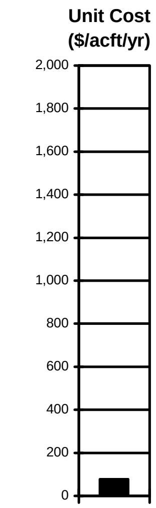
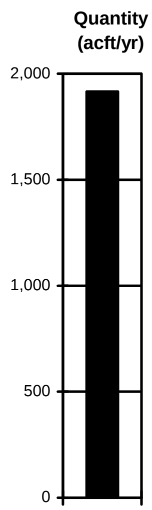
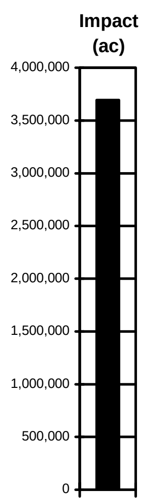
2006 South Central Texas Regional Water Plan
Water Management Strategy Summary Sheet







Name: Weather Modification - Nueces Recharge Basin

Description: Enhancing rainfall through seeding of clouds within the planning area with silver iodide in order to increase water supplies for direct use and for Edwards Aquifer recharge in Nueces Basin Recharge areas.

***Decade Needed*:** **2010 – 2060**

Cost, Quantity of Water, and Land Impacted

Unit Cost of Water:	**77**	**$/acft/yr**	**Increase in Sustained Yield from Edwards Aquifer**
Quantity of Water:	**1,916**	**acft/yr**	**Reliability = Firm**
Land Impacted:	**3,693,440**	**acres**	

Additional Considerations per Regional Water Planning Guidelines

Environmental Factors: May increase runoff and instream flows.

Impacts on Water Resources: Benefit to Edwards Aquifer water resources due to increased water for recharge. No apparent negative impacts on other water resources.

Impacts on Agricultural & Natural Resources: Potential benefit to farmers and ranchers through increased rainfall. Potential threats due to limited risk of increased flooding.

Other Relevant Factors per SCTRWPG: Additional water supply and costs are only applicable to increased sustained yield of the Edwards Aquifer and the Nueces and Blanco Recharge Basins. Costs and additional water supply would be different for other aquifer systems and watersheds. Weather modification costs were based on current costs of existing weather modification programs in South Central Texas Region.

Comparison of Strategies to Meet Needs: Low unit cost, and no conflicts with other recommended water management strategies.

Interbasin Transfer Issues: Not applicable.

Third-Party Impacts of Voluntary Transfers: Not applicable

Regional Efficiency: Good, provided continuous funding.

Water Quality Considerations: None or low impact.

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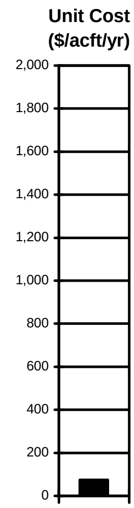

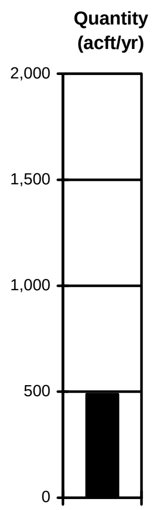

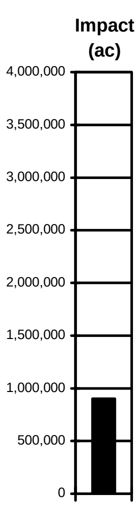

Name:* *Weather Modification - Blanco Recharge Basin

Description: Enhancing rainfall through seeding of clouds within the planning area with silver iodide in order to increase water supplies for direct use and for Edwards Aquifer recharge in Blanco Basin Recharge areas.
***Decade Needed*:** **2010 – 2060**

Cost, Quantity of Water, and Land Impacted

Unit Cost of Water:	**74**	**$/acft/yr**	**Increase in Sustained Yield from Edwards Aquifer**
Quantity of Water:	**488**	**acft/yr**	**Reliability = Firm**
Land Impacted:	**901,120**	**acres**	

Additional Considerations per Regional Water Planning Guidelines

Environmental Factors: May increase runoff and instream flows.

Impacts on Water Resources: Benefit to Edwards Aquifer water resources due to increased water for recharge. No apparent negative impacts on other water resources.

Impacts on Agricultural & Natural Resources: Potential benefit to farmers and ranchers through increased rainfall. Potential threats due to limited risk of increased flooding.

Other Relevant Factors per SCTRWPG: Additional water supply and costs are only applicable to increased sustained yield of the Edwards Aquifer and the Nueces and Blanco Recharge Basins. Costs and additional water supply would be different for other aquifer systems and watersheds. Weather modification costs were based on current costs of existing weather modification programs in South Central Texas Region.

Comparison of Strategies to Meet Needs: Low unit cost, and no conflicts with other recommended water management strategies.

Interbasin Transfer Issues: Not applicable.

Third-Party Impacts of Voluntary Transfers: Not applicable

Regional Efficiency: Good, provided continuous funding.

Water Quality Considerations: None or low impact.

4C.29 Weather Modification

4C.29.1 Weather Modification and Methods

Weather modification as it has been applied in Texas over the past 25 to 30 years involves cloud seeding to increase rain above what would have naturally occurred. The result of cloud seeding is referred to as rainfall enhancement. The concept of how this occurs is described below.

In natural rainfall, droplets are created from the presence of ice particles (crystals) in the cloud. These crystals are formed when freezing water contacts particles of dust, salt or sand. The ice crystals form a nucleus around which water droplets attach to make the size of the droplet increase. When the size of a droplet increases sufficiently, it becomes a raindrop and falls from the cloud. Cloud seeding is thought to increase the number of these "nuclei" available to take advantage of the moisture in the cloud to form raindrops that would not have otherwise formed. To be effective, seeding must be done at the correct time and in the correct manner.

As a cloud grows taller, the air temperature in the cloud cools and falls below the freezing point of water. This cooling effect means that the cloud droplets, which are much too small to fall as rain, are also cooled to a point where they respond to crystallization when contacted by an ice particle. Consequently, when there are fewer crystals to act as nuclei for raindrops, there will be less rain than would have been if more crystals were present. Although crude experiments to enhance rainfall were attempted in the U.S. as early as the mid-1800s, modern weather modification was begun in 1946 through an unintended laboratory event.

In 1946, V. Schaefer was involved with the General Electric Laboratory doing research to create artificial clouds in a chilled chamber. During one experiment, Schaefer believed the chamber was too warm, and, to cool it, he placed dry ice in the chamber. With the chilled water vapor in the chamber, ice crystals formed a cloud around the dry ice. Believing dry ice would not be practical to transport to emerging rain clouds, Schaefer's colleague, Bernard Vonnegut, searched for a chemical that almost exactly matched the chemical structure of ice crystals. It was found that silver iodide was such a chemical.[1] Silver iodide is termed "glaciogenic" because its chemical structure is like ice crystals. The other seeding chemical used when the cloud temperature is too warm for forming ice is calcium chloride (CaCl). Calcium chloride is "hygroscopic," which means it attracts water.

[1] Jensen, Ric, "Does Weather Modification Really Work?", Texas Water Resources, Summer 1994.

