Rain Enhancement of Aquifer Recharge across the West Texas Weather Modification Association Target Area

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ABSTRACT

Groundwater is critical to the economy and livelihood of west Texas, with particular importance to arid and semi-arid environments where precipitation is limited and highly variable. In the absence of significant surface-water resources, most land owners rely on groundwater as the sole resource for agricultural, municipal, and economic development needs. Unfortunately, groundwater resources in arid and semi-arid environments are stressed due to increased demands and variable recharge rates and mechanisms.

Rainfall enhancement has been shown using matched cloud analysis to increase precipitation by 8-20% across an eight-county area in west Texas during 2004–2013. This translates to an increase of rainfall as much as 2 in/yr. Confirmatory analysis at 10 rain gauges within the west Texas target area indicates that since 2004 precipitation exhibited an 8% increase when compared with precipitation at 15 rain gauges in the surrounding area outside of the target area.

A precipitation/recharge correlation developed for the semi-arid environment of west Texas was used to determine how much additional recharge has been realized from the rain-enhancement operations that were conducted for the eight-county target area. Using this correlation, recharge to the Edwards-Trinity Aquifer is calculated to have been enhanced by over 1.0 million acre-ft during the period of 2004–2013 across the eight-county target area.

Introduction

Understanding groundwater recharge is central to effective management of groundwater resources. Characterizing recharge in the arid and semi-arid environs of Texas is a challenge whose importance only increases with time. A multitude of factors affect how, when, and where recharge will occur; however, the dominant factor is precipitation. Because recharge is highly dependent on precipitation, variability in recharge rates has increased with the potential for climatic variability due to global climate change according to Kunkel et al. (2013). A range of anthropogenic remedies is sought and considered toward the goal of meeting increased water demands in light of threatened water resources. One possible technology with promise is the use of rain enhancement, to not only sustain growing crops, but to enhance recharge, particularly during winter months when evapotranspiration rates are lowest and cloud-seeding equipment is not normally used.

Background

During an experimental cloud-seeding program in the 1980's, rain-gauge analysis from Big Spring to San Angelo, Texas indicated that cloud seeding could effectively, efficiently, and economically increase precipitation (Griffith, 1990). Based on these encouraging results, in 1996, eight west Texas counties formed the West Texas Weather Modification Association to develop a rain-enhancement program to augment crop irrigation and suppress hail damage. The performance of this program has been assessed to ascertain its success in meeting its objectives and to determine whether the program has been effective and economical. Based on this assessment, it became apparent that additional benefits may be realized by the weather modification program in addition to crop irrigation and hail suppression. One notable additional benefit is the potential for weather modification to augment or enhance groundwater recharge.

Arid and semi-arid environments are attractive candidates for recharge enhancement by cloud seeding because recharge is limited or even negligible in these environments. The aquifer of interest in this particular study is the Edwards-Trinity Aquifer, which covers much of the Edwards Plateau in west-central Texas (Figure 1). The Edwards-Trinity Aquifer is a highly transmissive karstic carbonate aquifer that tends to recharge and discharge relatively quickly. The climate of the Edwards Plateau varies from humid subtropical in the east, with annual precipitation from approximately 32 in/yr in the east to 15 in/yr in the semi-arid west. In general, distributed recharge occurs across the upland areas of the Edwards Plateau and focused recharge occurs in the river beds that have incised into the plateau. Numerous discharge zones occur in incised canyons and along the margins of the Edwards Plateau.

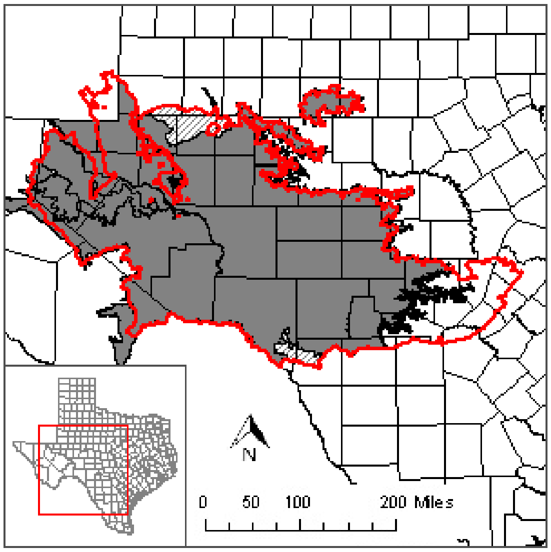

Figure 1. Edwards Trinity Aquifer (Texas Water Development Board 2013). Inset map shows the state of Texas with the red box indicating enlarged region.

Scanlon et al. (2003) estimated the recharge across several aquifers within Texas (Table 1). Scanlon et al. (2003) used a variety of analyses and technologies to calculate the recharge of several of the major aquifers in Texas (see Table 1). These approaches included groundwater modeling, baseflow separation of stream hydrographs, water-budget analysis, surface-water studies, channel-water budgeting, direct measurement (i.e., eddy covariance towers), tracer studies, and groundwater dating (Scanlon et al., 2003). As indicated in Table 1, they calculated that the Edwards-Trinity Aquifer receives recharge anywhere from 0.1 to 2 in/yr.

Baseflow separation of stream hydrographs has been shown to be useful in estimating recharge to the Edwards-Trinity Aquifer (Scanlon et al., 2003; Green and Bertetti, 2010; Green et al., 2013). This approach separates baseflow from surface overflow or storm flow in a stream hydrograph. The baseflow component is considered to be the groundwater contribution to stream flow and can be interpreted to equal recharge (Ford and Williams, 1996; White and White, 2001; Szilagyi et al., 2003; Scanlon et al., 2003; White, 2006). Various approaches are used to separate baseflow from a stream hydrograph including digital filtering (Nathan and MacMahon, 1990), analytical manipulation (Arnold et al., 1995; Arnold and Allen, 1999), and recession-curve displacement (Rorabough, 1964).

