Southwest Texas Rain Enhancement Association
2006 Edwards Aquifer Authority Final Report

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The Year in Review

2006 marked the fifth year of operations for the Edwards Aquifer Authority (EAA) by the Southwest Texas Rain Enhancement Association (SWTREA). The project this year was business as usual, with seeding taking place in Uvalde County from May until October. There was caveat this year. Due to the continuing drought of most of South Texas, seeding missions were hard to come by throughout most of the year. A few months of the year did see increased activity, but the majority of it was hot and dry. Drought conditions did tend to improve towards the latter part of the year with the development of a moderate El Nino episode in the South Pacific off the coast of South America. When El Nino's tend to develop, the southern half of the United States tend to benefit greatly from the increase intensity of the subtropical jet.

Seeding in the Authority target area of Uvalde County saw a total of twenty flights for the 2006 operational year compared to twenty flights in 2005. Also, with the continued cooperation between the two seeding projects, SWTREA flew a total of two missions in Medina County and one in Bandera County for the South Texas Weather Modification Assocation (STWMA). As seen above, there were more missions in 2005 than 2006, due to the lack of convection across the Aquifer area. Most of the systems seeded in the EAA target were classified as small clouds, or systems that were not large in area. 2006 was very dry for most parts of Texas as a whole. For the most part, a very aggressive seeding approach was taken over Uvalde County during the year due to the drought that was classified as severe to exceptional across the area.

At the conclusion of the 2006 operational season for the Authority EAA target area, October 31st, a radar evaluation was completed for the program. The findings are presented and discussed towards the end of this report. The flight logs for the 2006 seeding season are on the following page.

2006 Flight Log for SWTREA EAA Target Area

Flight Number	Date	Aircraft	Total Time (hours)	Material Used	Total Seeding Material Used AgI (g)	Rating
1	5/14/2006	162X	0.75	14(40g) BIP Flares	560	Very good
2	5/27/2006	370P	1	12(40g) BIP Flares	480	Good
3	6/1/2006	162X	0.4	8(40g) BIP Flares	320	Very good
4	6/18/2006	162X	0.55	8(40g) BIP Flares	320	Excellent
5	6/24/2006	162X	0.8	14(40g) BIP Flares	560	Very good
6	6/25/2006	370P	1.3	14(40g) BIP Flares	560	Very good
7	7/4/2006	162X	0.75	3(40g) BIP Flares	120	Very good
8	7/4/2006	162X	1.55	18(40g) BIP Flares	720	Excellent
9	7/5/2006	162X	0.2	3(40g) BIP Flares	120	Good
10	7/20/2006	370P	0.5	7(40g) BIP Flares	280	Good
11	7/22/2006	162X	2.2	27(40g) BIP Flares	1080	Excellent
12	8/4/2006	162X	0.75	3(40g) BIP Flares	120	Good
13	8/18/2006	162X	0.5	3(40g) BIP Flares	120	Good
14	8/23/2006	162X	0.2	2(40g) BIP Flares	80	Very good
15	8/23/2006	162X	0.5	7(40g) BIP Flares	280	Very good
16	8/28/2006	162X	0.75	7(40g) BIP Flares	280	Very good
17	8/29/2006	162X	1	9(40g) BIP Flares	360	Excellent
18	9/12/2006	370P	0.5	10(40g) BIP Flares	400	Good
19	9/17/2006	370P	0.15	8(40g) BIP Flares	320	Good
20	9/23/2006	162X	0.9	15(40g) BIP Flares	600	Very good

