TEXAS WEATHER MODIFICATION OPERATIONS IN 2009

Robert E. Rhodes[1*], Stephanie D. Beall[2], Todd R. Flanagan[3],
Jennifer Wright[4] and Arquimedes Ruiz-Columbié[5]

[1]WTWMA, 8696 Hangar Rd., San Angelo, TX 76904
[2]SWTREA, P.O. Box 1433, Carrizo Springs, TX 78334
[3]STWMA, 110 Wyoming Blvd. Pleasanton, TX 78064
[4]PGCD, P.O. Box 637, White Deer, TX 79097
[5]Active Influence & Scientific Management, 6506 86th St, Lubbock, TX 79424

ABSTRACT. Weather modification operations continued in 2009 over the state of Texas. During the 2009 season, a total of seven projects were operational in Texas conducting rain enhancement and, in one project, hail suppression operations. Operations for 2009 were very good over the western projects but rainfall and seedable conditions over the south was below average due to a prolonged drought. Most of the state was dry, with the exception of West Texas and parts of the Panhandle. This paper will serve as an update for the Texas projects in 2009, offering a comprehensive summary of each of the operational projects in the state. Additionally, this paper will provide an analysis of the Texas projects conducted by Active Influence and Scientific Management.

1. INTRODUCTION

Weather modification operations continued over Texas during 2009. While weather modification has occurred over the state for decades, recent operational programs have been consistently enhancing rainfall since the turn of the twenty-first century.

During the 2009 season, 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 EAA project is operated by the STWMA and the SWTREA. A map showing the location of all the projects is presented in Figure 1.

2. TEXAS WEATHER IN 2009

Weather over Texas during the year was different from the last two years. Drought persisted over South Texas throughout the majority of the year while parts of West Texas and the Panhandle were wet with several instances of record or nearly record rainfall totals. An area of high pressure laid over the Gulf and southern Texas through most of the convective season, inhibiting thunderstorms over South Texas. The Texas Panhandle and West Texas were subject to an increased number of well-structured frontal boundaries through mid-season. Frontal boundaries are typically not responsible for weather over west-central Texas after June.

The Texas coast often receives relief from tropical systems but the 2009 tropical season did not offer significant rainfall to Texas. However, the ridge, which prolonged significant drought over South Texas through August, lifted during the later half of September, bringing the region much desired relief. Figure 2 illustrates the radar-derived yearly rainfall for Texas.

3. PROJECT SUMMARIES

3.1 Panhandle Groundwater Conservation District (PGCD)

The conclusion of the Panhandle Groundwater Conservation District's (PGCD) 2009 Precipitation Enhancement Program marked the tenth year of cloud seeding in the Texas Panhandle. This season began with the first mission on April 26th and concluded on September 25th with the last mission. The mission on September 25th was the latest season flight since the inception of the program in 2000. Typically, the season runs from April 15th until September 30th; however, if suitable opportunities are present before the 15th the season will commence.

The 2009 seeding season contained 25 days with seeding events, which consisted of 32 seeding missions and 23 reconnaissance missions. Several days during the summer were marginal days for thunderstorm development, which resulted in more reconnaissance missions than any other year in the past. According to Active Influence and Scientific Management (AISM), during the seeding events we seeded 32 clouds which consisted of nine small clouds, 10 large clouds and 13 type B clouds.