Table 1. Recharge rates of large aquifers in Texas (Scanlon et al., 2003).

Aquifer	**Recharge Rate (in/yr)**
Carrizo-Wilcox	0.1 to 5.8
Gulf Coast	0.0004 to 2
High Plains	0.004 to 1.7
Edwards Trinity	0.1 to 2
Seymour	1 to 2.5

The conceptualization that river baseflow discharge equates to recharge is only valid if rivers are gaining. This assumption is met close to the headwaters of watersheds in the Edwards-Trinity Aquifer. Inherent in this calculation is that pumping is negligible, an assumption assumed valid in most regions of the Edwards-Trinity Aquifer because wells are sparse and most wells are limited to domestic and livestock demands. Rutledge (1998) recommended a limit on basin size of 500 mi^2 (320,000 acres) when using this method.

It is important to recognize that recharge calculated by baseflow separation using long-term river gauging data represents long-term average recharge and is not reflective of seasonal changes in recharge nor is it representative of annual variations between wet and dry years. Relatively long-term, river-discharge data have been recorded by the U.S. Geological Survey near the headwaters of surface watersheds in the Edwards Plateau which allows for meaningful calculation of average recharge using baseflow separation.

Recharge rates of 0.1 inch to 2 in/yr were calculated for the Edwards-Trinity Aquifer by Scanlon et al. (2003) using baseflow separation of stream hydrographs. Recharge of the western Edwards-Trinity Aquifer was further investigated by Green and Bertetti (2010). Calculations of recharge for eight counties in the western Edwards-Trinity Aquifer were adjusted to account for groundwater contributing areas that differed from surface watershed boundaries (Green and Bertetti, 2010; Green et al., 2012). The adjusted recharge rates for the eight counties are presented in Figure 2. The assumption that rivers are gaining is not valid for Menard County, thus baseflow separation of stream hydrographs cannot be used to calculate recharge for this region.

When plotted versus average annual precipitation, recharge data for the western Edwards-Trinity Aquifer area exhibited a linear correlation from which a regression equation was calculated (Green and Bertetti, 2010; Green et al., 2012).

$$\boxed{R = 0.15 * (P - 16.5) \text{ where } R = 0 \text{ when } P < 16.5 \qquad \text{Equation 1.}}$$

where R denotes recharge (in/yr) and P denotes precipitation (in/yr). Inherent in this correlation is that annual precipitation needs to exceed a threshold of about 16.5 inches before meaningful distributed recharge is realized. This simplified correlation is appropriate for long-term average precipitation rates and does not account for seasonal variability in precipitation, antecedent moisture content, nor storm type, intensity, and duration. Nonetheless, the correlation in Equation 1 is useful for approximating recharge for precipitation rates under average climatic conditions.

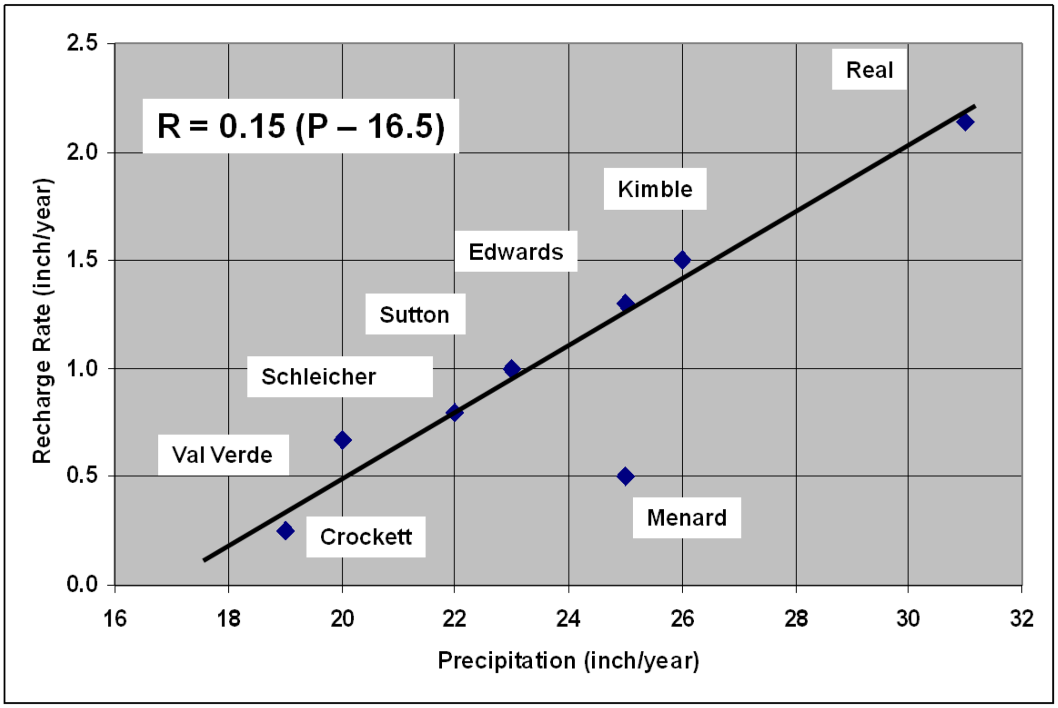

Figure 2. Graph of calculated recharge versus annual average precipitation for eight counties in the western Edwards-Trinity Aquifer. The black line is a linear approximation of the relationship between precipitation and recharge, excluding the outlier data point for Menard County (Green and Bertetti, 2010; Green et al., 2012).