20 flights

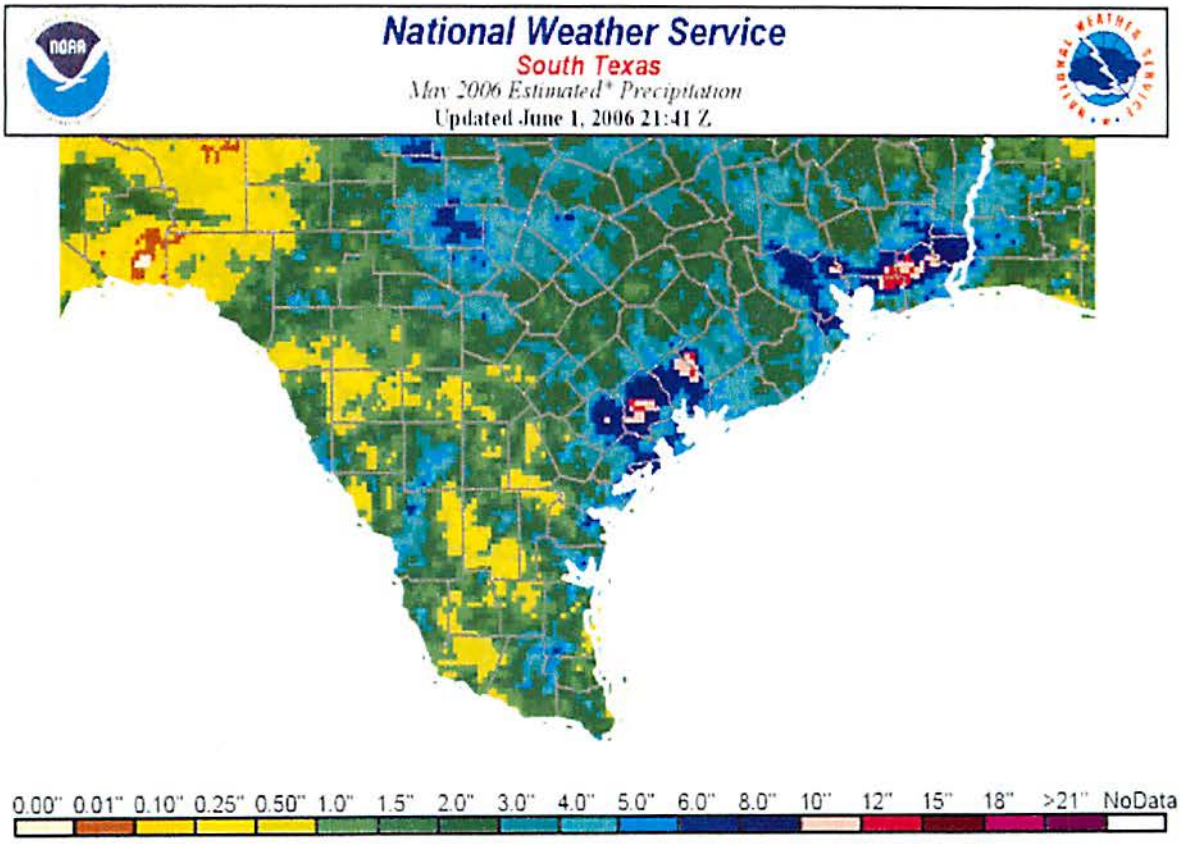
192 Hot Flares

7680 g AgI

Operational Summary

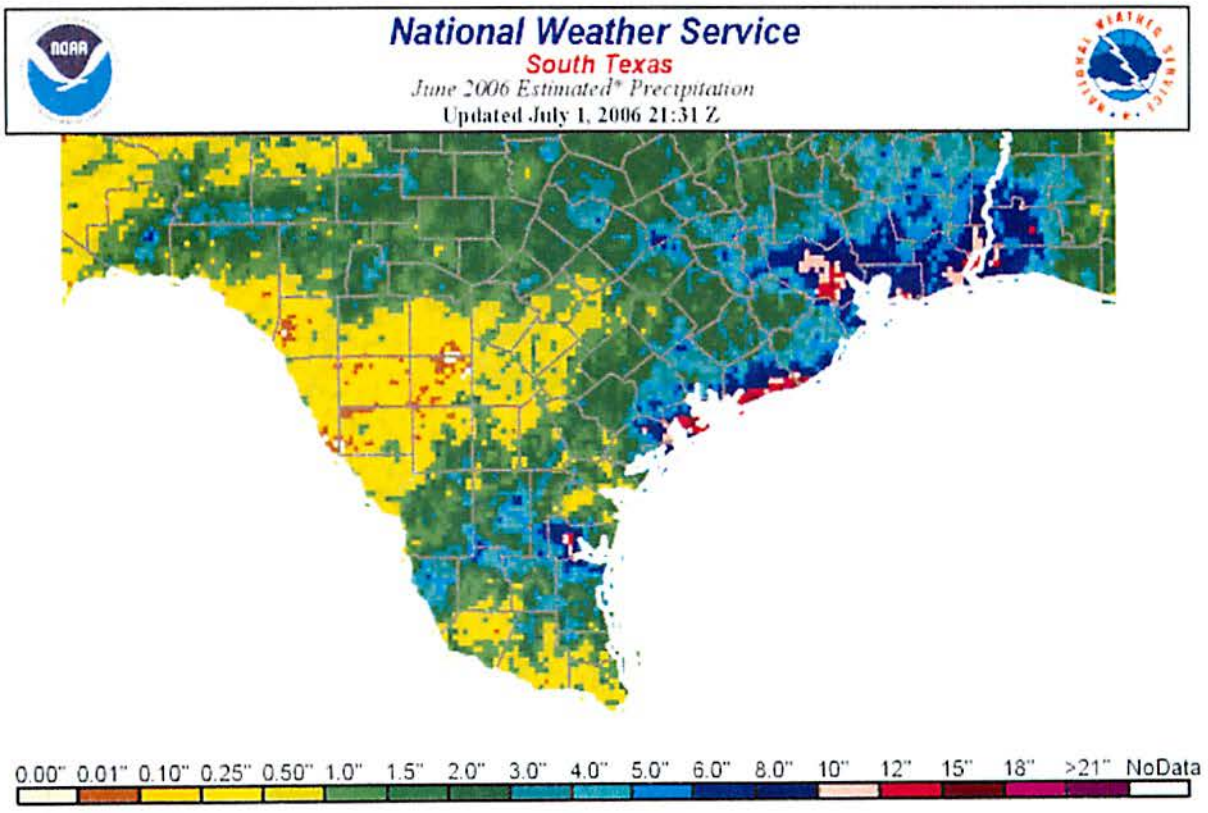
May 2006

With most of the area receiving some beneficial rains over the month, drought conditions across most of the EAA target were slightly eased. The weather pattern for the month was classified as active compared to the early spring months. With a more typical spring like pattern coming into the picture during the month of May, a few seeding flights took place in Uvalde County. High pressure dominated the area for the first couple weeks of the month, but as high pressure was replaced by a more active weather pattern, rains returned in the latter part of the month. A total of two flights took place in Uvalde County for the month of May.



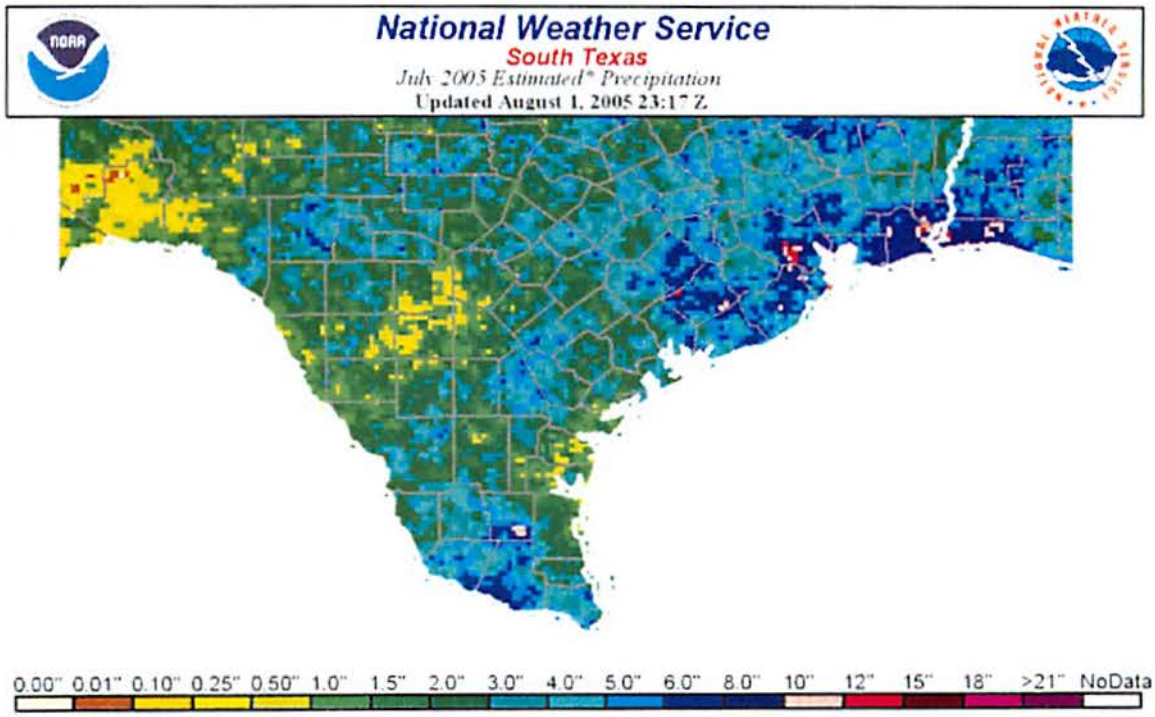
June 2006

The month started out quickly with a seeding mission on the first day of the month due to an upper to mid level low that was near the Corpus Christi area. After this flight, another flight did not take place in the Uvalde County area until the very early morning hours of the 18th. High pressure built in during these two weeks and the only type of shower and thunderstorm activity present was confined to mainly coastal areas where moisture was best when the sea breeze would come through in the late afternoon hours. Near the end of the month, activity did pick up due to a couple of different features that affected the area. One of which was a cold front that stalled out just to the north of the Texas Hill Country. The second round of missions near the end of the month was due to a very intense upper level low that was stationary in West/Northwest Texas for a number of days. A total of four flights took place in Uvalde County for the month of June.



