

1.7 Weather Modification (SCTN-5)

1.7.1 Weather Modification and Methods

Weather modification as it has been applied in Texas over the past 25 years involves cloud seeding to either create rain when none would have occurred or to increase rain above what would have naturally occurred. The result of cloud seeding is referred to as rainfall enhancement. The concept of how this occurs is described below.

In natural rainfall, droplets are created from the presence of ice particles (crystals) in the cloud. These crystals are formed when freezing water contacts particles of dust, salt or sand. The ice crystals form a nucleus around which water droplets attach to make the size of the droplet increase. When the size of a droplet increases sufficiently, it becomes a raindrop and falls from the cloud. Cloud seeding is thought to increase the number of these “nuclei” available to take advantage of the moisture in the cloud to form raindrops that would not have otherwise formed. To be effective, seeding must be done at the correct time and in the correct manner.

As a cloud grows taller, the air temperature in the cloud cools and falls below the freezing point of water. This cooling effect means that the cloud droplets, which are much too small to fall as rain, are also cooled to a point where they respond to crystallization when contacted by an ice particle. Consequently, when there are fewer crystals to act as nuclei for raindrops, there will be less rain than would have been if more crystals were present. Although crude experiments to enhance rainfall were attempted in the U.S. as early as the mid-1800s, modern weather modification was begun in 1946 through an unintended laboratory event.

In 1946, V. Schaefer was involved with the General Electric Laboratory doing research to create artificial clouds in a chilled chamber. During one experiment, Schaefer believed the chamber was too warm, and, to cool it, he placed dry ice in the chamber. With the chilled water vapor in the chamber, ice crystals formed a cloud around the dry ice. Believing dry ice would not be practical to transport to emerging rain clouds, Schaefer’s colleague, Bernard Vonnegut, searched for a chemical that almost exactly matched the chemical structure of ice crystals. It was found that silver iodide (AgI) was such a chemical (Jensen, 1994). Silver iodide is termed “glaciogenic” because its chemical structure is like ice crystals. The other seeding chemical used when the cloud temperature is too warm for forming ice is calcium chloride (CaCl). Calcium chloride is “hygroscopic,” which means it attracts water.

When AgI is introduced into a cloud, the number of ice crystals increases and the crystals contact water vapor causing it to freeze to the crystal. Considerable heat is released to the atmosphere during the freezing and crystal formation phase. The released heat causes the cloud to grow taller and its vertical wind velocity (updraft) to increase. This results in the cloud being able to pull in more moist air and, thus, create more raindrops. However, not all clouds are potential rainmakers. Generally, cloud seeding is performed with a meteorologist working in tandem with the pilot of the cloud seeding aircraft so that, with direction from the meteorologist, the pilot can target the most promising cloud(s).¹ The criteria used in Texas to find promising clouds, is to locate “feeder” cells near developing cloud formations which have temperatures below 23° F. The target cloud must also have sufficient moisture and airflow to be a candidate. About 20 or 30 minutes prior to the desired rainfall event, the candidate cloud is seeded when the airplane releases AgI particles in a plume, typically at the base of the cloud so the updraft can draw the particles upward and make more contact with water in the cloud. Seeding has another effect on large, potentially dangerous thunderstorms capable of causing hail. Seeding tends to mitigate the extreme freezing that results in forming large particles of ice (hail) and makes the moisture more likely to fall as rain.

The criteria for cloud seeding based on experience in Texas since the early 1970s are the following:

- The cloud must be “convective” meaning that it displays instability in the atmosphere.
- Temperature at the top of the cloud must be 23° F or less.
- The base of the cloud must be less than 12,000 feet elevation.

Clouds having the characteristics listed above exhibit a warm base, a strong updraft, and sufficient heat to carry water vapor to the cloud top.