Analysis of Rain Enhancement across the West Texas Weather Modification Association Target Area

The West Texas Weather Modification Association area covers 6.6 million acres and includes all of seven counties – Glasscock, Sterling, Reagan, Irion, Crockett, Schleicher, and Sutton – plus part of one, Tom Green (Figure 3). Since 2001, rain-enhancement operations in the state of Texas have been analyzed by a team at Texas Tech University (Ruiz-Columbiè et al., 2014). The assessments are based on the Thunderstorm Identification, Tracking, Analysis, and Nowcasting (TITAN) software which uses climate data to compare seeded storms with a control sample of unseeded storms. Currently, Texas Weather Modification Association programs, including the West Texas Weather Modification Association, use climate data provided by the National Weather Service through Weather Decisions Technologies, Inc to calculate the effectiveness of cloud seeding. Analysis of the effectiveness of rain enhancement in the West Texas Weather Modification Association area has been performed in accordance with the Texas Weather Modification Act of 1967 which states weather modification programs in the State of Texas must provide a quantitative analysis of their operations (Texas Water Development Board, 1971). The cloud-seeding assessments provided by Ruiz-Columbiè et al. (2014) for the period from 2004 through 2013 are used in this study to evaluate the feasibility of increasing recharge in a semi-arid environment by rain enhancement using cloud seeding. Measured annual precipitation with cloud seeding and calculated annual precipitation without cloud seeding are presented in Table 2 for each county for the period 2004 to 2013. Calculated increases in precipitation for each county for each year are presented in Table 3. Annual precipitation increased by cloud seeding expressed as a percentage is presented in Table 4.

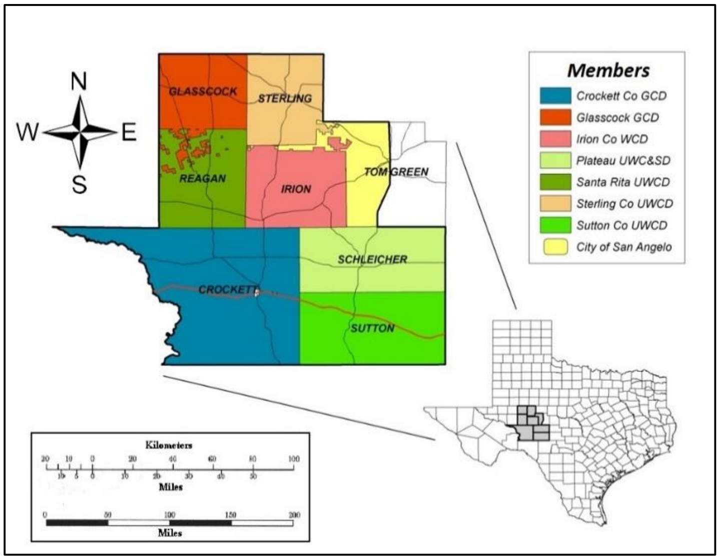

Figure 3. The Western Texas Weather Modification Association target area

Annual increases in precipitation varied from as low as 0.77 in/yr in Crockett County in 2011 to as high as 5.84 in/yr in Glasscock County in 2009 (Table 3). The 10-year averages varied from 1.49 in/yr in Crockett County to 3.01 in/yr in Irion County (Table 3). The augmented precipitation rates equate to increases to 8 to 20% over the 10-year study period across the West Texas Weather Modification Association target area.

Precipitation generated by seeding small clouds (volumes less than 10,000 kilotons) was compared by Ruiz-Columbiè et al. (2014) with precipitation from small clouds that were not seeded in Figure 4. Control clouds were selected based on parameters specified by the TITAN analysis package. Clouds that occurred on the same day, within the same air mass, and with similar characteristics before seeding qualified as control clouds. Precipitation fluxes for matched clouds are compared for the time period from the birth of the cloud through the death of the cloud. Within 5 minutes of seeding, the seeded clouds began to experience a precipitation flux showing higher intensity of rainfall that continued through the mature stage of the cloud, in this case up to 40 minutes after seeding commenced.

