A REVIEW OF THE TEXAS WEATHER MODIFICATION PROGRAMS IN 2007

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Abstract. Texas has had several weather modification programs over the past 40 years. More recently, in the past 10 years there have been 12 weather modification programs in existence in the state. In 2007, seven were operational, conducting rain enhancement and, in one instance, hail suppression operations. After two years of below normal rainfall, 2007 was above normal in much of the state, particularly southern and central Texas. As far as operations are concerned, projects in the northern and western part of the state saw a near normal year as far as number of seeding days, while the southern projects saw a below normal number of seeding days due to several intense rainfall episodes resulting in prolonged flooding. This paper will summarize the 2007 season for the different projects in the state as well as present an analysis of all the projects conducted by Active Influence and Scientific Management.

1. INTRODUCTION

Weather modification operations have been in existence in the state of Texas off and on since the late 1800's. Most recently, a resurgence of weather modification projects began in the mid 1990s and continues to this day. At one point in the early part of the new millenium, as many as 12 projects conducting weather modification operations were in existence. In 2007, seven projects were operational: Panhandle Groundwater Conservation District's (PGCD) precipitation enhancement project in White Deer, Seeding Operations and Atmospheric Research (SOAR) in Plains, Trans-Pecos Weather Modification Association (TPWMA) in Pecos, West Texas Weather Modification Association (WTWMA) in San Angelo, Southwest Texas Rain Enhancement Association (SWTREA) in both Carrizo Springs and Pleasanton, South Texas Weather Modification Association (STWMA) in Pleasanton, and the Edwards Aquifer Authority's (EAA) precipitation enhancement project. The latter project is absorbed by both SWTREA and STWMA. A map showing the location of all the projects is presented in Figure 1.

2. TEXAS WEATHER IN 2007

2007 ended up being one of the wettest years in recent history for many areas of Texas, particularly southern and central parts of the state. A weak El Niño pattern was present in January with several weather systems affecting the state. Rainfall was well above normal over the eastern half of the state, with locally over 3 inches measured in parts of the STWMA target area. February was much drier, with less than an inch of rain falling in all the target areas. March saw a return to much wetter conditions, with all target areas except SWTREA seeing upwards of 200% of the normal monthly precipitation. The jet stream was positioned over Texas with several disturbances laden with Pacific moisture aloft and Gulf moisture near the surface traversing the state. For some locations in STWMA, it was the wettest March ever recorded. By April, a more typical early spring pattern emerged with occasional severe weather episodes occurring within all target areas. Precipitation during April was quite varied, with most target areas seeing near to above normal rainfall; the exceptions being PGCD and SWTREA where below normal rainfall was measured. May saw the beginning of a wet period that would last through August. High pressure that usually begins to bridge across the entire southern United States in May and June did so but only periodically; most of the late spring and summer months saw a pattern where a weakness in the subtropical ridge existed over Texas. This was a favored area for upper level lows to spin up. Feeding on an abundance of tropical moisture, these lows generated periodic heavy rains across the state, especially over central and southern Texas. In the May-August period, over 10" of rain fell each month at several locations within both SWTREA and STWMA. This period of excessive rains resulted in many suspension days for these two projects as flooding became a common problem. Although the projects in west Texas and the panhandle also had a wet summer, flooding was less of a problem and thus seeding operations were active.