**Corresponding author*: R.E. Rhodes, WTWMA, 8696 Hangar Rd., San Angelo, TX 76904 USA; E-mail: meteorologist@wtwma.com

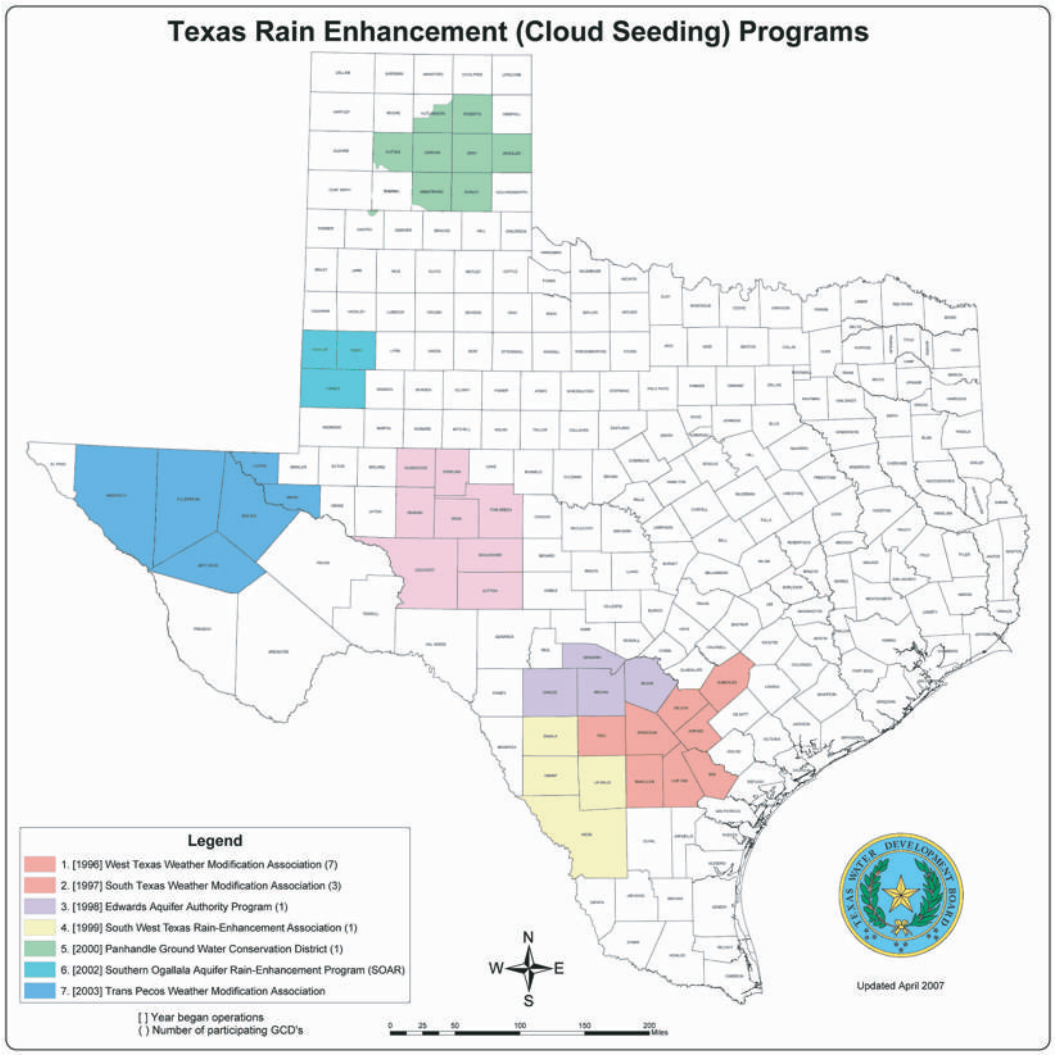

Figure 1. Locations of Weather Modification Programs in Texas in 2008

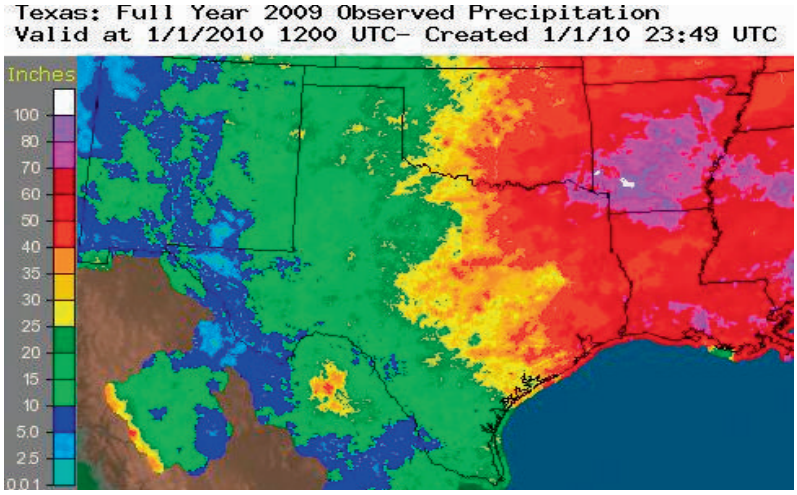

Figure 2. Radar-derived yearly precipitation for Texas in 2009. Image courtesy of NWS Precipitation Analysis website, http://www.srh.noaa.gov/rfcshare/precip_analysis_new.php .

The seeding of these clouds helped to produce an additional 717,900 acre-feet of water which translates to on average about 1.65 inches across the water District. Taking into account the raw rain gauge data, the 1.65 inches can be translated to a 10 percent increase per county in rainfall received.

The economic value of this additional 10 percent of rainfall remained about the same as the 2008 season. The total cost of the seeding program in 2009 was $200,693. Considering this figure plus what an additional 1.65 inch per acre is worth, the District cost per acre is about five cents.

While most of the south Texas cloud seeding projects report about a strong drought, the Texas Panhandle experienced exactly the opposite. April, the start of the season, began a little dry with the majority of the Panhandle considered moderately dry by the U.S. Drought Monitor. During May and June, the Texas Panhandle was mostly drought free, and this is also when the majority of the seeding missions took place. There were six seeding days in May and seven days in June. July's weather pattern was dominated by high pressure; therefore, only one seeding day occurred and the Panhandle began to see some dry areas set in. August through September saw the return of the seasonal cold fronts and trough passages which brought many opportunities for rainfall. Any dry areas that were present in July were all clear as of November.