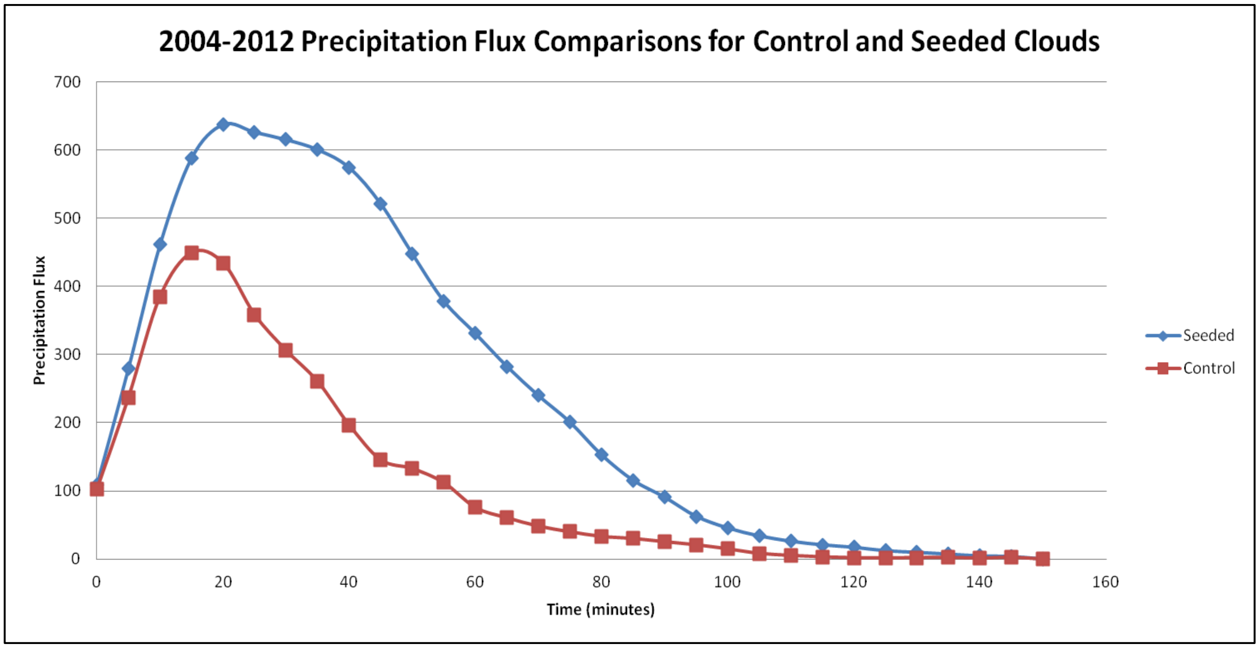

Figure 4. Precipitation flux (2004-2012) for seeded clouds versus control clouds (Ruiz-Columbiè et al., 2014). (kg/m^2-s)

Confirmatory Rain-Enhancement Analysis

To confirm the analysis by Ruiz-Columbiè et al. (2014), a rain-gauge analysis was conducted as part of this study to determine if the difference in precipitation measured at rain gauges within the West Texas Weather Modification Association target area versus precipitation measured outside of the target area was consistent with the analysis by Ruiz-Columbiè et al. (2014). Figure 6 shows the location of rain gauges used both within (those labeled in blue) and outside (those labeled in red) of the target area. Overall, 10 locations were found to have reliable historical data within the target area. Similarly there were 15 locations outside of the target that provide reliable data.

Precipitation measured at rain gauges within and outside of the West Texas Weather Modification Association target area is presented in Figure 5 in terms of percent of average rainfall for the period 1971–2013. Although there is naturally occurring variability in the data, there are two periods – mid to late 1980's and 2004–2010 – when precipitation within the West Texas Weather Modification Association target area exceeded precipitation in the control area. The mid- to late-1980's period coincides with the time that the Southwest Cooperative Program conducted randomized cloud seeding from Big Spring to San Angelo, Texas (Woodley 1990). The 2004–2010 period coincided with the time when rain enhancement by cloud seeding was conducted over the West Texas Weather Modification Association target area. This cloud seeding program was effective during 2004–2010 because of an abundance of candidate cloud resources. However, by late 2010 and into 2011, the target area experienced a severe drought resulting in a lack of cloud targets required for rain enhancement. The absence of effective rain enhancement during this latter period is indicated by agreement between precipitation measured within and outside of the West Texas Weather Modification Association target area for the period 2010–2013 in Figure 6.

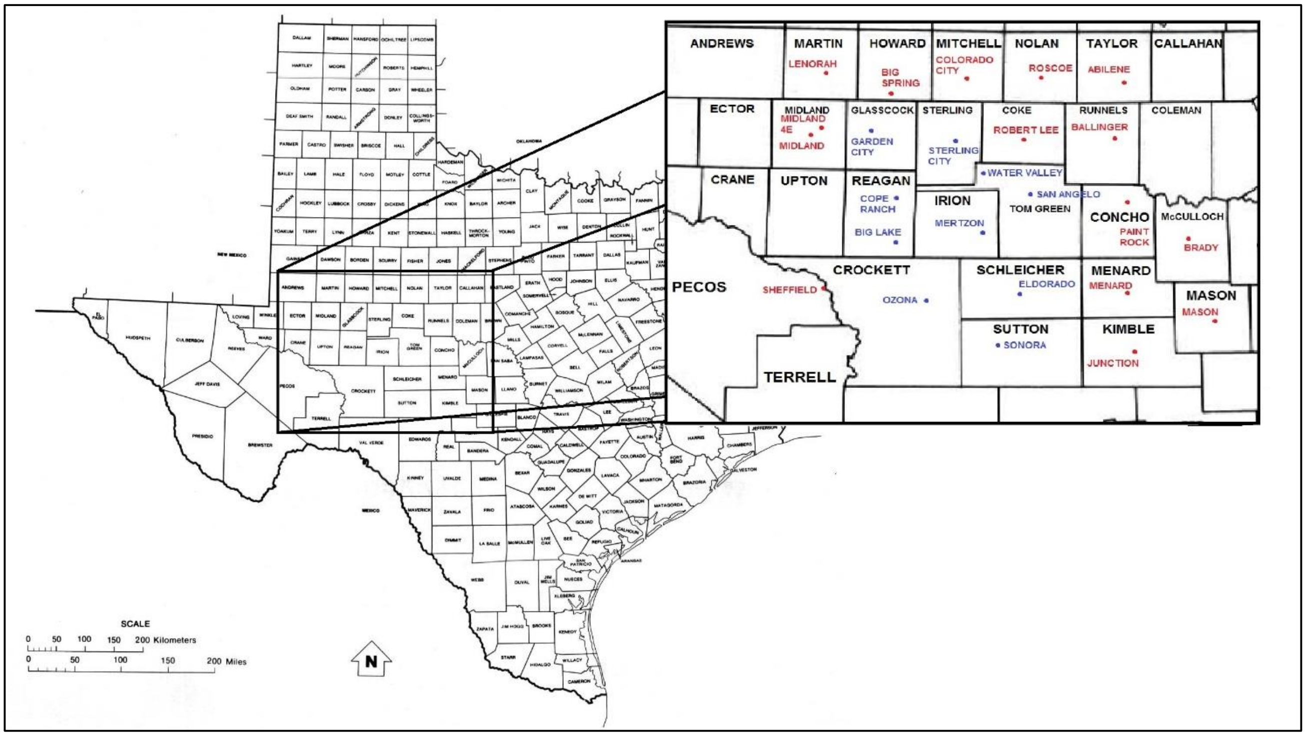

Figure 5. Rain Gauge Locations within (blue labels) and outside (red labels) of the target area.