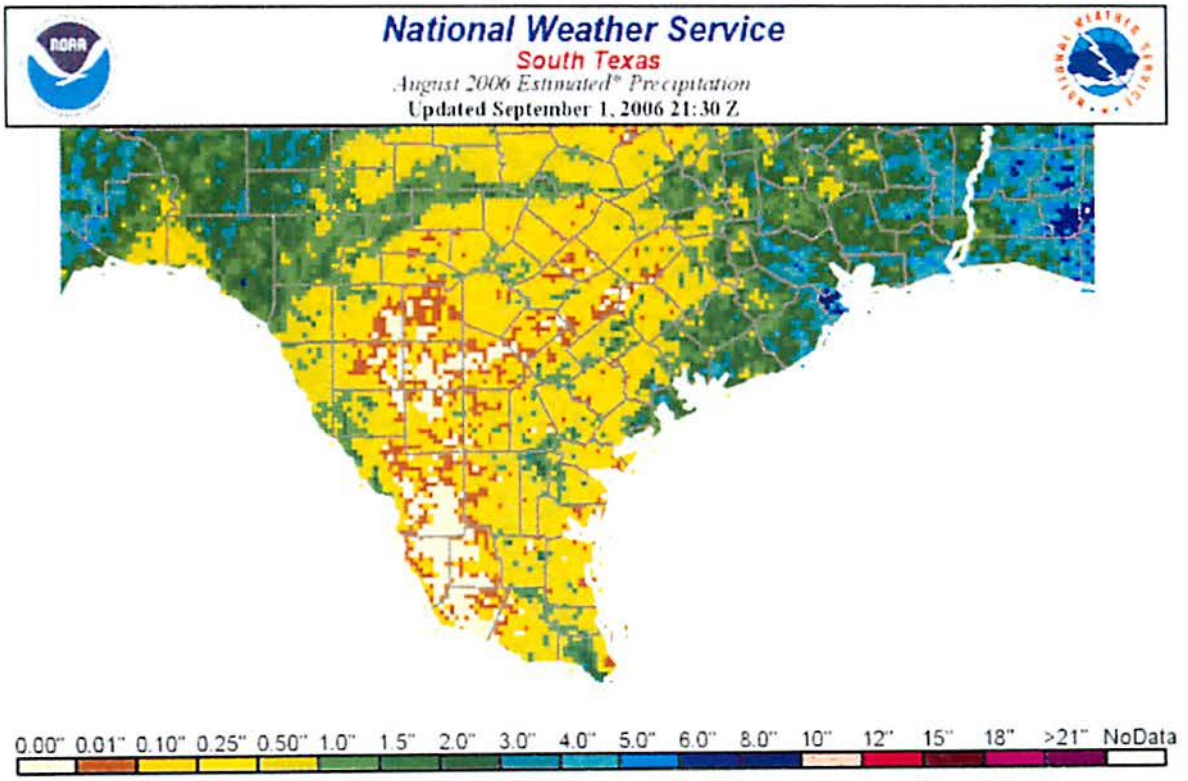
July 2006

The month got off to a quick start for the first week of July over the holiday weekend as an upper level low from the east moved into the area and was stationary for a couple of days. Most of the convection was confined to areas further south of Uvalde County, but convection on a couple occasions did make it into the EAA area. Showers and thunderstorms were very common over the area but most of which were not of seedable intensity as high pressure was suppressing any type of intense, long-lived convection. Closer to the end of the month, convection once again started to creep back into the Edwards Aquifer area as good instability and moisture combined with another upper level feature near the area. Also, near the end of the month, a very unusual feature for this time of the year crept into the Texas Hill County. A late July cold front stalled across the northern tier of the Hill County, providing a good focus for convection. A total of four seeding flights were conducted this month in Uvalde County.