All of the counties within PGCD received more rainfall in 2009 than in 2008 from April to October (Table 1). Rick Husband International Airport in Amarillo recorded 8.07 inches of rainfall in August, which beat the record of 7.55 inches in 1974, according to the National Weather Service in Amarillo, Texas.

Table 1. April-October rainfall averages comparing 2008-2009

	2008	2009	Departure
Armstrong	14.5	17.8	3.2
Carson	16.3	23.2	6.9
Donley	17.1	17	0.1
Gray	17.6	19.4	1.8
Potter	16.6	14.1	2.5
Roberts	18.1	17	1.1
Wheeler	22.3	19.1	3.3
District Normal 16.43			

Normally, during the seeding season the weather events are concentrated either in the west or in the east in the Panhandle; however, that did not occur this year. See Table 2. Most of the weather events included all or most of the Texas Panhandle; therefore, the seeding was spread out through all of the District Counties. Donley County saw the most seeding days with 10 followed by Carson and Gray counties with nine days. The least amount of seeding days occurred in Potter and Wheeler counties with only five days.

This year's season brought a few changes to the project. A new pilot, Harrison Hoffman, joined the staff in June. Also, a new upgraded TITAN computer (Thunderstorm Identification, Tracking Analysis and Nowcasting) supplied by Weather Decision Technologies, Inc., was put into operation. The upgraded systems were put in place in all of the Texas projects. These new computers were necessary to handle the National Weather Service radar upgrades to super resolution in 2008.

The 2009 seeding season was overall average, but successful with an average increase of rainfall of 10 percent throughout the PGCD counties. The Texas Panhandle was very lucky to not participate in the drought that dominated South and Southwest Texas.