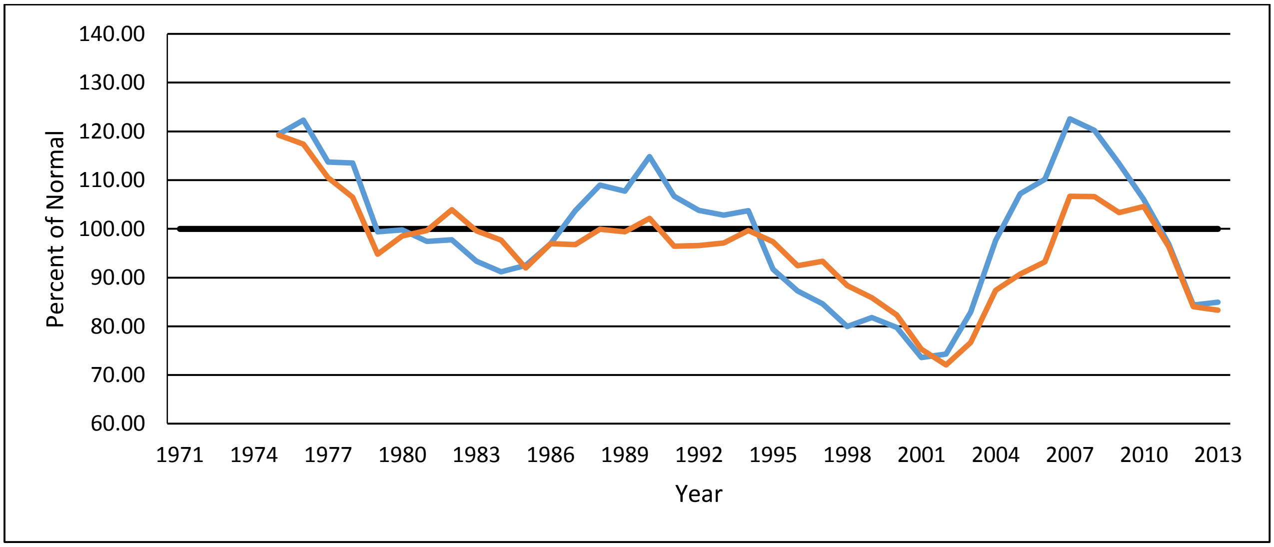

Figure 6. Percent relative to average rainfall relative to the period 1971–2013 within the West Texas Weather Modification Association target area (blue line) compared with outside (orange line) the target area.

The analysis of precipitation measured at the 25 rain gauges indicated precipitation was 102% of the long-term average precipitation within the West Texas Weather Modification Association target area for the period 2004–2012 (Figure 7). The long-term average rainfall for the West Texas Weather Modification Association target area is 16.6 in/yr, which, coincidently, is approximately the threshold below which negligible distributed recharge indicated in Equation 1 (Green and Bertetti , 2010; Green et al., 2012). Comparatively, outside of the target area, the 15 rain gauge locations yielded only 94% of the average precipitation. The 8% difference in precipitation calculated here is consistent with the 8 to 20% calculations by Ruiz-Columbiè et al. (2014) providing added evidence that cloud seeding did enhance precipitation. Precipitation data for the West Texas Weather Modification Association target area were also compared with rain-gauge data from east, west, and north of the target area to determine if these unseeded areas experienced collateral effects from the seeded area. As shown in Figure 7, the area east of the target area received nearly the same percentage of average precipitation in 2007 and surpassed the percent of average precipitation east of the target area compared to the target area in 2010. Data from the north and west did not exhibit this characteristic. This is interpreted as an indication that locations to the east of the rain-enhancement area experienced positive downwind impacts from cloud seeding in the West Texas Weather Modification Association target area. Since 2004, the area east of the target area has experienced rainfall levels equal to 99.8% of its long-term average precipitation, which is 7.2% greater than the precipitation averaged for all 7 rain gauges west and north of the target area. It is notable that the rain-gauge locations east of the target area exhibited more cloud resources and more precipitation over the last three years resulting in precipitation rates closer to the long-term average precipitation even though all areas were equally impacted by the recent drought. Overall, the rain-gauge analysis conducted as part of this study, along with the cloud comparison analysis conducted by Ruiz-Columbiè et al. (2014), indicated that weather modification by cloud seeding increased precipitation in the West Texas Weather Modification Association target area by 8-15% for the period 2004–2013.