When silver iodide is introduced into a cloud, the number of ice crystals increases and the crystals attach to water vapor causing it to freeze to the crystal. Considerable heat is released to the atmosphere during the freezing and crystal formation phase. The released heat causes the cloud to grow taller and its vertical wind velocity (updraft) to increase. This results in the cloud being able to pull in more moist air and, thus, create more raindrops. However, not all clouds are potential rainmakers. Generally, cloud seeding is performed with a meteorologist working in tandem with the pilot of the cloud seeding aircraft so that, with direction from the meteorologist, the pilot can target the most promising cloud(s).[2] The criteria used in Texas to find promising clouds, is to locate "feeder" cells near developing cloud formations which have temperatures below 23^{o} F. The target cloud must also have sufficient moisture and airflow to be a candidate. Based on a cloud seeding program conducted by the Edwards Aquifer Authority from 1999 to 2001, seeded events typically occurred during spring and summer months (April- September) and were performed on days with anticipated precipitation up to 3 inches based on radar.[3,4] About 20 or 30 minutes prior to the desired rainfall event, the candidate cloud is seeded when the airplane releases silver iodide particles in a plume, typically at the base of the cloud so the updraft can draw the particles upward and make more contact with water in the cloud. Seeding has another effect on large, potentially dangerous thunderstorms capable of causing hail. Seeding tends to mitigate the extreme freezing that results in forming large particles of ice (hail) and makes the moisture more likely to fall as rain.

The criteria for cloud seeding based on experience in Texas since the early 1970s are the following:

- The cloud must be "convective" meaning that it displays instability in the atmosphere.
- Temperature at the top of the cloud must be 23^{o} F or less.
- The base of the cloud must be less than 12,000 feet elevation.

Clouds having the characteristics listed above exhibit a warm base, a strong updraft, and sufficient heat to carry water vapor to the cloud top.

[2] Clouds may also be seeded using ground-based silver iodide dispensers. However, in this discussion, only the aircraft method is considered.
[3] Edwards Aquifer Authority, "Rainfall Data Summary and Assimilation", December 2002.
[4] Cloud seeding occurred in the Blanco Basin when daily precipitation was less than 3 inches and in the Nueces Basin when less than 2.5 inches.

A summary of recent cloud seeding experiments in Texas, Florida, Cuba, and Southeast Asia has been presented by the TCEQ in a public information document entitled, "Some Facts about Cloud Seeding from Recent Research on Rain Enhancement in Texas".[5] The TCEQ concludes the following:

- Cloud seeding with AgI increases rain generated by these clouds by extending the life of the clouds, by allowing the clouds to enlarge laterally so that they cover more area, and by slightly increasing the height of the clouds.
- Rain production of seeded clouds is more efficient than for non-seeded clouds.
- The timing of seeding and the selection of clouds are fundamental. These are such critical factors that "…seeding at the wrong time and in the wrong place(s) may actually decrease the rainfall."[6]

In 2004, the American Society of Civil Engineers (ASCE) published a standard practice for cloud seeding technology applications for precipitation enhancement projects.[7] The standard includes procedures such as personnel, decision-making, communications, safety issues, and seeding suspension criteria.

4C.29.2 Precipitation Enhancements from Weather Modification Programs in Texas

The findings from several Texas cloud seeding programs are summarized below. This will provide a basis for determining the reasonableness of assumptions for the potential quantities resulting from weather modification in the South Central Texas Region. The programs to be discussed are the Southwest Cooperative Program (SWCP), the Texas Experiment in Augmenting Rainfall through Cloud-Seeding (TEXARC), the Colorado River Municipal Water District (CRMWD) Program, the Edwards Aquifer Authority (EEA) Program, the South Texas Weather Modification Association (STWMA) Program, and the Southwest Texas Rain-Enhancement Association (SWTREA) Program. Each of these programs is described below

<u>Southwest Cooperative Program (SWCP)</u>: The program was begun in 1986 as a cooperative effort between Oklahoma and Texas "…to develop a scientifically sound, environmentally sensitive, and socially acceptable, applied weather modification technology for increasing water supplies…in the southern High Plains."[8] The area involved was 5,000 square

[5] Bomar, George, "Some Facts about Cloud Seeding from Recent Research on Rain Enhancement in Texas," Texas Commission on Environmental Quality, 1999.
[6] George Bomar, TCEQ Senior Meteorologist, Austin, Texas.
[7] American Society of Civil Engineers, "Standard Practice for the Design and Operation of Precipitation Enhancement Project", 2004.
[8] Bomar, George, William L. Woodley, and Dale L. Bates, "The Texas Weather Modification Program: Objectives, Approach, and Progress," Journal of Weather Modification, April 1999.

miles located between Midland-Odessa and Lubbock. Random cloud seeding experiments were conducted in 1986, 1987, 1989, 1990, and 1994.

During the period 1987 through 1990, 183 experiments were made (93 seeded, 90 non-seeded). The criteria for selection were the following:

- Liquid water content had to be at least 0.5 gm/m^3 and updrafts had to be at least 1,000 ft/min.
- The target had to be a multiple-cell convective unit.
- No cloud or cell height could exceed 10 km (above ground level).
- Some of the tops had to have temperatures -10^o C or colder.

The results confirmed increased rainfall. Compared to the non-seeded cells, the seeded cells displayed an increase in maximum height of 7 percent, an increase in the coverage of the rainfall event of 43 percent, an increase in the storm duration of 36 percent, and an increase in rain volumes.[9]

Texas Experiment in Augmenting Rainfall through Cloud Seeding (TEXARC): The State of Texas implemented the program in 1994 and 1995 to investigate physical processes within large storms in the San Angelo area. This research was focused on understanding the best ways of seeding clouds to make them more efficient producers of water, rather than quantifying the results. The results showed that seeding must be within the super-cooled updraft region of the cloud in order to increase rainfall. From this research it was shown that the seeding agent must be carefully placed either directly in the top of the updraft, or at the entrance to the updraft at the base of the cloud.

Colorado River Municipal Water District (CRMWD) Program: Having been started in 1971, this is the longest-running operational weather modification program in Texas. The target area is roughly the upper Colorado River Basin upstream from Spence Reservoir, comprising some 3,600 square miles. The goals for the program have always been first, to increase water supplies to Lake Thomas and Spence Reservoir, and secondly, to increase rainfall to agricultural areas. The reported long-term results are that there was a 34 percent increase (above normal historic precipitation) in the seeded areas and a 13 percent increase in non-seeded areas.[10,11]

[9] Rosenfeld, D. and W. L. Woodley, "Effects of Cloud Seeding in West Texas: Additional Results and New Insights," Journal of Applied Meteorology, 1993.
[10] Jones, R., "A Summary of the 1988 Rainfall Enhancement Program and a Review of the Area Rainfall and Primary Crop Yield," Report 88-1 of the Colorado River Municipal Water District, 75 pages, 1988.
[11] Jones, R., "A Summary of the 1997 Rainfall Enhancement Program and a Review of the Area Rainfall and Primary Crop Yield," Report 97-1 of the Colorado River Municipal Water District, 54 pages, 1997.

