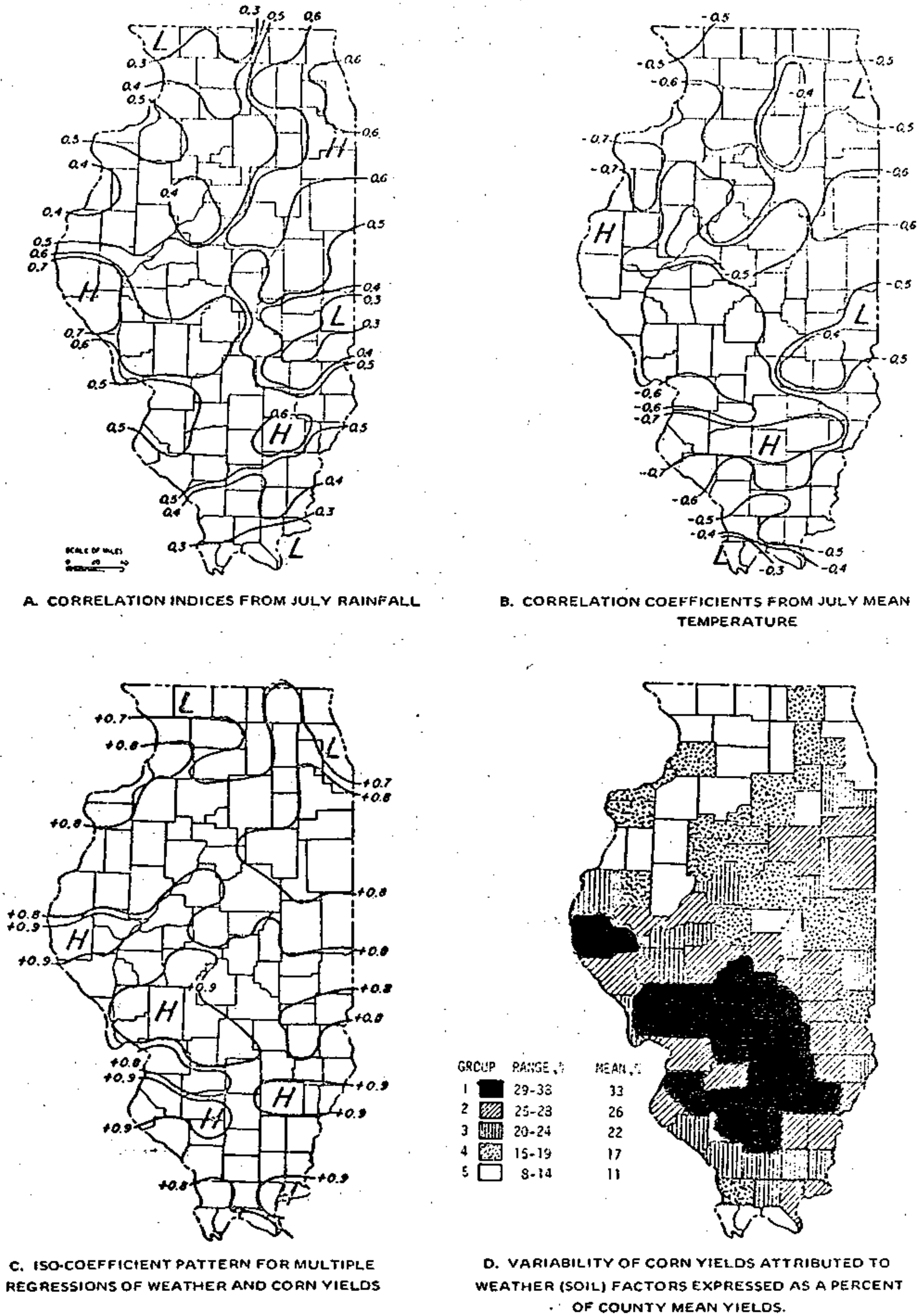

Figure 2. Illinois Weather-Corn Yield Relations.

Patterns such as Figure 2c were coupled with soil maps to construct Figure 2d. Here the variability of corn yields attributed to weather (plus soil) factors are expressed as a percent of the county mean yields. These county "weather impact indices" range from a low of 8% to a high of 38% of various county yields. These indices were sorted into five groups forming state regions as shown (Figure 2d), and the map key has the mean regional percentages. These mean values indicate that variability of weather accounts for on the average, between 11 and 33% of the total corn yields in Illinois. This gives a good approximation of the impact of weather on corn yields during this 34-year period, and also reveals how regionally variable is this impact.

Farm-Scale Weather Impacts

Another way to measure weather and technological impacts on agriculture is to examine farm data. Studies of yields of 68 farms in a 400 mi^2 area of East Central Illinois, where the Water Survey maintained a meso-scale weather network of 49 stations for 9 years, allowed a careful study of relationship of individual farm corn yields with weather and technology factors collected at each farm (Changnon and Neill, 1968).

Graphs based on best-fit linear relationships for non-weather factors appear in Figure 3, and the dashed lines enclose 95% of the 612 data points. Nitrogen fertilizer applications had a correlation coefficient of +0.41 with yields; plant populations had a coefficient of +o.35, whereas year (time) had a correlation of +0.7. There was no relationship to the soil differences in the region indicating farm practices had eliminated impacts of soil differences. The time of planting also had no correlation with yields obtained during the 9-year sample period.

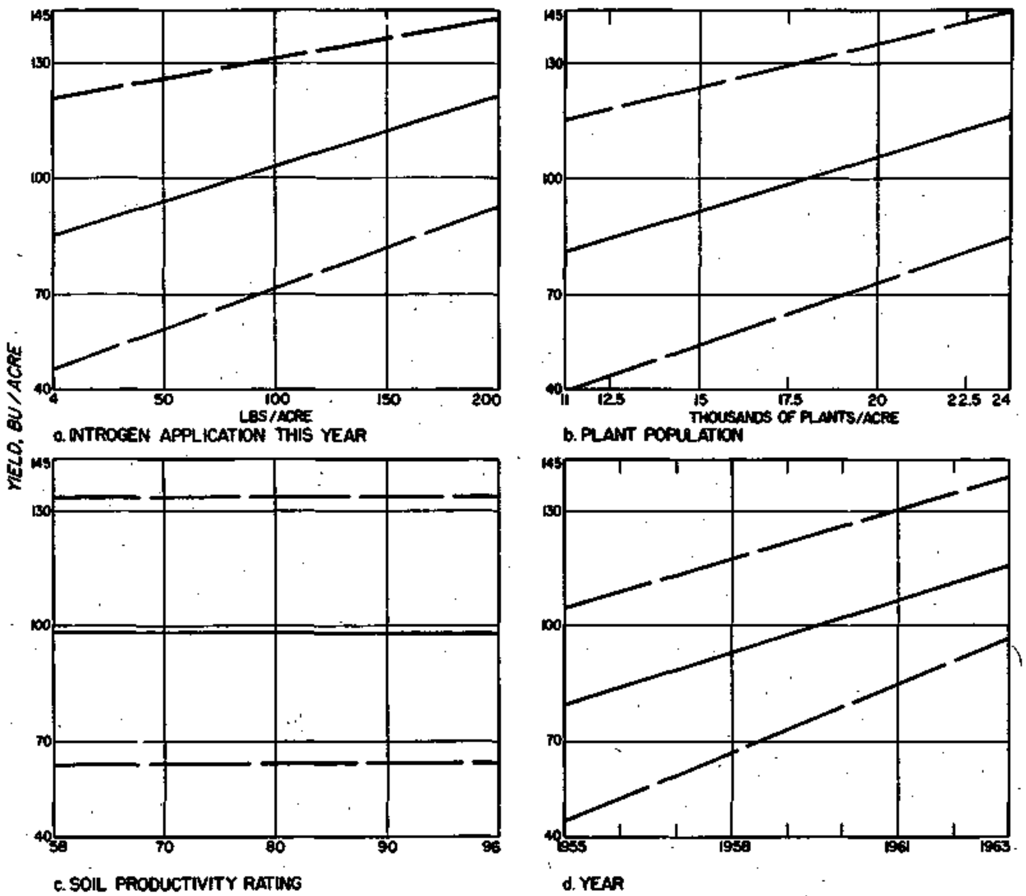

Figure 3. Relation of Corn Yields with Technological Practices, Soil and Time, Central Illinois Network (1954-1963).

Figure 4 presents graphs for the relationshps between yields and precipitation and temperature for the months of June, July, and August. Importantly, a relatively dry June, 0.5 to 2 inches, was best for corn, presumably by forcing deep rooting of corn, making it better able to withstand dry-hot stresses later in the summer. June temperature is best around 73°F which is near normal. The July results show, as with the. state results (Figure 2), that a cool July is best. Optimum July rainfall in this farm area is found to be 5 to 7 inches, nearly twice the normal. Similarly, a cool and rainy August is desirable for high corn yields. The weather-yield correlations showed coefficients of 0.7 for August mean temperatures, -0.5 for July temperature, +0.34 for July rainfall, and -0.22 for June rainfall.

A major weather-related problem for Illinois and Midwestern agriculture is too much rain in critical protions of the growing seasons (see Table 1 and 2). A study of the frequency of growing seasons with two consecutive months of heavy rains in Illinois (Table 3) reveals that when these "wet seasons" exist, they tend to occur in clusters of 2, 3, or 4 years. Such a cluster occurred in the 1972-1974 period, the first such cluster since the late 1940's. The number per decade further illustrates the uneven temporal distribution of these wet seasons. The lack of wet years, as well as the lack of dry years, in the 1954-1971 period, resulted in a stable weather regime that was good for agriculture.

Optimal Weather

The two major Illinois crops, soybeans and corn, are full season crops requiring 6 to 8 months of growth. Thus, they are susceptible to many possible variances of weather. For example, each data of delay in the planting of corn after May 7 is estimated to result in a yield loss of 1 bu/acre per day. This

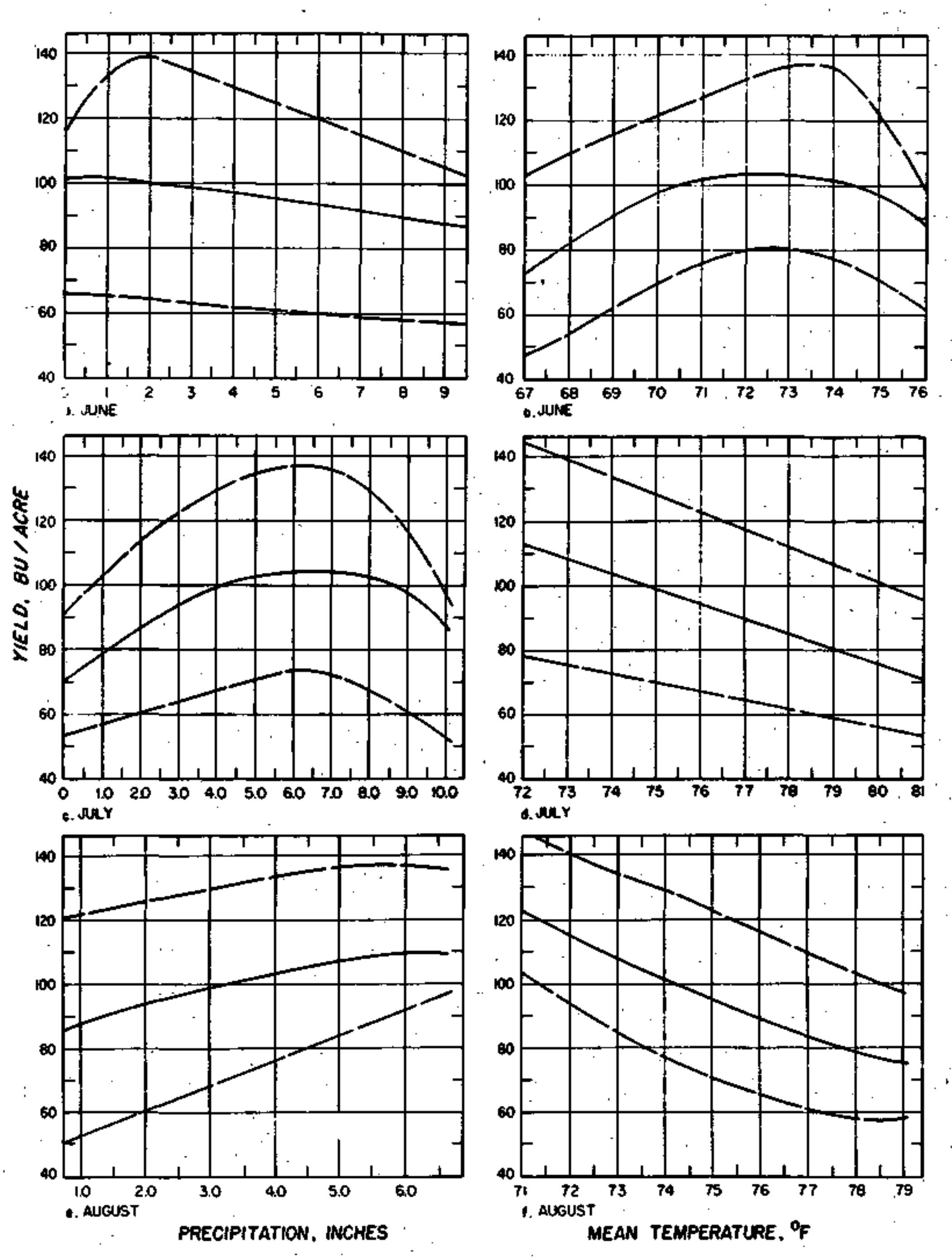

Figure 4. Relation of Corn Yields with Monthly Weather Conditions in Central Illinois Network, 1954-1963.

raises the issue of the weather sequence needed to fit the intricacies of the corn-bean technology being used in the 1970's. Table 4 presents a summary of the agriculturally desirable weather for Illinois along with an indication of generally bad 1974 crop conditions (Changnon, 1975). Not all of the 1974 conditions were undesirable. Importantly, a complicated series of optimal weather events must persist from early April through mid-October to reach maximum yields.

Agricultural specialists of the University of Illinois developed for PACE a qualitative analysis, based on their various specialties, of the influence of above-normal rainfall throughout the growing season. The resulting graph appears as Figure 5. The principal message conveyed concerns the complexities and conflicts in water needs for modern agriculture. Technological practices have a variety of needs for wet or dry (above or below normal) weather at varying times. Of considerable importance is the major advantage of above-average rainfall during July and August. This type of information has a considerable impact on the design of weather modification efforts and on its use in any part of the growing season. Clearly, sophisticated tailoring of precipitation modification is needed to obtain optimal benefits. Nevertheless, the growth in the use of irrigation in Illinois, which was rapidly expanding in the late 1970's, reflects the farmer-level interest in the yield increases to be obtained through additional water. However, the use of irrigation to aid crop production in Illinois will be limited by available supplies. Survey studies have estimated that only 20% of the agricultural lands in Illinois could be irrigated due to limitations on available water, soil types, and land slopes (Sasman et al, 1974). Clearly, in many parts of Illinois, the use of irrigation and its consumption of surface and ground water supplies will face strong competition in the growth of other probably more important water uses.

Table 4. Desirable Corn and Soybean Weather for the 1970's in Illinois,

Dates		Activities	Conditions Needed to Optimize Yields	Conditions in 1974
April 1-24	:	Tillage and nitrogen application	8 to 10 work days	8 days
April 25-May 7	:	Corn planting	6 to 7 work days	2 days
May 7-15	:	Application of herbicides	1" rainfall (in 2-3 days)	3" rainfall (in 4 days)
May 15-31	:	Bean planting	7 work days	3 days
June	:	Growth	1" to 3" rainfall few showers for beans; relatively dry for corn and hay cutting	7" to 10" rainfall
July	:	Growth	6" to 7" rainfall in at least 3 times, cool and not too wet	0.5" to 1.5" and hot
August	:	Growth	4" to 5" rainfall and cool	2" to 5" rain and normal temperatures
Sept-October	:	Harvesting, fall plowing and some fertilization	Relatively dry and latest possible frost	Dry with very early frost

Table 5. Water Requirements for Different Weather Types in Region 11 for 1963 Technology Level.

