ANNUAL EVALUATION REPORT 2016 **State of Texas**

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Cloud seeding operations 2016 began over the Texas Weather Modification Target Area in March (March 7th, first operational day for the WTWMA target area) . This annual report is a compilation of the evaluation reports already made and published for four local projects: Panhandle, WTWMA, TPWMA, and STWMA target areas (EAA target area is included in the last one). A total of **306 clouds** were seeded and identified by TITAN in **119 target area operational days**. Table 1 summarizes the general figures:

Table 1: Generalities

First evaluated operational day: **March 7th, 2016 (WTWMA)**
Last operational day: **November 11th, 2016 (STWMA)** **Season: 250 days**

Net Number of operational days: 119

Most active period: May to September: 103		~ 87 % of the operational days,
Less active months:	March: 2	~ 2 % of the operational days
	November: 2	~ 2 % of the operational days

According to the daily reports, operational days were qualified as:

Seventy-eight with excellent performance
Twenty-eight with very good performance
Twelve with good performance
One with fair performance

Number of seeded clouds: 306
(179 small seeded clouds, 81 large seeded clouds, 46 type B seeded clouds)

Missed Opportunities: none (with lifespan longer than 1 hour)

Small Clouds

Table 2 shows the average results from the classic TITAN evaluations for the 179 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (179 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65.4 min	42.7 min	1.53	53 (**40**)
Area	65.6 km^2	42.5 km^2	1.54	54 (**39**)
Volume	220.0 km^3	132.3 km^3	1.66	66 (**42**)
Top Height	8.9 km	8.1 km	1.10	10 (**3**)
Max dBz	51.7	49.9	1.03	3 (**1**)
Top Height of max dBz	3.7 km	3.7 km	1.00	0 (**-1**)
Volume Above 6 km	57.3 km^3	31.0 km^3	1.85	85 (**45**)
Prec.Flux	446.1 m^3/s	264.3 m^3/s	1.69	69 (**49**)
Prec.Mass	2067.0 kton	775.7 kton	2.66	166 (**126**)
CloudMass	168.6 kton	95.5 kton	1.76	76 (**45**)
η	12.3	8.1	1.51	51 (**56**)

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 **1181 AgI and 100 hygroscopic flares** were used in this sub-sample with an excellent timing (**95 %),** for an effective AgI dose about **65 ice-nuclei per liter,** which might have reached slightly higher levels in some individual cells. An excellent increase of 126 % in precipitation mass together with an increase of 45 % 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 (40 %), area (39 %), volume (42 %), volume above 6 km (45 %), and precipitation flux (49 %) are notable. There were slight increases in maximum reflectivity (1 %), and in top height (3 %). The seeded sub-sample seemed 56 % more efficient than the control sub-sample. Results are evaluated as **excellent** for this sub-sample.

An increase of 126 % in precipitation mass for a control value of 775.7 kton in 179 cases means:

Δ_1 **= 179 x 1.26 x 775.7 kton ≈ 174 951 kton ≈ 241 886 ac-f**
(mean layer: 14.8 mm ≈ 0.59 in)

Large Clouds

The sub-sample of 81 large seeded clouds received a synergetic analysis. In average the seeding operations on these large clouds affected 82 % of their whole volume, with a perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of **2066 AgI and 185 hygroscopic flares** were used in this sub-sample for an effective silver iodide average dose near **95 ice-nuclei per liter**.

Also in average, large clouds were 23 minutes old when the operations took place; the operation lasted about 36 minutes, and the large seeded clouds lived 250 minutes (4 hours and 10 minutes).