Edwards Aquifer Authority (EAA) Program: (*substantial portions of this program description were reproduced from the EEA web page, e-aquifer.com, and are presented here unedited*)

"The Edwards Aquifer Authority board of directors voted in the fall of 1997 to obtain a permit to conduct precipitation enhancement, or cloud seeding, from the Texas Natural Resources Conservation Commission (now TCEQ). The Authority contracted with Weather Modification, Inc., to complete and submit the permit application on the Authority's behalf, and work with the TCEQ. The permit was granted by TCEQ in October 1998 and was valid for 4 years from January 1999 through December 2002. The permit allowed the Authority to conduct precipitation enhancement anytime during the year, including the traditional period of April through September. The Authority committed $500,000 for the 1999 program with half the expenses reimbursed by the TCEQ."

"Each county in the target and South Central Texas Water Advisory Committee (SCTWAC) areas of the program can appoint a representative to sit on a Precipitation Enhancement Advisory Group. The group will work with the Authority in alerting the contractor about local conditions. The ways this committee has worked included communicating saturation conditions so that flights are suspended to avoid flood conditions and during periods when crops are being harvested. The assumption for enhanced aquifer recharge was 10 percent above the recharge quantity, which would occur without enhancement."

From 1999 through 2001, the Edwards Aquifer Authority contracted Weather Modification Inc. to perform weather modification services for the EAA Precipitation Enhancement Program over the 12 target counties presented in Table 4C.29-1. Woodley Weather Consultants[12] evaluated the data collected, which included 39 seeding events for the Blanco Basin and 21 seeding events for the Nueces Basin. This study area included six of the 12 target counties, including Kendall, Blanco, Hays, Comal, Real, and Uvalde Counties. In 2003, a study[13] was conducted to determine enhanced recharge attributable to the 1999 to 2001 seeding events, which concluded that the total increased recharge during the 3-year period was 1,972 acft in the Nueces Basin (a 0.29 percent increase) and 1,332 acft in the Blanco Basin (1.13 percent increase).[14]

[12] Edwards Aquifer Authority, "Rainfall Data Summary and Assimilation," December 2002.
[13] LBG-Guyton Associates, "Assessment of Recharge Benefit from Enhanced Rainfall," June 2003.
[14] Note: Only half of the Nueces Basin was in the cloud seeding zone, which may have reduced the impact of cloud seeding on recharge in that basin.

Table 4C.29-1.
Edwards Aquifer Authority Weather Modification Program Counties

Target Counties	*Operational Counties*	*SCTWAC Counties*[1]
Bandera, Bexar, Blanco, Caldwell, Comal, Guadalupe, Hays, Kendall, Kerr, Medina, Real (east of U.S. Highway 83), and Uvalde	Gillespie, portions of Atascosa, Burnet, Frio, Kimble, Llano, Real, Wilson, and Zavala	Calhoun, DeWitt, Goliad, Gonzales, Karnes, Nueces, Refugio, San Patricio, Victoria, Atascosa, Wilson, Uvalde, Medina, Bexar, Comal, Hays, Guadalupe, and Caldwell
[1]Coastal Bend Water Advisory Committee (SCTWAC), as created by Senate Bill 1477.		

In 2002, the Authority's Precipitation Enhancement Program was reduced to target Bandera, Bexar, Medina, and Uvalde Counties. South Texas Weather Modification Association was contracted by the Authority to seed Bexar, Bandera, and Medina Counties. Southwest Texas Rain Enhancement Association was contracted to seed Uvalde County. The current weather modification programs in South Central Texas and counties where they operate are presented in Figure 4C.29-1.

South Texas Weather Modification Association (STWMA) Program: This program was started in 1997 when the Evergreen Water District hired a contractor to conduct cloud seeding. In 1998, the addition of two pilots, a meteorologist, and the purchase of two planes enhanced this program considerably. The counties involved in the cloud seeding include Atascosa, Bee, Frio, Karnes, Live Oak, McMullen, and Wilson. Since 2002, Bexar, Bandera, and Medina Counties have been added to the program. According to the 2004 STWMA Annual Evaluation Report, an increase of 1,225,900 acft (2.23 inches) was reported across the ten-county program area attributable to 45 seeding events between April 2, 2004, and October 27, 2004. This translates to a precipitation increase of 10.4 percent, on average, with the weather modification program. The average increase in precipitation over the Edwards aquifer (Bandera, Medina, and Bexar Counties) was calculated at 7.3%. The thirteen counties in Region L included in the program are presented in Table 4C.29-2 along with reported precipitation increases. Uvalde County precipitation increases were reported by SWTREA. The highest precipitation increase was recorded for Atascosa County, at 14.8 percent.

Southwest Texas Rainfall Enhancement Association (SWTREA) Program: This program was begun in 1999 and is currently operated by the Wintergarden Groundwater Conservation District in Carrizo Springs, Texas. This program was the first of the nine existing weather