Table 2. PGCD Seasonal Summary

2009	Days	Seed Flights	Recon Flights	Flight Hours
April	2	3	3	7
May	6	9	0	18
June	7	9	6	30
July	1	1	6	10
August	4	5	6	19
September	5	5	2	11
Totals	25	32	23	95

3.2 West Texas Weather Modification Association (WTWMA)

Seeding operations started on March 25th and ended on October 8th with 56 operational days. Table 3 contains a summary. The number of operational days is the most on record for West Texas; previously, operations were conducted over 53 days in 2006 (see Table 4). Overall 190 clouds were seeded with 2,382 flares during 103 flights. The number of seeded clouds is the most since changing radar sources from 74-C to WSR-88D feed. In sum 9 reconnaissance

flights were flown while making an attempt to find seedable clouds on marginal days. Pilots flew 267 flight hours. Full time pilot, Levi Sleeper, flew for the duration of the season; part time pilot availability and erratic storm development throughout the season made for a few late flight initiations. Some moderate repairs on aircraft, mainly the Piper Aztec 6730Y, had minor effects on operations.

Table 3. WTWMA Seasonal Summary

2009	Days	Flights	Recon	Hrs	Flares	Rainfall
25-Mar.	1	2	0	4	60	1.73
April	3	5	1	11.8	50	4.61
May	10	18	2	55.8	582	0.12
June	12	22	2	63.9	487	1.74
July	9	18	2	39.7	267	4.64
August	13	23	1	54.6	543	1.89
Sept	7	12	0	32.8	359	5.66
8-Oct.	1	3	1	4.5	54	2.92
Totals	56	103	9	267.1	2402	23.31

Throughout the rainy season of 2009, West Texas received a larger sum of rain than most of Texas. As of November 16, a value (23.85in) at San Angelo was above normal by 4.27 inches. Top 10 rainfalls at the San Angelo Regional airport during April and July in addition to periodic large rainfall events throughout the summer led to a well above normal season. Midland International was well below normal until July, receiving 6.55 inches during the month. August was the most active this season with 13 operational days. Precipitation and percent of normal maps show that much of Texas was well below normal except for West Texas and parts of central Texas during March and April. Most of Texas was dry through May. Western parts of the target area were well above normal in June and West-central Texas above normal in July. West Texas is shown to be dry August through September but drought stricken East-central and South Texas began to see some relief. The 2009 tropical season was very limited in the Atlantic Ocean and Caribbean without hurricanes moving onto the Texas Gulf Coast. The Pacific tropical season was more active with several instances of tropical moisture moving over Mexico and into West Texas.

The statistical reports conducted by AISM shows the majority of seeding operation results were excellent or very good; with average seasonal increases to precipitation at 17%. Arrival time to small clouds (91%) was excellent. Small clouds showed increases for precipitation mass at 102%, cloud mass increases of 55%, lifetime increases at 27%, increases to cloud area at 39%, cloud volume increases of 41%, and volume above 6km of 48%. Increases in precipitation mass by county were shown between 6% and 35.5%. Crockett County was below 10% but the low value is a consequence of large area. Reagan County was most favored in number of seeded clouds. In addition to glaciogenic seeding, West Texas also started a case study using one supplementary hygroscopic flare. Unfortunately, only 3 cases could be matched with a proper control sample. Further information can be read in the AISM evaluation (Ruiz-Columbié 2009. Total increases in precipitation for the target area were calculated at 1,851,542 acre-feet.

Table 4. WTWMA Multi-year comparison

	WTWMA (2002-2009)				
	Seeded-Clouds	Operational Days	Flares Used	Increase Million ac-f	Annual Rainfall
2002	285	47	3024	0.78	14.41
2003	265	50	3184	0.76	19.76
2004	109	46	1140	1.35	30.48
2005	133	39	1524	1.26	20.4
2006	157	53	1810	1.7	17.65
2007	95	46	1166	1.19	32.05
2008	78	38	1420	1.18	19.00
2009	190	56	2382	1.85	25.54

3.3 Southwest Texas Rain Enhancement Association (SWTREA)

This year, 2009, was an unusual year over the southwestern most portion of Texas. Weatherwise, it was a hot and dry summer for most locations. As for weather modification, it was actually above average. This typically occurs during dry years. Usually in a drought, there is a lack of suitable clouds to go after. This makes the weather modification project operators even more diligent in their efforts to increase rainfall over the area. As a result, there were more reconnaissance flights this year than normal, with a total of 16 occurring during 2009. The early spring months offered a slow start to weather modification activities while the rest of the season was quite busy. The busiest month of the season was May, with a number of hail suppression flights taking place and in turn, a large amount of seeding material used. Flight activity increased dramatically during the latter half of the season as a strong area of high pressure that dominated the weather pattern for much of the summer months weakened. This information can be seen in Table 5. Another strange occurrence this

year was that for the first time in six years, no flights occurred in the month of October. This was due to a number of the systems being embedded, which means that the thunderstorms were embedded in light rain, or low ceilings that hampered seeding at base.