Type	July-Aug. Conditions[a]	Frequency (%)	Yield (bu/acre): No Added Water	Yield (bu/acre): Maximum Increase from Added Water	Increase (%)	Additional Water Required to Obtain Maximum Yields (in.)
A	AA-AB	3	46.2	0.4	0.9	0.6
B	NA-BB	9	60.3	0.0	0.0	0.0
C	BA-NN	3	59.7	0.0	0.0	0.0
D	BA-BN	8	66.8	0.0	0.0	0.0
E	BA-AB	3	48.0	2.3	4.8	1.8
F	AN-AA	8	46.8	9.3	20.0	3.7
G	AN-NA	6	39.5	12.4	31.4	4.2
H	NN-NN	6	55.8	5.2	9.3	2.8
I	NN-NB	6	48.9	6.5	13.3	3.2
J	BN-BA	4	53.1	5.1	9.6	2.7
K	BN-AN	6	51.8	7.9	15.3	3.5
L	BN-BN	4	59.7	5.1	8.5	2.8
M	AB-AA	8	36.4	13.4	36.8	4.8
N	AB-NN	5	36.7	15.8	43.1	4.9
O	AB-AB	8	30.3	14.7	48.5	4.7
P	NB-BA	8	47.4	12.0	25.3	4.4
Q	NB-BN	5	42.4	12.4	29.2	4.0

[a]Conditions of A (above normal), N (near normal), and B (below normal) listed in order of July temperature, July rain, August temperature, and August rain.

Table 6. Frequency of Water Needs for Maximum Corn Yields in Regions 2 and 11 at the 1963 Technology Level.

Frequency, Number of Years in 20-Year Period	Increase in Yields Over That Without Added Water: Bu/acre	Percent	Water Required (in.)
	Region 2		
2	10.6	14	4.6
6	6.8	7-10	3.8
3	4.1	4-5	2.8
3	2.5	2-3	2.3
6	0	0	0
	Region 11		
4	14.6	37-49	4.8
4	12.3	25-31	4.2
4	7.9	13-20	3.5
3	5.1	8-10	2.8
1	1.4	1-5	1.2
4	0	0	0

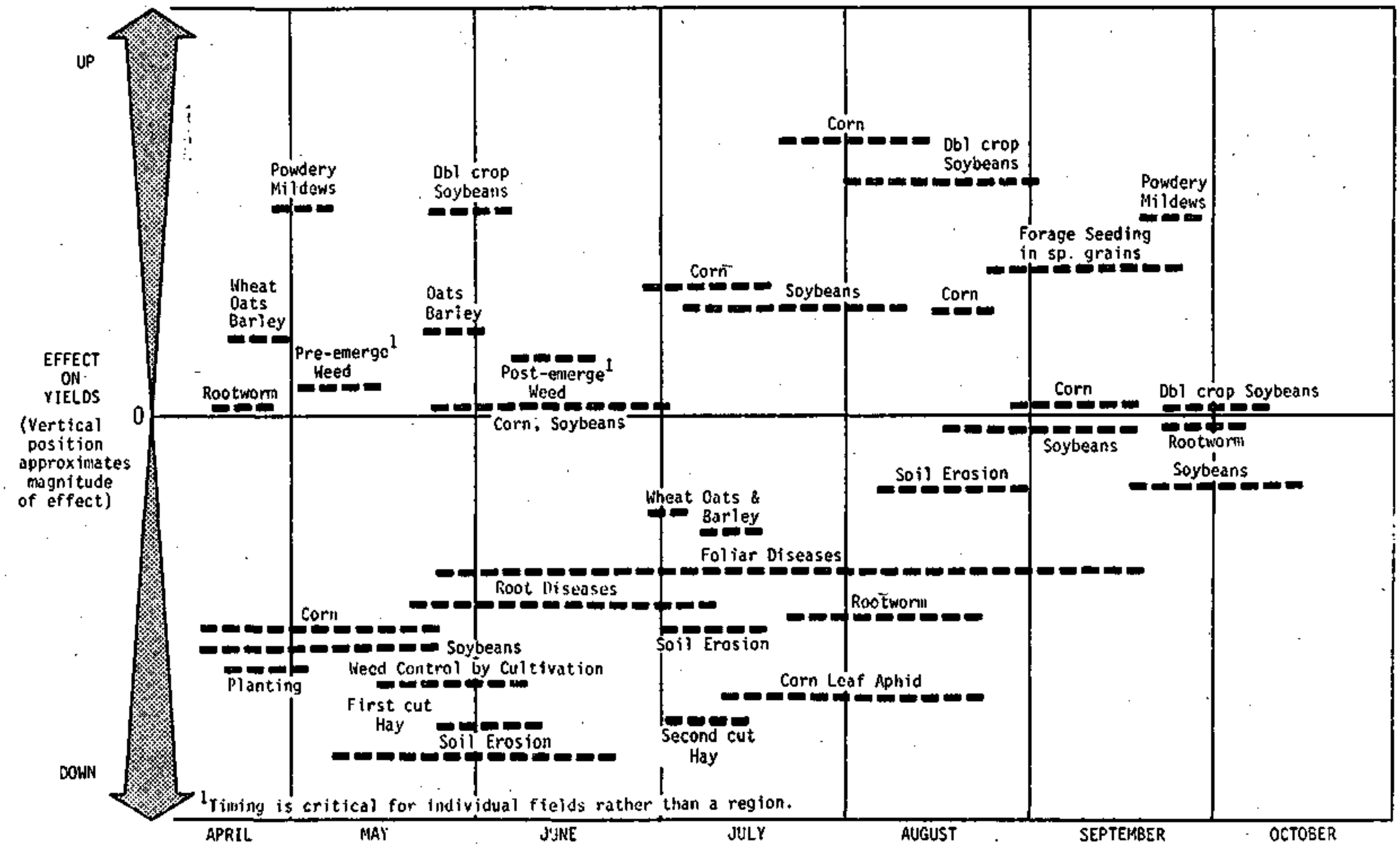

Figure 5. Effect of Above-Normal Rainfall on a Variety of Illinois Agricultural Activities and Crop Growth Factors.

Changnon (1969) made an extensive study to estimate water requirements for maximizing crop yields in Illinois. A method was developed enabling determination of the annual water need for all crop land in the state, with the need at any place being expressed as a frequency of demand per year during an average 20-year period. The types of crop-season weather that existed in each of 12 crop regions (Figure 6), and the frequency of the weather types was identified. Long-term weather records at stations in each of the regions were analyzed to develop a seasonal weather type common to each region. The weather types were based on weather variables used in the regression analyses. A growing-season weather type was considered to be formed if two or more years (in 1901-1962) had similar July-August rain and temperature conditions.

Weather data values for these seasonal weather types (identified for each region) were inserted in the regression equations developed for each region. Then, the July rainfall was systematically increased by 0.2 inch amounts until corn yields began to decrease. Decreases eventually occur because too much rainfall leads to decreases in yields. Once the amount of July rainfall needed to produce a maximum corn yield had been determined, this new July rainfall amount was inserted in the region's equation, and then the August rainfall was systematically increased to ascertain how much more was needed in that month to obtain an optimal yield.

The resulting amounts of water needed to produce maximum corn yields in south central Illinois (region 11); on the basis of 1963 technology levels; and for all 17 weather types in that area are shown in Table 5. All water values in the table are rainwater values.

Examination of the results for each of the Illinois crop-weather regions revealed that several weather types had similar maximum yield increases associated with similar amounts of added water. This suggested that although the weather conditions of the types were different, the conditions of some types interact to produce similar effects on corn yields. For instance, in Table 5 weather types M, N, and O (which were all types with hot-dry Julys, but otherwise different Augusts) had similar water values needed to achieve these increases. Therefore, the weather types of similar yield-water increases were combined and the frequency of these needs was expressed for an average 20-year period, as shown in Table 6. Results for Region 11 show that the maximum corn yield increases of 37 to 49% are possible in 4 of 20 years with 4.8 inches of added water. An application of 4.6 inches of added water in Region 2 would produce only a 14% increase in yields and that would occur in only 2 of 20 years. Regional differences result largely because of soil differences.

From a weather modification standpoint, inspection of Table 5 reveals that yield increases could be obtained in all the weather types except A through D, which all had above-normal July rainfall. About 16 out of 20 years in most regions of the state would benefit by added water in July and August.

It should be noted that Water Survey scientists have also studied the economic impacts of a variety of other weather conditions (Changnon, 1972; 1977; 1969). These other studies have addressed impacts of severe convective storms (hail, lightning, winds, tornadoes, floods) and of severe winter storms.

IMPACTS OF PRECIPITATION MODIFICATION ON AGRICULTURAL PRODUCTION AND ECONOMICS

Introduction

Much of what is known about the potential impacts of planned weather modification has come from simulation studies. That is, regression relationships have been developed, based on historical records between precipitation and crop yields or streamflow, and then in the models, precipitation was altered through simulation of likely rainfall changes. These simulations provide useful estimates of potential impacts and benefits to be obtained. The study of potential precipitation changes and their effects on agriculture has been aided by research into effects of inadvertent weather modification. The area with urban-produced summer rainfall increases at St. Louis has been studied to measure a variety of impacts on agricultural production, water resources, and the local economy. These results provide more explicit findings about the impacts. The extensive Illinois studies of agricultural impacts flowing from hail suppression are largely not presented here, but many results are available (Changnon and Morgan, 1976; Changnon et al, 1977).

Midwestern Impacts

Reasonable, order-of-magnitude assessments of the regional impact of weather modification on midwestern crop yields were made (National Academy of Sciences, 1976). The types of modification that were considered included rain augmentation and hail suppression and their influences on corn and soybeans in the 5-state Corn Belt. These were based on regressions of yields and weather, including technology changes. The simulated precipitation change chosen was a 10% increase and a 30% reduction in hail loss. Although this was hypothetically applied across the 5-state Corn Belt, it is not clear that this level of change is possible across such a large area.

Table 7 is a summary of the estimated impact of weather changes in the key production areas with the simulated changes. Values show that for all crops considered on this national scale, the gain in production from a 10% increase in precipitation would be about 93% of the total gain. The national gain from the 30% reduction in hail losses provides the other 7 percent.

The ability to help stabilize crop yields and minimize the extremes from weather modification was recognized as a further benefit to farming operations, beyond the yield increases shown in Table 7. In fact, some stabilizing of crop production could be one of the greatest potential benefits of added precipitation through weather modification (Changnon et al, 1977).

Table 8 shows that the percentage response of corn to 10% additional precipitation during July and August is more than 2.5 times greater in dry years than wet years. Although the potential probability exists, precipitation additions during wet periods in the Corn Belt generally has little value since water supplies are usually already adequate or excessive.

The production response of corn to additional precipitation in stress years applies to the various portions of the Corn Belt, as well as to the entire Corn Belt. This is shown in Table 9. Response to additional precipitation in Indiana and Ohio is very large in dry years, but very negligible in wet years. In Illinois and Indiana, the largest response in corn and soybeans comes during dry years.

Increases in precipitation of the order of 5 to 10% over substantial midwestern areas would cause observable increases in agricultural production at a cost significantly less than the value of the product. Weather modification

Table 7. Annual Average National Additional Production of Selected Commodities and Goods, Based on 10 Percent Additional Precipitation and 30 Percent Reduction in Hail Damage During Critical Periods in Main Production Areas[a].

Crops/Goods	Additional Quantity Produced ($\times 10^6$)
Corn	
Added precipitation	38.0 bu
Reduced hail	8.4 bu
Total	46.4 bu
Wheat	
Added precipitation	34.0 bu
Reduced hail	30.6 bu
Total	64.6 bu
Soybeans	
Added precipitation	18.4 bu
Reduced hail	4.7 bu
Total	23.1 bu
Western range	
Forage	52,500 lb
Range cattle	4,375 lb
Irrigation water	
Added orographic snowpack	10.0 acre-ft

[a]Quantities shown are for illustrative purposes only and *do not* imply a weather modification capability.

Table 8. Average Percentage Change in Yield, Various Crops, for Dry, Normal, and Wet Years with a 10 Percent Increase in Precipitation.

Crop	Dry Years[a]	Normal Years[a]	Wet Years[a]
Corn[b]	2.8	2.2	1.1
Wheat[b]	2.3	2.3	2.5
Range forage[c]	8.5	8.5	8.5
Soybeans[b]	3.0	3.3	3.6

[a]Each category consists of one-third of total sample.
[b]Main production areas.
[c]17 western states west of 100°W meridian.

Table 9. Average Percentage Changes in Yields from 10 Percent Precipitation Augmentation (July-August Rainfall).

State or Region	Corn	Soybeans
Illinois		
Dry	+3.9	+2.8
Normal	+2.3	+2.5
Wet	+2.3	+0.7
Indiana		
Dry	+4.7	+3.4
Normal	+2.3	+2.9
Wet	+0.3	+2.0
Iowa		
Dry	+1.9	+0.3
Normal	+1.3	+1.6
Wet	+1.1	+3.4
Missouri		
Dry	+2.6	+1.4
Normal	+2.1	+2.8
Wet	+2.0	+4.4
Ohio		
Dry	+4.4	+6.6
Normal	+3.3	+6.7
Wet	+0.2	+7.8
Corn Belt		
Dry	+2.8	+3.0
Normal	+2.2	+3.3
Wet	+1.1	+3.6

Table 10. Variable-Change and Constant-Change Seeding Models Used to Modify Naturally Occurring Rainfall.

Daily rainfall (inches)	Variable percentage change for given model						
	E	A	B	C	X	Y	Z
0.10 or less	150	100	75	50	−50	−75	−100
0.11–0.50	75	50	30	20	−30	−50	−75
0.51–1.00	30	20	10	0	−10	−30	−50
Over 1.00	10	0	−10	−20	0	−15	−50
Constant-change model percentages	40	25	12		−15	−30	

was noted by the NAS report to be most advantageous when employed along with other modern agricultural technologies.

Illinois Simulation Research

In an Illinois study (Huff and Changnon, 1972) two types of hypothetical seeding models were used to simulate yield effects using crop yield-weather regression equations developed for several state regions (Figure 6). One type of seeding model (the constant-change model) investigated the effects of various constant percentage increases applied to the naturally occurring monthly rainfall. The second model type (the variable-change model) was considered more realistic. It assumed that seeding effectiveness is altered with the intensity of naturally-occurring daily rainfall. The variable change models were applied to the daily rainfall values in each of the crop regions (see Figure 6) for each of the 38 years investigated (1931-1968). Three constant change models and 7 variable change models were used and these covered the expected range of a future seeding capability.

Figure 6 shows the locations of the 13 regions of equivalent yield characteristics in the Illinois study. Each has a soil-weather relationship that is essentially unique and is based on county weather-yield relations (Changnon and Neill, 1967). Table 10 shows the hypothetical models used in the Huff and Changnon (1972) study. The upper part shows the percentages assigned to each of the variable change models. For example, model A which is used frequently for illustrative purpose, assumes a 100% rainfall increase on days with naturally-occurring rainfall of 0.01 to 0.1 inch, but none for rains ≥1 inch. Essentially three increase models were used (E, A, and B), along with a crossover model, C, and three decrease models, X, Y, and Z. In the lower part of Table 10, the constant change models are shown.

Figure 7 illustrates the differential effect of seeding operations on corn over periods of 1 to 5 years of project duration. Probability curves are shown for corn yield changes in bushels per acre for model A in region 11S in south central Illinois, an area with poor soil conditions. Table 11 shows the similar values for all 13 state areas and for seeding operations of 1 to 5 years. As might be expected, the possibility of a major benefit is typically greater in a 1-year operation (selected at random), but the possibility of a disbenefit (a loss in yield) is also greater with short period operations, as shown in Figure 7.

In Figure 8, the variance in seeding benefits that may occur between regions of Illinois is shown (Swanson et al, 1972). The difference in benefits between different models in the same region is illustrated in Table 12. Figure 8 shows the comparative frequency distributions for corn in three regions, based on model A and a single year type of operation. As indicated by the intersection of regional curves with a 0 yield-change line, the probability of a yield benefit is 92% for region 3 in east central Illinois. Table 12 provides the comparative corn yield changes obtained from the use of variable change models based on continuous seeding operations in all regions. It is apparent that the rainfall yield from seeding must be well understood under operational conditions to benefit materially corn yields over a substantial period of time in Illinois. The decrease models (X, Y, and Z) are essentially nonbeneficial, and the variable increase models of E and A are the best.