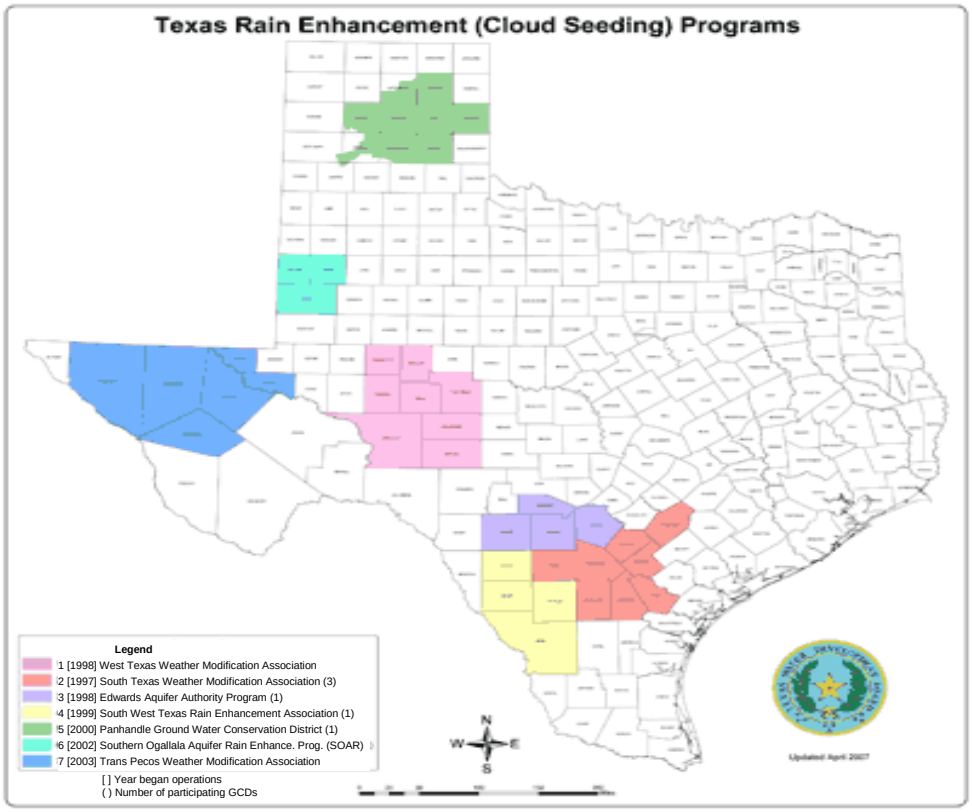

Figure 1. *Locations of Weather Modification Programs in Texas in 2007.*

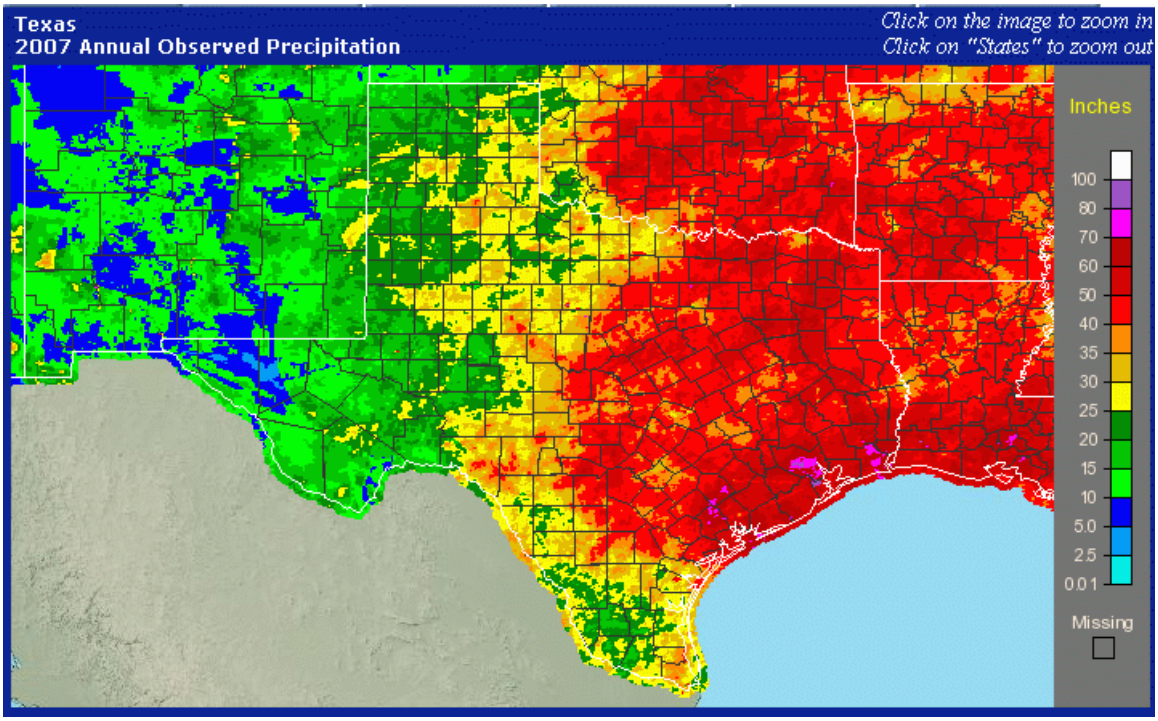

Figure 2. *Radar-derived yearly precipitation for Texas in 2007. Image courtesy of NWS Precipitation Analysis website, http://www.srh.noaa.gov/rfcshare/precip_analysis_new.php .*

One of the biggest weather events of the summer for Texas was Tropical Storm Erin in mid-August, the remains of which moved form near Corpus Christi on the 16th to western Oklahoma/eastern Texas panhandle late on the 18th. Along this track, widespread 1-3" rains fell with isolated spots in excess of 5". A return to drier weather in September resulted in below normal precipitation for the WTWMA and STWMA target areas, with above normal rainfall (2-6") reported in PGCD, SOAR and SWTREA target areas. In October, the La Niña pattern became better established, and this effectively shut off the heavy rains of the past several months as the jet stream and associated storm track moved well north of Texas. This pattern continued through the remainder of the year. Figure 2 illustrates the radar-derived yearly rainfall for Texas.