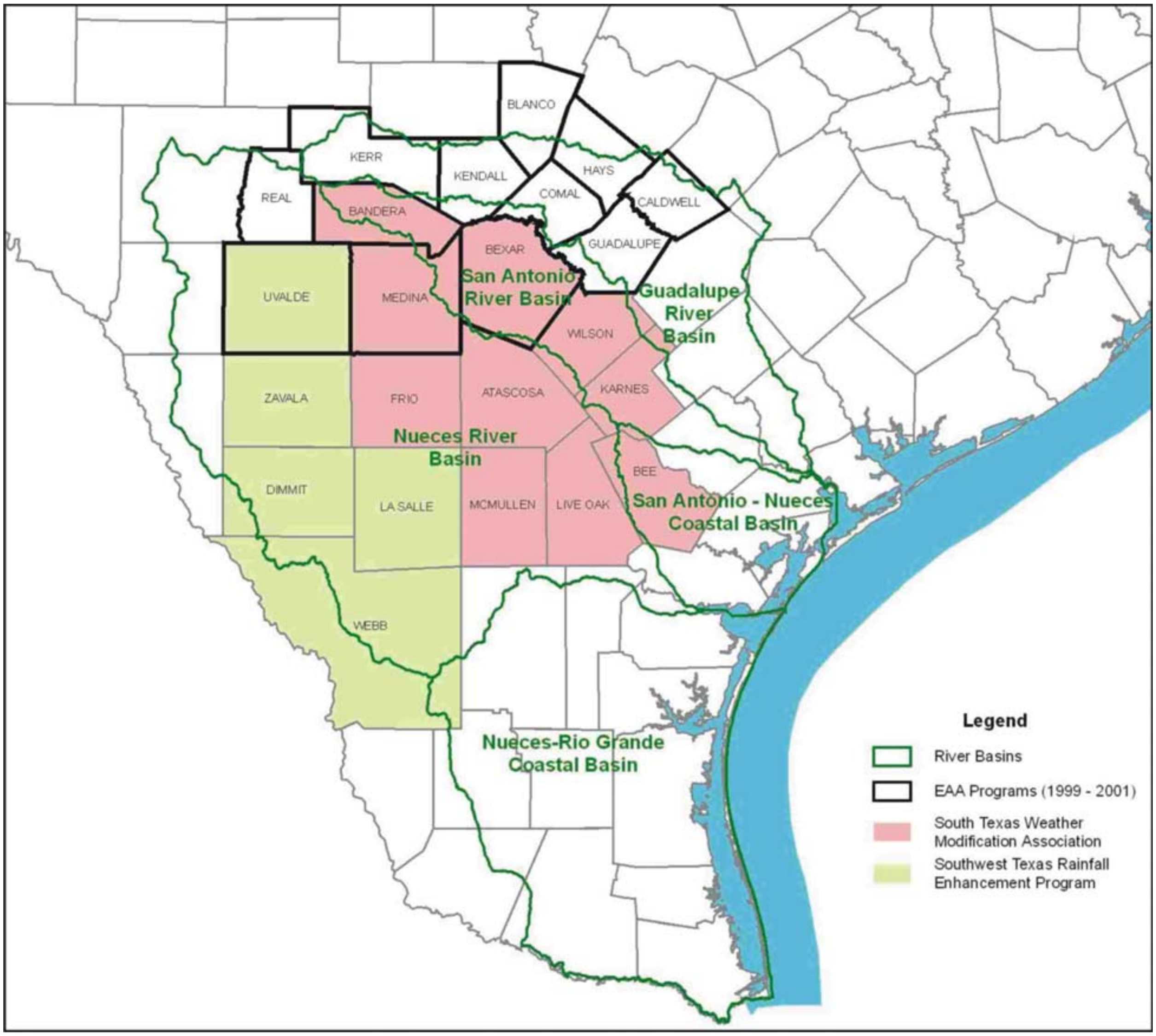

Figure 4C.29-1. South Central Texas Weather Modification Programs

modification programs in Texas to evaluate the suppression of hail. The original program consisted of Dimmit, LaSalle, and Webb Counties but was expanded in 2002 to include Uvalde County. According to the 2003 SWTREA Annual Evaluation Report, an increase of 36,773 acft (0.78 inches)[15] was reported over Uvalde County associated with 18 seeding events between May 26, 2003, and October 6, 2003. This translates to a precipitation increase of 5 percent for Uvalde County with the SWTREA weather modification program. The SWTREA four-county program area lies within the Nueces River Basin and South Central Texas Planning Area.

[15] Precipitation increase (in inches) was calculated by dividing acft increase by area of seeded sample (acres).

Table 4C.29-2.
Weather Modification Precipitation Enhancements in Region L Counties

Region L Counties	***Increases in Precipitation***		
	(acft)	***(inches)***	***(% increase)***
Atascosa	221,600	3.37	14.8
Bexar	79,300	1.19	5.0
Dimmit	4,800	0.07	NR
Frio	157,700	2.61	12.3
Goliad	5,900	0.13	NR
Gonzales	3,500	0.06	NR
Guadalupe	22,800	0.60	NR
Karnes	115,700	2.89	13.0
La Salle	59,000	0.74	NR
Medina	114,000	1.61	7.2
Uvalde*	36,773	0.73	5
Wilson	75,700	1.76	8.1
Zavala	25,500	0.32	NR

Source: STWMA Annual Evaluation Report 2004, except for Uvalde County from SWTREA Annual Report 2003.

NR= Not Reported

Rainfall Enhancement Programs Underway in Texas during spring 2004: There were nine cloud seeding programs in Texas that were funded, at least partially, by State funds from the Texas Department of Agriculture. The funds were apportioned in amounts up to $0.045 per acre to help counties pay for weather modification programs. The State contributed $1.82 million to sponsoring programs during the spring and summer of 2003. No new funds were appropriated by the 2003 (78th) Legislative Session and State funds were exhausted by spring 2004. However, these programs were continued through the seeding season of 2004 despite a lack of State support. The programs, the counties they cover and the approximate areas of coverage are presented in the Table 4C.29-3.

There have been several studies performed to quantify the increase of recharge attributable to weather modification. A USGS study on Upper Seco Creek Basin used an HSPF

Table 4C.29-3.
Cloud Seeding Programs Underway in Texas during Spring 2004

Cloud Seeding Program	*Counties Involved*	*Area (sq. miles)*
Colorado River Municipal Water District	Borden, Mitchell, and parts of Dawson, Howard, Sterling, Nolan, and Scurry	3,500
West Texas Weather Modification Association	Glasscock, Reagan, Crockett, Sutton, Schleicher, Irion and part of Tom Green	9,688
South Texas Weather Modification Association	Frio, Atascosa, McMullen, Live Oak, Bee, Karnes, Wilson, Bexar, Medina, Bandera	10,318
Southern Ogallala Aquifer Rain Program	Gaines, Terry, and Yoakum (Texas); and 2 million acres in eastern New Mexico near Gaines and Yoakum Counties	3,192 (in Texas)
North Plains Groundwater Conservation District	Dallam, Sherman, Hansford, Ochiltree, Lipscomb, and parts of Hartley, Moore, and Hutchinson	6,563
Panhandle Groundwater Conservation District	Carson, Donley, Gray, Roberts, and Wheeler	6,309
West Central Texas Weather Modification Association	Nolan, Taylor, Callahan, Eastland, Coke, Runnels, Coleman, Brown, and Comanche	7,656
Trans Pecos Weather Modification Association	Culberson, Loving, Reeves, and Ward	7,958
Southwest Rain Enhancement Association	Uvalde, Dimmit, La Salle, Zavala, and Webb	9,141

model to simulate weather modification and assumed a rainfall increase of 10% for Seco Creek subbasins for the entire 1991-1998 simulation period (USGS, 2002). The Edwards Aquifer Authority sites in their 2003 Edwards Aquifer Authority Hydrogeologic Data Report that "weather modification can increase precipitation by as much as 21%."

An Edwards Aquifer Recharge study conducted by Guyton in 2003, which used results from the 1999-2001 EAA Precipitation Enhancement Program, assumed an average 10% total rainfall attributed to cloud seeding. The 1999-2001 Precipitation Enhancement Program data points deemed reliable (5 (out of 21 days) in the Nueces Basin and 8 (out of 39 days) in the Blanco Basin) were then used to assess the recharge benefits from enhanced rainfall for seeded events from 1999-2001. The study showed that if enhanced precipitation was assumed as one inch on each day for which cloud seeding was considered successful then a total increased recharge of 1% for the Nueces Basin and 4.2% for the Blanco Basin would be expected during the 3-year period (LBG Guyton, 2003). According to WWC data for the 13 days when cloud seeding was considered successful, 9 days the total enhanced precipitation was less than one inch (69% of the time).

The STWMA estimates 20-25% increase in rainfall due to cloud seeding, when compared to radar data rainfall predictions. Seeding typically occurs from April through September and seeding opportunities are limited to specific clouds as described earlier (correspondence Todd Flanagen, STWMA, 2004).

For the 2006 Plan, the South Central Texas Region Water Planning Group (SCTRWPG) requested a more detailed analysis of a long-term weather modification program. This effort included application of Pilot Recharge Models of the Nueces and Blanco River Basins (HDR, 2002) to quantify increases in streamflow and recharge enhancement to the Edwards Aquifer associated with weather modification. This recharge enhancement information was then processed by an Edwards Aquifer model (GWSIM4) to quantify potential increases in sustained yield. GWSIM4 Edwards Aquifer groundwater flow model developed by the Texas Water Development Board simulates Edwards aquifer response in terms of water levels and springflows for specified recharge and pumping rates.