Table 13 provides an additional measure of the economic benefits that can be derived from application of variable change seeding models. A comparison is shown of the added income per seeded acre that the various models can produce, based on median values in the 13 regions. This also provides an indication

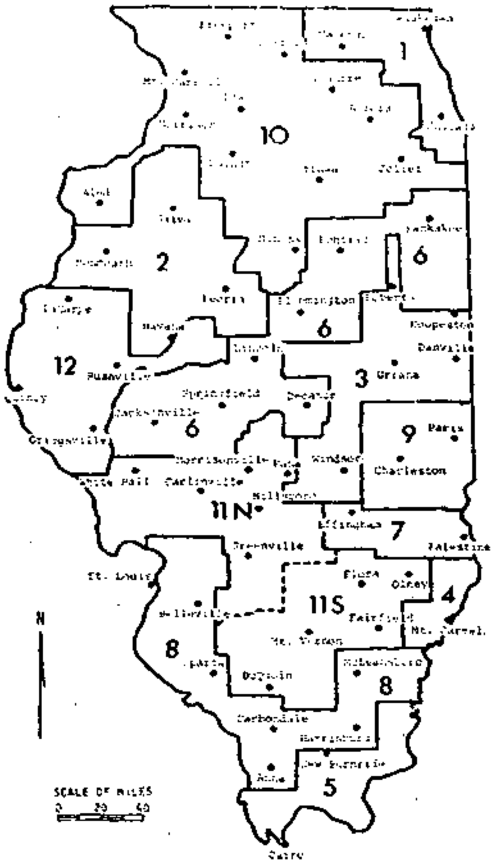

Figure 6. Location of Regions and Rainfall Sampling Stations.

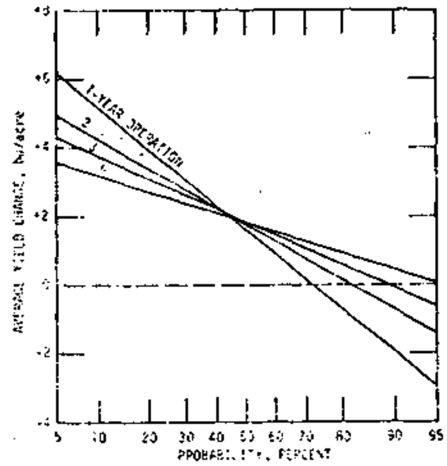

Figure 7. Effect of Seeding Operation Length on Average Yield Changes in Region 11S with Model A.

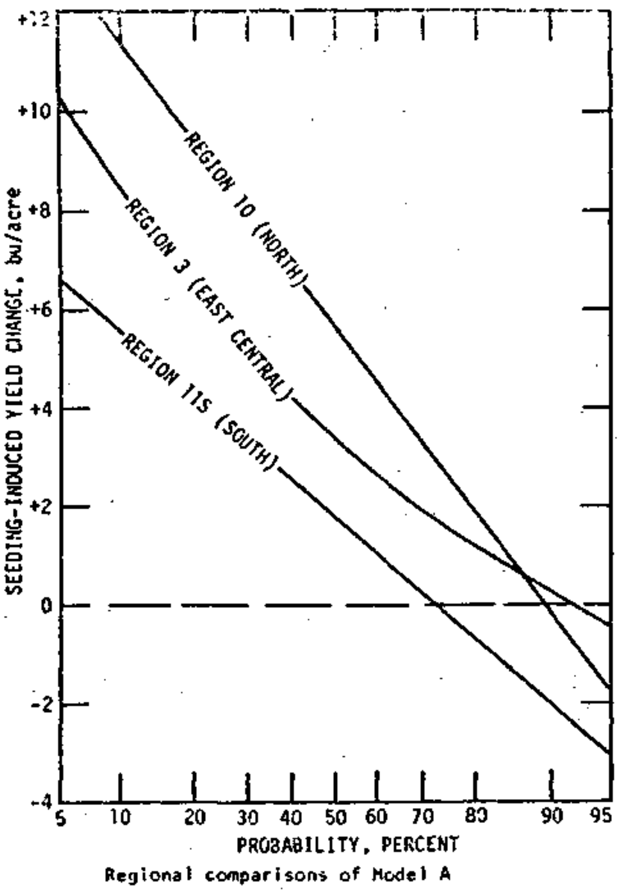

Figure 8. Comparative Frequency Distributions of Seeding-Induced Corn Yield Changes.

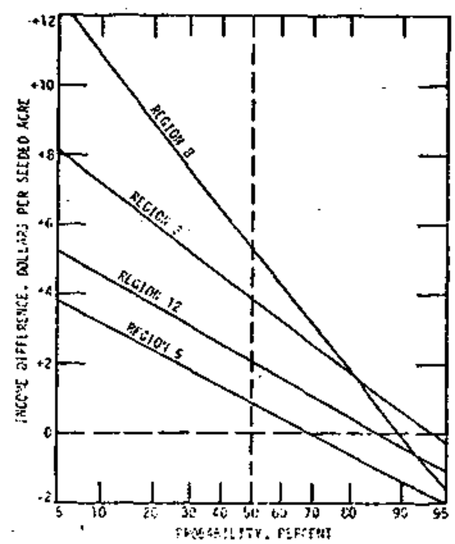

Figure 9. Variation of Economic Benefits Between Regions With Variable-Change Optimum Model.

Table 11. Frequency Distribution of Corn Yield Changes Resulting from Application of Seeding Model A for Durations of 1 to 5 Years with 1968 Technology.

	Yield change (bu/acre) for given probability (%) and seeding duration (yrs)											
Region	10	20	30	5?	70	90	10	20	30	50	70	90
	1-year operation						2-year operation					
1.	10.4	7.2	5.0	1.3	-2.4	-7.6	8.1	5.9	4.1	1.2	-1.8	-6.1
2	4.5	3.3	2.6	1.5	0.4	-1.2	4.0	3.1	2.5	1.5	0.6	-0.9
3	8.3	6.5	5.2	3.5	2.0	0.2	6.?	5.8	4.9	3.7	2.5	0.7
4	8.1	6.5	5.5	4.2	3.0	0.4	7.2	5.8	5.0	4.0	3.1	1.3
5	1.2	0.5	0.0	-0.9	-1.7	-2.9	0.8	0.2	-0.2	-0.8	-1.5	-2.4
6	5.6	4.0	2.8	C.9	-1.2	-4.8	5.2	3.6	2.4	0.6	-1.3	-4.0
7	12.6	9.3	7.5	5.9	5.0	3.0	10.2	8.5	7.5	6.3	5.4	3.3
8	8.0	6.1	4.8	2.7	0.5	-2.7	6.0	4.8	3.9	2.5	1.1	-0.9
9	13.0	9.2	7.3	5.3	3.5	1.0	10.9	8.2	7.8	5.3	4.1	2.5
10	11.8	9.6	8.1	5.5	3.0	0.1	9.8	8.3	7.2	5.5	3.7	1.6
UN	8.2	6.0	4.7	3.3	1.5	-0.6	7.4	5.7	4.7	3.2	2.0	C.5
US	4.7	3.6	3.0	2.0	0.8	-1.5	4.0	2.9	2.5	1.9	1.1	-0.6
12	2.8	2.3	1.9	1.2	0.2	-1.0	2.3	.1.9	1.5	1.0	0.4	-0.5
	3-year operation						5-year operation					
1	7.4	5.1	3.5	0.9	-1.8	-5.8	6.5	4.6	3.2	1.0	-1.3	-4.5
2	3.2	2.6	2.2	1.5	0.8	-0.2	2.6	2.0	1.7	1.2	0.9	0.5
3	6.4	5.5	4.8	3.7	2.7	0.8	5.9	5.3	4.5	3.6	2.6	1.2
4	6.6	5.4	4.7	3.8	3.0	1.4	6.5	5.6	5.0	4.0	3.1	1.6
5	0.5	0.0	-0.3	-0.8	-1.4	-2.2	0.3	-0.1	-0.4	-0.9	-1.4	-2.1
6	4.3	2.8	1.8	0.3	-1.2	-3.3	4.1	2.7	1.8	0.4	-0.9	-2.4
7	9.4	8.2	7.5	6.4	5.5	3.8	8.5	7.6	7.1	6.2	5.5	4.1
8	4.9	4.0	3.4	2.3	1.2	-0.4	4.2	3.6	3.1	2.3	1.5	0.4
9	9.8	8.1	7.7	5.3	4.3	3.4	8.6	7.6	6.9	5.7	4.9	3.9
10	8.5	7.3	6.4	5.2	4.0	2.3	7.2	6.3	5.8	5.0	4.4	3.7
11N	6.5	5.3	4.8	3.3	2.2	0.3	5.4	4.7	4.2	3.4	2.5	1.4
11S	3.5	2.9	2.6	2.0	1.3	-0.1	3.0	2.7	2.4	2.0	1.5	0.5
12	2.0	.1.7	1.4	1.2	0.5	-0.2	1.8	1.5	1.3	1.0	0.3	0.0

Table 12. Average Yield Differences for Corn Resulting from Continuous Application of Variable-Change Models.

Region	Yield differences (bu/acre) for each given model						
	E	A	B	C	X	Y	Z
1	-1.0	+0.8	+1.2	+1.0	-2.3	-5.7	-11.6
2	+2.8	+1.4	+0.2	-0.7	-1.6	-3.1	-4.6
3	+6.2	+3.5	+1.8	+0.5	-0.8	-2.8	-4.9
4	+4.5	+3.8	+2.6	+1.3	-2.4	-6.3	-12.0
5	-2.1	-1.1	-0.3	+0.3	+0.5	+1.3	+1.8
6	+0.5	+0.5	-0.2	-1.1	-3.6	-6.9	-11.8
7	+11.0	+6.7	+3.0	-0.1	-3.6	-8.9	-14.6
8	+4.8	+2.4	+0.3	-1.4	-3.9	-7.3	-11.0
9	+11.4	+5.9	+1.8	-1.2	-3.1	-6.9	-9.7
10	+9.6	+4.2	+1.7	-2.0	-7.4	-15.8	-26.8
11S	+3.3	+1.8	+0.4	-0.7	-2.1	-4.3	-6.9
11N	+5.9	+3.2	+1.0	-0.8	-2.5	-5.4	-8.3
12	+1.4	+0.3	+0.3	-0.4	-1.5	-3.1	-5.3
Median	+4.5	+2.4	+1.0	-0.7	-2.4	-5.7	-9.7
Average	+5.2	+2.6	+0.9	-0.9	-3.7	-7.8	-13.1

Region	Yield difference (%) for each given model						
	E	A	B	C	X	Y	Z
1	-1.2	+0.9	+1.4	+1.2	-2.7	-6.8	-13.8
2	+3.1	+1.5	+0.2	-0.8	-1.7	-3.4	-5.0
3	+6.6	+3.7	+1.9	+0.5	-0.9	-3.0	-5.2
4	+6.5	+5.5	+3.7	+1.9	-3.4	-9.0	-17.2
5	-3.5	-1.8	-0.5	+0.5	+0.8	+2.1	+3.0
6	+0.5	+0.5	-0.2	-1.2	-3.9	-7.4	-12.7
7	+14.6	+8.9	+4.0	-0.1	-4.8	-11.9	-19.4
8	+6.8	+3.4	+0.4	-2.0	-5.5	-10.3	-15.5
9	+12.3	+6.4	+1.9	-1.3	-3.3	-7.4	-10.5
10	+10.1	+4.4	+1.8	-2.1	-7.8	-16.7	-28.3
11N	+6.8	+3.7	+1.2	-0.9	-2.9	-6.3	-9.6
11S	+4.9	+2.7	+0.6	-1.0	-3.1	-6.4	-10.3
12	+1.5	+1.0	+0.3	-0.4	-1.6	-3.4	-5.7
Median	+5.2	+2.8	+1.2	-0.8	-2.8	-6.6	-11.2
Average	+5.8	+2.9	+1.0	-1.0	-4.1	-8.7	-14.6

Table 13. Comparison of Added Income Per Seeded Acre with Various Seeding Models, Based on 13-Region Medians.

Model	Added income per acre (dollars) equalled or exceeded for given probability (%)								Breakeven Point (%)
	5	10	20	30	50	70	90	95	
Optimum	12.5	11.0	9.0	7.4	5.4	2.8	0.0	-1.6	92
E	12.4	10.5	8.8	7.1	4.2	2.5	-0.9	-3.2	85
A	8.6	7.4	6.1	4.9	2.5	0.8	-0.9	-1.9	77
B	5.8	4.4	3.8	2.6	1.1	-0.2	-2.6	-3.6	66
C	3.4	2.4	1.6	0.8	-0.4	-1.4	-3.8	-5.1	42
X	1.2	-0.1	-0.9	-1.5	-2.6	-3.8	-5.6	-8.8	10

of statewide benefits that could be attained. For each model, Table 13 shows the added income for selected probability levels. Also the breakeven point, or probability of an economic gain in year selected at random, is shown. For example, assuming the entire state was being subjected to a seeding program, model A indicates the probability of an income increase of $8.6 per acre in 5% of the years (on a typical farm), a $2.5 or greater increase in 50% of the years, and a loss of $1.9 or more in 5% of the years (the 95% level). On the average Illinois farm, the application of model A would achieve an economic gain in 70% of the years. It is important to note however, that in these economic analyses, the State of Illinois was treated as a distinct entity without an economic interaction between the crop yield changes and national market prices.

Huff and Changnon (1972) also considered another aspect, the differential effect of seeding on various crops in a given region. Table 14 shows these inter-relationships between corn and soybeans. In region 3 in central Illinois, it was found that model A would have helped both corn and soybean crops in 22 out of the 38 years in the sampling period, and would have harmed both yields of crops in two years. In the remaining 14 years corn would have benefitted while soybeans were having their yields slightly depressed by the model A seeding. The 13-region (statewide) average for model A showed both crops helped in 27 years, both harmed in 3 years, and differential effects in 8 years.

Table 15 summarizes the average effect of seeding-induced rainfall on corn and soybean yields through use of variable change models. State average yields changes are shown for the two crops with each model. It is apparent that the percentage yield change is very similar for the two crops and the various models. This also shows that rain increase models are desirable, on the average, and that relatively large percentage increases in July-August rainfall, as typified by model E, would be most desirable in Illinois.

Table 14. Frequency Distribution of Years Seeding Helped or Hurt Corn and Soybean Yields with Model A.

Region	Total number of years				Number of years		Number of times helped in opposite effect years	
	Corn		Soybeans					
	Helped	Hurt	Helped	Hurt	Both Helped	Both Hurt	Corn	Soybeans
1	25	13	32	6	24	5	1	8
2	31	7	17	21	13	3	18	4
3	35	3	23	15	22	2	13	1
4	33	5	35	3	33	3	0	2
5	13	25	17	21	8	16	5	9
6	21	17	30	8	20	7	1	10
7	37	1	38	0	37	0	0	1
8	30	8	33	5	30	5	0	3
9	37	1	37	1	37	1	0	0
10	36	2	32	6	31	1	5	1
11N	32	6	35	3	31	2	1	4
11S	31	7	32	6	26	1	5	6
12	28	10	29	9	27	8	1	2
Median	31	7	32	6	27	3	1	3
Average	30	8	30	8	26	4	4	4

Table 15. State Averages of Yield Changes Associated with a Continuous Seeding Program Using Variable-Change Models.

Average yield change	Yield change for given model						
	E	A	B	C	X	Y	Z
				Corn			
Bushels per acre	+5.2	+2.6	+0.9	−0.9	−3.7	−7.8	−13.1
Percent	+5.8	+2.9	+1.0	−1.0	−4.1	−8.7	−14.6
				Beans			
Bushels per acre	+1.2	+0.8	+0.3	−0.2	−1.2	−2.5	−4.2
Percent	+4.2	+2.8	+1.0	−0.7	−4.2	−8.7	−14.7

Another analysis was made to determine the economic gains that would result from progressively improving capability to augment the natural rainfall in the July-August period. For this purpose, a starting capability corresponding to variable model C (see Table 10) was assumed. In these studies, it was assumed that seeding effectiveness could gradually be increased in time from that represented by model C to models B, A, and E. Results are illustrated in Table 16 for five regions of Illinois. In central Illinois (region 3) improving the seeding capability from model C to B would result in a median income gain of $1.05 per seeded acre. Additional improvements from B to A would provide a gain of $1.05 per acre. The overall gain in going from a C capability to a model E capability would be $3.20 per seeded acre in central Illinois.

Table 17 provides an additional measure of the economic benefits that could be derived from the application of variable change seeding models. No cost of seeding is included. A comparison has been shown of the added income per seeded acre with various models, based on median values for the 13 regions (Swanson et al, 1972). This provides an indication of the statewide benefits that could be attained. For example, assuming the entire state was subjected to a seeding program, model A indicates the probability of income increase of $8.6 per acre in 5% of the years on a typical farm.