Table 5. SWTREA Seasonal Summary

Month	Seeding Flights	Recon Flight	Flight Hours	Flares	AgI (g)
March	2	1	3.3	31	1240
April	1	1	3	53	2120
May	11	4	30.9	364	14560
June	7	2	11.6	155	6200
July	11	4	27.5	231	9240
August	9	1	18.9	130	5200
September	10	3	17.9	119	4720

Table 6 shows results from the past two seeding seasons. One thing to remember when looking at this table is that 2008 was a drought year and 2007 was a very wet year. In drought years, weather modification activities are more frequent and in wet years they are less frequent due to possible flooding and suspensions of operations due to very wet conditions. Project staff and the project target area remained the same as last year. For the most part, the year of 2009 was a tough one due to drought but nevertheless there were enough opportunities for a successful seeding season.

Table 6. SWTREA Bi-Annual Comparison

Month	Total number Flights		Flight Time Hours		Number of Flares		AgI Used	
	'07	'08	'07	'08	'07	'08	'07	'08
March	1	0	1.2	0	26	0	1,040	0
April	4	5	2.9	7.1	15	137	600	5,360
May	6	6	10.6	6	120	144	4,800	5,760
June	5	8	6.9	14.3	50	115	2,000	4,600
July	1	9	1.2	10.9	11	119	440	4,760
Aug.	13	18	23.4	30.7	160	229	6,400	9,160
Sept.	4	5	3.7	8.4	13	127	520	5,080
Oct.	4	1	4.6	1.1	30	14	1,100	560

3.4 South Texas Weather Modification Association (STWMA)

The 2009 season marked the 13th year of operations for the South Texas Weather Modification Association. In terms of operations, it was a near-normal year with 76 seeding flights over 44 days (see Table 7) along with an additional 13 reconnaissance flights. This compares to the 12-year average of 39 seeding days, 69 seeding flights and 7 reconnaissance flights. The long-term drought that began near the end of 2007 continued for much of the year before a dramatic shift in the weather patterns – likely attributed to the onset of El Niño – occurred in September. Despite the drought, there were many small convective clouds that presented themselves for seeding opportunities, and these accounted for the majority of seeding events during the year. Also, with the purchase of the Aztec twin engine plane late last year, nighttime seeding became possible.

Table 7. STWMA Seasonal Summary

MONTH	SEED DAYS	FLIGHTS	HOURS	AMOUNTS
March	0	1r	0.5	0
April	0	0	0	0
May	10	19+6r	48.9	11,680g
June	5	8	16.6	4,560g
July	11	20+3r	44.7	14,320g+6,000g
Aug.	10	17	28.2	6,600g+3,000g
Sept.	8	12+3r	21.8	4,920g+2,000g
TOTALS	44	76+13r	160.7	42,080g+11,000g

Table summary of operations in 2009. Under Flights, r refers to reconnaissance flight only, while the values to the right of the plus sign under *Amounts* refer to the amount of hygroscopic material (CaCl) used for seeding.

The first opportunity for seeding came on March 26th when a powerful storm system affected the state. A flight was launched but eventually low ceilings and the onset of severe weather resulted in the flight being a reconnaissance only. April would come and go with no seeding opportunities and below normal rainfall for the majority of the area; one exception was northern Wilson County where excessive rains from thunderstorms resulted in over six inches of rainfall in that area. During a two-day period in the second week of the month, record lows in the mid 30s were followed by record highs near 100°F.