4C.29.3 Using Hydrologic Simulation Program Fortran to Simulate Weather Modification

4C.29.3.1 Introduction

HDR conducted a study in June 2002 on behalf of the Edwards Aquifer Authority to develop Pilot Recharge Models of the Nueces and Blanco River Basins (HDR, 2002) to provide accurate daily recharge data to the Edwards Aquifer with sufficient accuracy to model enhanced recharge associated with new recharge dams, precipitation enhancement (weather modification), and brush management initiatives. The Pilot Recharge Models for the Nueces and Blanco River Basins used the Hydrologic Simulation Program-Fortran (HSPF) Release 11 to calculate daily recharge to the Edwards Aquifer. The pilot recharge models of the Nueces and Blanco Recharge Basins use hydraulic and hydrologic routines within HSPF to translate daily streamflow, rainfall, and evaporation into recharge and downstream flow by simulation of interception, overland flow, infiltration, evapotranspiration, shallow storage, deep percolation, and other hydrologic processes.[16]

[16] Edwards Aquifer Authority, Pilot Recharge Models of the Nueces and Blanco River Basins, June 2002.

The 2002 Pilot Recharge Models included for the Nueces Recharge Basin, eight land segments subdivided on the basis of geologic characteristics and observed streamflow loss rates and seven river reaches defined in accordance with an intensive streamflow loss survey conducted by the USGS (HDR, 2002). The land segments of the Nueces Basin extend over contributing (2), recharge (3), confined zones (2), and Leona Gravels (1) as well as associated reaches. The Blanco Recharge Basin included seven land segments and six river reaches (with additional reaches representative of seven existing flood retardation structures that serve to enhance Edwards Aquifer recharge) created according to the same method used for the Nueces Basin. The land segments of the Blanco Basin extend over contributing zone (1), recharge zones (4), confined zones (2), and Leona Gravels (1) as well as associated reaches. While the model works very well for estimating recharge based on historical conditions, since it was calibrated with a USGS gage on the upstream side of the recharge zone for both Nueces and Blanco Basins, it did not simulate the hydrology of the contributing zone upstream of the recharge zone. In order to include contributions from the drainage areas upstream of the recharge zone, it was necessary to modify the HSPF Pilot Recharge Models. The model modifications are described below.

4C.29.3.2 Baseline Conditions

To more accurately reflect baseline conditions and weather modification for the Blanco and Nueces Basins, the HSPF Pilot Recharge Models were modified in the following ways:

- Land segments were added upstream of the Nueces Recharge Basin (two segments) and Blanco Recharge Basin (one segment) to simulate upstream Nueces and Blanco watersheds contributing to the recharge zone(s). The Nueces Recharge Basin and Blanco Recharge Basin are shown in Figure 4C.29-2 and 4C.29-3, respectively.
- The Nueces River Basin period of record was extended from 1950 through 1998 to 1934 through 1998. Similarly, the Blanco River Basin historical simulation period of record was extended from 1956 through 1998 to 1934 through 1998. These adjustments were made to include in the model simulations the drought of record, which occurred in the 1950s.