Figure 9 (page 22) is based upon the use of variable change "optimum" model (defined as the choice of the model that performed best in a given year), and it illustrates how the economic benefits may vary between individual regions. This shows that region 8 (with clay soils) has the highest median income benefit among the regions shown, but its year-to-year gain has a substantially greater range. The differences shown are related strongly to the soil properties of the region and to a lesser extent to the climatological differences in daily rainfall distributions.

Table 16. Comparison of Median Income Gain with Improving Seeding Capability.

Region	Model Sequence	Gain (Dollars) Per Seeded Acre
3	C-B	1.05
	B-A	1.05
	A-E	1.10
6	C-B	1.35
	B-A	1.60
	A-E	1.05
10	C-B	3.40
	B-A	3.40
	A-E	3.60
11S	C-B	1.70
	B-A	2.00
	A-E	1.90
12	C-B	0.85
	B-A	0.90
	A-E	0.80
State Average	C-B	1.98
	B-A	2.15
	A-E	1.98

Table 17. Comparison of Added Income per Seeded Acre with Various Seeding Models, Based on 13-Region Medians.

Model	Added income per acre (dollars) equalled or exceeded for given probability (%)								Break-even point (%)
	5	10	20	30	50	70	90	95	
Optimum	12.5	11.0	9.0	7.4	5.4	2.8	0.0	−1.6	85
E	12.4	10.5	8.8	7.1	4.2	2.5	−0.9	−3.2	85
A	8.6	7.4	6.1	4.9	2.5	0.8	−0.9	−1.9	77
B	5.8	4.4	3.8	2.6	1.1	−0.2	−2.6	−3.6	66
C	3.4	2.4	1.6	0.8	−0.4	−1.4	−3.8	−5.1	42
X	1.2	−0.1	−0.9	−1.5	−2.6	−3.8	−5.6	−8.8	10

Table 18. Estimated Results for Crop Production in Terms of Average Net Income (Dollars per Acre).

Strategy			*Northeast Kansas: wheat*	*Southwest N. Dakota: wheat*	*N-central Iowa: corn/soybeans*	*E-central Illinois: corn/soybeans*	*W-central Texas: cotton*	*Central N. Carolina: tobacco*
A	**No hail insurance, no hail suppression**		25.58	7.52	53.93	49.55	1.89	361.06
Hail insurance strategies								
B	**Value of production**		25.25	7.08	60.05	50.05	3.12	330.13
C	**40% deductible on value of production**		25.91	7.42				
D	**Cost of production**		25.44	7.18	57.04	49.82	3.99	331.21
E	**40% deductible on cost of production**		25.78	7.44				
F	**All-risk crop insurance**		24.86	7.13	53.29			
G	**All-risk and cost of production hail insurance combined**		24.52	6.69	59.42			
Hail suppression possibilities								
	Reduction in crop damage	***Change in rainfall***						
H	**20%**	**10% decrease**	22.60	7.42	52.40	47.46	1.70	343.83
I	**20%**	**no change**	25.74	7.62	55.50	49.63	3.57	364.21
J	**20%**	**10% increase**	28.47	7.83	58.62	51.80	5.43	385.54
K	**50%**	**10% decrease**	22.34	9.18	56.35	48.33	9.01	350.32
L	**50%**	**no change**	27.35	9.40	59.45	50.50	9.86	370.71
M	**50%**	**10% increase**	30.11	9.62	62.58	52.67	11.75	392.03
N	**80%**	**10% decrease**	25.98	11.35	60.30	49.20	14.72	356.82
O	**80%**	**no change**	29.12	11.56	63.40	51.37	15.64	377.20
P	**80%**	**10% increase**	31.88	11.67	66.53	53.54	17.60	398.53

In general, the Huff-Changnon analytical results on the effects of simulated rainfall increases indicate that in all regions of Illinois, corn and soybeans crops would be benefitted economically, in the majority of the growing seasons, through a cloud seeding program, provided that the seeding had a capability to produce rainfall increases of 10% or more in July and August. However, clear definition of the rainfall changes from the seeding treatment must be known, or damage, rather than benefit, could result. Reaction to potential seeding was found to vary substantially between regions in Illinois when the same seeding capability (model) was applied.

Hail Suppression and Joint Rainfall Modification

In a recent technology assessment addressing hail suppression, economic impacts of hail suppression and the related modification of summer rainfall was addressed, primarily as it would affect the individual farmer. To account for the year-to-year variability of hailstorms, the individual farmer-analysis considered both the average income and the variability of income for various strategies the farmer could adopt (Changnon et al, 1977). Historic yield variability coefficients and present day technology were used to create net income for each strategy in the prospective of a farmer contemplating his next season production decision. For each of the several strategies considered, the previously described process generated a net income estimated for each year of the simulation series. These estimates were then averaged, as shown in Table 18, and an estimate of the early income variability was determined for each strategy. Table 18 presents the coefficient of variation for Illinois and the five other areas considered. Only the more attractive strategies are presented in these tables.

In the Illinois regions, with no hail insurance or hail suppression, the average net income was estimated to be $49.50 per acre, based on simulations for 1948-1974. The standard deviation of the net income series was only $11.83, resulting in a coefficient of variation of 24. These estimates are specific to Macon County in central Illinois. Hail losses in this area are much less than in the other western areas. Hail losses average only 1.5% for corn and 3.7% for soybeans. Hail insurance strategies lead to lower income variation, as indicated by the reduced coefficients of variations in Table 19. Because of the slight hail losses in Illinois, hail suppression results in relatively minor benefits, to a farmer, either in terms of average income or variability of income. The 80% effectiveness level with no rainfall changes (strategy 0 in table) contributes only a 4% increase in average net farm income. Ten percent rainfall fluctuations in the months of June through August are positively related to a 4 to 5% change in net income at each of the three (20, 50, and 80%) hail damage reduction levels. At any given hail reduction level, the income increase due to a 10% increase in rainfall is about $2.00 which is a 4 to 5% gain. Comparison of the no-change and the 10% increase in rainfall for 20% hail loss (Table 19) provides a reduction in the coefficient of variation of income from 23 to 22. The relative importance of the three rainfall strategies, labeled as J, M, and P, are shown in Figure 10. None of these 10% summer rainfall increases have sizeable income influences, but they are much greater than the hail suppression benefits, either for the reduction of income variations, or increases in income.

Table 19. Estimated Results for Crop Production in Terms of Coefficient of Variation.

Strategy	Northeast Kansas: wheat	Southwest N. Dakota: wheat	N-central Iowa: corn/soybeans	E-central Illinois: corn/soybeans	W-central Texas: cotton	Central N. Carolina: tobacco
A No hail insurance, no hail suppression	117	273	34	24	2715	100
Hail insurance strategies						
B Value of production	106	264	15	20	1592	108
C 40% deductible on value of production	105	256				
D Cost of production	106	257	18	21	1276	108
E 40% deductible on cost of production	109	253				
F All-risk crop insurance	116	269	30			
G All-risk and cost of production hail insurance combined	110	278	19			
Hail suppression possibilities (Reduction in crop damage; Change in rainfall)						
H 20%, 10% decrease	130	265	31	24	3047	104
I 20%, no change	115	258	29	23	1461	99
J 20%, 10% increase	106	252	27	22	963	93
K 50%, 10% decrease	119	205	20	22	598	102
L 50%, no change	107	201	19	21	551	97
M 50%, 10% increase	99	197	18	21	464	91
N 80%, 10% decrease	111	168	14	21	390	100
O 80%, no change	100	166	13	20	370	95
P 80%, 10% increase	93	166	12	20	330	90

Table 20. Effects of Summer Precipitation Anomalies on Crop Yields in Effect Area.

	Yield, bushels/acre Corn	Soybeans
Net yield shifts, all summers	+2.6	+1.3
Hail-wind losses	−0.6	−0.2
Yield shifts without hail-wind losses	3.2	1.5
Predicted shifts based on average rain changes input into rain-crop yield equations (Changnon and Neill, 1966; Changnon, 1968)	+2 to +3	+1 to +2

Table 21. Attitudes of Illinois Citizens Toward Weather Modification Issues. (in percent of the total in each column)

Position toward types of hail suppression program	Experimental	Operational
Strongly oppose	5	9
Oppose	16	19
Neutral	25	39
Favor	48	30
Strongly favor	6	3

Can weather modification	Increase moisture?	Decrease hail?
No	11	14
Perhaps, doubt it	4	4
Don't know	31	62
Think so	15	7
Yes	39	13

Decision making about experimental hail or rain program in Illinois	Who should decide?	Who will decide?
Don't know	7	13
Local residents	49	20
Federal alone	1	4
State alone	28	44
State + federal	6	8
Scientists & others	9	8

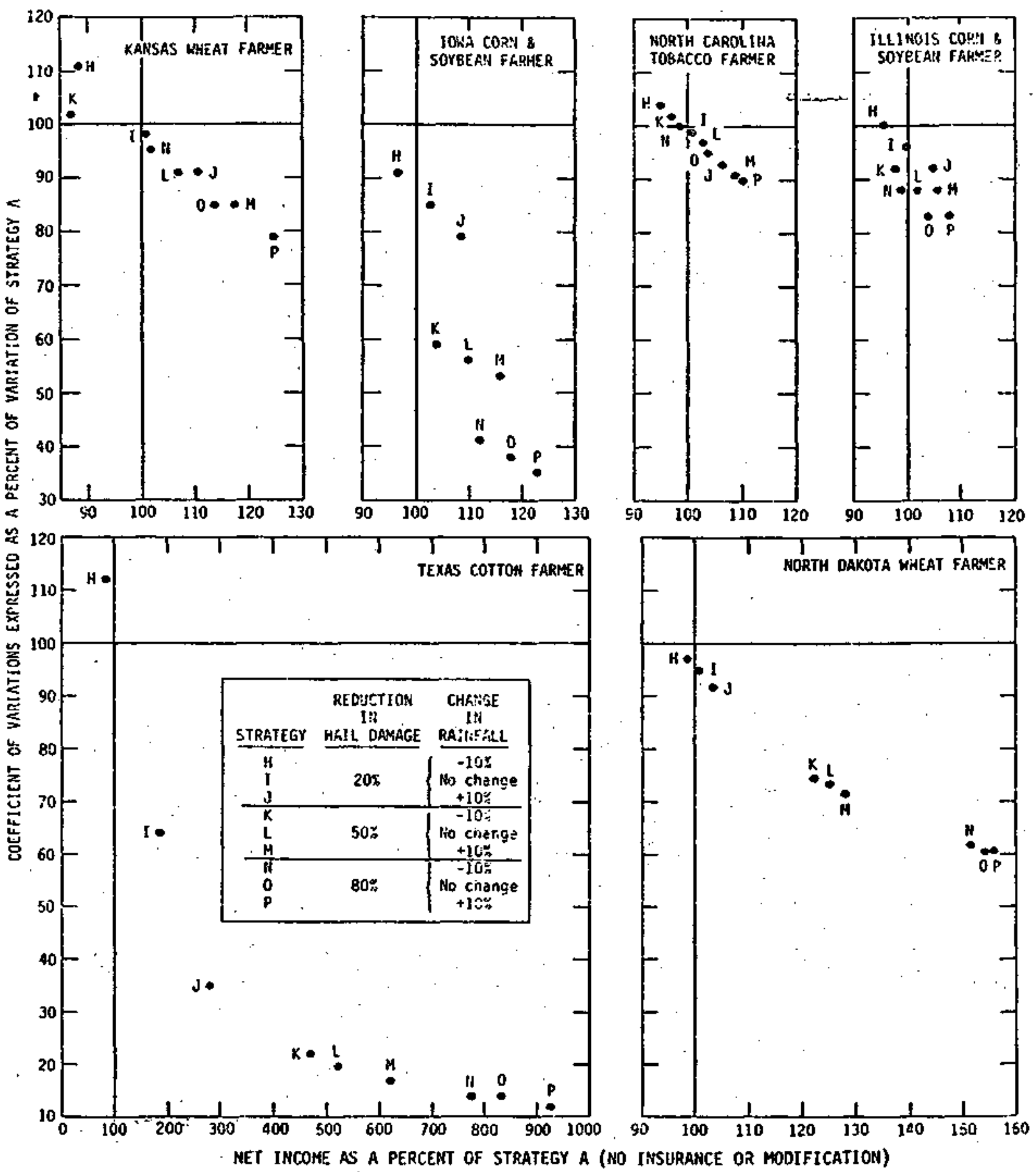

Figure 10. How Net Incomes Change by Strategies and Regions.

Impacts of Inadvertent Weather Modification

The 1971-1975 METROMEX studies at St. Louis revealed a variety of changes in summer precipitation conditions due to urban influences. In a 2-county area east of St. Louis, the average rainfall was increased from 5 to 30% coupled with additional storminess including 25 to 80% increases in hail, thunderstorms, heavy rainfall rates, and frequency of heavy rainstorms. Obviously, these changes impact in a variety of ways on agricultural production and agricultural activities.

Figure 10a presents results for a study of corn yield differences. It involved a double target-control analyses done for the pre-urban effected era (1930-1945) and the urban-effected era (1961-1976) and for two regions (the target or effect area and the control area). The differences between the "target" influenced area and the control areas are shown by types. No yield change appeared in wet seasons, and the greated change (4.9 bu/acre) occurred in the dry summer seasons (Changnon et al, 1977b).

The results of the yield analyses are summarized in Table 20 (page 32). These show that the yield increases in corn and soybeans, without the target's associated hail-wind losses, would be 3.2 bu/acre for corn and 1.5 bu/acre for soybeans. Studies of crop-yield and weather relationships using 1931-1965 data in the area (Changnon and Neill, 1967) indicated that the observed rainfall increases in July and August should produce increases of this magnitude. The yield shifts (Table 20) without the hail-wind losses are as great as those predicted by the urban rain increase when inserted in weather-yield regression relationships. The gains from the summer rainfall increases have essentially overcome the losses due to added hail and wind, and any presumed decreases due to added atmospheric pollution and soil erosion. The net yield increases, as shown in Table 20, are 2.6 bu/acre for corn and 1.3 bu/acre for soybeans.

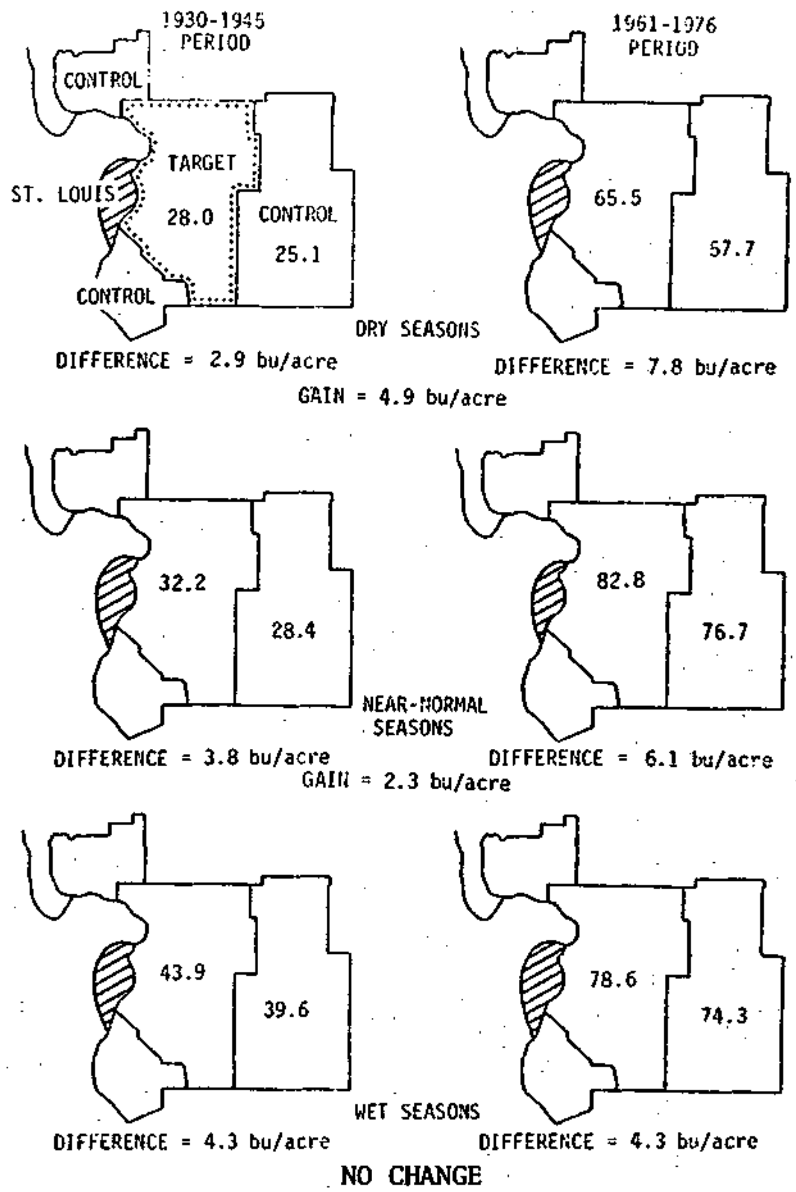

Figure 10a. Average Corn Yields in the Target and Control Counties in Wet and Near-Normal and Dry Summers for 1930-1945 and 1961-1976 Periods.