3. PROJECT SUMMARIES

3.1 Panhandle Groundwater Conservation District (PGCD)

Panhandle Groundwater Conservation District's 2007 Precipitation Enhancement Program's first mission occurred on March 28th and the last mission occurred on September 26th. Typically, the season runs from April 15th until September 30th; however, if suitable opportunities are present before the 15th the season will commence earlier.

This year seeding occurred on 38 days, eight less days than in 2006; however, the additional rainfall amount across the district increased from 2.75 inches in 2006 to 2.80 inches in 2007 (Ruiz-Columbié 2007a). The increase can be attributed to seeding larger clouds during 2007 that had a longer lifetime, and larger area and volume. Due to longer cloud lifetimes many seeding days had two to three seeding missions. 2007, with a total of 59 missions, had only one less seeding mission than 2006.

During 2007 PGCD flew one seeding mission in March, six seeding missions in April, eight seeding and five reconnaissance missions in May, 10 seeding missions in each of June and July, 10 seeding and four reconnaissance missions in August, and five seeding and one reconnaissance missions in September. The district made the most of opportunities when conditions were favorable.

The total number of flares used in 2007 was 1004, 482 less than in 2006. Both 40 gram and 80 gram burn-in-place (BIP) and 20 gram ejectable flares were fired during the 2007 season. Of the 612 total BIP flares, 554 were fired within the district which includes Carson, Donley, Gray, Roberts, Wheeler and parts of Potter, Armstrong, Hemphill and Hutchinson counties and the other 58 flares were released in the buffer zone which includes Hansford, Ochiltree, Lipscomb, Moore, Hartley, Oldham, Deaf Smith, Swisher, Briscoe, Hall, Childress and Collingsworth counties in Texas and Ellis, Roger Mills and Beckham counties in Oklahoma. Of the 392 total ejectable flares, 356 were fired within the district and 36 were released in the buffer zone.

Not only during 2007 did seeding slightly increase the amount of rainfall across the district, but the cost per acre-inch was also lowered from $0.017 in 2006 to $0.011 in 2007. Overall the 2007 season was slightly less active than 2006, but just as successful.

3.2 Seeding Operations and Atmospheric Research (SOAR)

The 2007 season was a successful one at SOAR, with 27 days on which seeding activities took place. All of the seeding activities fell between May 1 and August 31. A total of 1027 ejectable flares and 135 BIP flares were used for seeding in the tri-county target area of Yoakam, Terry and Gaines. One day in May saw seeding take place, increasing to five in June. July was the busiest month for seeding, with 14 days during the month seeing operations take place. August was the second busiest month with 7 operational days of seeding. No seeding took place after the end of August.

3.3 Trans-Pecos Weather Modification Association (TPWMA)

The TPWMA had a less active year in 2007 compared to nearby projects at Plains and San Angelo, with 21 days of seeding taking place. Operations were run remotely from the SOAR office at Plains. Rainfall in 2007 was more plentiful compared to 2006, and this presented more opportunities for seeding. 293 BIP flares were used over the course of the season for seeding. The vast majority of events in the TPWMA target area were orographically-driven, with convection developing over the Davis Mountains.

3.4 West Texas Weather Modification Association (WTWMA)

2007 West Texas seeding operations started on March 26th and ended on October 3rd with 46 operational days. 95 clouds were seeded with 1263 flares during 82 flights. 14 reconnaissance flights were

flown while making an attempt to find seedable clouds on marginal days. Pilots flew 188 hours. Several part-time pilots are valuable assets to seed clouds at various times of the day throughout the active season. There are limited cases when a pilot is unattainable for seeding at time of convective initiation. A few repairs on aircraft had minor effects on operations. TITAN software operated without any major issues. On several occasions, the Southern Region Headquarters' server went offline, resulting in lost radar data.

