THE 1996-97 OKLAHOMA WEATHER MODIFICATION PROGRAM

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ABSTRACT

Previous weather modification efforts and programs conducted in Oklahoma and other Great Plains states have demonstrated considerable promise. Results from these programs, combined with the severe socio-economic impacts suffered by Oklahoma during the drought of 1995-96, prompted the state to enact and develop a weather modification program. Preliminary results from Phase I of the program appear promising, although independent evaluation of the program will not be complete until conclusion of Phase II in the spring of 1997.

1. BACKGROUND

Prior to 1996, a comprehensive statewide weather modification program had not been implemented in Oklahoma. However, many representatives of state government and citizens alike have long considered this unique, though somewhat unproven, approach to water resource management to be both an effective and promising tool. This persistent interest in seeking the investigation of rainfall enhancement through artificial means prompted the Oklahoma Legislature to pass the Oklahoma Weather Modification Act in 1972. This legislation provided for the encouragement and regulation of weather modification activities and, as amended in 1973, assigned the responsibility of its administration to the Oklahoma Water Resources Board, the state's water management agency.

While the proclaimed moderate success of test programs elsewhere in the U.S. and world have convinced many of the effectiveness of weather modification technology, others remain skeptical. Undoubtedly, the true success of weather modification is difficult to measure and, as a result, additional research into the technology is crucial. In an effort to alleviate uncertainties surrounding use of the science, the 1980 *Oklahoma Comprehensive Water Plan* (OCWP) recommended that the Governor and Legislature support the development and implementation of a comprehensive weather modification program specifically for Oklahoma. As a result of this recommendation, the OWRB, Bureau of Reclamation and Texas Water Commission joined forces during the mid-1980's under the Southwest Cooperative Program to demonstrate state-of-the-art cloud seeding technology and its promise in increasing summertime rainfall in the Southern Plains region.

Findings from that multi-year effort, combined with more recent results from other states' programs, suggested that increases in summertime convective rainfall of 10 to 30 percent and reductions in hail loss from 25 to 45 percent are achievable through carefully planned and conducted programs. The documented, though sometimes disputed, successes of these programs induced authors of the 1995 update of the OCWP to recommend that the State of Oklahoma identify the state's need for (and subsequent role in) a carefully focused, multi-year cloud seeding demonstration program to determine the ultimate utility of weather modification as a water resource management tool.

2. THE OKLAHOMA CLIMATE

Oklahoma lies across two divergent climatic regions. The state's relatively long distance from the moderating effect of the oceans and an absence of mountains to the north often allows cold arctic winds to reach Oklahoma during the winter, which is normally short and mild. In the spring, large thunderstorms develop when warm, moist air from the Gulf of Mexico converges with colder northern, humid eastern and dry western air masses, often producing tornadoes and large hail. Summers in Oklahoma are usually long and hot, punctuated by droughts of varying degree and duration. Fall, though often wet, normally features mild days and cool nights. May ranks as the wettest month while January is the driest.

Annual rainfall (Figure 1) varies from more than 50 inches in the relatively warm and humid pine forests of the Ouachita Mountains in southeast Oklahoma to approximately 16 inches in the high plains of the western Panhandle where warm days and cool nights predominate. The state-averaged precipitation is 33.5 inches. The annual mean temperatures in Oklahoma vary from approximately 54 to 62 degrees Fahrenheit from west to east with a state average of 60.5 degrees. Average snowfall accumulations range from less than five inches in the southeast to 25 inches in the northwest and Panhandle. The growing season, defined as the period between the average date of the latest freeze in the spring and the first freeze in the fall, ranges from 170 days in the Panhandle to 240 days in south central Oklahoma.

MEAN ANNUAL PRECIPITATION 1961-1990
(In Degrees F)

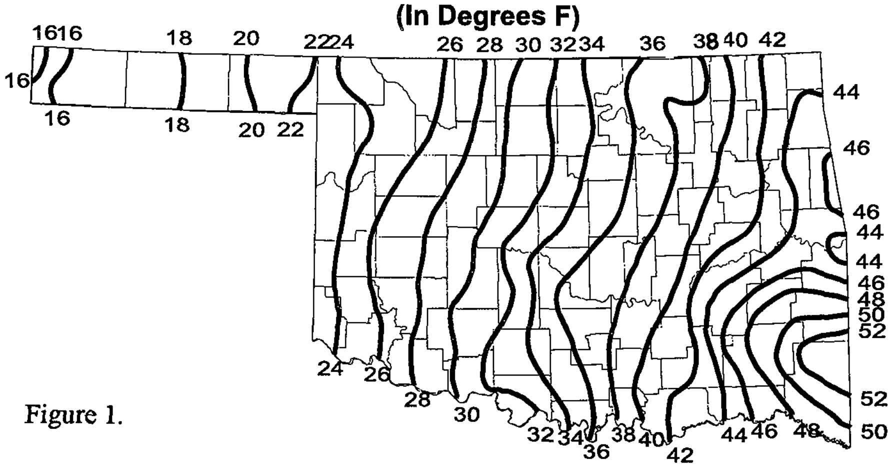


Figure 1.