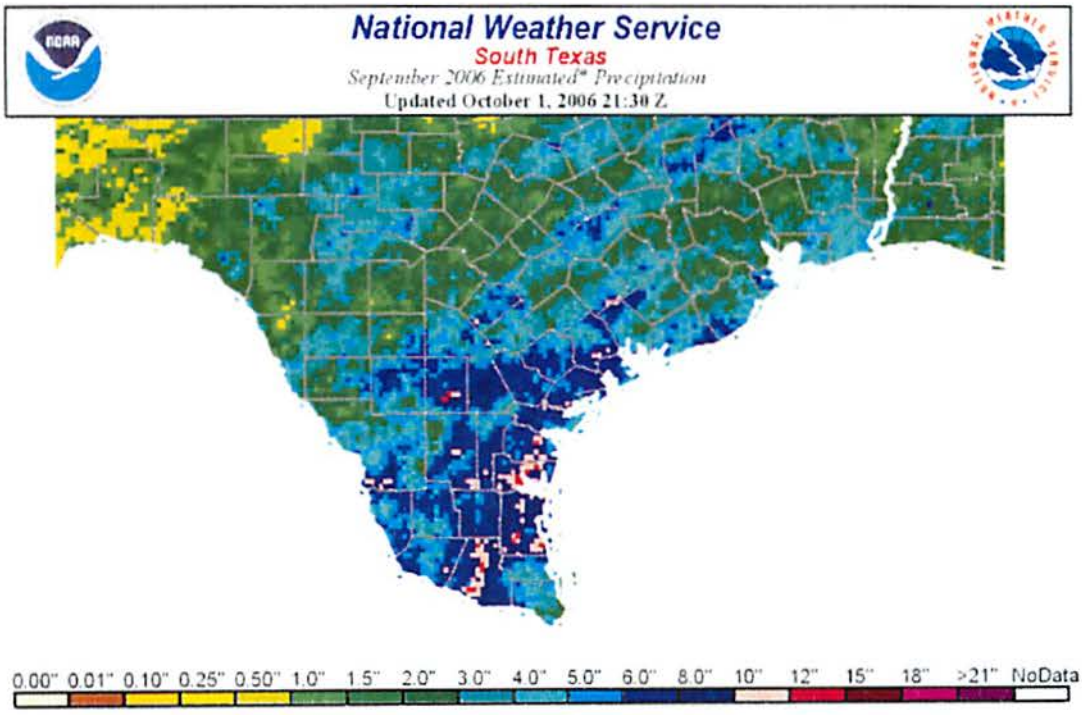
August 2006

Compared to the month of August in past years, this August was definitely a dry one. The month started off very slowly due to a large area of high pressure and its associated ridge that remained stationary over the central U.S for the first couple weeks of the month. As the month went on, the pattern began to shift and a few airmass thunderstorms formed as the ridge created extremely warm temperatures for the third week of August. The last week of the month finally brought some relief, temperature and convection wise, as a few cold fronts stalled north of the area, setting off outflow boundaries from convection that was occurring north of the Texas Hill County. A total of six seeding flights were conducted in Uvalde County for the month of August.