The average farm acreage in the effect (target) area has, since 1961, been 56 acres in corn and 69 acres in soybeans. Coupling the net yield increases (Table 20) with these acreages indicates that the average impact (benefit) of the altered weather on a typical farm has been 146 more bushels of corn per year and 90 more bushels of soybeans. Extending these values to the 2-county effect area (2642 farms) reveals a regional annual increase of 385,732 bushels of corn and 237,000 bushels of soybeans. The 10% average July-August rain increase over the 2-county area produces a 3% (corn) to a 4% (soybeans) increase in the major crop yields.

Translation of these values to monetary gains depends on price assumptions. In recent years prices have typically been $2.00 per bushel for corn and $6.00 per bushel for soybeans. Use of these values and the average yield gains per farm (for 1961-1976) indicates a net monetary gain per farm of $832 ($292 for corn and $540 for soybeans).

The gains for the effect area are sizeable. The added corn production (at $2.00 per bushel) is $771,464, and that for soybeans (at $6.00 per bushel) is $1,422,000. Thus, the average area gain at these prices has been about $2.2 million per year.

The yield gains are greatest in dry summers (7.5% for corn and 6.0% for soybeans) when the increases are of appreciable value to the farmers. In the wet summers no corn yield effect is realized and that to soybeans (1 bu/acre or 3%) is slight. This greater increase in dry and near-normal summers with little or no increase in wet summers has resulted in a more stable farm income. Thus, there has been both greater income and more income stability from this locally modified weather.

Effects on Agricultural Practices

The previously described effects on crop production of the urban-induced rain anomaly had further, third-order impacts on agricultural practices and related activities (Changnon et al, 1977). Some local farmers perceived their local weather-related yield benefits (and losses due to more severe storms), and they adjusted to them in several ways.

One way for a farmer to adjust to the weather is in his crop planting strategies. Temporal shifts of acres planted in soybeans or corn in the effect area, as opposed to acreage shifts in the 5-county area, were studied. The net yield analysis showed that the owner (and tenant) of an average farm gained $832 annually due to the urban weather anomaly, and most of this increase ($540, or 65%) was due to increases in soybean yields.

The soybean acreage shifts showed a relative gain of 6% in the number of acres planted in the effect area, as compared to those in the control area. A similar analysis of the corn acreage showed a relative decrease with the growth in acreage planted to corn in the effect area being 10% less than the growth in the control area.

Another possible reflection of the impact of the urban weather anomaly on yields was in the value of agricultural lands. The temporal shift, revealed in the comparison of effect and control area values, showed a 3.6% greater increase in the values of agricultural land in the effect area.

Other impact studies in the effected area east of St. Louis showed that the additional hail led to purchases of 12% more crop-hail insurance liability in the effect areas, as opposed to the control area. This has not yet been reflected in insurance rates. Similarly, the higher rainfall rates and increased erosion have led to different design criteria being used by the Soil Conservation Service in the area. In the net, the analyses of the impacts due to the St. Louis summer rainfall modification reveal that the agricultural interests (farmers and agribusinesses) east of St. Louis have generally benefitted from the rain changes.

PUBLIC ATTITUDES

A public attitude sampling project was conducted in central Illinois during the spring of 1974. The goal was to sample central Illinois citizens so as to gain accurate information a) on the impact of weather on their lives, and b) on their attitudes toward weather modification. Such information was considered an essential part of the design of any future experiment, the advice utlimately given the State on the desirability of such a project, and proper institutional arrangements.

The project was jointly conducted under the direction of Human Ecology Research Services, Inc. (HERS), a Colorado firm experienced in sampling and interpreting weather modification attitudes, and by the Illinois State Water Survey.

Under the direciton of HERS personnel, about 300 persons, chosen at random from the proposed project area in central Illinois, were questioned at length (a typical interview took 45 minutes for 108 questions). These answers were interpreted by HERS, and a report was furnished to the Water Survey (Krane and Haas, 1974).

The interview schedule was composed primarily of items used in previous and on-going field research on the public response to weather modification. Most of the items had been pre-tested in face-to-face telephone interviews in Colorado, Florida, Montana, New York, South Dakota, and Utah.

Interview schedule items were designed to elicit information on the following variables:

1) Attitudes toward weather, weather modification, and science;
2) Belief in the efficacy of cloud seeding technology;
3) Awareness of weather modification activity;
4) Awareness of the Illinois State Water Survey;
5) Evaluation of proposed local programs;
6) Preferred decision-making and funding procedures;
7) Socio-demographic characteristics.

It is important to reiterate that the survey was conducted prior to the start of any local cloud seeding. Thus, Illinois residents had not experienced a weather modification program.

Basically, attitudes about weather and nature (God) in Illinois were found to be similar to those found in other states. Results for 6 of the 108 questions appear in Table 21 (page 32). The majority, 54%, favored an experimental hail suppression program, whereas only 33% favored an operational program. Answers to questions about successful weather modification indicated that 54% believed that moisture could be increased, but only 20% thought hail could be decreased. In fact, 62% just did not know about a hail suppression capability. With regard to decision-making about weather modification, half thought local residents should decide, but only 20% believed locals would decide. There also was a strong indication that the state, rather than the federal government, should and will decide on weather modification in Illinois. Table 22 presents key findings.

Table 22. Summary of 16 Key Findings about Public Attitudes in 1974.

1. The public view toward weather modification in Illinois before any experimental program is favorable.
2. Studies in Colorado and South Dakota prior to the start of local seeding programs resulted in findings very similar to those from Illinois.
3. Although general attitudes toward weather modification in the three states (prior to any seeding program) are comparable, a major difference is that Illinois residents are not as likely to anticipate personal economic benefit from effective cloud seeding programs.
4. Expressions of support for cloud seeding in Illinois:
    a. The majority favored experimentation with cloud seeding to find out if it works (63%). Only one out of five expressed disagreement with the concept of experimentation.
    b. Nearly three-fourths agreed that Illinois state agencies should use such things as cloud seeding if it could help farmers avoid crop losses.
    c. Two-thirds agreed that it is appropriate to try to directly control extreme weather conditions by using the most effectual techniques known.
5. Some expressions of concern or doubt about cloud seeding technology in Illinois:
    a. As many as half agreed with the statement, "... cloud seeding is very likely to upset the balance of nature." However, when asked specifically if cloud seeding might damage the ecology of an area, the proportion dropped to less than one-third.
    b. Nearly one-half (48%) agreed that cloud seeding probably violates God's plans for man and the weather.
    c. The sample was equally divided on the statement, "Man should take the weather as it comes...." (45% agreed; 44% disagreed). A little more than half agreed that alternatives such as cheaper insurance and improved weather forecasting might be preferable to modifying the weather.
6. Belief in the efficacy of cloud seeding:
    a. A little more than half (54%) believed that cloud seeding can be effective for increasing rainfall; only 15% indicated doubt.
    b. With respect to hail suppression, the clear majority felt uncertain about the effectiveness of the technology; only one out of five believed it can be efficacious.
7. Anticipated benefit or harm from a local program:
    a. Few persons felt they would be economically harmed from effective programs for hail suppression (2%), for increasing rainfall (8%), or for decreasing rainfall (15%).
    b. Clearly, persons anticipated personal benefit from a program which could effectively reduce hailfall (60%), and from programs to manage rainfall, either for increasing rain (74%) or for decreasing rain (33%).

Table 22 (continued).

8. Relatively few Illinois respondents were aware of weather modification efforts in general. However, as many as 43% claimed to have heard of programs which attempted to increase rainfall, and 29% claimed to be aware of hurricane modification efforts.

9. Only one respondent (of 274) was aware of Illinois' comprehensive weather modification law.

10. The majority were uncertain or doubted that inadvertent weather modification is changing the weather, but as many as 37% felt that this may be the case. Nevertheless, an overwhelming majority felt that unintended cloud seeding should be better understood before undertaking planned modification efforts.

11. Awareness of the Illinois State Water Survey (ISWS):
    a. A little more than half of the sample claimed they were aware of the ISWS prior to this survey.
    b. Among those claiming knowledge of the agency's existence, one-third said the ISWS is responsible for water resources and water control; 18% said the agency collects weather data; 11% felt the agency engaged in research related to weather and water.
    c. Only one out of 10 knew that the ISWS is conducting a hail research project.
    d. About 60% indicated confidence in the agency to conduct experimental cloud seeding, while one-third were uncertain.
    e. Although one-fourth either did not want such a program, or didn't care whether it is for hail suppression or rainfall management, the most frequently expressed preference was for the program to include both types of experimental cloud seeding.

12. Decision-making regarding local cloud seeding programs:
    a. Nearly half indicated that *local* input should be involved in the decision about a local cloud seeding experiment (32% said local residents, 17% said agriculturalists). However, a large proportion felt that the state government or the ISWS should decide (28%).
    b. With respect to who *will* decide, only one-fifth felt that local input will be considered, while more feel that the state (32%) or the ISWS (11%) will make the decision.
    c. The preferred procedure in Illinois for decision-making regarding an *operational* program was seen as "a referendum submitted to the vote of all citizens in the proposed affected area."

13. Funding regarding local cloud seeding programs:
    a. The most frequent response for both *preferred* and *predicted* funding of a local experiment was the "state government." However, more persons felt that local residents *will* have to contribute (26%) than felt that they *should* pay for such a program (12%).
    b. The most satisfactory arrangements for financing of an *operational* program were thought to be "federal taxes" or "voluntary subscription of farmers." This would seem to indicate that for the present most non-farm respondents would not want support for an operational program to come from a local or state tax base.

Table 22 (continued).

14. Evaluation (favorable toward) of proposed local cloud seeding:
    a. More than half (54%) were in favor of a cloud seeding *experiment* for central Illinois while only one-third favored the notion of an *operational* program at this time. A large number were undecided about both types of programs, while at least one-fifth indicated opposition.
    b. For those favoring the experiment, most felt that it is desirable to determine if cloud seeding is effective for reducing hail damage. Among those opposing the experiment, the major reason given was fear that negative effects on the weather or nature will occur.
    c. Twenty-nine percent anticipated they might take supportive action for an experimental program, while only 8% felt that they would do anything to oppose an experiment.
    d. If the issue of an experimental program came to a vote, 50% felt they would vote in favor, compared to 23% who felt they would vote against the program.

15. Factors contributing to evaluation of a proposed local program:
    a. The best predictors of favorableness toward local cloud seeding experimentation were general attitudes toward weather, weather modification, and science.
    b. Anticipated economic benefit or harm from an effective program predicted moderately well acceptance of an experimental program.
    c. Belief that cloud seeding is efficacious also predicted evaluation of a proposed local program. That is, persons believing that cloud seeding can be effective for reducing hail and increasing moisture were likely to favor a local experiment.
    d. Knowledge of weather modification activities elsewhere in the country showed weak correlation with favorableness toward a local program.

16. Socio-demographic characteristics and their relationship to evaluation of weather modification:
    a. Younger persons were more likely than older persons to be favorable toward the technology and its application; more likely to believe that cloud seeding can be effective; and less likely to feel that adverse side effects might occur from cloud seeding.
    b. Males tended to be more favorable inclined than females toward weather modification. They were more knowledgeable of cloud seeding activities, and less skeptical about potentially disruptive effects resulting from the technology.
    c. Higher educated respondents were generally more favorable toward weather modification, were more knowledgeable, had greater belief that the technology can produce desired results, and were in favor of local experimentation.
    d. Respondents in low income families tended to be opposed to the technology in general and to proposed local programs. Additionally, they did not anticipate personal benefit from the application of cloud seeding, ans were likely to feel that cloud seeding may have adverse side effects.

Table 22 (continued).

e. Rural residents were more likely than small town or city residents to perceive economic benefit from effective hail suppression and rainfall management programs. Also, rural residents were the most likely to favor a local experiment at this time, but they were the least likely to favor direct application of the technology (an operational program).

BIOSPHERIC IMPACTS

The research into the potential impacts of weather modification on the biosphere has been directed to certain biospheric impacts. Included in this has been the background monitoring of silver, the primary material apt to be used in cloud seeding, and the impacts to the water resources and select fauna of the state.

Precipitation and Streamwater Sampling of Silver

The purpose of this work was to measure "background" concentrations of silver (Ag) at locales in south central Illinois (Gatz, 1974). Such an assessment of 1972-1973 conditions was done 1) to obtain baseline values for comparison against Ag concentrations in precipitation collected during any future cloud-seeding experiment or operations; 2) to evaluate the feasibility of using the Ag content of precipitation to identify precipitation treated by seeding material; and 3) to monitor the possible levels and their impacts in the biosphere.

Four precipitation sampling sites and one river sampling site were used to collect samples from November 1972 through May 1973. Precipitation samples were collected for each precipitation event, and river samples were collected at weekly intervals.

A summary of sample collections and analytical results is given in Table 23. All of the river samples collected were analyzed, but only 82 of 138 precipitation samples were found suitable for analysis. This was caused primarily by a lack of sufficient water volume for extraction of Ag. Table 23 also shows mean soluble Ag concentrations, both arithmetic and weighted by rainfall. Arithmetic means give equal weight to each rainfall, and thus ordinarily yield higher concentrations,

Table 23. Summary of Results — Silver in Precipitation and River Samples in Illinois (1972-1973).

Station	Sample Type	Number of Samples Collected	Number of Samples Analyzed	Mean soluble Ag Concentration, ng/liter	
				Arithmetic	Rainfall-weighted
Centralia	Precipitation	7	4	37	14
Forbes	Precipitation	35	31	103	98
Ina	Precipitation	32	28	99	71
Mt. Vernon	Precipitation	34	19	80	69
TOTAL	Precipitation	138	82	93	73
Waltonville	River	24	24	70	--

Table 24. Observed Silver Concentrations in Precipitation (ng/liter).

Area	No Seeding Operations		Seeding Operations		
	Number of Samples	Mean Concentration Observed	Number of Samples	Maximum Concentration Observed	Median Concentration Observed
Sierra Nevada	169	4.2	60	400	20
Eastern Nevada	25	22.0	13	80	55
Bridger Range, Montana	17	36.0	35	20,000	550
Rocky Mountains, Colorado	48	43.0	186	1,000	300
Lake Erie, N.Y.	40	23.0	60	2,000	100

since the lighter rains commonly contain the highest concentrations. The rainfall-weighted mean concentration gives the true average concentration that would result if all the individual rains had been accumulated in one collector (without evaporation) and were analyzed as a single sample.

Mean concentrations (arithmetic) range from 37 ng/liter at Centralia to 103 ng/liter at Forbes State Park. Rainfall-weighted means range from 14 to 98 ng/liter, with the lowest and highest of both means at the same respective stations. Because of the small number of samples, however, the results for Centralia should not be considered representative of that site. Silver concentrations at each sampling station have been plotted against dates of sample collection in Figure 11. Although sample collection was confined primarily to winter, spring, and early summer, no particular seasonal trends are evident, either in the river water, or at any precipitation sampling stations.

The precipitation sampling method allows for the possibility that some Ag found in the precipitation samples may actually have entered the collector by dry deposition. If this were the case, one should expect that Ag deposition would be positively correlated with the duration of sample bottle exposure, although wind speed would probably also be a strong factor. At individual stations, the following correlation coefficients were computed between soluble Ag deposition, pg/cm^2, and sample duration in hours:

Centralia	r = 0.76	(4 samples)
Forbes	r = -0.04	(31 samples)
Ina	r = 0.14	(28 samples)
Mt. Vernon	r = 0.41	(19 samples)

Only the Mt. Vernon correlation is significant at the 10% level.

Aside from merely recording the observed Ag concentrations for possible later comparison against seeded precipitation, it is of interest to compare the concentrations in Illinois precipitation against similar measurements elsewhere.