A summary of recent cloud seeding experiments in Texas, Florida, Cuba, and Southeast Asia has been presented by the TNRCC in a public information document entitled, “Some Facts about Cloud Seeding from Recent Research on Rain Enhancement in Texas” (Bomar, 1999). The TNRCC concludes the following:

¹ Clouds may also be seeded using ground-based silver iodide dispensers. However, in this discussion, only the aircraft method is considered.

- Cloud seeding with AgI increases rain generated by these clouds by extending the life of the clouds, by allowing the clouds to enlarge laterally so that they cover more area, and by slightly increasing the height of the clouds.
- Rain production of seeded clouds is more efficient than for non-seeded clouds.
- The timing of seeding and the selection of clouds are fundamental. These are such critical factors that "...seeding at the wrong time and in the wrong place(s) may actually decrease the rainfall." (Bomar, 1999)

1.7.2 Potential Rainfall Quantities from Weather Modification

The findings from several Texas cloud seeding programs are summarized below. This will provide a basis for determining the reasonableness of assumptions for the potential quantities resulting from weather modification in the South Central Texas Region. The programs to be discussed are the Southwest Cooperative Program (SWCP), the Texas Experiment in Augmenting Rainfall through Cloud-Seeding (TEXARC), the Colorado River Municipal Water District (CRMWD) Program, the Edwards Aquifer Authority (EEA) Program, and the Southwest Texas Rain-Enhancement Association (SWTREA) Program. Each of these programs is described below

Southwest Cooperative Program (SWCP). The program was begun in 1986 as a cooperative effort between Oklahoma and Texas "...to develop a scientifically sound, environmentally sensitive, and socially acceptable, applied weather modification technology for increasing water supplies...in the southern High Plains" (Bomar, et. al., 1999). The area involved was 5,000 square miles located between Midland-Odessa and Lubbock. Random cloud seeding experiments were conducted in 1986, 1987, 1989, 1990, and 1994.

During the period 1987 through 1990, 183 experiments were made (93 seeded, 90 non-seeded). The criteria for selection were the following:

- Liquid water content had to be at least 0.5 gm/m^3 and updrafts had to be at least 1,000 feet/minute.
- The target had to be a multiple-cell convective unit.
- No cloud or cell high could exceed 10 km (above ground level).
- Some of the tops had to have temperatures -10° C or colder.

The results confirmed increased rainfall. Compared to the non-seeded, the seeded cells displayed an increase in maximum height of 7 percent, an increase in the coverage of the rainfall

event of 43 percent, an increase in the storm duration of 36 percent, and an increase in rain volumes of 130 percent (Rosenfeld and Woodley, 1993).

Texas Experiment in Augmenting Rainfall through Cloud Seeding (TEXARC). The State of Texas implemented the program in 1994 and 1995 to investigate physical processes within large storms in the San Angelo area. This research was focused on understanding the best ways of seeding clouds to make them more efficient producers of water, rather than quantifying the results. The results showed that seeding must be within the super-cooled updraft region of the cloud in order to increase rainfall. From this research it was shown that the seeding agent must be carefully placed either directly in the top of the updraft, or at the entrance to the updraft at the base of the cloud.

Colorado River Municipal Water District (CRMWD) Program. Having been started in 1971, this is the longest-running operational weather modification program in Texas. The target area is roughly the upper Colorado River basin up stream from Spence Reservoir, comprising some 3,600 square miles. The goals for the program have always been first, to increase water supplies to Lake Thomas and Spence Reservoir, and secondly, to increase rainfall to agricultural areas. The reported long-term results are that there was a 34 percent increase (above normal historic precipitation) in the seeded areas and a 13 percent increase in non-seeded areas (Jones, 1988, 1997).