Rainfall for much of west Texas was above normal due to an atypical pattern. Three factors played a role in the wet season: The jet stream remained in lower latitudes through early summer, lying across an area from southern California to west-central Texas. Several stagnant cut-off upper-level low pressure systems spun over parts of Texas. Lastly, influences from tropical systems allowed for heavy rainfall, particularly from the remnants of Tropical Storm Erin in August. Monthly rainfall totals are available in Table 1 showing 2007 was a very wet year with a yearly total of 32.05" at San Angelo, 11.74" above normal.

March established only one day for seedable conditions and results were favorable. The general pattern setting in for spring limited seedable conditions on many occasions either with overnight precipitation or very low cloud ceilings. April allowed for four seeding days amongst several migrating upper-level lows. May produced five days with seedable conditions amongst several cut-off upper-level lows held over the Great Plains by a persistent surface high and upper-level ridge over the eastern United States while the subtropical jet held a position over southern Baja and central Mexico. Cut-off lows were responsible for rain in June and allowed for seven days of operations. July was the most active this season with fourteen operational days and the conditions were more typical as airmass thunderstorms became more numerous. August began with short-wave impulses producing scattered showers across the region with very high totals over localized areas. A high pressure ridge then set up over the central Plains. The ridge became prominent over the western states and the southeast which would allow for a stagnant upper low/shear axis to develop later. August contained six days of seedable conditions. September was drier over west Texas but still allowed for six operational days. One event over San Angelo allowed over an inch-and-a-half but departure for the month was below normal. October allowed for two operational days; however a ridge cutoff the precipitation for the region leaving the fall drier than normal.

3.5 Southwest Texas Rain Enhancement Association (SWTREA)

The Southwest Texas Rain Enhancement Association operates a weather modification program for a four-county area in southwest Texas from March to November. Additionally, southwest Texas contracts with the Edwards Aquifer Authority (EAA) to do operational cloud seeding for Uvalde County from May to September. SWTREA's target area includes 9,133 square miles from the Balcones Escarpment to the Rio Grande River. The project is entering its 10th year of twenty four hours a day, seven days a week weather modification operations during the season. This includes both rain enhancement and hail suppression operations.

Weather modification operations for 2007 in SWTREA were far below normal. SWTREA normally averages about 75 flights a year. Only 32 flights took place this year, a little less than one half of what usually occurs. The main reason for the drastic drop in flights was the wet pattern over the southern U.S. for the spring and summer months. Suspension of the project occurred for almost six weeks during the summer months due to river flooding, saturated soils and abundant tropical convection over the area providing heavy rainfall. June and July, where the bulk of the flights for the year are normally accumulated, only yielded four flights.

Table 1. *Monthly Rainfall for 2007 and departure from normal at San Angelo, TX.*

January	1.86		1.04		July	1.84		0.74
February	0.55		-0.63		August	6.55		4.50
March	3.86		2.87		September	2.55		-0.40
April	2.66		1.06		October	0.83		-1.74
May	4.74		1.65		November	0.89		-0.21
June	5.54		3.02		December	0.18		-0.76
					Annual	32.05		11.74

For the 2007 seeding season, 32 flights took place over 24 operational days. Of these, four were classified as hail suppression. Additionally, a total of six reconnaissance flights took place. A total of 54 flight hours were logged with 425 BIP flares totaling 17,000g of AgI burned. Table 2 summarizes SWTREA's weather modification activities for 2007.

3.6 South Texas Weather Modification Association (STWMA)

The STWMA is an eight-county area in south-central Texas with base operations in Pleasanton, south of San Antonio. The project runs year-round, conducting daytime cloud seeding operations. The project also has a contract with the EAA to conduct rain enhancement operations over Bexar, Medina and Bandera counties between May and September. As such, the STWMA, with over 6.6 million acres during the main seeding season, is the largest weather modification project in Texas.

The 2007 seeding season for STWMA began with the first mission on April 28th and concluded with the final mission on October 8th. A total of 40 flights over 23 days of seeding took place, the majority of which occurred from August 15th onward. Very heavy rains fell between May and August, and although this was welcome relief from the drought of the previous two years, it resulted in several suspension periods. No operations took place during the month of July due to excessively wet grounds and heavy rains. This has only occurred once before in the 11-year history of the STWMA, in July 2002 during a very wet period when catastrophic flooding affected the EAA counties of the target area. With the excessive rainfall, 2007 fell well short of the 11-year average of 68 flights and 38 seeding days. Table 3 summarizes the monthly operations.