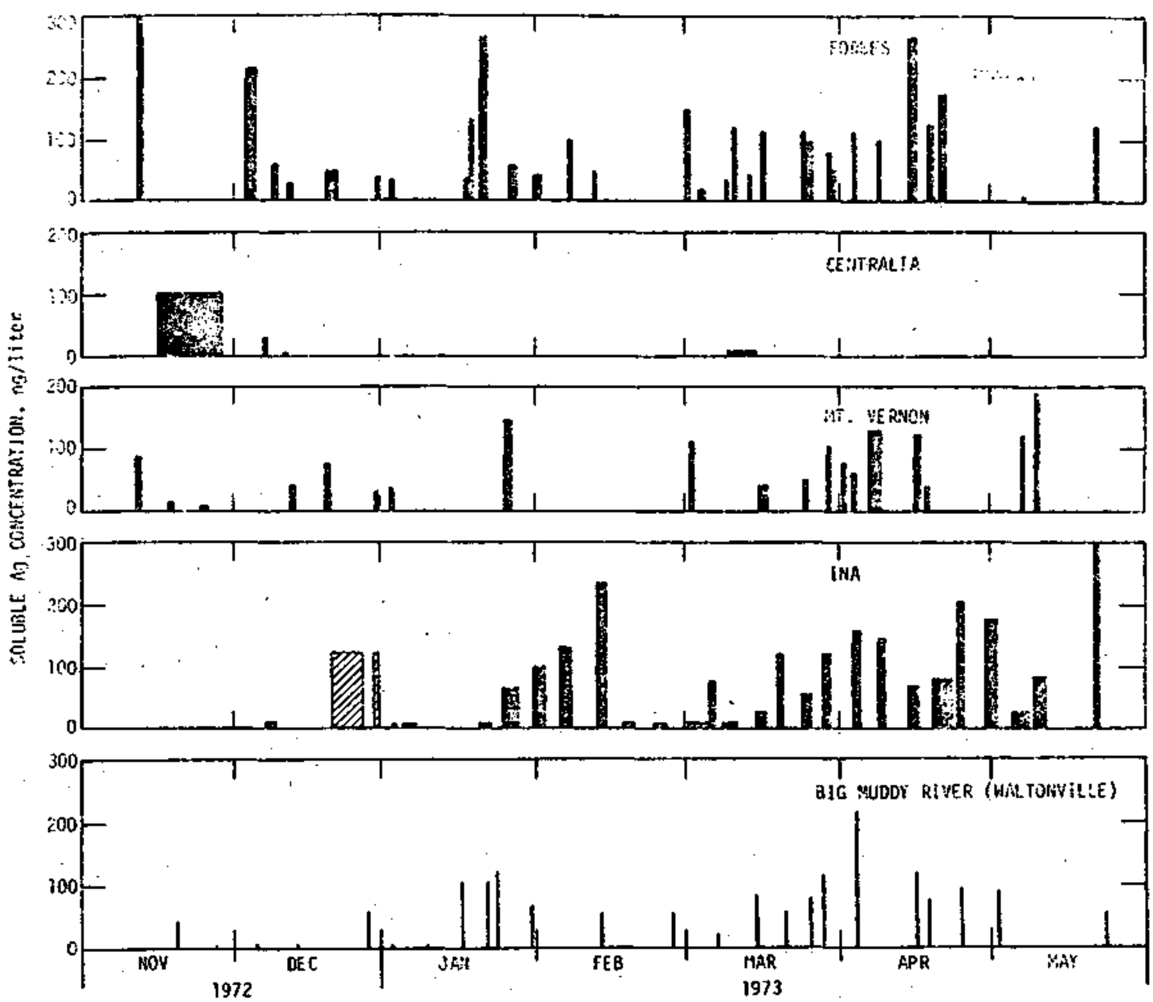

Figure 11. Silver Concentrations in Relation to Sampling Date. Adjacent Hatched Bars Indicate Separate Rain Periods in Same Sample.

In particular, it is useful to compare these results with those obtained under both seeding and non-seeding conditions elsewhere to see whether Ag analysis could be considered as a method of identifying seeded precipitation in Illinois.

Table 24 (Warburton and Young, 1972) summarizes Ag concentrations observed in precipitation both during, and in the absence of, seeding operations, primarily in western states. Comparison of these values with those in Table 23 show that mean Ag concentrations in Illinois are generally larger than the no-seed values found elsewhere. The Illinois values even match or exceed median concentrations observed *during* seeding operations in the Sierra Nevada, Eastern Nevada, and Lake Erie areas.

These comparisons suggest that it might be difficult to detect seeded Ag in the presence of background Ag in Illinois precipitation. However, it must be stressed that differences in storm type, as well as in seeding methods and rates, must be considered very carefully when comparing data on Ag concentrations in precipitation. Seeding operations in the western United States focus primarily on ground-based seeding of widespread storms, while the program envisioned for Illinois would concentrate on aircraft seeding of convective storms. Silver analyses of precipitation from both seeded and unseeded convective storms in Alberta have been reported by Summers (1972). Summers' detection limit for Ag (100-200 ng/liter) was not sufficient to detect silver in most unseeded precipitation samples. Nevertheless, concentrations up to 4200 ng/liter were detected in convective storms seeded with approximately 1 kg of Ag.

Our experience in releasing lithium and indium tracers into Illinois convective clouds and recovering them in precipitation may also be helpful here. Tracer injections of the order of 1 kg into thunderstorm updrafts generally result in concentrations of tracer in precipitation between 100 and 1000 ng/liter. If the results were to be similar for Ag, the seeded Ag could not be positively identified at all times on the basis of Ag concentration. However, our experience with tracers also suggests that element *ratios* are far more sensitive indicators of the presence of tracer materials than concentration alone. Thus, if it is possible to identify another element to serve as a tracer for the osurce of background Ag (perhaps K, or Ti, or Ca if the source is soil dust), then a small amount of seeded Ag might change the Ca/Ag ratio, say, by a factor of 10 or more from that typical of local soils. The same amount of Ag might change the Ag concentration by a factor of perhaps 2, which would probably be in the normal range of variability of the background Ag.

Water Resources and Planned Weather Modification

Huff (1973) made an extensive investigation of the potential benefits of simulated seeding-induced increases in runoff on the alleviation of surface water shortages in Illinois. Illinois data were employed to assess 1) the general magnitude of water-supply augmentation that could be realized under various assumed seeding-induced increases in natural precipitation, and 2) the relative effects of climatic, physiographic, and geomorphic features upon seeding-induced benefits. Techniques were used to derive regression equations that reflect the importance of various meteorological and hydrological factors in defining basin runoff. A total of 14 Illinois basins (Figure 12) with continuous runoff records for a minimum of 30 years were selected to provide a measure of potential water-supply benefits under various basin characteristics. Seeding-induced precipitation would be most beneficial in the southern one-third of the state from both water supply and agricultural considerations (Figure 13). Next, an investigation was made of the frequency of serious water shortages in Illinois with major emphasis on impounding reservoirs. This was done to obtain an estimate of the potential economic benefits from weather modification. Limited consideration was given also

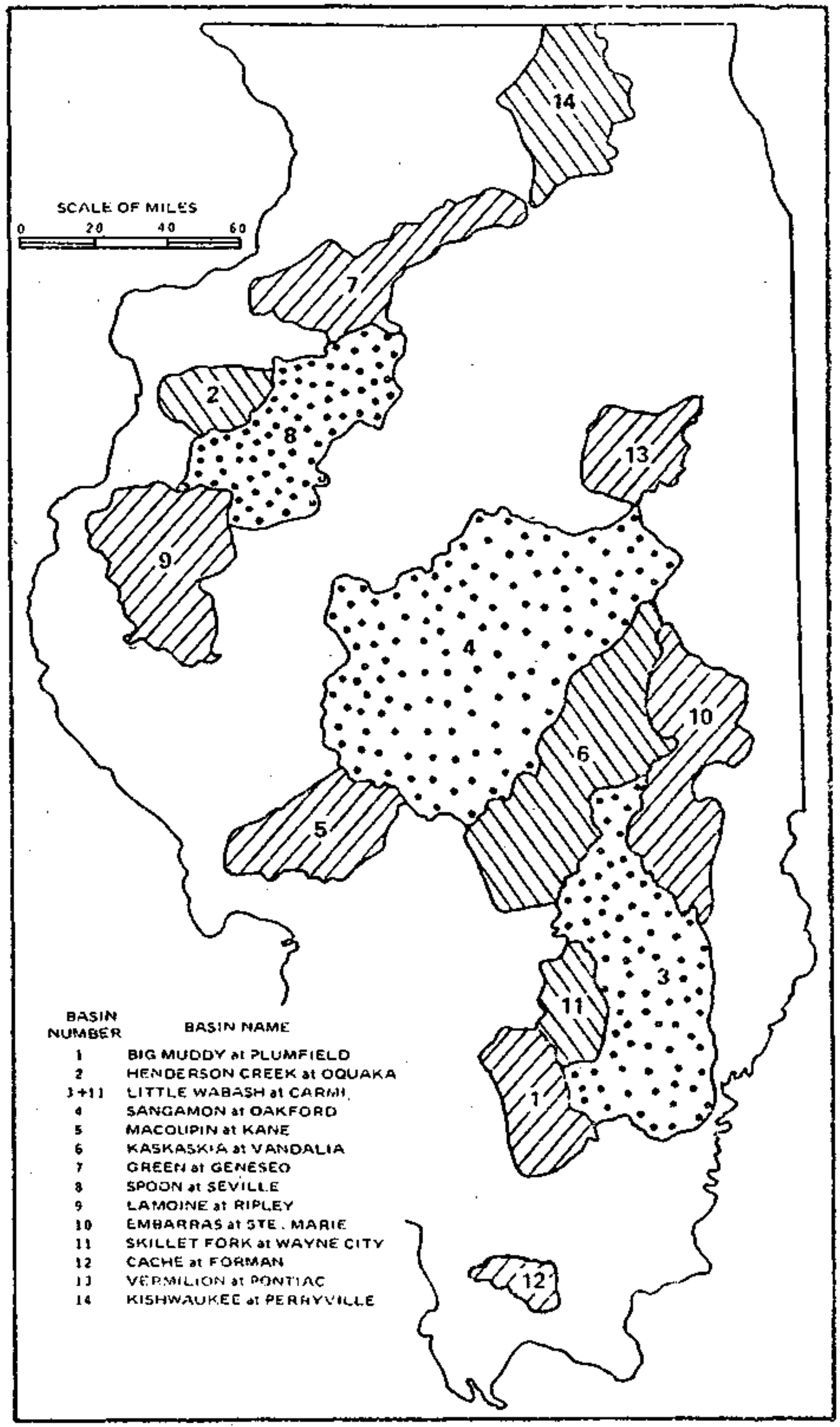

Figure 12. Basins Used in Water-Supply Study.

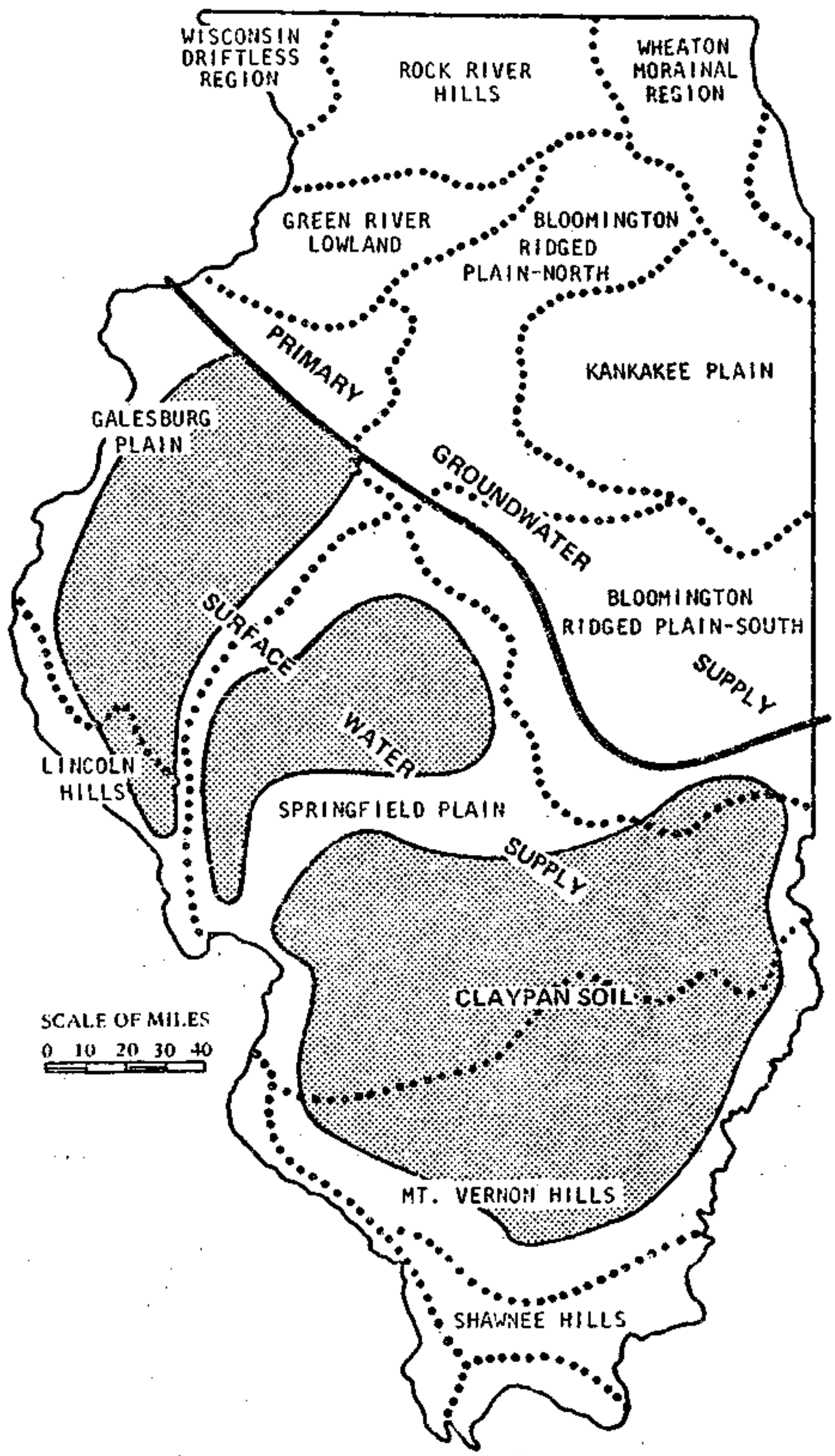

Figure 13. Physiographic and Primary Water-Supply Regions.

to the consequences of additional erosion and sedimentation that might be induced by rainfall augmentation.

Average runoff increases in each basin for each season and sub-season were calculated assuming a capability to increase the major precipitation contributors to the seasonal runoff by an average of 20%. Results are summarized in Tables 25-26, which show average runoff increases in both inches and percent. The median (state) increase in natural runoff (no seeding) is approximately 2.3 times the precipitation increase in the October-March period (46% vs 20%), 1.6 times during December-March, 2.5 times in the total warm season, and 2.7 times in the July-August period. The percentage increase in basin runoff is not dictated by basin size. The above results provide generalized estimates of potential enhancement under *average year-to-year conditions.* Obviously, seeding would be most beneficial in relative dry weather when water supplies are under stress.

Operational seeding constraints were ignored in the above analyses, but these could occur as a result of several causes. These include conditions when high streamflow poses a potential flood threat, insufficient storage capacity in reservoirs, interference with planting and harvesting, forecasts of severe weather (heavy rainfall, hail or tornadoes) in the potential seeding region, plentiful soil moisture from previous precipitation, failure to recognize favorable weather conditions for seeding (forecasting failures), and problems with the seeding system. A study of operational constraints in Kansas estimated that only about 50% of the potential events to get an increase in runoff from cloud seeding could be utilized, on the average. This reduction, applied to the runoff increases in Tables 25-26, provides a more realistic estimate of the average seeding-induced increases to be expected from a continuous year-to-year seeding operation. Seasons with below-normal precipitation, especially cold seasons, would be expected to have much

Table 25. Average Runoff Increases in Cold Season Resulting from 20% Seeding-Induced Precipitation Increases, Based on All Years of Data.