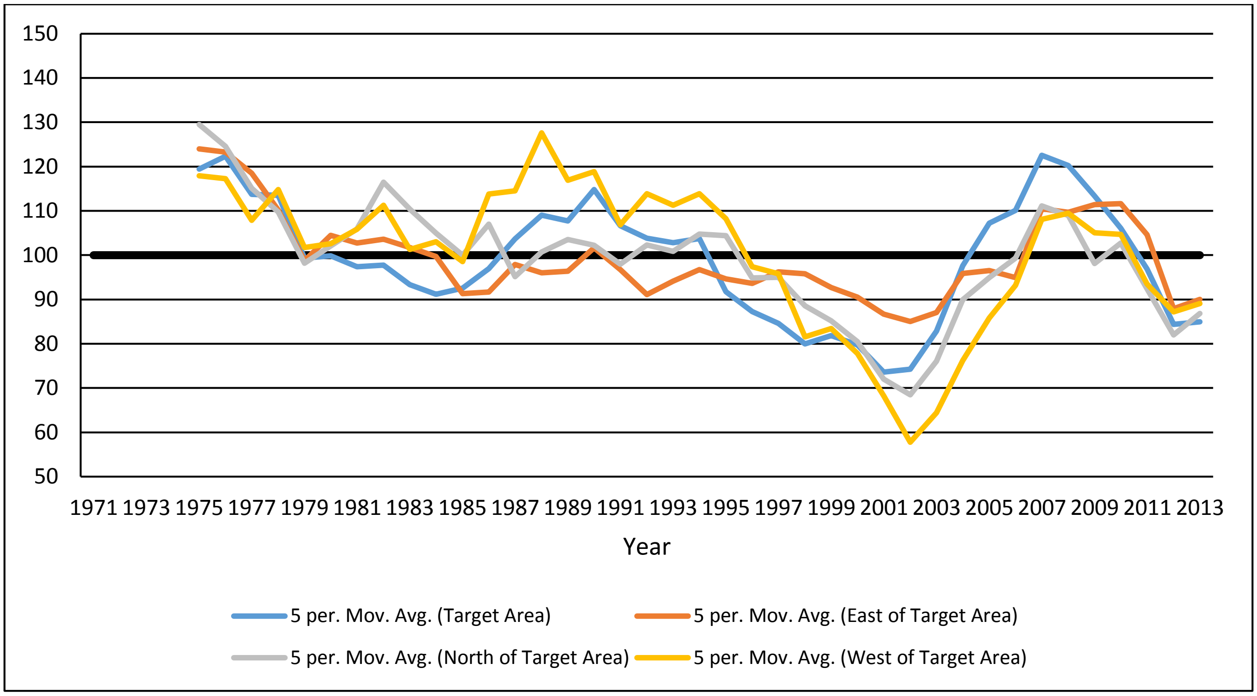

Figure 7. Percent relative to average rainfall within the target (blue line) area, east (orange line) of the target area, north (gray line) of the target area, and west (yellow line) of the target area.

Analysis of Recharge due to Rain Enhancement

Recharge calculated using measured precipitation for each county in the West Texas Weather Modification Association target area is graphically illustrated in Figure 8. The amount of recharge increased by cloud seeding was calculated for each county within the West Texas Weather Modification Association target area using the rain-enhancement data by Ruiz-Columbiè et al. (2014) and calculating the amount of recharge for annual precipitation amounts using the precipitation/recharge relation in Equation 1 (Table 5). Increases in recharge attributed to rain enhancement were determined by comparing the actual calculated recharge with recharge that would have been experienced if there were no rain enhancement (Table 3). For example, in

Crockett County, recharge calculated for precipitation of 31.02 and 28.31 in/yr for 2004 (Table 5) is calculated to be 2.18 and 1.77 in/yr under cloud seeding and no cloud seeding conditions, respectively. This equates to enhanced recharge of 60,856 acre-ft in 2004 and a cumulative increase in recharge of 186,690 acre-ft in Crockett County for the 10-year period of rain enhancement (Table 7).

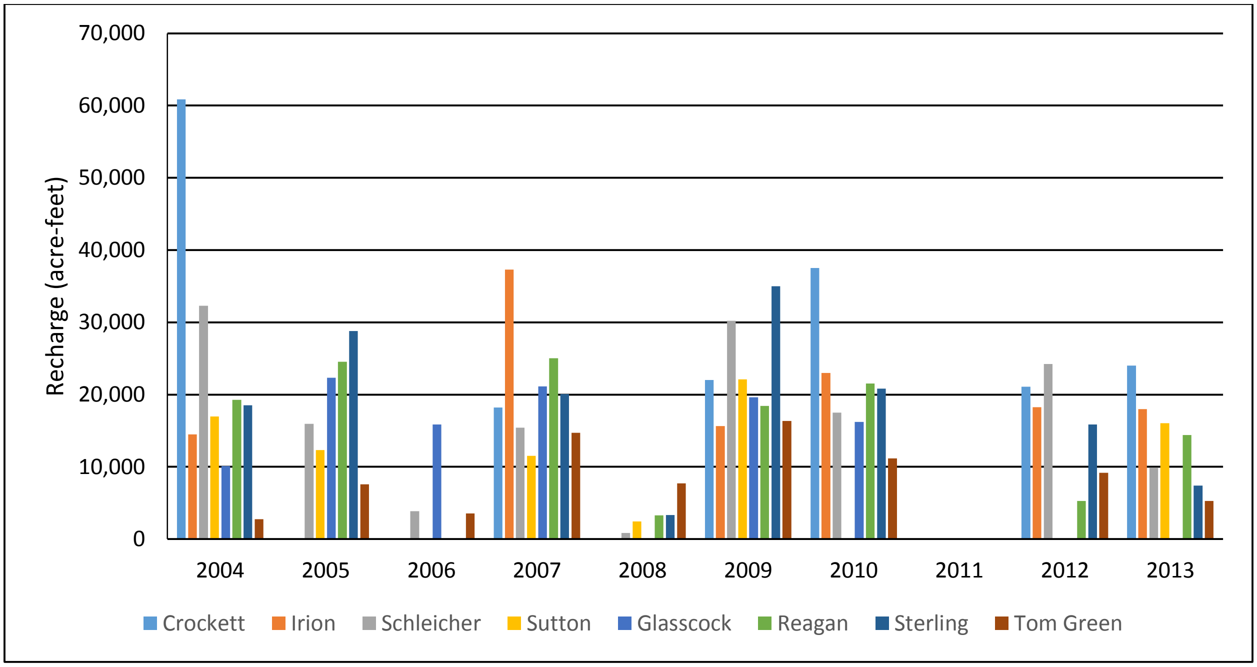

Figure 8. Estimated recharge for each county in the West Texas Weather Modification Association target area (2004–2013).