Table 2. *Weather modification activities for SWTREA in 2007.*

Month	Number of flights	Flares used (40g BIP Flares)	AgI Used
March	1	26	1,040g
April	1	15	600g
May	6	120	4,800g
June	3	50	2,000g
July	1	11	440
August	13	160	6,400g
September	3	13	520g
October	2	30	1,100g

Table 3. *Weather modification activities by month for STWMA in 2007.*

Month	Days	Flights	Flares (40g BIP)	AgI used (g)
April	1	2	7	280
May	4	5	101	4040
June	3	7	74	2960
July	0	1	0	0
August	8	13	125	5000
September	6	10	71	2840
October	1	2	44	1760
Total	23	40	422	16880

4. 2007 STATE EVALUATION BY ACTIVE INFLUENCE AND SCIENTIFIC MANAGEMENT

Since 2000, Active Influence and Scientific Management (AISM) has been performing a yearly analysis of all seeded clouds in the state of Texas. Individual analyses of each project are also conducted. The analysis involves looking at a seeded cloud as identified by the TITAN (Thunderstorm Identification, Tracking, Analysis and Nowcasting) softwarewhich uses, since 2004, WSR-88D data from radars covering the various target areas in the state. The evolutions of these identified seeded clouds are then compared to the evolutions of control clouds that best match the seeded clouds in their early life. Several factors are compared between seeded and control clouds such as lifetime, area, volume and precipitation mass. In this section we will look at the results of all seeded small clouds, defined as those clouds with radar-derived precipitation mass values less than 10,000 kilotons. Note that this analysis does not include data from both the SOAR and TPWMA projects. Table 4 shows the results of the AISM analysis of all seeded small clouds in the state of Texas. Bold values in parentheses are modeled values, whereas **η** is defined as the quotient of Precipitation Mass divided by Cloud Mass, and is interpreted as efficiency. A total of 356 flares were used in this sub-sample with an excellent timing (86%) for an effective dose near 115 ice-nuclei per litre, which might have reached slightly higher levels in some individual cells. An excellent increase of 107% in precipitation mass together with an increase of 42% in cloud mass illustrates that the seeded clouds grew at expenses of the environmental moisture (they are open systems) and used only a fraction of this moisture for their own maintenance. The increases in lifetime (35%), area (29%), volume (43%), volume above 6 km (76%) and precipitation flux (55%) are notable. There are slight increases in maximum reflectivity (2%) and in top height (3%). The seeded sub-sample seemed 45% more efficient than the control sub-sample. Results are evaluated as excellent for this sub-sample.

An increase of 107% in precipitation mass for a control value of 997.6 kton in 72 cases means:

Δ_1 = 72 x 1.07 x 997.6 kton = 76,855 kton = 62,329 ac-ft

Large clouds – those with precipitation masses greater than 10,000 kton – and Type B clouds – those clouds, large or small, that were not seeded until they were at least an hour old as seen on radar – were also analyzed. Large clouds that were seeded in Texas produced an additional **1,746,888 ac-ft** of water, and Type B clouds that were seeded in Texas produced an additional **1,318,075 ac-ft** of water as determined by the AISM analysis. The apparent total water produced by all seeded clouds in Texas was **3,127,818 ac-ft** in 2007 (Ruiz-Columbié 2007b).

Table 4. *Seeded Sample versus Control Sample (72 couples, averages)*

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	45 min	1.44	44 **(35)**
Area	65.9 km^2	45.4 km^2	1.45	45 **(29)**
Volume	193.0 km^3	119.6 km^3	1.61	61 **(43)**
Top Height	8.4 km	7.7 km	1.08	8 **(3)**
Max dBZ	53.2	51.3	1.04	4 **(2)**
Top Ht of max dBZ	4.2 km	4.3 km	0.98	-2 **(0)**
Volume above 6 km	45.0 km^3	22.2 km^3	2.03	103 **(76)**
Precip Flux	520.2 m^3/s	313.3 m^3/s	1.66	66 **(55)**
Precip Mass	2314.3 kton	997.6 kton	2.32	132 **(107)**
Cloud Mass	156.0 kton	91.6 kton	1.7	70 **(42)**
η	14.8	10.9	1.36	36 **(45)**

5. SUMMARY

The 2007 season saw many clouds seeded in the state of Texas. The seven existing projects in the western two-thirds of the state had varying degrees of seeding success, with a near normal year as far as weather modification activities go in west and north Texas. Although abundant rains fell over southern Texas in one of its wettest years, seeding operations were reduced as flooding persisted for much of the summer. The AISM analysis for 2007 indicated positive effects as a result of seeding, with over three million acre-feet of additional water produced over and adjacent to target areas in the state.

6. REFERENCES

Ruiz-Columbié, A., 2007a. Panhandle (White Deer) annual evaluation report, 2007. pp 5.

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