Basin	October-March In.	October-March %	December-March In.	December-March %
Big Muddy	3.00	42	2.04	33
Little Wabash	2.83	47	1.74	33
Skillet Fork	3.77	60	2.14	38
Cache	3.04	30	3.18	35
Embarras	2.61	46	1.63	33
Macoupin	2.11	63	1.06	39
Kaskaskia	2.44	50	1.49	36
Sangamon	2.13	58	1.26	43
Spoon	1.41	38	0.71	24
La Moine	1.52	46	0.81	30
Vermillion	1.94	62	0.70	24
Henderson Creek	1.54	44	0.88	30
Green	1.50	42	0.67	24
Kishwaukee	1.49	38	0.87	28
Median	2.12	46	1.16	33

Table 26. Average Runoff Increases in Warm Season Resulting from 20% Seeding-Induced Precipitation Increases, Based on All Years of Data.

Basin	April-September In.	April-September %	July-August In.	July-August %
Big Muddy	2.39	48	0.68	87
Little Wabash	2.70	55	0.48	61
Skillet Fork	2.56	53	0.31	50
Cache	2.85	43	0.51	65
Embarras	2.66	54	0.47	61
Macoupin	2.87	69	0.47	55
Kaskaskia	2.51	53	0.41	51
Sangamon	2.19	46	0.51	53
Spoon	2.48	53	0.46	46
La Moine	2.29	51	0.52	53
Vermillion	3.25	65	0.46	55
Henderson Creek	2.29	51	0.54	56
Green	1.82	44	0.22	24
Kishwaukee	1.44	39	0.20	27
Median	2.49	52	0.47	54

smaller constraints. Failures then would be limited primarily to failures in recognizing potential seeding conditions and equipment failures that might abort seeding operations. Therefore, a 10-20% constraint would appear more logical in the really dry periods.

Table 27 shows that a 20% increase in precipitation during July-August in near to below normal runoff conditions produces only a small increase in runoff. Thus, the median increase is only 0.08 inch, with a range from 0.05 to 0.15 inch among the 14 basins. Such increases would provide little help in alleviating water supply shortages.

The general conclusion (Huff, 1973) from analyses of data for near normal to below-normal seasons is that substantial increases in runoff for augmentation of surface water supplies could be achieved, provided that an average seeding induced increase of 20% in the prertinent precipitation parameters could be achieved, and assuming that a seeding program is carried out continuously during such seasons. The opportunity for increasing surface runoff in such situations appears to be somewhat better in the cold season when soil moisture demands and evapotranspiration are less than in the warmer part of the year. However, when droughts of the order of 10-year to 25-year recurrences prevail, frequency distributions of seasonal low flow and consideration of both meteorological and hydrological factors do not suggest major returns from a seeding program.

The difficulty in producing substantial increases in runoff to alleviate surface water-supply deficiencies in dry periods, is clearly illustrated in Table 28, where a major decrease in percentage of precipitation converted to runoff is emphasized. This table shows that the average increase in runoff from an assumed 20% increase in precipitation from seeding in a dry year ranges from 24 to 39% (runoff ratio) among the five basins, compared with the average for all years combined.

Table 27. Average Runoff Increases in Warm Season Resulting from 20% Seeding-Induced Increases in Precipitation, Based on Near-Normal to Below-Normal Years of Runoff.

Basin	April-September In.	April-September %	July-August In.	July-August %
Big Muddy	0.80	27	0.07	39
Little Wabash	1.55	50	0.15	48
Skillet Fork	1.51	53	0.06	18
Cache	1.40	36	0.06	22
Embarras	0.91	28	0.09	24
Macoupin	1.25	53	0.10	36
Kaskaskia	1.01	32	0.12	32
Sangamon	1.17	34	0.06	11
Spoon	0.94	31	0.05	8
La Moine	1.01	36	0.11	24
Vermillion (North)	1.46	43	0.08	28
Henderson Creek	0.26	9	0.14	33
Green	0.18	6	0.07	11
Kishwaukee	0.49	18	0.07	15
Median	1.01	33	0.08	26

Table 28. Comparison of Average Runoff Augmentation During Cold Season Between All Years Combined, Near-Normal to Below-Normal Years, and Below-Normal Years, Assuming 20% Seeding-Induced in Precipitation.

Basin	Runoff increase (in.) for given type season: All years	Near- to below-normal	Below-normal	Runoff ratio-: Near- to below-normal	Below-normal
Big Muddy	3.00	2.26	1.17	0.75	0.39
Embarras	2.61	2.00	0.62	0.77	0.24
Kaskaskia	2.44	1.61	0.58	0.66	0.24
La Moine	1.52	1.20	0.54	0.80	0.36
Spoon	1.41	0.76	0.53	0.54	0.38
Median	2.44	1.61	0.58	0.75	0.36

* Ratio of runoff augmentation in below-normal and near-normal to below-normal seasons to runoff augmentation for all seasons combined

Stall (1965) published results of a study regarding the relation between impounding reservoir net yield and pumpage in Illinois dry periods. Most Illinois reservoirs can withstand a 40-year drought (low-flow) before completely emptying. Subsequent additional analyses lowered the low flow frequency to a 25-year drought condition. Although there was considerable scatter about the mean, it was most frequently on the high side; that is, some Illinois communities have reservoirs capable of operating throughout a 50-year drought or longer. A few communities would have problems in a drought of a 15-year or 20-year frequency.

Conceivably, seeding-induced rainfall could also be helpful to those municipalities that take their water supply directly from rivers through use of low-head, run-of-the-river impoundments. These are used mostly by small communities, and there are 40 such installations in Illinois along various rivers.

There is also a possibility that seeding-induced rainfall which only causes a minor rise in a major river, such as the Mississippi, could be useful. This basin storage would provide additional water for use along rivers where large amounts are withdrawn. However, it is nearly impossible to place a dollar value on this type of use. The Survey also has made extensive studies of the water resource impacts related to precipitation changes on the Great Lakes (Stout, 1974).

Summary. Table 29 shows a condensed comparison of the average seeding-induced increases in runoff during the cold and warm seasons, based upon the assumed 20% increase in the natural precipitation from seeding activities and no constraints on seeding operations. This comparison is shown for the five basins with the longest continuous runoff records. Reference to the cold season tabulations shows R/P decreasing from a median value of 0.30 for all years of record combined (climatic average), to 0.22 for near-normal to below-normal

Table 29. Comparison of Average Seeding-Induced Increases in Runoff During Cold and Warm Seasons from 20% Increase in Precipitation.

Cold season comparisons

Basin	All years combined: No-seed runoff (inches)	R/P	Seeding increase in.	%	Near to below-normal years: No-seed runoff (inches)	R/P	Seeding increase in.	%	Below-normal years: No-seed runoff (inches)	R/P	Seeding increase in.	%
Big Muddy	7.05	0.38	3.00	42	4.44	0.28	2.26	51	2.07	0.15	1.17	57
Embarras	5.69	0.35	2.61	46	3.66	0.25	2.00	55	1.60	0.13	0.62	39
Kaskaskia	4.92	0.28	2.44	50	2.99	0.22	1.61	54	1.33	0.11	0.58	44
La Moine	3.31	0.26	1.52	46	2.22	0.19	1.20	54	1.05	0.10	0.54	52
Spoon	3.68	0.30	1.41	38	2.33	0.21	0.76	32	1.32	0.13	0.53	40
Median	4.92	0.30	2.44	46	2.99	0.22	1.61	54	1.33	0.13	0.58	44

Warm season comparisons

Basin	All years combined: No-seed runoff (inches)	R/P	Seeding increase in.	%	Near to below-normal years: No-seed runoff (inches)	R/P	Seeding increase in.	%	Below-normal years: No-seed runoff (inches)	R/P	Seeding increase in.	%
Big Muddy	5.00	0.22	2.39	48	2.92	0.14	0.80	27	1.74	0.10	--	--
Embarras	4.93	0.22	2.66	54	3.23	0.16	0.91	28	2.04	0.12	--	--
Kaskaskia	4.76	0.21	2.51	53	3.12	0.15	1.01	32	1.82	0.10	--	--
La Moine	4.51	0.19	2.29	51	2.80	0.15	1.01	36	1.61	0.09	--	--
Spoon	4.68	0.21	2.48	53	3.03	0.13	0.94	31	1.97	0.11	--	--
Median	4.76	0.21	2.48	53	3.03	0.15	0.94	31	1.82	0.10	--	--

years, and to 0.13 for below-normal years. The percentage of precipitation converted to runoff in dry seasons (below-normal) is less than 50% of the average seasonal value. The seeding-induced runoff under these conditions shows the below-normal seasons having only about 25% of that achieved by the 20% precipitation increase in an average season (0.58/2/44). The reduction in precipitation converted to runoff (R/P) is even greater for three south central and southern basins (Big Muddy, Embarras, and Kaskaskia).

The warm season comparisons show similar relations. Thus, the median R/P decreases from 0.21 to 0.10 between all years combined and below-normal years; that is, the *percentage of rainfall converted to runoff in dry periods averages less than 50% of that in a normal warm season.*

The net result of this investigation of potential seeding-induced increases in runoff from cloud seeding was that seeding to augment water-supply storage would be desirable in near-normal to slightly below normal years for those midwestern communities where additional storage is available in such periods. The Illinois calculations indicate that substantial increases in runoff could be achieved in such weather conditions, as indicated in the condensed summary of Table 29. However, the conversion of precipitation to runoff in below-normal years is small, averaging only 10 to 13% (Table 29), and large seeding-induced increases in precipitation would be required to obtain substantial alleviation of water-supply deficiencies. This would be difficult to achieve with the atmospheric conditions that typically exist in moderate to severe drought conditions. The drought problem is further clarified by reference to Table 30, abstracted from Huff and Changnon (1964), which shows frequency distributions of annual R/P ratios for the five basins of Table 29. Only 7% to 10% of the natural precipitation is converted to runoff in a typical once in 10-year drought. This percentage lowers to 3% to 5% in 25-year droughts, and to a range of 2% to 4% in a 50-year drought.

However, the possibility that seeding may be of assistance during temporary breaks in light to moderate droughts in the Midwest cannot be eliminated. This is certainly true where local shortages may become very acute, in which case even a small contribution from seeding would be usually helpful and economically acceptable. It is possible that increases of the magnitude shown in Table 29 for average conditions in below-normal cold seasons could be helpful *(if achievable)* under some conditions, especially in small communities where reservoir storage facilities are inadequate or where water is being taken directly from a small stream for municipal usage.

Although this investigation of potential seeding-induced increases in runoff from cloud seeding indicated that substantial gains in streamflow could be achieved in near-normal to slightly below-normal years, hydrologic considerations indicate that weather modification would not provide a major benefit in water supply in Illinois, unless it could provide substantial additions in relatively severe drought periods. Impounding reservoirs in Illinois can withstand a 25-year drought. A few communities would have problems in a drought of 15-year to 20-year frequency, but some could operate in a 50-year drought. Potential benefits from seeding in augmenting shallow groundwater supplies are estimated to be small by Survey groundwater hydrologists.

Water Resource Impacts Related to Inadvertent Urban Precipitation Modification

The St. Louis urban-induced increases in area summer rainfall, in the number and intensity of heavy rainfall events, and in pollutants in the rainfall all impact on most local water characteristics and activities related to water resources. These impact areas include water supply, sewage treatment water quality, flooding, and the design of hydrologic structures (Changnon et al., 1977).

An analysis of streamflow data for two small basins downwind (east) of St. Louis was performed to examine for possible changes due to the increased summer rainfall. This was accomplished by comparing the warm-season values of runoff for one small basin (Canteen Creek), centered in the area of recent rainfall increase, with those of another small basin (Indian Creek) located on the edge of the high rainfall area. The warm season runoff increase on Canteen Creek that is related to the urban-induced rainfall increase is 11%. Thus, one impact of more total summer rain is greater runoff. Knowledge of the hydrologic cycle, coupled with the runoff and heavy rainfall results, indicated the urban-produced rainfall increase yields about a 5% increase in shallow groundwater recharge in the summer.

In general, summer season increases in runoff have a beneficial impact on sewage treatment. Increased streamflow means more dilution and lower concentrations of pollutants in the stream water. The 30 to 50% increases in heavy rain events and rain rates east of St. Louis have led to increased frequency of surcharges, or bypasses or urban wastewater treatment plants in the area. A 40% increase has developed in recent years as the urban anomaly developed and intensified. These bypasses lead to added stream and river pollution downstream of local treatment plants.

The occurrence of more heavy, short-duration rainfall rates and more storm events also lead to more high runoff rates producing flooding and soil erosion. A portion of the urban-related summer rainfall anomaly occurs in the American Bottoms, a 454-km^2 floodplain that is poorly drained. The 40 to 80% increases in heavy storm events related to urban effects are a significant factor in the 100% increase in local suburban flooding. This flooding delays traffic and damages property, and led to the passage of a bond issue in one community for an improved storm and sewer drainage system.

The urban-related increases in runoff from the more frequent heavy rainfall events also affect the operation and management of hydraulic structures in the floodplain. Major canals, storage basins, and flood gates exist to drain and/or control the flow of water within the floodplain and between the floodplain and the Mississippi River. The floodwater management problem in the floodplain is not resolved, and major canals and floodwater storage basins are being planned for construction in the floodplain. Total cost of proposed projects is $73.6 million.

The urban-related increases in rainfall rates have also affected soil erosion, especially in the rolling farmlands east of the floodplain. First, 55% of all the erosion in this area occurs in summer, the time of the rain anomaly. The added erosion (2.8 tons) represents a 34% increase, much of which is transported in local streams thus degrading local water quality. The added soil load in the streams, particularly that from the higher elevation rural area within the anomaly area east of St. Louis, has considerable impact on streamwater quality and on the floodplain. Silting in the flood-control storage basins, and the costs of its removal, have become major problems.

Weather Influences on Rabbits

An investigation was made of the relationships of Illinois weather and crops to cottontail rabbit populations from 1955 through 1971 (Havera, 1973). Such an investigation was desired to ascertain whether precipitation changes produced by weather modification might produce an effect on the ecosystem, as reflected in the rabbit population. Monthly weather parameters, weather factors during critical periods of the cottontail's life cycle, and crop acreages for four Illinois game regions were analyzed with cottontail harvest and census data. The rabbit data were from five areas of the state (Fig. 14).

The weather factors among the best five weather parameters for each rabbit index that were important in more than one region are given in Table 31. It was anticipated that this procedure would provide a general picture of the weather factors that influenced the cottontail populations during the study period. The parameters that occur in Table 31 and have also appeared in other analyses are the negative effects of the number of days with precipitation ≥1.0 inch in January, the percentage of possible sunshine in March and July, total precipitation in April, and the number of days with precipitation ≥0.10 inch in September. Favorable factors were precipitation in July and minimum temperature in August.

In most regions of Illinois, corn and soybean crops would be benefitted economically by a July-August cloud seeding program. Therefore, correlations of total precipitation in July and August and July plus August with the number of cottontails killed (per hunter trip) were run and are given in Table 32. In all regions, total precipitation in July and July plus August was positively correlated with the number of cottontails killed per trip from 1956 through 1971. In general, the magnitudes of the correlation coefficients indicate that precipitation in July and August and July plus August had a favorable but not a critical effect on cottontail harvest. Therefore, precipitation enhancement that would not result in large departures from the long-term average of precipitation in July and August would not be expected to have a direct adverse effect on rabbit populations.