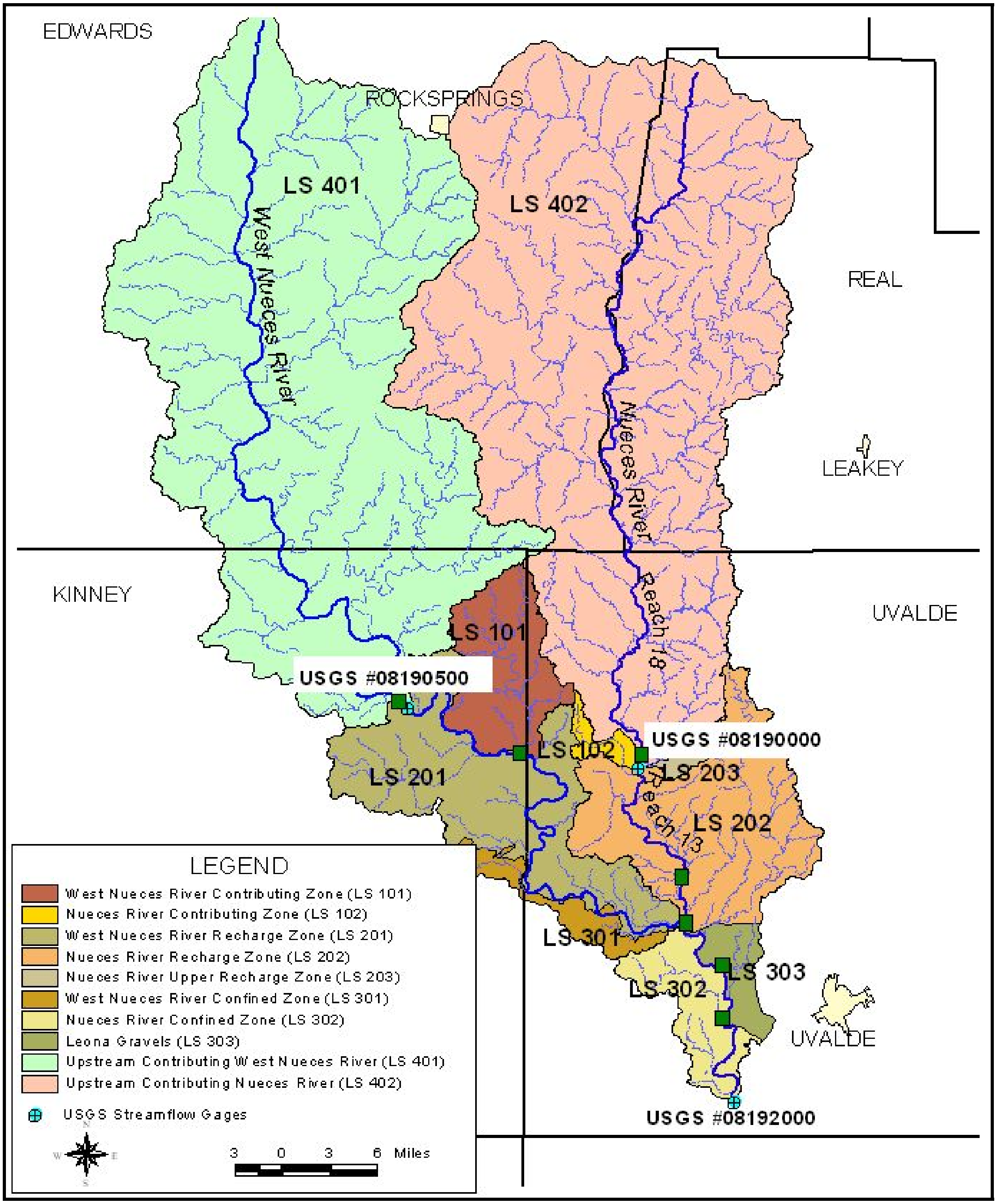

Figure 4C.29-2. Land Segments and River Reaches in the Nueces Recharge Basin

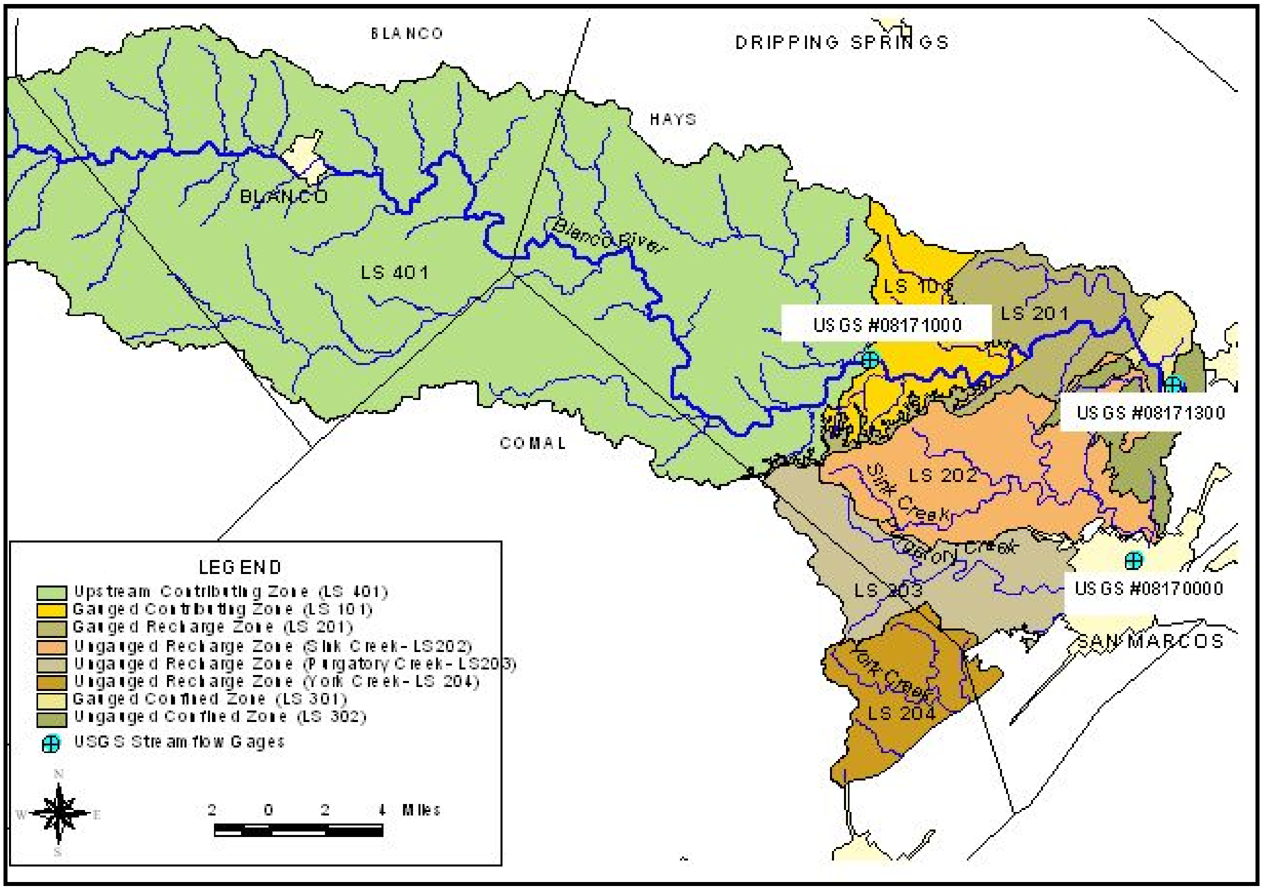

Figure 4C.29-3. Land Segments and River Reaches in the Blanco Recharge Basin

- The model parameter associated with lower zone evapotranspiration (LZETP), an index to the density of deep rooted vegetation, was changed from an annual average to a monthly distribution to account for seasonal variations (this subject is described in further detail in Section 4C.28).

Daily precipitation gage data were obtained from the National Weather Service (NWS), Edwards Aquifer Authority (EAA), and the USGS. The active precipitation stations used in the Pilot Study were used to extend the period of record for the Nueces River Basin (previously 1950-1998) and Blanco River Basin (previously 1956-1998) to include 1934-1998. For new land segments (two in Nueces River Basin and one in Blanco River Basin), the nearest active precipitation stations to the new land segments were used for daily precipitation data from 1934-1998.

Monthly gross water surface evaporation rates were obtained from the Texas Water Development Board (TWDB) for one degree quadrangles representative of the Nueces and

Blanco Recharge Basins for January 1934 through December 1998 for the two new land segments in Nueces River Basin and one new segment in the Blanco River Basin. For land segments contained in the original Pilot Models, the period of record was extended to January 1934. The procedure used to apply monthly evaporation quadrangle data to land segments, also used for the original Pilot Model study was based on an inverse relationship of distance from the center of the land segment to center of the evaporation quadrangle.

Precipitation and evaporation files were updated for the entire period of record (1934-1998) and new land segments with associated streams were added for upstream contributing zones, the new contributing zones were calibrated using historical USGS streamflow gage data. For the Nueces Basin, USGS #08190500- West Nueces at Bracketville was used to calibrate the West Nueces upstream contributing zone and USGS #08190000- Nueces at Laguna for the Nueces upstream contributing zone. For the Blanco Basin, USGS# 08171000- Blanco River at Wimberley located upstream of the recharge zone was used. Detailed calibration procedures and results are included in Appendix D. The new contributing zones for the Nueces and Blanco Basins were well calibrated to evaluate weather modification effects on recharge (Appendix D).

4C.29.3.2 Baseline + Weather Modification Conditions

The precipitation files used for the HSPF simulation were adjusted to account for weather modification. For this study, the amount of enhanced precipitation was calculated by considering (1) enhanced rainfall on a seasonal basis (based on cloud seeding during spring and summer months) and (2) an applying an estimated daily rate for increased precipitation to every day within the "optimal seeding" season. This enabled HSPF to model enhanced recharge of a long-term weather modification program considering that any day within the optimal seeding time was eligible for seeding provided preferable cloud conditions.

The following equation was used to evaluate expected daily increases in rainfall associated with weather modification for each day during the optimal season (April- September) for the entire simulation period from 1934-1998. Calculated enhanced rainfall was based on South Central Texas weather modification programs (i.e., EAA, STWMA, and SWTREA).

$$\frac{SE}{PREC} * \%Increase$$

Where:

SE = Seeded events with precipitation

PREC = Reported days with rainfall

% Increase = Average increase in precipitation attributed to weather modification

For example, during the 2002 STWMA program, 8 of 19 seeded events occurred on days with precipitation. A total of 29 days during the study period (in this case, April-October) had recorded rainfall, meaning that 8 out of 29 days had the potential of additional rainfall with weather modification. As mentioned earlier in Section 4C.29.2, the STWMA determined the average increase in precipitation attributed to weather modification is 7.3% over the Edwards Aquifer. Therefore, a 2% increase in rainfall occurred each day with the weather modification program.

$$\frac{8}{29} * 7.3\% = 2\%$$

Results from the EAA, STWMA, and SWTREA weather modification programs show precipitation increases ranging from 1 to 7%, based on atmospheric conditions and the frequency of cloud seedings. In April 2005, the Region L staff workgroup recommended that HSPF analyses include a 5% precipitation increase for the Nueces Recharge Basin and 6.5% precipitation increase for the Blanco Recharge Basin to simulate quantities of water available for recharge due to weather modification.