The month of May would turn out to the busiest May since the inception of the program with 25 flights taking place over ten days, primarily during the latter half of the month. As is normally the case with convective rains, monthly totals varied considerably; while a good portion of the target area saw below normal rainfall, there were spots where rainfall totals were 150-200% of normal. May also signaled the return of the counties within the jurisdiction of the Edwards Aquifer Authority.

June, normally one of the wetter months of the year, turned out to be extremely dry with most locations in the target area receiving less than a quarter inch of rainfall. Five days during the month presented seedable clouds, including the first night mission on June 2nd. Around mid-month, a strong area of high pressure aloft parked over the area with a string of 100°F+ highs occurring – a foreshadowing of the intense heat that would follow later in the summer.

July was an average month in terms of the amount of seeding activity that occurred, with eleven days seeing seeding operations take place; these were spread out throughout the month. Many areas, particularly over the southern counties of the target area, saw below normal rainfall once again. Normally by July, convection is primarily generated by the seabreeze boundary and/or strong heating within a high precipitable water (PWAT) airmass (>1.75"); both were largely absent this month. In many cases, convection moved into the area from the north or developed along the Balcones Escarpment. The intense heat continued, with over 20 days of highs at or above 100°F. The experimental use of hygroscopic flares for seeding began in July, but these were used sparingly.

The intense heat continued into and peaked in August, with over 25 days recording highs at or above 100°F. The June to August period would end up being the hottest three-month period ever for many locations in south Texas. By month's end, Pleasanton had recorded 67 days with highs at or above 100°F! Rainfall was scarce as it was in June, with all but two small areas in the target area seeing well below normal rainfall. Still, small convective clouds were present on several days, with ten days seeing seeding operations take place. The majority of these missions occurred during the last week, when a major change in the weather pattern began. September saw the welcome rains that were sought after for many months, with the vast majority of the target area seeing above normal rainfall spread out evenly through the month. Some locations saw in excess of ten inches of rain. Tropical airmass intrusions with exceptionally high PWATs (>2.30") were common; unfortunately this also resulted in many unsuitable clouds for seeding. Still, there were eight days during the month where seeding occurred. The final day of seeding for the year occurred on September 28th. Wet weather continued through October, November and into December with the El Niño signal strengthening in the Pacific.

The annual radar analysis provided by AISM showed that seeding effects were positive in south-central Texas. The analysis indicated an average increase in rainfall of 11%, translating to over 540,000 acre-feet of water from 131 seeded clouds.

4. 2008 STATE EVALUATION BY ACTIVE INFLUENCE AND SCIENTIFIC MANAGEMENT

Cloud seeding missions began in March and ended in October. The PGCD, WTWMA, STWMA, SWTREA, and TPWMA were included within the 2009 Evaluation.

A total of 466 clouds were seeded and identified by TITAN software over 171 target area operational days. Overall 91 operational days were qualified as excellent, 40-very good, 27-good performance, 5-fair performance, and three were categorized as experimental. For the 466 clouds, 218 were designated small clouds, 126 large clouds, and 117 Type-B seeded clouds.

Small clouds (see Table 8) were seeded with 914 flares and received an excellent timing of 86% for an effective dose of 55 ice-nuclei per liter. Individual cells likely received closer to the desired dosage of 100 ice-nuclei per liter. An excellent increase of 95% in precipitation mass together with an increase of 43% 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 (27%), area (35%), volume (34%), volume above 6 km (39%), and precipitation flux (42%) are notable. There are slight increases in maximum reflectivity (1%), and in top height (3%). The seeded sub-sample seemed 40% more efficient than the control sub-sample. Results are evaluated as excellent for this sub-sample. The Estimated increases received from small clouds are 170,545 acre-feet.