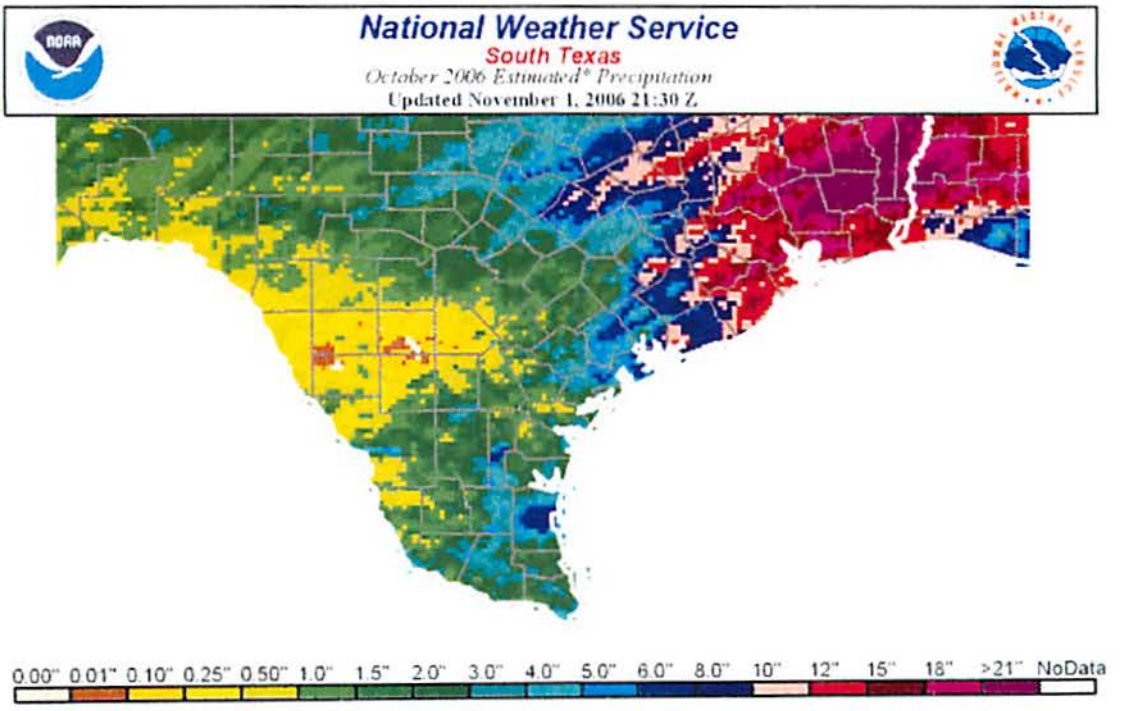
September 2006

After a very dry summer, dry conditions continued into the month of September. The weather pattern however did show signs of changing as the seasons were starting to change. A series of cold fronts came through the area during the month. The first front of the month defiantly produced the best rain chances as moisture from both the Pacific and Gulf of Mexico areas were advected into the area in advance of the front. The fronts that came through later in the month were both good rain producers and also produced some cooler temperatures for the area after a very hot summer. A total of three missions were conducted in Uvalde County during the month of September.



October 2006

After a rather busy September, October was not only slow for the EAA target area but also for the SWTREA target area. Rainfall was not the problem this month; the problem was that most of the rainfall was not convection in nature, something that is required for rain enhancement. Cold fronts seemed to come through the region rather regularly throughout the month, but most of which were dry fontal passages. Stratiform rain frequented the region on many days this month. A total of one mission was flown in the last month of rain enhancement operations for the Edwards Aquifer Authority.



2005/2006 EAA COMPARISON

YEAR	2005			2006		
MONTH	# of flights	Total Seeding Material	# of seeding days	# of flights	Total Seeding Material	# of seeding days
MAY	3	1,100g AgI	2	2	1,040g AgI	2
JUNE	0	0g AgI	0	4	1600g AgI	4
JULY	6	2,120g AgI	6	5	2,320g AgI	4
AUGUST	6	2,280g AgI	6	6	1,240g AgI	5
SEPTEMBER	1	80g AgI	1	3	1,320g AgI	3
OCTOBER	2	640g AgI	2	0	0g AgI	0
TOTAL	19	5,360g AgI	18	20	6,520g AgI	18

89,400 ac/ft of enhanced rainfall

The preceding table gives a historical glance at a comparison of the Authority seeding activities for 2005 and 2006. This is useful to see what kind of activity has been ongoing throughout the last two years of the Authority project.

Meteorological Perspective of Seeding in 2006

This section will be a summary of perceived efforts of cloud seeding as determined by radar trends. From the annual evaluation provided in the first appendix, for Uvalde County, an increase of 1.07 inches was determined, overall a 7.8% increase from seasonal vales. One thing to note in particular was the types of systems that were seeded. This year, small clouds were most common in the EAA target for seeding. This differs from normal due to the fact that there are usually an equal number of small clouds and large clouds. Most convection for the year in Uvalde County did produced positive results according to radar trends. A few events did not offer very good seeding conditions due to large complexes of rain having undefined bases.

May offered a total of two missions, both of which were classified as rain enhancement. These missions took place near the mid point and the end of the month due to the lack of severe weather for the area this season. May is usually the most active month severe weather wise, but this year, like last year, lacked in activity.

June offered a total of four missions for the month. The more interesting fact of these missions was the fact that all of them seemed to produce very good to excellent results.

July offered a total of four missions for Uvalde County. For most of the month, high pressure dominated the area, which is very typical for this area during the summer months. However, a mid July cold front did affect the area and offered a little summer relief from the heat.

August gave way to an abundance of tropical activity to the south , but left the EAA target area very dry, like most months of this year. A total of four missions took place in Uvalde County this month.

In September, activity was again held at a minimum due to the continuing drought situation over South Texas. A total of three missions took place in Uvalde County for the month. Conditions near the end of the month started to change, as they usually do this time of year.

October was the last month in which seeding operations were conducted for the EAA target area. Only one mission was conducted over Uvalde County this month. Cooler temperatures did start to affect the area but most of the frontal passages that transversed the region were lacking the adequate moisture for convection

Overall, with a total of twenty flights for the EAA target area, the season is summarized as average. From looking at the observed and normal precipitation for the town of Uvalde, one can conclude that a lack of convective rainfall in the summer months, led to a very dry year for Uvalde County. Normal annual precipitation for Uvalde, TX is around 23 inches. The observed rainfall for Uvalde, TX for 2006 was around 14 inches. This is almost 10 inches below normal for this station. However, by the conclusion of 2006 and the beginning of 2007, precipitation for Uvalde County increase dramatically and drought conditions eased substantially for the area due to the effects of El Nino.