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (81 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	250 min	200 min	1.25	25
Area	1397 km^2	1140 km^2	1.23	23
Volume	6186 km^3	5057 km^3	1.22	22
Volume Above 6 km	2315 km^3	1897 km^3	1.22	22
Prec.Flux	13 172 m^3/s	9 900 m^3/s	1.33	33
Prec.Mass	90 942 kton	56 373 kton	1.61	61

An increase of 61 % in precipitation mass for a control value of 56 373 kton in 81 cases implies:

Δ_2 **= 81 x 0.61 x 56 373 kton ≈ 2 785 390 kton ≈ 2 258 951 ac-f**
(mean layer: 24.6 mm ≈ 0.97 in)

Type B Clouds

The sub-sample of 46 type B seeded clouds also received a synergetic analysis.
In average the seeding operations on these type B clouds affected 21 % of their whole volume with a quasi-excellent timing (87 % of the material went to the clouds in their first half-lifetime). A total of **1001 AgI and 82 hygroscopic flares** were used in this sub-sample for an effective silver iodide average dose about **90 ice-nuclei per liter.**

Also in average, type B clouds were 118 minutes old when the operations took place; the operation lasted about 32 minutes, and the type B seeded clouds lived 295 minutes (4 hours and 55 minutes)

Table 4 shows the results:

Table 4: Type B Seeded Sample versus Virtual Control Sample (46 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	295 min	285 min	1.04	4
Area	2102 km^2	2002 km^2	1.05	5
Volume	9130 km^3	8642 km^3	1.06	6
Volume Above 6 km	2738 km^3	2587 km^3	1.06	6
Prec.Flux	14 438 m^3/s	13 500 m^3/s	1.07	7
Prec.Mass	121 347 kton	110 372 kton	1.10	10

An increase of 10 % in precipitation mass for a control value of 110 372 kton in 46 cases implies:

Δ_3 = 46 x 0.10 x 110 372 kton ≈ 507 711 kton ≈ 411 754 ac-f

(mean layer: 5.3 mm ≈ 0.17 in)

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 2 812 591 ac-f ≈ 2.81 millions ac-f

(~ 790 ac-f per small storm; ~ 27 900 ac-f per large storm; ~ 8 950 per B storms)

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:

Table 5: Results per county

Panhandle Ground Water Conservation District Program

County	Initial seeding	Extended seeding	Acre-feet (increase)	Inches (increase)	Rain gage (season value)	% (increase)
Armstrong	**12**	**15**	**112 800**	**2.28**	**21.11 in**	**10.8**
Carson	**9**	**15**	**117 700**	**3.60**	**20.68 in**	**17.4**
Donley	**6**	**16**	**77 400**	**1.55**	**23.40 in**	**6.6**
Gray	**6**	**20**	**99 800**	**2.07**	**25.16 in**	**8.2**
Potter	**3**	**6**	**83 000**	**1.71**	**20.06 in**	**8.5**
Roberts	**7**	**15**	**65 700**	**1.32**	**18.88 in**	**7.0**
Wheeler	**2**	**11**	**52 800**	**1.10**	**24.21 in**	**4.5**
Outside		9	99 700			
Sub-total	**45**	**98**	**708 900** **(~14 % outside the target area)**			
Local Average (only for the bold values)				**1.95 in**	**21.93 in**	**9.0 %**

West Texas Weather Modification Association Program

County	Initial Seeding	Extended Seeding	Acre-feet (increase)	Inches (increase)	Rain (season value)	% (increase)
Sterling	**14**	**15**	**110 500**	**1.39**	**18.13 in**	**7.7 %**
Reagan	**26**	**28**	**174 700**	**2.77**	**19.33 in**	**14.3 %**
Irion	**19**	**22**	**147 600**	**2.62**	**21.42 in**	**12.2 %**
Tom Green	**9**	**11**	**111 300**	**2.73**	**27.05 in**	**10.1 %**
Crocket	**16**	**17**	**172 700**	**1.14**	**18.41 in**	**6.2 %**
Schleicher	**16**	**18**	**165 900**	**2.34**	**25.89 in**	**9.0 %**
Sutton	**9**	**11**	**92 800**	**1.21**	**21.50 in**	**5.6 %**
Outside TA	2	7	~ 80 200	(~ 7.6 % of the total amount)		
Sub-total	**111**	**129**	**1 055 700 ac-f**			
Local Average (only for the bold values)				**2.02**	**21.67 in**	**9.3 %**