The modified HSPF Pilot Model contains a precipitation input file for each land segment in the Nueces (Figure 4C.29-2) and Blanco (Figure 4C.29-3) Recharge Basins. The precipitation files for the Nueces Basin were adjusted to simulate recharge resulting from weather modification by increasing precipitation by 5% for all days (April-September) when daily precipitation was $\neq 0$ and ≤ 2.5 inches. For land segments in the Blanco Basin (Figure 4C.29-2), the precipitation files were altered to simulate recharge resulting from weather modification by increasing precipitation by 6.5% for all days (April-September) when daily precipitation was $\neq 0$ and ≤ 3 inches. The seeding period and rainfall criteria were obtained from the 1999-2001 EAA Precipitation Enhancement Program, which included cloud seeding over the Nueces and Blanco Basin study areas.

4C.29.3.3 Recharge Enhancements (Attributable to Weather Modification)

After performing the HSPF simulations with and without weather modification, the difference in recharge was computed to quantify the enhanced recharge to the Edwards Aquifer for Nueces and Blanco Recharge Basins. The Nueces Recharge Basin provides recharge to the Edwards Aquifer from land segments (contributing and recharge zones), and their associated reaches. Recharge to the Edwards Aquifer from the Blanco Recharge Basin occurs from land segments (contributing and recharge zones), reaches, and flood retardation structures.

Recharge data from the HSPF model were evaluated for the entire 65 year simulation (1934-1998) and 5-year drought of record (1952-1956) to determine the amount of enhanced recharge with weather modification within land segments of the Nueces and Blanco Recharge Basins, as shown in Figures 4C.29-2 and 4C.29-3.

The Nueces Basin drought of record was from 1952 through 1956, according to NWS precipitation gauge data (16.8 inches of rainfall, based on 5-year precipitation average from 1934-1998). According to HSPF model results for the 65 year model simulation (1934-1998), on the watersheds shown in Figure 4C.29-2 is estimated to increase recharge in the Nueces Recharge Basin an average of 7,659 acft/yr (a 6.7% increase when compared to recharge without weather modification) as shown in Table 4C.29-4. For the 5-year drought period (1952-1956), the estimated increase in Edwards Recharge in the Nueces Recharge Basin is 2,639 acft/yr (or 6.3%).

Table 4C.29-4.
Summary of Nueces Basin Recharge
(with and without weather modification)

Nueces Recharge	Baseline (without Weather Modification	Baseline + Weather Modification	Change Due to Weather Modification	% Change in Recharge
Average Annual Recharge acft (1934-1998)	115,063 acft	122,722 acft	7,659 acft	6.7%
Average Drought Recharge acft (1952-1956)	41,829 acft	44,468 acft	2,639 acft	6.3%

The Blanco Basin drought of record was from 1952 through 1956, according to NWS precipitation gauge data (25.4 inches of rainfall, based on 5-year precipitation average from 1934-1998). According to HSPF model results for the 65 year model simulation (1934-1998), weather modification on the watersheds shown in Figure 4C.29-3 is estimated to increase recharge in the Blanco Recharge Basin an average of 4,250 acft/yr (a 6.4% increase when compared to recharge without weather modification) as shown in Table 4C.29-5. For the 5-year drought (1952-1956), the estimated increase in Edwards Recharge in the Blanco Recharge Basin is 1,093 acft/yr (or 9.2%).

Table 4C.29-5.
Summary of Blanco Basin Recharge
(with and without weather modification)

Blanco Recharge	***Baseline (without Weather Modification***	***Baseline + Weather Modification***	***Change Due to Weather Modification***	***% Change in Recharge***
Average Annual Recharge acft (1934-1998)	65,969 acft	70,219 acft	4,250 acft	6.4%
Average Drought Recharge acft (1952-1956)	11,877 acft	12,970 acft	1,093 acft	9.2%

The Nueces Recharge Basin receives a greater amount of enhanced recharge with weather modification because it has a larger watershed area (1,200,000 acres in the recharge portion of the Nueces Basin) than the Blanco Recharge Basin at 340,000 acres.

The monthly changes in Edwards Aquifer Recharge from the updated HSPF Pilot Recharge Model of the Nueces and Blanco Recharge Basins (with-without weather modification) are shown in Tables 4C.29-6 and 4C.29-7.

Even though precipitation was enhanced only during April-September, enhanced recharge in the Nueces and Blanco Recharge Basins frequency occurred outside those months. As seen in Tables 4C.29-6 and 4C.29-7, the amount of enhanced recharge October-March is significantly less than April-September and gradually decreases every month after September. This is primarily due to increased storage during the months with enhanced rainfall. The precipitation that enters the groundwater system (i.e. does not evaporate or become runoff) becomes storage and is slowly released (interflow) to the Nueces and Blanco river reaches, respectively. Other parameters that may affect enhanced recharge (to a lesser extent) during months when no enhanced precipitation occurs are delayed runoff and total actual evapotranspiration from land segments.

Table 4C.29-6.
Change in Historical Edwards Aquifer Recharge (with-without weather modification) from the HSPF Pilot Recharge Model of the Nueces Recharge Basin