APPENDIX

ANNUAL EVALUATION REPORT 2006 EAA

Arquímedes Ruiz-Columbié
Active Influence & Scientific Management

Cloud seeding operations 2006 began over EAA target area in May. This annual report serves as a summary of results. A total of **33 clouds** were seeded and identified by TITAN in **21 operational days**. Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **May 2nd 2006**
Last operational day: **October 10th 2006**

Number of operational days: 21
(Four in May, three in June, four in July, five in August, three in September, and two in October)

According to the daily reports operational days were qualified as:

Eight with excellent performance
Six with very good performance
Seven with good performance

Number of seeded clouds: 33
(22 small seeded clouds, 5 large seeded clouds, 5 type B seeded clouds, and 1 seeded cloud did not get proper files)

Missed Opportunities: none (with lifetime longer than 45 minutes)

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 30 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (22 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	70 min	40 min	1.75	75 (**59**)
Area	66.0 km^2	35.1 km^2	1.88	88 (**26**)
Volume	166.1 km^3	81.1 km^3	2.05	105 (**33**)
Top Height	7.8 km	7.5 km	1.04	4 (**3**)
Max dBz	50.9	49.3	1.03	3 (**1**)
Top Height of max dBz	4.1 km	4.0 km	1.03	3 (**2**)
Volume Above 6 km	18.0 km^3	5.2 km^3	3.46	246 (**47**)
Prec.Flux	593.1 m^3/s	288.8 m^3/s	2.05	105 (**34**)
Prec.Mass	2613.8 kton	770.1 kton	3.39	239 (**140**)
CloudMass	136.5 kton	66.8 kton	2.04	104 (**33**)
η	19.1	11.5	1.66	66 (**63**)

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 102 flares were used in this sub-sample with an excellent timing **(94 %)** for an effective dose about **105 ice-nuclei per liter**. The seeding operations lasted in average about 15 minutes. An excellent increase of **140 %** in precipitation mass together with an increase of 33 % 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 (59 %), area (26 %) volume (33 %), volume above 6 km (47 %), and precipitation flux (34 %) are notable. There were slight increases in maximum reflectivity (1 %), and in top height (3 %). The seeded sub-sample seemed 63 % more efficient than the control sub-sample. Results are evaluated as **excellent.**

An increase of 140 % in precipitation mass for a control value of 770.1 kton in 30 cases means:

Δ_1 = 22 x 1.40 x 770.1 kton = 23 719 kton = 19 236 ac-f

Seeded Sample vs seeded control (22 couples X increase in % in precipitation mass X control value in kilotons = Ktons converted into acre-feet

Large Clouds

The sub-sample of 5 large seeded clouds received a synergetic analysis. In average, the seeding operations on these large clouds affected 57 % of their whole volume; with a perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of 41 flares were used in this sub-sample for an effective dose about **90 ice-nuclei per liter.**

Also in average, large clouds were 27 minutes old when the operations took place; the operation lasted about 21 minutes, and the large seeded clouds lived 245 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (5 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	245 min	200 min	1.23	23
Area	2961 km^2	2613 km^2	1.13	13
Prec.Mass	29 255 kton	19 527 kton	1.50	50

An increase of 50 % in precipitation mass for a control value of 19 527 kton in 5 cases may mean:

Δ_2 = 5 x 0.50 x 19 527 kton = 48 818 kton = 39 591 ac-f

Type B Clouds

The sub-sample of 5 type B seeded clouds received a synergetic analysis. In average, the seeding operations on these type B clouds affected 22 % of their whole volume; with an excellent timing (80 % of the material went to the clouds in their first half-lifetime). A total of 28 flares were used in this sub-sample for an effective dose about **175 ice-nuclei per liter**.

Also in average, type B clouds were 135 minutes old when the operations took place; the operation lasted about 33 minutes, and the type B seeded clouds lived 300 minutes.

Table 4 shows the results:

Table 4: Type B Seeded Sample versus Virtual Control Sample (7 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	300 min	275 min	1.09	9
Area	1994 km^2	1904 km^2	1.05	5
Prec.Mass	28 950 kton	25 174 kton	1.15	15

An increase of 15 % in precipitation mass for a control value of 25 174 kton in 5 cases may mean:

Δ_3 = 5 x 0.15 x 25 174 kton = 18 881 kton = 15 312 ac-f

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 74 139 ac-f

(Increase due mainly to the initial seedings done over EAA target area)

Micro-regionalization

Increases in precipitation mass were analyzed county by county in an attempt to better describe the performance and corresponding results. **Table 5** below offers the details:

County Seeding	Initial Seeding	Extended (increase)	Acre-feet (increase)	Inches (increase)	Radar (season value)	% (increase)
Bandera	5	6	7 800	0.18	16.59 in	1.1
Medina	5	7	8 400	0.12	7.69 in	1.6
Bexar	4	6	24 500	0.37	10.36 in	3.6
Uvalde	19	23	89 400	1.07	13.70 in	7.8
Total	**33**	**42**	**130 100**			
Average				**0.44**	**12.09 in**	**3.5**

(**Initial seeding** means the number of clouds seeded when the operations began; whereas **extended seeding** means the counties favored by seeding after the initial operations took place. Season 2007 had most of the seedable conditions outside EAA target area which eventually drifted into the target area favoring it).