Edwards Aquifer Authority (EAA) Program. (*substantial portions of this program description were reproduced from the EEA web page, e-aquifer.com, and are presented here unedited*)

“The Edwards Aquifer Authority board of directors voted in the Fall of 1997 to obtain a permit to conduct precipitation enhancement, or cloud seeding, from the Texas Natural Resources Conservation Commission (TNRCC). The Authority contracted with Weather Modification, Inc., to complete and submit the permit application on the Authority's behalf, and work with the TNRCC. The permit was granted by TNRCC in October 1998 and is valid for four years from January 1999 through December 2002. The permit allows the Authority to conduct precipitation enhancement anytime during the year, including the traditional period of April through September. The Authority has committed \$500,000 for the 1999 program with half the expenses reimbursed by the TNRCC.

“The target area of the program covers over 6 million acres at a cost of about 4 cents an acre.” (Table 1.7-1.)

**Table 1.7-1.
Edwards Aquifer Authority Weather Modification Program Counties**

Target Counties	Operational Counties	SCTWAC Counties*
Bandera, Bexar, Blanco, Caldwell, Comal, Guadalupe, Hays, Kendall, Kerr, Medina, Real (east of U.S. Highway 83) and Uvalde	Gillespie, portions of Atascosa, Burnet, Frio, Kimble, Llano, Real, Wilson and Zavala	Calhoun, DeWitt, Goliad, Gonzales, Karnes, Nueces, Refugio, San Patricio, Victoria, Atascosa, Wilson, Uvalde, Medina, Bexar, Comal, Hays, Guadalupe and Caldwell

* South Central Texas Water Advisory Committee (SCTWAC), as created by SB 1477.

“Each county in the target and South Central Texas Water Advisory Committee (SCTWAC) areas of the program can appoint a representative to sit on a Precipitation Enhancement Advisory Group. The group will work with the Authority in alerting the contractor about local conditions. The ways this committee has worked included communicating saturation conditions so that flights are suspended to avoid flood conditions and suspending flights during harvesting of crops.”

“The first year of this program operated from April 15 to September 15, 1999. Consequently, no definitive results regarding estimated rainfall enhancement will be available for several months. The assumption for enhanced aquifer recharge was 10 percent above the recharge quantity, which would occur without enhancement.”

Rainfall Enhancement Programs Underway in Summer 1999. Several active cloud seeding programs were performed during the summer of 1999 including some as part of the programs described above. The programs, the counties they cover and the approximate areas of coverage are presented in the Table 1.7-2.

Although rainfall enhancement through cloud seeding has been practiced and studied in Texas and other states for many years, the benefits of rainfall enhancement for increasing water yield are not well determined. There is documentation regarding other benefits of cloud seeding, particularly with regard to impacts on agricultural production. The following section provides descriptions of quantified benefits resulting from cloud seeding in Texas and an estimate of the benefits to the region.

**Table 1.7-2.
Cloud Seeding Programs Underway in Texas during Summer 1999**

Cloud Seeding Program	Counties Involved	Area (sq. miles)
Colorado River MWD	Borden, Mitchell, and parts of Dawson, Howard, Sterling, Nolan, and Scurry	3,500
West Texas Weather Modification Association	Glasscock, Reagan, Crockett, Sutton, Schleicher, Irion and part of Tom Green	9,688
South Texas Weather Modification Association	Frio, Atascosa, McMullen, Live Oak, Bee, Karnes, Wilson	6,891
High Plains Underground Water Conservation District	Yoakum, Terry, Lynn, Cochran, Hockley, Lubbock, Bailey, Lamb, Hale, Parmer, Castro, Floyd, and part of Deaf Smith, Potter, Randall, and Crosby	12,438
Texas Border Weather Modification Association	Val Verde, Kinney, and Maverick	5,922
Edwards Aquifer Authority Program	Medina, Bandera, Kerr, Kendall, Blanco, Hays, Caldwell, Comal, Guadalupe, Bexar, and part of Real	8,500
Southwest Rain Enhancement Association	Uvalde, Zavala, Dimmit, La Salle, and Webb	9,141

1.7.3 Potential Quantities of Water Supply Resulting from Weather Modification in the South Central Texas Region

The benefits resulting from cloud seeding in the South Central Texas Region may include improvements in environmental and economic conditions. Environmental conditions in a stream, estuary, or lake can be improved by increased freshwater flows and the improvements can be measured using water quality parameters and aquatic life. Economic conditions can be improved by increasing crop production, by increasing animal production as a result of increasing the food supply, and by increasing ground and surface water supplies. Increasing water supplies can further improve economic conditions by affecting recreation, agriculture, municipal, and industrial activities in beneficial ways.