This analysis indicates the eight counties experienced increased recharge per county of approximately 8,100 to 18,400 acre-ft/yr for the period 2004–2013. Crockett County, with the largest area, experienced the greatest enhanced recharge of 18,400 acre-ft/yr (Table 7). Schleicher, Sterling and Tom Green counties had recharge rates of approximately 15,000 to 16,000 acre-ft/yr. Iron and Reagan counties experienced increased recharge of 12,200 to 13,200 acre-ft/yr and slightly less in Glasscock and Sutton counties. Over the ten-year period of 2004–

2013, the weather modification program is estimated to have enhanced recharge to the West Texas Weather Modification Association target area by over 1.0 million acre-ft.

These calculations are based on several assumptions. Precipitation and recharge have been calculated for averages calculated over ten years. Factors such as storm intensity, duration, seasonality, and antecedent moisture conditions have not been include in these long-term estimates. Nonetheless, for average climatic conditions, these calculations suggest that significant recharge is realized by enhanced precipitation. Lastly, it is important to recognize precipitation from cloud seeding that occurs during the summer months may not result in as much recharge that would occur from cloud seeding conducted during winter months when evapotranspiration rates are less. This seasonal simplification may bias recharge enhancement estimates.

There were 17 occurrences when weather modification is inferred to have resulted in counties receiving distributed recharge because without the added rainfall, the annual precipitation was less than the minimum threshold of approximately16.5 inches of precipitation required for distributed recharge. Five of these occurrences occurred in Reagan County where an additional 63,000 acre-ft was produced over the 10-year period as a result of weather modification. The other 12 cases occurred in Irion (3), Schleicher (3), Sutton (1), Tom Green (3), Sterling (1) and Glasscock (1) counties. These 12 additional cases provided roughly 145,000 acre-ft of recharge that is interpreted would not have occurred without weather modification for a total of over 200,000 acre-ft of enhanced recharge.

Discussion and Conclusions

Increases in recharge for an eight-county region in west Texas has been estimated using assessments of increased precipitation due to weather modification (Ruiz-Columbiè et al., 2014).

Over 1.0 million acre-ft of recharge to the Edwards-Trinity Aquifer is estimated to have been realized during 10 years of weather modification conducted by the West Texas Weather Modification Association over the eight-county target area. With irrigation increasing across the region, population increases, and increasing water demands for the oil field activity as well as the changing climate and the threat of a continued drought, the additional 1.0 million acre-ft of recharge has provided considerable relief to a region experiencing increased water demands and stressed water resources. The cost of the West Texas Weather Modification Association weather modification program totaled approximately $1.5 million for the 10 years of the program examined in this evaluation (2004–2013). This equates to a cost of $1.50 per acre-ft of enhanced recharge. Although the prime motivations for the weather modification program were to enhance rainfall for crops and to suppress hail damage, the added benefit of the program in terms of enhanced recharge to groundwater resources is shown to be substantial and cost effective.

Acknowledgments

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Table 2. Annual precipitation by county measured with cloud seeding (with) and calculated for without cloud seeding (w/o) (Ruiz-Columbie et al., 2014) (in/yr)

County	**Crockett**		**Glasscock**		**Irion**		**Reagan**		**Schleicher**		**Sterling**		**Sutton**		**Tom Green**	
Year	with	w/o	with	w/o	with	w/o	with	w/o	with	w/o	with	w/o	with	w/o	with	w/o
2004	31.02	28.31	30.22	28.82	29.21	27.49	27.24	25.19	31.36	28.28	22.39	19.88	42.11	40.65	30.49	29.60
2005	14.73	13.07	21.00	17.90	15.81	12.45	29.37	26.76	27.78	26.26	24.37	20.47	21.29	20.23	20.38	17.92
2006	12.05	9.70	21.16	18.96	12.87	8.10	13.01	10.17	16.87	13.44	15.53	12.31	13.77	10.46	17.65	15.93
2007	30.60	29.79	32.79	29.86	26.31	21.88	24.78	22.12	29.41	27.94	24.38	21.66	30.71	29.72	32.04	27.26
2008	15.04	13.12	12.75	11.76	13.27	10.31	16.85	12.91	16.58	13.87	16.95	13.83	16.71	16.03	19.00	15.89
2009	20.51	19.53	19.22	13.38	18.36	14.76	18.46	14.95	21.89	19.01	31.51	26.77	25.41	23.51	25.53	20.22
2010	23.85	22.18	24.31	22.06	19.23	15.74	18.79	15.50	18.17	16.33	23.38	20.56	10.73	8.50	20.13	15.84
2011	7.37	6.60	7.95	6.84	9.10	7.68	8.45	7.47	7.83	6.46	5.64	4.80	7.53	6.63	9.21	7.67
2012	19.86	18.92	15.97	12.94	21.87	19.70	17.06	14.40	18.95	16.64	24.98	22.83	14.11	13.05	21.96	18.98
2013	20.24	19.17	16.28	14.95	18.09	15.95	18.03	15.83	21.76	20.82	16.30	15.30	22.80	21.42	20.21	18.49

Table 3. Calculated increase in precipitation rate by county realized by increased precipitation from cloud seeding (in/yr)

	Crockett	**Glasscock**	**Irion**	**Reagan**	**Schleicher**	**Sterling**	**Sutton**	**Tom Green**
2004	2.71	1.40	1.72	2.05	3.08	2.51	1.46	0.89
2005	1.66	3.10	3.36	2.61	1.52	3.90	1.06	2.46
2006	2.35	2.20	4.77	2.84	3.43	3.22	3.31	1.72
2007	0.81	2.93	4.43	2.66	1.47	2.72	0.99	4.78
2008	1.92	0.99	2.96	3.94	2.71	3.12	0.68	3.11
2009	0.98	5.84	3.60	3.51	2.88	4.74	1.90	5.31
2010	1.67	2.25	3.49	3.29	1.84	2.82	2.23	4.29
2011	0.77	1.11	1.42	0.98	1.37	0.84	0.90	1.54
2012	0.94	3.03	2.17	2.66	2.31	2.15	1.06	2.98
2013	1.07	1.33	2.14	2.20	0.94	1.00	1.38	1.72
Average	1.49	2.42	3.01	2.67	2.16	2.70	1.50	2.88