Final Comments

1) Results are evaluated as **excellent**; the limiting factor was the low number of seedable conditions;

2) The micro-regionalization analysis showed increases per county; seedable conditions were more frequent over Uvalde County and southeastern zones outside (for instance Atascosa County) where greater increases in PrecMass were obtained although the other zones received downwind benefits; the average increase in precipitation, referred to rain gage seasonal value, is about **3.5 %**;

3) Radar estimations of precipitation should be considered as measurements of trend. Nevertheless, seeding operations appeared to improve the dynamics of seeded clouds.

APPENDIX

Mesoscale Convective System (MCS) is a large complex of showers and thunderstorms at least 100 km (~60 miles) across, and may be as large as 500 km (~310 miles) across.

Shortwave, or shortwave trough, refers to a small-scale area of lower pressure, sometimes accompanied by showers and thunderstorms.

Cell refers to an updraft-downdraft couplet in a cloud. Clouds with several updraft-downdraft couplets are called **multicell** clouds. A storm with a single updraft-downdraft couplet (often rotating) that lasts for several hours is called a **supercell.**

Pre-frontal trough refers to an elongated area of low pressure found ahead of an advancing cold front. In south Texas, the passage of a pre-frontal trough usually signals the end of precipitation, as winds tend to turn more to the west or northwest, cutting off moisture supply.

Precipitable Water is the total amount of water vapor in a column of air above a given location. This value is expressed in inches. High precipitable water values (>1.5 inches) are indicative of the potential for heavy rain. Tropical airmasses usually have a precipitable water value in excess of two inches.

Convective temperature is the temperature required at or near the ground in order for convection (surface-based) to occur.

TUTT, or Tropical Upper Tropospheric Trough, refers to a upper level cold core area of low pressure found in the tropical and sub-tropical regions of the Earth. These disturbances are sometimes associated with shower and thunderstorm activity, and are associated with tropical waves.

Theta-e, or equivalent potential temperature, is the temperature a parcel or bubble of air would reach if it was lifted until all of the moisture condensed out, then brought back down to 1000 mb (at/near surface). A forecaster looks at theta-e to see how moisture is distributed over a region. High theta-e values are associated with moist airmasses, which storms may develop in and feed on.

Jet streak refers to the maximum wind speed within a river of faster-moving air (jet stream). Forecasters may look for jet streak locations at 850mb, 700mb, 500mb, and 250 mb in order to assess the possibility of strong/severe thunderstorms.

Cap refers to a warm layer of air aloft which acts as a lid, suppressing convection. The strength of the cap varies with time and location.

Convective Inhibition is the amount of energy required to overcome the cap, or the amount of energy required by a parcel of air to initiate deep convection (i.e., thunderstorms).

Lifetime refers to the length of time a cloud was detected on radar, with a reflectivity maximum of at least 32 dBZ.

Area refers to the two-dimensional space (length x width) covered by a cloud.

Precip Flux refers to the radar-derived volume of water falling through the bottom of the cloud per second.

Precip Mass refers to the total mass of water and ice for all droplets/crystals larger than 100 μm (10^{-4} m) in a cloud.

Small seeded clouds are those clouds with a radar-derived Precip Mass less than 10,000 kilotons.

Large seeded clouds are those clouds with a radar-derived Precip Mass greater than 10,000 kilotons.

Type B clouds are those clouds, small or large, that were not seeded until they were at least one hour old, as determined by their presence on radar.

Control clouds are those clouds within 100 km of the radar that were NOT seeded. Control clouds are used to determine the effectiveness of seeding, as it represents "what would have happened" if seeding had not taken place.

Effective dosage refers to the amount of seeding material that was placed in the cloud. It

is expressed as a concentration of ice nuclei per liter of air.

Radar analysis numbers came from Archie Ruiz's final report of the 2005 season for the EAA.

Acknowledgements

2006 was another successful season for the cloud seeding in the Edwards Aquifer Authority target area. The assessment was done and showed positive effects. This project could not be possible without the hard work and dedication of many people. In this section those appropriate parties will be thanked.

Also, to the SWTREA project manager, chief pilot and secretary, Ed Walker and Debbie Farmer. Also, thanks go out to Cole VanCleve that was with the project during the summer months, when the most help was needed. The continuing cooperation between SWTREA and the South Texas Weather Modification Assocation (STWMA) allows both projects to operate at the most productive level.