ANNUAL EVALUATION REPORT 2022 **STWMA (Pleasanton)**

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Cloud seeding operations in the year 2022 began over South Texas Weather Modification Association target area in April. This annual report serves as a summary of the results. A total of **98 clouds** were seeded and identified by TITAN in **32 operational days**. Table 1 on page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **April 4th, 2022**
Last operational day: **September 7th, 2022**

Number of operational days: 32
(Four in April, two in May, six in June, ten in July, nine in August, and one in September)

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

Eighteen with excellent performance
Four with very good performance
Three with good performance

Six with technical problems (no TITAN data available)

Number of seeded clouds: 98
(69 small-seeded clouds, 17 large-seeded clouds, 12 type B seeded clouds)

Flares used: 806 BIP-AgI, and 99 hygroscopic (during the evaluated operational days)

Missed Opportunities: one (with lifetime longer than 1 hour), ~ 1 % of resources.

July 2nd: **# 1084 over Karnes County** (22:24 – 00:00 UTC)

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 69 small-seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (69 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	60 min	45 min	1.33	33 (**22**)
Area	52.9 km^2	38.1 km^2	1.39	39 (**29**)
Volume	177.2 km^3	125.7 km^3	1.41	41 (**33**)
Top Height	8.6 km	7.9 km	1.09	9 (**2**)
Max dBz	51.7	50.5	1.02	2 (**3**)
Top Height of max dBz	3.6 km	3.6 km	1.00	0 (**-4**)
Volume Above 6 km	43.2 km^3	18.7 km^3	2.31	131 (**75**)
Prec.Flux	446.1 m^3/s	229.0 m^3/s	1.95	95 (**49**)
Prec.Mass	1667.4 kton	513.7 kton	3.25	225 (**105**)
CloudMass	168.2 kton	89.0 kton	1.88	88 (**39**)
η	9.9	5.8	1.71	71 (**48**)

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 **462 AgI-BIP and 63 Hygroscopic flares** were used in this sub-sample with a good timing **(77 %)** for an average silver iodide effective dose of about **90 ice nuclei per liter**. The seeding operation for small clouds lasted about **9 minutes** on average. An excellent increase of 105 % in precipitation mass together and an increase of 39 % in cloud mass illustrates that the seeded clouds grew at the expense of the environmental moisture (they are open systems) and used only a fraction of this moisture for their own maintenance. The increases in lifetime (22 %), in area (29 %), in volume (33 %), in volume above 6 km (75 %), and in precipitation flux (49 %) are notable. There was a slight increase in top height (2 %) and in maximum reflectivity (3 %).

The seeded sub-sample was 48 % more efficient than the control sub-sample. Results are evaluated as **very good** for this subsample.

An increase of 105 % in precipitation mass for a control value of 513.7 kiloton in 69 cases means:

Δ1= 69 x 1.05 x 513.7 kiloton ≈ 37 218 kiloton ≈ 30 183 ac-f (layer: 10.2 mm ≈ 0.40 in)

Large Clouds

The sub-sample of 17 large-seeded clouds received a synergetic analysis. On average, the seeding operations on these large clouds affected 73 % of their whole volume with perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of **209 AgI-BIP and 22 hygroscopic flares** were used in this sub-sample for an average effective silver iodide dose of about **20 ice nuclei per liter**.

Also, on average, large clouds were 30 minutes old when the operations took place; the operation lasted about 20 minutes, and the large-seeded clouds lived 200 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (17 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	200 min	170 min	1.18	18
Area	273 km^2	228 km^2	1.20	20
Volume	1351 km^3	1107 km^3	1.22	22
Volume Above 6 km	630 km^3	433 km^3	1.45	45
Prec.Flux	3688 m^3/s	2803 m^3/s	1.32	32
Prec.Mass	29 794 kton	18 621 kton	1.60	60

An increase of 60 % in precipitation mass for a control value of 18 621 kton in 17 cases may mean:

Δ2= 17 x 0.60 x 18 621 kton ≈ 189 934 kton ≈ 154 037 ac-f
(Layer: 40.9 mm ≈ 1.61 in)

Type B Clouds

The sub-sample of 12 type B seeded clouds also received a synergetic analysis. On average, the seeding operations on these type B clouds affected 10 % of their whole volume with very good timing (80 % of the material went to the clouds in their first half-lifetime). A total of **135 AgI-BIP and 14 hygroscopic flares** were used in this sub-sample for an average effective silver iodide dose of about **45 ice nuclei per liter.**

Also, on average, type B clouds were 85 minutes old when the operations took place; the operation lasted about 19 minutes, and the type B seeded clouds lived 230 minutes.