Table 4. Percent increase in annual precipitation attributed to cloud seeding

	Crockett	**Glasscock**	**Irion**	**Reagan**	**Schleicher**	**Sterling**	**Sutton**	**Tom Green**
2004	9.57	4.86	6.26	8.14	10.89	12.63	3.59	3.01
2005	12.70	17.32	26.99	9.75	5.79	19.05	5.24	13.73
2006	24.23	11.60	58.89	27.93	25.52	26.16	31.64	10.80
2007	2.72	9.81	20.25	12.03	5.26	12.56	3.33	17.53
2008	14.63	*8.42*	*28.71*	30.52	19.54	22.56	4.24	19.57
2009	5.02	43.65	24.39	23.48	15.15	17.71	8.08	26.26
2010	7.53	10.20	22.17	21.23	11.27	13.72	26.24	27.08
2011	11.67	16.23	18.49	13.12	21.21	17.50	13.57	20.08
2012	4.97	23.42	11.02	18.47	13.88	9.42	8.12	15.70
2013	5.58	8.90	13.42	13.90	4.51	6.54	6.44	9.30
Average	**8.25**	**13.62**	**19.51**	**16.18**	**11.40**	**15.14**	**7.87**	**15.34**

Table 5. Calculated annual recharge by county with cloud seeding (with) and without cloud seeding (w/o) (in/yr)

County	**Crockett**		**Glasscock**		**Irion**		**Reagan**		**Schleicher**		**Sterling**		**Sutton**		**Tom Green**	
Year	with	w/o	with	w/o	with	w/o	with	w/o	with	w/o	with	w/o	with	w/o	with	w/o
2004	2.18	1.77	2.06	1.85	1.91	1.65	1.61	1.30	2.23	1.77	0.88	0.51	3.84	3.62	2.10	1.97
2005	0.00	0.00	0.68	0.21	0.00	0.00	1.93	1.54	1.69	1.46	1.18	0.60	0.72	0.56	0.58	0.21
2006	0.00	0.00	0.70	0.37	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.17	0.00
2007	2.12	1.99	2.44	2.00	1.47	0.81	1.24	0.84	1.94	1.72	1.18	0.77	2.13	1.98	2.33	1.61
2008	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.01	0.00	0.07	0.00	0.03	0.00	0.38	0.00
2009	0.60	0.45	0.41	0.00	0.28	0.00	0.29	0.00	0.81	0.38	2.25	1.54	1.34	1.05	1.35	0.56
2010	1.10	0.85	1.17	0.83	0.41	0.00	0.34	0.00	0.25	0.00	1.03	0.61	0.00	0.00	0.54	0.00
2011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.50	0.36	0.00	0.00	0.81	0.48	0.08	0.00	0.37	0.02	1.27	0.95	0.00	0.00	0.82	0.37
2013	0.56	0.40	0.00	0.00	0.24	0.00	0.23	0.00	0.79	0.65	0.00	0.00	0.95	0.74	0.56	0.30

Table 6. Calculated increase in recharge rate by county realized by increased precipitation from cloud seeding (in/yr)

	Crockett	**Glasscock**	**Irion**	**Reagan**	**Schleicher**	**Sterling**	**Sutton**	**Tom Green**
2004	0.41	0.21	0.26	0.31	0.46	0.38	0.22	0.13
2005	0.00	0.47	0.00	0.39	0.23	0.59	0.16	0.37
2006	0.00	0.33	0.00	0.00	0.06	0.00	0.00	0.17
2007	0.12	0.44	0.66	0.40	0.22	0.41	0.15	0.72
2008	0.00	0.00	0.00	0.05	0.01	0.07	0.03	0.38
2009	0.15	0.41	0.28	0.29	0.43	0.71	0.29	0.80
2010	0.25	0.34	0.41	0.34	0.25	0.42	0.00	0.54
2011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.14	0.00	0.33	0.08	0.35	0.32	0.00	0.45
2013	0.16	0.00	0.24	0.23	0.14	0.00	0.21	0.26

Table 7. Calculated increase in recharge by county realized by increased precipitation from cloud seeding (acre-ft)

	Crockett	**Glasscock**	**Irion**	**Reagan**	**Schleicher**	**Sterling**	**Sutton**	**Tom Green**	**Total**
2004	60,856	10,091	14,476	19,286	32,303	21,124	16,983	5,486	**180,605**
2005	0	22,345	0	24,555	15,942	32,822	12,330	15,163	**123,157**
2006	0	15,858	0	0	3,881	0	0	7,089	**26,827**
2007	18,189	21,119	37,283	25,025	15,417	22,892	11,516	29,464	**180,905**
2008	0	0	0	3,293	839	3,787	2,443	15,410	**25,772**
2009	22,007	19,606	15,654	18,440	30,205	39,892	22,101	32,731	**200,635**
2010	37,502	16,218	22,976	21,544	17,515	23,733	0	22,375	**161,863**
2011	0	0	0	0	0	0	0	0	**0**
2012	21,109	0	18,263	5,268	24,227	18,094	0	18,369	**105,330**
2013	24,028	0	13,381	14,394	9,859	0	16,052	10,602	**88,317**
Total	**183,690**	**105,237**	**122,032**	**131,806**	**150,188**	**162,345**	**81,424**	**156,689**	**1,093,411**

*Area adjusted to ¼ of the county to account for only ½ of the county in the rain enhancement program and only ½ of that area was over the Edwards-Trinity Aquifer