Only Texas, Kansas and Iowa report more tornado sightings than does Oklahoma. Although they can occur at any time, tornados most often appear during the spring months of April and May moving along cold fronts from the southwest to northeast.

3. STUDY, AUTHORIZATION AND DEVELOPMENT OF THE OKLAHOMA WEATHER MODIFICATION PROGRAM

Last spring and summer, as the State Legislature's Committee on Agriculture considered establishment of a state weather modification program, and as the state suffered through one of its most severe droughts on record, the encouraging results from projects in neighboring states revealed that the technology could have numerous socio-economic benefits for Oklahoma. Programs in Kansas, North Dakota and Texas, which all employ aircraft-based seeding programs, have reported at least moderate success in rainfall enhancement while more significant results have apparently been realized from hail reduction (in Kansas and North Dakota only; to date, Texas has not utilized that technology).

During the Legislature's review of program development, which included citizen representatives, proponents of establishment of a state-sponsored aerial seeding program in Oklahoma cited several major factors in support of program implementation, including the regular occurrence of sufficient clouds which are suitable for seeding purposes (though recognizing that formation of these clouds is limited during dry times). In addition, the state is home to a unique system of sophisticated weather observation and research tools available through the Oklahoma Mesonetwork (MESONET) and Next Generation Weather Radar (NEXRAD) programs which contribute a tremendous source of information and guidance for the state's cloud seeding effort. These and related factors convinced Governor Frank Keating and the Legislature that an operation-oriented weather modification demonstration program patterned after those in Kansas, North Dakota and Texas would have a good chance for success in Oklahoma.

However, as mentioned, perhaps the greatest impetus for program implementation was the Oklahoma drought of 1995-96, which initiated in the fall of 1995. While the impacts of that drought were numerous and far-reaching in Oklahoma, as throughout most of the southwest U.S., the greatest impacts were, by far, felt by the state's agricultural community. Growers of wheat, Oklahoma's second largest agricultural commodity with an average of $500 million in cash receipts, were especially hard hit. From October 1995, when the majority of the state's wheat crop was planted, throughout much of the ensuing spring, drought conditions persisted in all major wheat-producing counties of Oklahoma. As a result, the 1996 wheat crop was barely half of the normal and the smallest in 25 years.

In those areas with little or no wheat to harvest and with cattle prices at their lowest in 20 years, bankruptcies and foreclosures increased substantially. Economic impacts were exacerbated through the alarming increase in wildfires and forest fires which resulted in the widespread loss of grazing pastures, range land, woodlands and forests. The Oklahoma Department of Agriculture estimated in May (conditions began improving substantially in June) that losses due to the drought would cost the state between $1 and $1.2 billion.

Bolstered by favorable recommendations from the Agriculture committee, the Oklahoma State Legislature passed Enrolled House Bill 2824, appropriating $1 million from the Constitutional Reserve ("Rainy Day") Fund for initiation of the Oklahoma Weather Modification Program. The legislation was signed by Governor Keating on May 21 and, following a lengthy bid solicitation process, the state's contract with Weather Modification, Inc., authorizing the North Dakota-based organization to conduct program activities, was approved by the State Department of Central Services on July 18.

Objectives of the program were not to implement "drought relief" measures, but rather to establish a long-term water resources management tool to increase rainfall and decrease damages due to hail. The OWRB, in cooperation with WMI and others involved in program development, placed a priority on the utilization of appropriate scientific methods and the accurate measurement of the effects and results of cloud treatment. Through seeding of clouds where opportunities arise throughout the state, the OWRB would coordinate the monitoring of climate and soil moisture conditions to identify "priority" areas for seeding and "stand down" areas for which seeding activities would be prohibited. Equipment dedicated to the project by WMI included two project radars with aircraft tracking (global positioning satellite) and data archiving capabilities; three cloud-top project aircraft (twin engine, pressurized); the availability of a high performance cloud-top seeding cloud physics measurement plane (for Phase II of the program); and silver iodide seeding materials and supplies.

The OWRB also entered into a contract with the Oklahoma Climatological Survey, at the University of Oklahoma, to independently evaluate project results and, specifically, verify change of rain on the ground as well as improvements in seeding methods based upon cloud measurements. Project reporting was also a priority with weekly and monthly operation summaries provided by WMI, as well as annual project and evaluation reports.