Table 4 shows the results:

Table 4: Type B Seeded Sample versus Virtual Control Sample (17 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	230 min	215 min	1.07	7
Area	519 km^2	505 km^2	1.03	3
Volume	3228 km^3	3132 km^3	1.03	3
Volume Above 6 km	1862 km^3	1766 km^3	1.05	5
Prec.Flux	8551 m^3/s	8214 m^3/s	1.04	4
Prec.Mass	246 714 kton	230 573 kton	1.07	7

An increase of 7 % in precipitation mass for a control value of 230 573 kton in 17 cases may mean:

$\Delta 3 = 17 \times 0.07 \times 230\ 573$ kton $\approx$ 193 681 kton $\approx$ 157 076 ac-f
(Layer: 31.1 mm $\approx$ 1.22 in)

The total increase: $\Delta 1 + \Delta 2 + \Delta 3$ = 341 296 ac-f

(~ 437 ac-f per small, 9 060 ac-f per large, 13 090 ac-f per type B)

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 for operations (season: May to October):

County Seeding	Initial Seeding	Extended (increase)	Acre-feet (increase)	Inches (increase)	Rain Gage (season value*)	% (increase)
Uvalde	**11**	**16**	**74 600**	**0.89**	**11.63 in**	**7.7**
Bandera	**19**	**23**	**37 200**	**1.01**	**8.99 in**	**11.2**
Medina	**14**	**18**	**34 200**	**0.46**	**5.98 in**	**7.8**
Bexar	**11**	**15**	**47 200**	**0.70**	**5.48 in**	**12.8**
Frio	**3**	**6**	**9 500**	**0.17**	**6.41 in**	**2.7**
Atascosa	**14**	**16**	**15 800**	**0.24**	**6.09 in**	**3.9**
McMullen	**2**	**3**	**13 500**	**0.23**	**13.78 in**	**1.7**
Wilson	**9**	**13**	**28 000**	**0.66**	**6.09 in**	**10.8**
Karnes	**7**	**9**	**24 700**	**0.62**	**8.49 in**	**7.3**
Bee	**7**	**8**	**51 800**	**1.11**	**12.36 in**	**9.0**
Subtotal	**97**	**77**	**336 500**			
Outside	1	2	4 800 (~ 1 % of total)			
Total	**98**	**129**	**341 300**			
Average				**0.61**	**8.53 in**	**7.5 %**

(**Initial seeding** means the counties where the operations began, whereas **extended seeding** means the counties favored by seeding after the initial operations took place).

*** Seasonal precipitation values: April-August 2022 (no TITAN data in September)**

Final Comments

- Results are evaluated as **excellent**; average timing: **81 %**, average dose: **70 icn/L**; missed opportunities: **one**, about 1 % of resources.

- The micro-regionalization analysis showed increases per county; different zones received downwind benefits; the average increase in precipitation, referred to as rain gauge seasonal value (April-August), was about **7.5 %.**

- Radar estimations of precipitation should be considered as measurements of trend. Clearly, seeding operations improved the dynamics of seeded clouds.

- In 2022, the total increase in the region, estimated at about 0.337 million acre-feet over the target area, should be considered a great help to freshwater natural resources.

- Dual seeding was well used during the 2022 campaign: 99 hygroscopic flares were utilized in the analyzed sample (average: about 1 hygroscopic flare per seeded cloud).

- TITAN did not work properly in 6 operational days. It is estimated that about 25 seeded clouds were not evaluated (about 20 % of the total resources).