Performance data from cloud seeding programs typically focus on the rainfall event and parameters such as storm duration, cloud height, storm coverage (cloud area), and rainfall amount, rather than water supply parameters like increased stream flows and increased reservoir storage. Where water supply parameters have been measured in cloud seeding programs, the results appear to be positive. For example, Colorado River Municipal Water District (CRMWD)

reservoir storage increased from 14,000 acft to 200,000 acft in Lake Spence and from 26,000 acft to 30,000 acft in Lake Thomas since the inception of cloud seeding in the Big Spring and Snyder areas (Jensen, 1999). Also, the Twin Buttes and Fisher Reservoirs increased from a combined 40,000 acft to a combined 230,000 acft during a cloud seeding program sponsored by the City of San Angelo between 1985 and 1989 (Jensen, 1999).

To determine how much additional water supplies can be developed from weather modification in the South Central Texas Region requires a sequence of information. This information sequence includes: (1) the quantity of additional rainfall developed through cloud seeding; (2) the quantity of additional runoff; and (3) the quantity of additional runoff that was ultimately transported to a reservoir or was recharged to an aquifer. In the 1994 Edwards Aquifer Recharge Enhancement Project, Phase IV A, normal and enhanced recharge rates were computed for target recharge sites. The enhanced rates were developed to simulate the additional quantities of recharge that would naturally enter the aquifer without the benefit of man-made recharge structures. This 1994 Edwards Aquifer recharge study provides a baseline case from which to compute an example of potential water supply development from weather modification, as is explained below.

One way to estimate the potential for enhancing recharge through weather modification would be to increase the precipitation at an assumed rate and recompute enhanced recharge. The EAA program described above covers the same region as the areas modeled in the 1994 study. Therefore, an estimate has been made using the Sabinal River watershed (241 square miles) model with an assumed increase in rainfall over the same years studied previously in order to determine whether estimates for recharge would show increases if rainfall increased. This modeling and resulting computations show an annual average increase in estimated recharge of 9 percent, assuming a 15 percent increase in rainfall during the warm months (April through September) for the years 1990 through 1996 (Table 1.7-3). The model shows an annual average estimated increase of 3,173 acft (0.02 acft/acre) of recharge from the Sabinal River watershed. Although the EAA cloud seeding program covers the same areas previously modeled, an estimate of total increase in recharge resulting from the program was not developed. Since the increase in rainfall in an area where there is no pre-or post- cloud seeding data can only be assumed, it would be an inequitable comparison with most other options to extrapolate computer modeling results like those above over the entire region. To be an equitable comparison, the

results of cloud seeding in terms of increased rainfall, aquifer recharge, and reservoir storage would have to be predictable, verifiable, and comparable to unit firm yields developed from other options. Since these criteria cannot be met at this time, no such estimates can be made.

Table 1.7-3.
Simulation of Increased Annual Edwards Aquifer Recharge
Due to a 15 Percent Increase in Precipitation — Sabinal River Watershed

Year	Baseline Recharge Estimate (acft)	Recharge Estimate with 15 percent Increased Precipitation (acft)	Difference (acft)	Percent Difference
1990	32,526	35,822	3,296	10%
1991	41,319	45,361	4,042	10%
1992	67,724	72,719	4,995	7%
1993	27,761	29,745	1,984	7%
1994	24,219	26,833	2,614	11%
1995	30,855	33,574	2,719	9%
1996	<u>10,537</u>	<u>13,093</u>	<u>2,556</u>	<u>24%</u>
Average	33,563	36,736	3,173	9%

¹ The Sabinal River watershed has an area of 241 square miles, or 154,240 acres.