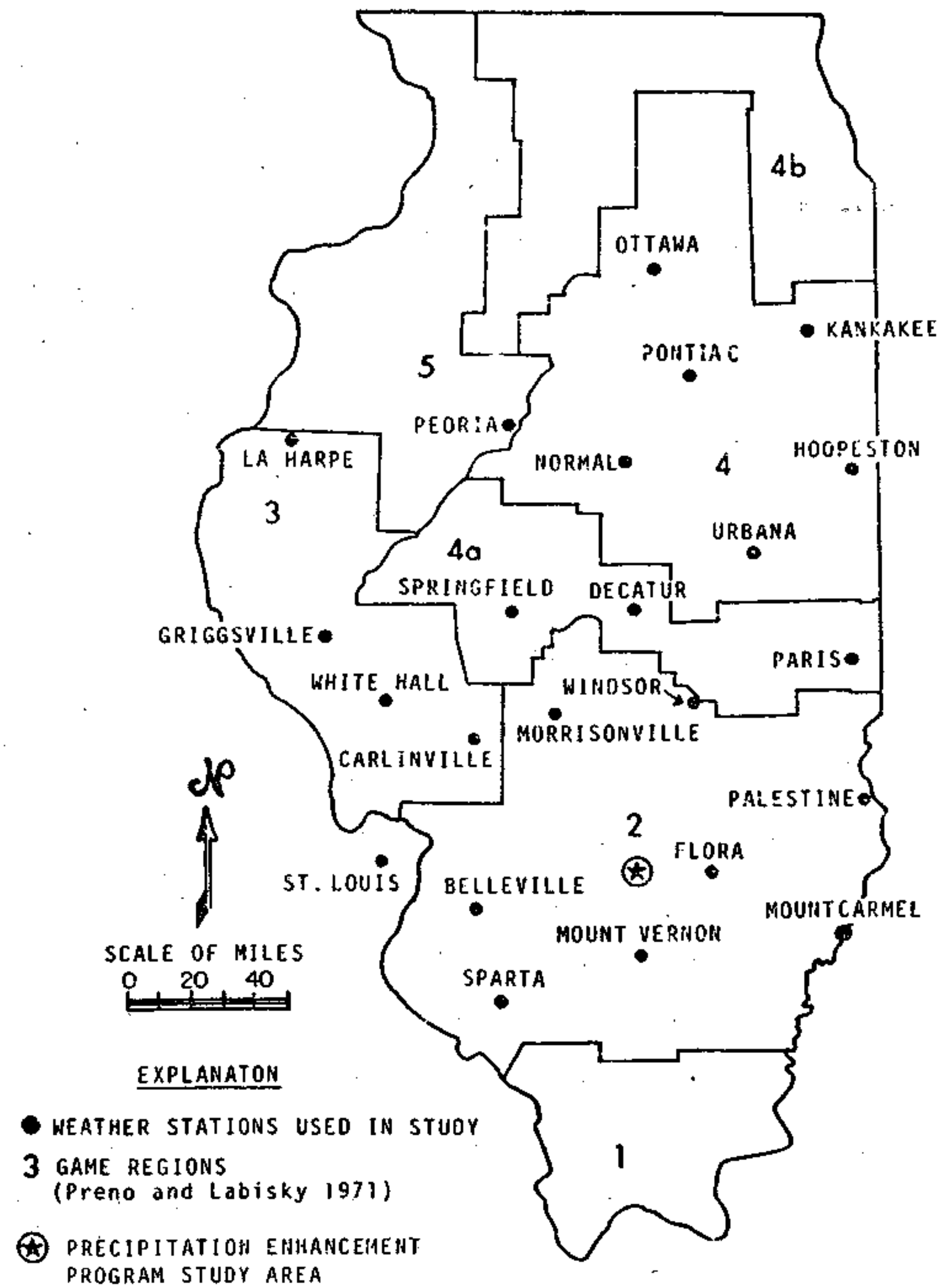

Figure 14. Game Regions and Selected Weather Stations for Cottontail-Weather Analysis.

Table 30. Freqeuncy Distribution of Annual Runoff/Precipitation Ratios (R/P) in 12-month Droughts.

	R/P for given frequency (years)		
Basin	10	25	50
Big Muddy	0.07	0.03	0.02
Embarras	0.07	0.03	' 0.02
Xaskaskia	0.10	0.05	0.03
La Moine	0.08	0.04	0.02
Spoon	0.09	0.05	0.04
Median	0.03	0.04	0.02

Table 31. Correlation Coefficients of Weather Parameters Occurring in Two or More Game Regions Among the Five Monthly Weather Variables That Account for the Most Variance in the Cottontain Indices.

Month and weather Variables	March Census[a] Game Region				July Census[b] Game Region				Rabbits per Trip[c] Game Region			
	2	3	4	4a	2	3	4	4a	2	3	4	4a
January												
Number of days with precipitation ≥1.0 inch						-0.38						-0.44
March												
Percent of possible sunshine			-0.44	-0.56[d,e]							-0.44	
April												
Total precipitation							-0.40			-0.58[d]		
May												
Number of days with precipitation ≥0.10 inch	+0.50[d]											+0.50
July												
Number of days with precipitation ≥0.10 inch						+0.47						+0.56[d]
Number of days with precipitation ≥1.0 inch			+0.22	+0.34			+0.43[e]					
Percent of possible sunshine	-0.29				-0.59[d,e]				-0.47	-0.56[d]		
August												
Minimum temperature			+0.54[d]	+0.35			+0.47					
September												
Number of days with precipitation ≥0.10 inch							-0.61[d]		-0.45		-0.47	

[a] Cottontail variable was compared with the 13 individual months (February-February) preceding the census and with the month of census.

[b] Cottontail variable was compared with the 13 individual months (June-June) preceding the census and with the month of the census.

[c] Cottontail variable was compared with the 11 individual months (December-October) preceding the hunting season and the 3 months (November-January) during the hunting season.

[d] $P \leq 0.05$.

[e] Correlation is with the cottontail variable 1 year later.

Table 32. Correlation Coefficients of Total Precipitation for July and August and July Plus August with the Number of Cottontails Killed Per Hunter Trip in Game Regions 2, 3, 4, and 4a, 1956-1971.

Game Region and Month	Sixteen Year Mean of Total Precipitation in Inches	Correlation Coefficient of Total Precipitation
Game Region 2		
July	4.39	+0.28
August	3.18	+0.44
July & August	7.57	+0.50*
Game Region 3		
July	4.35	+0.46
August	3.59	-0.08
July & August	7.96	+0.31
Game Region 4		
July	4.50	+0.17
August	2.78	+0.02
July & August	7.28	+0.17
Game Region 4a		
July	4.27	+0.37
August	2.93	-0.27
July & August	7.20	+0.14

*$P \leq 0.05$.

Linear correlation and stepwise multiple regression analyses of monthly weather parameters with cottontail harvest and census data revealed that several weather parameters were associated with fluctuations in cottontail abundance during the study interval. The cottontail populations were apparently influenced by several weather factors during the same year and the same weather factor affected the rabbit populations differently at various times of the same year. Generally, during the months of December, February, and March, snowfall was unfavorable to cottontail populations. Warm temperatures in January along with precipitation were weakly favorable to Illinois rabbits. During the spring, cottontails were unfavorably related to the percentage of possible sunshine in March, and warm temperatures and total precipitation in April. Cottontails reacted favorably to precipitation and reduced sunshine in July. Minimum temperature in August was favorable. The number of days with precipitation ≥0.10 inch during September and October were negatively correlated with the rabbit data. The weather parameter that had the best relationship with high and low years of cottontail harvest was total snowfall from December through March.

Although the direct effect of precipitation enhancement would not appear to jeopardize cottontail abundance, we cannot say that increased precipitation would not be important. There may be other species of wildlife that are more sensitive to precipitation or changes in precipitation than cottontails. Although additional summer rainfall in moderate amounts may favor the growth of succulent vegetation that is necessary for the maintenance and growth of cottontails, succeeding years of increased summer rainfall may favor succession to more mesic types of plants that may be favorable or unfavorable to different species of animals. If the changes in the type of vegetation are great enough, an entirely different community of plants and animals will exist. Animals that cannot adapt to or exist in the new habitat will be replaced by ones that can.

Other indirect effects of increased precipitation must be considered. The types of diseases, the susceptibility to diseases, changes in reproductive rates, changes in predation or other such factors that influence populations but are hard to quantify would not be revealed in this study. Cottontail populations are strongly tied to the kinds of crops grown in Illinois. Corn and soybeans are significantly and negatively correlated with cottontail populations. If precipitation enhancement would influence farmers to increase corn and soybean acreage, this increase would likely result in a reduction of favorable habitat not only for cottontails, but for other wildlife species as well.

LEGAL AND INSTITUTIONAL ACTIVITIES

The growing evidence that weather modification offered a means to increase precipitation and to suppress hail led the Illinois State Water Survey into a variety of research programs related to weather modification.

In 1971, a concerted program aimed at answering existing questions relating to precipitation enhancement was initiated.

Since Illinois then had no legislation regarding the monitoring of control of weather modifications in the State, a prime requirement for the proper execution of future experiments, and for the general protection of the citizens of Illinois from improperly conducted weather modification operations, was enactment of proper legislation. Thus, one of the study-activity areas concerned weather modification control legislation for Illinois (Ackermann et al., 1974). The central goal of this particular activity area was to secure an Illinois law that would permit and regulate weather modification within Illinois, with the law based on the most meaningful regulations found among the weather control laws of the other states with laws.

The most important reason for enacting a proper permissive-control law was that it was deemed valuable and beneficial for the citizens of Illinois. It needed to be enacted, hopefully before emergency conditions such as a drought, brought upon good and bad weather modification activities. Droughts in 1976 and 1977 have led to operational projects. Failure of poorly executed efforts might lead to a hurried, ill-conceived, and possibly restrictive weather modification law.

Securing the weather modification control law for Illinois involved four phases. The *first phase* consisted of a review of state and federal weather modification legislation to determine their applicability to Illinois. After this literature review came two concurrent phases. The *second phase* was the actual development and writing of the statutory text using existing statutes from other states as appropriate. The *third phase,* which of necessity was concurrent with the second phase, involved public interaction. This effort consisted of meeting with various state officials, agricultural interest groups, and many citizens to discuss weather modification and to emphasize the need for proper legislation. The *fourth phase* in this legislative activity consisted of getting the bill implemented within the Illinois Legislature and approved by the governor. These efforts required nearly two years to accomplish, beginning in October 1971 and ending with the passage of the Illinois Weather Modification Law, House Bill No. 770, by the State Legislature in June 1973 and its signing by Governor Daniel Walker on 12 September 1973 (Illinois Statutes chapter 146 3/4).

The objectives of the Illinois law are to encourage weather modification operations and research and development and to minimize possible adverse effects of such activities (Sec. 2). In order to accomplish these purposes, the Illinois Weather Modification Control Act contains three types of provisions:

1) it sets up an *institutional structure* to handle regulation of cloud seeding activities;
2) it contains substantive *regulatory provisions* controlling intentional atmospheric manipulation in the state; and
3) it establishes basic rules *of procedure* according to which the regulatory provisions will be enforced.

Institutional Structure

The Illinois law sets up an institutional structure designed to effectuate *regulation* of weather modification activities within the state. In a few other states a governmental agency is specifically authorized by law to carry out weather control *operations;* and in some jurisdictions the weather modification law provides a method for obtaining *financing* for cloud seeding by local governmental units. The Illinois statute is merely regulatory. Three entities are involved in the process of control of modifiers:

1) The Weather Modificaiton Board;
2) The Department of Registration and Education; and
3) The State courts.

The Weather Modification Board is composed of five residents of Illinois who are appointed by the Director of the Department of Registration and Education. In selecting members of the Board the Director "shall include individuals with qualifications and practical experience in agriculture, law, meteorology and water resources." The Board holds an annual meeting and such other meetings at such times and places as it shall determine (Sec. 5). Although the law delegates the regulatory authority to the Director of the Department of Registration and Education, he can exercise his powers and duties under it "only upon recommendation and report in writing of the majority of the members of the Board" (Sec. 4). *Thus, the Board is the basic regulatory agency.*

The Department of Registration and Education is an umbrella agency which supervises, working through various advisory groups like the weather Modification Board, most of the professional licensing in Illinois. Licensing is done in the name and by the authority of the Director of the Department.

The enactment brings the state courts into the institutional structure by giving persons adversely affected a right to judicial review of final administrative decisions of the Department.

Regulatory Provisions

The key to regulation of weather modification in Illinois is a ban on unauthorized cloud seeding. "[N]o person may engage in weather modification activities: (a) without both a professional weather modification license . . . and a weather modification operational permit . . .; or (b) In violation of any term, condition or limitation of such license or permit" (Sec. 10). Control is through use of the power to grant or deny permission to seed clouds.

By administrative regulation some activities may be exempted from the license and permit requirements. Exemption may be granted for research activities, fire, frost, or fog protection, and "[a]ctivities normally conducted for purposes other than inducing, increasing, decreasing or preventing hail, precipitation or tornadoes."

Professional licenses are issued in accordance with criteria and procedure established by the Board. Such criteria "shall be consistent with the qualifications recognized by national or international professional and scientific associations concerned with weather modification and meteorology." The applicant must demonstrate his competence to pay a license fee (Sec. 12). The fee for an original one year license is $100; for annual renewal it is $20 (Sec. 13).

Operational permits are also issued in accordance with Board-established criteria and procedure. Applicants must have a professional license, give proof of financial responsibility (See Sec. 20), pay the permit fee of one percent of the cost of the operation with a $100 minimum fee (See Sec. 18), and set forth an operational plan for the project. The plan must have a) "specific statement of its nature and object, 2) a map of the proposed operating area which specifies the primary target area and shows the area reasonably expected to be affected, a statement of the approximate time during which the operation is to be conducted,

3) a list of the materials and methods to be used in conducting the operation, 4) an emergency shut down procedure (conditions under which operations must be suspended) and 5) other detailed information.

There is a mechanism in the law for ascertainment of public attitudes about proposed projects. Notice of a hearing *may* be given by newspaper, radio or television announcement in the area expected to be affected by operations under a proposed permit, and a hearing *may* be held to find out what the public thinks about the impact of granting or withholding a permit (Sec. 17c). There is no requirement, though, that a hearing must be held nor that the testimony given at a hearing bind the Department.

Permits are subject to various limits and conditions. They may be limited as to primary target area, time of the operation, materials and methods to be used in conducting the operation, emergency shut down procedure, and other operational requirements (Sec. 17e). Permit conditions may be modified in the public interest (Sec. 21). A separate permit is needed for each operation and it is good for one year, but there may be conditional approval for projects intended to run longer (Sec. 19), and permits can be renewed (Sec. 22).

The Department can suspend or revoke a permit if the holder no longer has the qualifications necessary for its issuance or has violated the act or regulations issued under it (Sec. 23). Licenses can also be suspended or revoked upon a finding of incompetency, dishonest practice, or violation of the act of regulations (Sec. 16). When appropriate, permits and licenses can be restored (Sec. 24).

Effective governmental administration depends upon the availability of adequate information. The Illinois act states that permit holders "shall keep such records and file such reports at such time or times and in the manner and form as may be required by the rules and regulations made under this Act."

Failure to comply with the act or any administrative rule issued in accordance with its provisions is a misdemeanor, and each day such violation continues constitutes a separate offense (Sec. 29). Weather modifiers may also be subject to civil liabilities. Intentional harmful actions or negligent conduct which causes injuries can be the basis for actions for damages; and activities which are carried out in violation of the law or regulations are regarded as negligence *per se* and thereby will be the basis for a judgment for injuries caused by them without the need to prove carelessness by the operator. Otherwise a plaintiff must prove fault by the modifier because the law stipulates that weather modificaiton is not an ultrahazardous activity and that mere dissemination of substances into the atmosphere is not a trespass (Sec. 27). Neither the state nor its employees are liable for injuries caused by persons conducting weather modification operations (Sec. 27).

The Weather Modification Control Act provides that the "Department may represent the State in matters pertaining to plans, procedures or negotiations for interstate compacts relating to weather modification" (Sec. 9). It does not, however, have any references to other out-of-state aspects of in-state cloud seeding.

Rules of Procedure

The basic approach of the statute is to set forth a regulatory skeleton and authorize the Board and Department to put flesh on it through use of the power to make administrative rules *and regulations.* Blanket authority is delegated by the General Assembly to the Department to make "reasonable rules and regulations necessary to the exercise of its powers and the performance of its duties under" the law (Sec. 6). By use of this power, weather modification regulation can be tailored to fit the specific circumstances involved and can be adjusted as they change. Flexibility is thus built into the law.

legislation. Similar laws have been adopted subsequently in Wisconsin and Indiana.

In exercising its rulemaking power as well as its licensing authority, the Department can rely on information forthcoming from reports submitted by permittees (Sec. 26), can use its own expert knowledge, and can investigate weather modification operations.

The Board also gets information through hearings. When suspension, revocation, refusal to renew, or modification of operational permits is involved, normally there must be a due process-type hearing prior to the administrative decision and order. This can be waived by the party affected, and in the case of emergencies the hearing can be postponed until after the project is temporarily shut down.

Summary

A systematic, well-planned activity, primarily involving staff members of the Illinois State Water Survey and Professor Ray Jay Davis of the University of Arizona as a consultant, led from a recognized need for a weather modification statute in 1971 through its completion and enactment as law in 1973. The activity was conceived in an ordered manner beginning with an intensive literature review to determine the status of the legislation and the legal aspects of weather modification; then the development of a statutory document using the experience of other states; concurrently informing the public and agricultural interest groups who in turn reviewed and altered it; and finally the implementation of the statute which was helped by the Illinois Agricultural Association and then secured through the skillful handling of it in the legislature by the sponsors of the bill.

This effort has resulted in a weather modification permissive-control law that is considered to be a "model law" for state weather modification

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