South Texas Weather Modification Association Program

County	Initial Seeding	Extended Seeding	Acre-feet (increase)	Inches (increase)	Rain Gage (season value)	% (increase)
Uvalde	**6**	**10**	**80 500**	**0.94**	**22.47 in**	**4.2**
Bandera	**3**	**5**	**38 200**	**1.05**	**23.00 in(*)**	**4.6**
Medina	**8**	**13**	**43 800**	**0.57**	**22.59 in**	**2.5**
Bexar	**5**	**11**	**26 400**	**0.40**	**34.99 in**	**1.1**
Frío	**8**	**11**	**40 700**	**0.70**	**22.93 in**	**3.1**
Atascosa	**27**	**40**	**93 500**	**1.41**	**29.88 in(*)**	**4.7**
McMullen	**9**	**17**	**73 100**	**1.23**	**24.76 in**	**5.0**
Wilson	**10**	**18**	**36 600**	**0.86**	**31.46 in**	**2.7**
Karnes	**21**	**27**	**48 400**	**1.22**	**28.11 in**	**4.3**
Bee	**14**	**17**	**56 800**	**1.21**	**30.09 in(*)**	**4.0**
Outside	9	15	18 400 (3.3 % of the total amount)			
Sub-total	**120**	**184**	**556 400**			
Local Average				**0.96**	**27.03 in**	**3.6**

Trans-Pecos Weather Modification Association

County	Initial Seeding	Extended Seeding	Acre-feet (increase)	Inches (increase)	Rain Gage (season value)	% (increase)
Culberson	**1**	**2**	**9 200**	**0.04**	**9.79**	**0.4 %**
Reeves	**15**	**17**	**68 900**	**0.48**	**9.01**	**5.3 %**
Pecos	**9**	**13**	**79 200**	**0.33**	**6.90**	**4.8 %**
Ward	**4**	**6**	**42 000**	**0.95**	**9.67**	**9.8 %**
Loving	**1**	**2**	**13 500**	**0.37**	**11.44**	**3.2 %**
Outside (downwind effect over Winkler, Ector and Crane Counties)			53 000 (~ 20 % of the total increase)			
Sub-total	**30**	**41**	**265 800**			
Local Average				**0.43 in**	**9.36 in**	**4.7 %**

Table 6: Synoptic Summary

Program	Initial seeding	Extended seeding	Acre-feet increase	Increase in inches	Season Rain in inches	%
PGCD	**45**	**98**	**708 900**	**1.95 in**	**21.93 in**	**9.0**
WTWMA	**111**	**129**	**1 055 700**	**2.02 in**	**21.67 in**	**9.3**
STWMA	**120**	**184**	**556 400**	**0.96 in**	**27.03 in**	**3.6**
TPWMA	**30**	**41**	**265 800**	**0.43 in**	**9.36 in**	**4.7**
Totals	**306**	**452**	**2 586 800 ac-f**			
Averages				**1.34 in**	**20.00 in**	**6.7 %**

Outside the target areas (downwind effect): 251 300 ac-f (~ 10 % of the total increase)

Total amount of flares used: 4248 (AgI) plus 367 (Hygroscopic)

Final Comments

1) Results are evaluated as **excellent** (no miss-opportunities, 95 % average timing, 75 in/l average glaciogenic dose).

2) The micro-regionalization analysis showed increases per county; the average increase in precipitation, referred to an average seasonal value, was about **7.0 %**; a total increase of about 2.6 million acre-feet should be considered as a great help to fresh water natural resources.

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

4) During the 2016 cloud seeding campaign in Texas, hygroscopic seeding played an important role in the operations. When possible, **it is important to perform dual seeding operations in order to obtain the desire synergy.** Cloud base temperature is an excellent indicator of hygroscopic seeding opportunities: cloud bases colder than about 10 °C may indicate the presence of too many CCN (cloud condensation nuclei) and the needs to potentiate the droplet collision-coalescence mechanism for the formation of precipitation.