1.7.4 Environmental Effects of Weather Modification

Although cloud seeding weather modification is not a new technique, the effectiveness of weather modification has been difficult to measure. Since Texas has established a permit procedure, administered by TNRCC, data are being collected for a more scientific study of cloud seeding effectiveness and management. Originally conceived as a means to end droughts, experience shows that cloud seeding may work best during periods of normal rainfall. Weather modification is now considered a long-term water augmentation strategy for freshwater supplies.²

The amount of silver iodide and calcium chloride used during a seeding event is negligible and too dispersed to have a measurable effect on the environment. Safe handling and storage of these materials prior to dispersal are a larger concern. Both are normally used in

² Bomar, George, TNRCC Senior Meteorologist, Austin, Texas.

industrial applications and printing. Therefore, procedures for handling and storing silver iodide are well documented. There are no known environmental problems associated with this option.

1.7.5 Estimated Costs of Weather Modification

The EAA program is in its first year of operation and has not reported official results for 1999. The cost is \$500,000 per year. Using the EAA program coverage area (8,500 square miles), the resulting unit cost of this program is about 8.3 cents per acre.

1.7.6 Implementation Issues

In terms of a measurable and dependable regional water supply option, weather modification in the form of cloud seeding appears to be a beneficial, but uncertain, source of usable water. However, data are not adequate to specify firm yield. With the following conditions regarding factors that influence aquifer yield, it may be possible to gain a sense of the potential increase in Edwards Aquifer recharge that might result from cloud seeding:

1. Assume an increase in rainfall during warm months resulting directly from cloud seeding.
2. Assume that the increased rainfall is managed to prevent flooding but falls at a time when antecedent soil moisture is high enough to create runoff.
3. Assume that the runoff created occurs at locations above or over recharge structures.

One important potential benefit of cloud seeding is that a part of the agricultural water supply needs (irrigated and dryland crops and rangelands) could be met. For example, higher rainfall would lower the quantities of irrigation water that has to be withdrawn from the aquifers and streams of the South Central Texas Region, and dryland production would benefit from increased rainfall. This could be a significant water supply option for agricultural uses. Over a sufficient period, agricultural production data could be developed to demonstrate that crop yield, animal production, and other measurable agricultural parameters have increased as compared to the same data prior to beginning the cloud seeding program. For a relatively minor cost, cloud seeding could perhaps meet some of the agricultural needs, as well as making contributions to aquifer recharge and streamflows of the region that could be developed to meet municipal and industrial needs

This option is evaluated in the Table 1.7-4 to provide an overall comparison with other regional options.

**Table 1.7-4.
Evaluations of Weather Modification to Enhance Water Supplies**

Impact Category	Comment(s)
a. Quantity reliability and cost of treated water	<ul style="list-style-type: none"> • Low, uncertain quantity and timing • Low cost
b. Environmental factors	<ul style="list-style-type: none"> • none
c. State water resources	<ul style="list-style-type: none"> • No apparent negative impacts on other water resources • Potential benefit to Edwards, Trinity, and Carrizo Aquifers water resources due to increased water for recharge • Potential benefit to farmers and ranchers through increased rainfall
d. Threats to agriculture and natural resources in region	<ul style="list-style-type: none"> • Potential threats due to flooding
e. Recreational	<ul style="list-style-type: none"> • none
f. Comparison and consistency equities	<ul style="list-style-type: none"> • Cost reported in annual unit area cost only
g. Interbasin transfers	<ul style="list-style-type: none"> • Not applicable
h. Third party social and economic impacts from voluntary redistribution of water	<ul style="list-style-type: none"> • Not applicable
i. Efficient use of existing water supplies and regional opportunities	<ul style="list-style-type: none"> • Improvement over existing conditions
j. Effect on navigation	<ul style="list-style-type: none"> • none