Prior to initiation of state-sponsored weather modification activities, and continuing through the early stages of program implementation, substantial debate on the technology took place within the scientific community, political arena and media. One of the state's top atmospheric science consultants told the *Tulsa World* in a July 21 front-page story that the state is pursuing a "quick and dirty... emergency relief" answer to drought. Instead, he said, Oklahoma requires a scientifically sound plan with a long-term objective and it needs an appropriate system to objectively measure the results. In that same article, the head of Oklahoma's largest ranching operation and a long-time advocate of weather modification, pointed to the economic benefits of cloud seeding to the state's agricultural industry. This individual had subcontracted with Southwestern Kansas Groundwater District, who independently manages its own weather modification program, to conduct cloud seeding activities over company-owned ranch land in the adjacent Panhandle region until a state program was initiated.

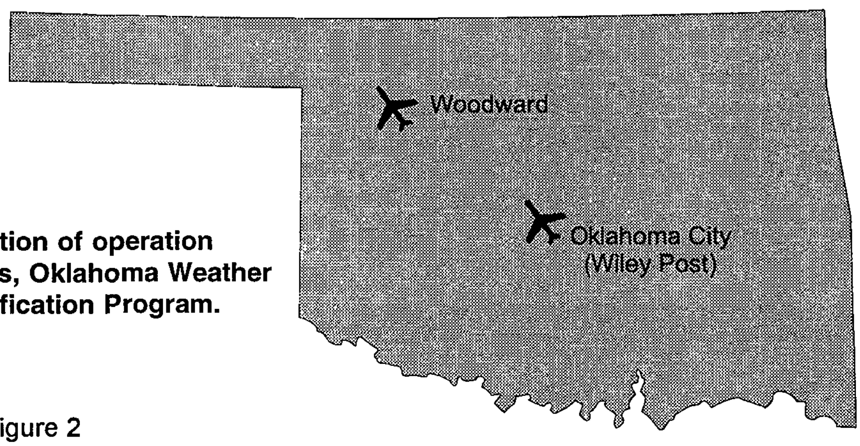
While the television and print media exhibited an acute interest in Oklahoma's program, they rarely took sides on the controversial issue of weather modification. However, the *Tulsa World* left little doubt on its position in the final paragraph of a November 11 editorial:

> *The Legislature next session will have to review the operation and decide whether to continue it. Here's a suggestion: If the governor and lawmakers have an extra million bucks to whoop off on some feel-good deal, why not just throw a statewide barbecue or buy circus tickets or donate it to charity? The benefits of those things would be easier to measure -- and they'd have about the same effect on the weather.*

It remains to be seen how the media and public sentiment will affect the future of Oklahoma's weather modification program.

4. PHASE I PROGRAM ACTIVITIES

On August 20, the state's first cloud seeding operations were conducted from Woodward, in northwest Oklahoma (Figure 2). The initial program design called for clouds to be seeded statewide. However, due to widespread rains, some localized saturated soil conditions and limited harvesting within the state, the OWRB decided to routinely evaluate and identify selected areas for cloud seeding. During the ensuing weeks, and as more Gulf moisture and clouds suitable for seeding surged into Oklahoma, the OWRB and WMI targeted only those climatic regions that would benefit from rainfall enhancement operations. Hail suppression operations were not impacted and were permitted statewide.



Location of operation bases, Oklahoma Weather Modification Program.

Figure 2

During the initial weeks of the program, broad areas of deep moist and unstable conditions moved over the region in association with Hurricanes Dolly and Fausto. As expected, cloud seeding opportunities and rainfall were widespread during these events. Following the tropical rains associated with the hurricanes, generally light to moderate south to southeast surface winds prevailed. The southerly flow component provided the moisture needed in combination with daytime heating for the development of isolated rain showers and thunderstorms. A number of these cloud complexes developed over the southwestern portion of the state and were seeded. However, this activity did not have the widespread rain coverage associated with the hurricane events.

On September 9, a second base of operations was established at Wiley Post Airport in Bethany, Oklahoma. Seeding operations from this facility focused on cloud development over the eastern two-thirds of the state. From the Woodward facility, seeding efforts were concentrated over the western portion of the state. As necessary, joint seeding operations were conducted in situations where cloud systems were too large to be treated effectively using a single aircraft.

By mid-September, the general circulation pattern had changed and the region experienced an abrupt end to clouds developing as a result of convection. At this time, the majority of developing precipitation events and cloud seeding opportunities were associated with the passage of surface cold fronts and upper level troughing conditions. As expected, deepest cloud development was usually along and behind the surface front. However, an unexpected number of these cloud formations reached hail potential and, as a result, most seeding opportunities focused on hail suppression operations. Radar observations routinely identified cloud top heights in excess of 45,000 feet with reflectivity values ranging from 45 to 55 dBZ at altitudes above 20,000 feet. Similar observations were reported by the National Weather Service Next Generation Weather Radar (NEXRAD) systems. Project seeding pilots frequently encountered and reported updrafts velocities of 1500 feet per minute (FPM) while making penetrations in feeder clouds in the vicinity of parent clouds. Additionally, moderate to heavy amounts of supercooled liquid water were found. During most flights, air frame icing was so extensive that seeding aircraft were required to descend to warmer altitudes to remove accumulated ice.