Large clouds received 1,879 flares with an effective dose near 75 ice-nuclei per liter. On average, large clouds were 29 minutes old when the operations took place; the operation lasted about 32 minutes, and the large seeded clouds lived 215 minutes (3 hours and 35 minutes). The estimated increases received from large clouds are 2,264,139 acre-feet. Similarly, Type-B clouds received 2,223 flares with an effective dose near 60 ice-nuclei per liter. On average, Type B clouds were 124 minutes old when the operations took place; the operation lasted about 39 minutes, and the Type B seeded clouds lived 295 minutes (4 hours and 55 minutes). The estimated increases received from Type-B clouds are 1,331,414 acre-feet.

The total increases over the State of Texas throughout the 2009 season are estimated at 3,766,098 acre-feet. Percent of increases are broken down per county of the seeded region; PGCD micro-regionalization shows 15.6% increases over

Donley and 4.2% over Roberts. TPWMA shows Ward County allowed for 22.6% increases and 3.7% over Culberson. The best increases for WTWMA were 36% over Glasscock County and least of 6% over Crockett County (mainly due to county size); SWTREA held an 11.9% increase over Uvalde and 6.6% increase over La Salle; STWMA best results were seen over McMullen County at 16.1% and 5.8% over Bandera. South and Southwest Texas saw a significant drought throughout the seeding season holding average rainfall over the State of Texas to nearly 12 inches.

Results for the 2009 season were evaluated as excellent and a typical average seasonal increase in precipitation of 11.5% was recorded. Anti-hail seeding operations appeared to partially mitigate hail formation in corresponding storms. The Texas Weather Modification Association also began to use salt flares in addition to silver iodide flares in 2009. Too few cases were evaluated to gain a respective statistical evaluation; however, use of both flares appears to have a positive affect (Ruiz-Columbié 2008).

For many people, the increases in precipitation mass of over one million acre-feet are rather incomprehensible. Annually, a single person consumes 265 gallons (.008 acre-feet) of water. Household water uses on average is 50-100 tons which is equivalent to .445 and .885 acre-feet respectively. Additionally, water used to irrigate crops for making clothing and the food we eat is estimated at 1500-2000 tons or 13.27-17.70 acre-feet (Pearce 2007). Collectively, a single person uses on average 18.6 acre-feet each year. In the State of Texas, the cost of water ranges greatly from $300-$1,200 but for the purposes of this explanation we will use an average value of $750 per acre-foot. Using these values, the cost of water per person is $13,950 per year. The average statewide budget for weather modification operations is $1.6 million. AISM estimated the total increases in precipitation at 3,766,098 ac-ft in 2009 yields a cost of one acre-foot of water at $.42.

5. SUMMARY

During the 2009 season, a very large number of clouds were seeded in the state of Texas. A prolonged drought hindered seedable clouds over South Texas while West Texas and the Panhandle conditions performed above average. AISM's annual analysis concluded that the majority of seeded clouds were in the small category, all seeded cloud categories yielded increases in precipitation mass, with an inspiring 3.7 million acre-feet of water produced in the state's target and surrounding operational areas.

REFERENCES

Ruiz-Columbié, A., 2009: Annual evaluation report 2009, State of Texas. pp 9.

Pearce, Fred, 2006: *When the Rivers Run Dry: Water-The defining crisis of the twenty-first century*. Boston: Beacon Press.

Table 8. Seeded Sample versus Control Sample (218 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	45 min	1.44	44 **(27)**
Area	73.9.0 km^2	49.7 km^2	1.49	49 **(35)**
Volume	251.6 km^3	158.0 km^3	1.58	58 **(34)**
Top Height	8.4 km	7.9 km	1.07	7 **(3)**
Max dBZ	53.5	51.3	1.04	4 **(1)**
Top Ht of max dBZ	3.8 km	3.8 km	1.00	0 **(-2)**
Volume above 6 km	66.9 km^3	40.3 km^3	1.62	62 **(39)**
Precip Flux	530.2 m^3/s	311.0 m^3/s	1.73	73 **(42)**
Precip Mass	2285.0 kton	1015.4 kton	2.30	130 **(95)**
Cloud Mass	191.4 kton	112.5 kton	1.71	71 **(43)**
η	12.0	8.9	1.36	36 **(40)**