With the exception of northeast Oklahoma, precipitation data indicated that most of the state's climatic divisions were experiencing near to slightly above normal rainfall during the ongoing Water Year 1996. As a result, cloud seeding operations were focused in the Northeast climate division. While good seeding opportunities and rainfall were generally encountered 40 miles east of a line from Oklahoma City to Ponca City, few seeding opportunities occurred east of a north to south line through Cleveland and Bristow, Oklahoma.

During October, program operations continued to identify good to excellent cloud seeding opportunities for conducting both rainfall enhancement and hail suppression activities. Generally, this would not have been expected or anticipated due to the onset of fall, which is typified by cooler daytime temperatures and less chances of precipitation through convection, leading, in turn, to fewer cloud seeding opportunities.

While there were no occurrences of precipitation purely associated with the convection process, there seemed to be more frontal passages than expected. More importantly, there was a relatively high incidence of moisture either accompanying frontal passage or moisture flowing northward from the Gulf of Mexico in advance of the surface front. In either case, there appeared to be an unusually high frequency of naturally developing cumuli clouds and cloud seeding opportunities during the month. In addition, for the month of October, more rain events associated with stratified clouds (overrunning), rather than with cumuli clouds, were expected.

Program seeding pilots, in conducting aerial seeding operations, often reported moderate to heavy amounts of supercooled liquid water, incidents of airframe icing and updraft speeds of 1500 FPM. These meteorological parameters typically suggest that clouds are well-suited for the introduction of artificial ice nuclei. Throughout the month, it was not uncommon for radar observations to show strong vertical cloud top heights often exceeding 40,000 feet, with radar measurements showing moderate to strong vertical transport of water droplets.

During Phase I of the Oklahoma Weather Modification Program, a total of 32 aerial seeding flights were conducted (see table). These flights accrued 75.7 hours of flight time and employed the use of 1,245 minutes (almost 21 hours) of silver iodide aerial seeding generator time, 107 burn-in-place flares and 864 ejectable flares. Seeding materials were dispensed in accomplishing both rainfall enhancement and hail suppression activities.

5. CONCLUSION

Based upon real-time radar observations and seeding conditions reported by pilots during Phase I of the Oklahoma Weather Modification Program, it appears that program objectives were generally satisfied, although the Oklahoma Climatological Survey's full evaluation of pro-

PHASE 1
1996 OKLAHOMA WEATHER MODIFICATION PROGRAM ACTIVITIES

MONTH/AIRCRAFT #	AUGUST N34OFR[1]	SEPTEMBER N34OFR	SEPTEMBER N8SS[2]	OCTOBER N89585[3]	OCTOBER N8SS	TOTALS
Aerial Seeding Flights	5	7	8	6	6	32
Aircraft Hours	6.2	15.6	22.3	11.4	20.2	75.7
Burn-in-place Flares Utilized	23	66	12	---	6	107
Ejectable Flares Utilized	23	289	317	105	130	864
Silver Iodide Generator Time (minutes)	---	---	340	318	587	1245

1. based at Woodward Airport.
2. based at Wiley Post Airport, Oklahoma City.
3. replacement for N340FR (Woodward), returned to North Dakota due to faulty radar system.

gram results will not be complete until sometime after the conclusion of Phase II, scheduled to begin March 20 and run through May 31, 1997. In spite of the current absence of a long-term statistical data base, it appears that the 1996 Oklahoma cloud seeding program should have achieved positive results, similar to those realized in Kansas, North Dakota and Texas where increases in rainfall have generally ranged from seven to 14 percent and hail damage has been reduced from 27 to 45 percent (in Kansas and North Dakota only).

In anticipation of Phase II, the State Legislature has plans to convene a second interim study committee to further investigate the role of weather modification as an ongoing state program and identify potential funding mechanisms. To provide an even broader perspective, there are plans to expand the committee to include agricultural agencies and organizations, the weather and science community, municipal and rural organizations, tourism interests and other sectors routinely impacted by water shortages and drought conditions. In the coming year, deliberation by state decision makers and involved citizens of such pivotal issues as program effectiveness and long-term funding will likely determine the fate of weather modification as a proactive means to ease the detrimental economic and social impacts of future drought episodes and its role as a water resources development tool in Oklahoma.

Acknowledgments

The authors would like to thank John Girdzus, Alan Lisonbee, Patrick Sweeney and other staff of Weather Modification, Inc., for their substantial contributions to Section 4 of this paper (Phase I Program Activities) as well as their professionalism which was exhibited during Phase I of the Oklahoma Weather Modification Program.