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Grand Total
1,934	0	0	0	234	371	152	966	691	2,961	320	256	1,424	7,373
1,935	228	242	206	1,797	3,170	2,774	1,124	937	4,242	953	373	729	16,774
1,936	242	178	447	372	4,621	1,600	4,376	1,637	4,576	1,057	570	254	19,932
1,937	194	264	408	217	459	4,328	2,433	763	1,738	3,438	1,274	1,067	16,582
1,938	572	213	245	1,800	4,570	1,902	879	1,493	1,629	650	411	358	14,723
1,939	499	207	145	704	2,198	1,116	2,593	6,163	1,081	1,424	1,025	606	17,761
1,940	505	495	311	718	3,114	1,247	682	258	230	214	159	149	8,083
1,941	127	114	120	2,445	2,943	599	2,365	411	1,638	310	220	192	11,484
1,942	213	167	161	466	323	152	936	776	5,314	357	84	182	9,132
1,943	199	168	159	393	518	1,696	345	283	2,193	765	347	417	7,482
1,944	283	272	87	101	1,380	2,666	290	1,774	1,167	656	247	224	9,147
1,945	226	124	134	1,550	427	243	156	135	196	348	100	92	3,731
1,946	80	65	64	173	3,389	734	195	182	1,441	506	221	176	7,225
1,947	252	81	101	556	582	1,880	667	414	211	198	166	142	5,249
1,948	119	102	94	292	380	374	1,209	320	646	304	192	172	4,203
1,949	148	205	34	1,177	1,035	1,611	513	1,218	1,300	1,348	196	267	9,053
1,950	166	119	153	136	743	719	618	298	350	188	158	139	3,787
1,951	121	100	104	93	791	539	150	129	108	323	93	85	2,636
1,952	73	58	56	203	733	199	143	115	107	84	103	80	1,954
1,953	77	55	57	52	53	49	32	425	2,854	215	119	111	4,100
1,954	96	75	73	64	1,059	1,314	310	221	178	450	147	130	4,116
1,955	115	93	90	77	236	427	949	217	90	37	72	82	2,484
1,956	68	57	56	51	51	46	45	28	55	35	21	28	541
1,957	26	22	29	2,678	5,034	2,754	702	409	678	1,092	365	317	14,104
1,958	155	34	162	487	1,307	1,666	547	286	2,220	1,630	334	82	8,910
1,959	26	201	204	1,077	1,170	2,714	1,694	387	607	2,549	113	219	10,961
1,960	194	142	52	186	108	126	1,610	1,791	367	379	116	48	5,118
1,961	59	62	32	156	81	1,963	4,864	203	155	169	49	111	7,903
1,962	94	86	108	96	105	278	131	192	178	94	80	102	1,544
1,963	83	72	78	151	494	91	101	98	205	203	132	121	1,828
1,964	100	95	88	259	242	117	110	212	-1,815	1,012	418	267	1,105
1,965	172	52	97	484	3,482	259	142	151	338	179	270	268	5,896
1,966	213	172	98	2,312	907	209	126	1,677	1,846	516	304	263	8,642
1,967	244	190	184	388	171	155	167	372	2,526	940	473	102	5,911
1,968	247	223	79	533	4,046	501	602	246	485	209	304	156	7,632
1,969	214	144	143	149	1,477	508	189	566	703	3,353	583	484	8,514
1,970	126	709	-110	187	327	385	431	308	3,708	296	196	160	6,724
1,971	166	155	146	211	140	2,608	1,118	4,913	550	1,454	158	162	11,780
1,972	51	283	164	197	254	340	381	1,437	504	378	217	176	4,381
1,973	302	213	142	342	164	1,880	3,254	314	896	1,394	83	34	9,018
1,974	165	122	148	166	1,917	255	256	182	2,365	506	123	345	6,550
1,975	234	276	127	430	3,377	874	1,145	2,082	483	337	249	244	9,859
1,976	212	170	160	2,458	5,638	726	4,668	1,057	3,630	1,228	210	151	20,307
1,977	108	52	24	2,022	2,805	81	245	261	348	318	218	132	6,616
1,978	112	99	129	84	184	933	143	139	209	132	366	318	2,846
1,979	110	205	143	1,247	251	4,489	162	156	174	165	131	110	7,343
1,980	97	81	76	67	2,272	137	87	740	795	372	309	255	5,289
1,981	207	157	162	3,838	844	2,942	516	182	398	745	56	20	10,067
1,982	151	111	127	101	2,646	546	466	305	252	228	184	185	5,302
1,983	248	151	155	136	559	1,165	231	214	365	405	327	106	4,063
1,984	185	105	95	80	86	77	73	73	64	161	172	96	1,269
1,985	43	30	8	171	620	1,266	412	246	963	966	186	186	5,097
1,986	312	131	156	148	722	3,886	541	334	752	777	182	245	8,186
1,987	45	103	98	729	10,100	7,764	1,191	969	1,097	87	69	142	22,393
1,988	120	93	87	83	173	697	379	178	358	183	147	128	2,624
1,989	259	96	91	91	92	168	101	314	81	75	139	57	1,566
1,990	50	36	45	1,515	1,790	355	4,975	1,104	822	579	394	284	11,948
1,991	318	309	277	255	276	249	220	198	2,824	599	87	257	5,868
1,992	142	76	43	486	3,598	4,061	534	266	290	163	124	121	9,905
1,993	104	90	87	226	247	93	94	89	79	64	50	46	1,268
1,994	41	35	28	408	3,900	227	81	96	1,145	547	304	340	7,153
1,995	227	133	105	107	846	793	235	368	2,750	207	380	143	6,297
1,996	122	99	95	81	163	79	146	141	2,989	1,284	273	210	5,681
1,997	114	176	488	1,514	1,258	7,785	433	251	386	557	198	165	13,326
1,998	142	119	85	97	120	115	120	5,397	1,659	1,010	510	124	9,497
Average (1934-1998)	168	144	124	617	1,494	1,272	855	735	1,134	642	248	224	7,659
Drought Avg. (1952-1956)	86	68	66	89	426	407	296	201	657	164	92	86	2,639

Table 4C.29-7
Change in Historical Edwards Aquifer Recharge (With- Without Weather Modification) from the HSPF Pilot Recharge Model of the Blanco Recharge Basin

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Grand Total
1,934	0	0	0	572	308	35	106	111	197	76	198	541	2,145
1,935	150	63	98	407	2,868	1,913	642	196	3,648	223	31	238	10,478
1,936	12	30	1	319	1,731	383	1,134	452	1,905	312	161	84	6,524
1,937	49	0	138	182	256	1,395	528	214	175	920	156	291	4,304
1,938	43	19	0	2,556	916	717	528	29	120	86	227	84	5,325
1,939	287	174	179	352	743	572	1,853	533	347	336	318	130	5,825
1,940	183	263	146	648	583	2,664	302	182	117	113	191	14	5,405
1,941	24	57	-9	1,839	1,311	1,455	430	19	77	376	30	69	5,678
1,942	0	23	0	859	687	312	1,197	1,469	1,502	200	5	0	6,255
1,943	23	0	13	64	194	357	1,093	24	1,174	170	206	367	3,684
1,944	226	39	14	178	2,733	305	26	499	500	88	263	146	5,017
1,945	25	-3	3	387	182	489	240	15	75	393	40	67	1,913
1,946	-2	16	12	464	817	2,491	121	392	2,019	401	395	16	7,143
1,947	13	12	46	183	1,258	45	19	97	81	21	13	66	1,854
1,948	7	47	30	55	292	183	191	145	177	99	90	50	1,367
1,949	112	42	13	4,328	253	1,028	320	150	111	236	81	131	6,805
1,950	68	13	18	579	539	971	226	218	468	167	79	38	3,384
1,951	15	50	29	52	708	857	168	87	201	87	45	42	2,340
1,952	36	12	24	412	99	46	36	361	575	1	56	57	1,716
1,953	0	0	23	131	53	64	376	164	217	102	23	15	1,168
1,954	11	0	0	3	91	88	21	52	25	83	45	19	438
1,955	16	21	18	66	642	490	266	169	128	70	39	27	1,951
1,956	17	15	10	5	16	13	7	16	37	15	25	16	190
1,957	14	19	12	1,646	534	-366	71	33	3,326	332	-32	62	5,651
1,958	82	86	9	281	1,159	81	410	0	2,104	265	44	12	4,532
1,959	0	11	4	1,705	1,058	658	85	262	154	2,319	-65	-16	6,175
1,960	0	-9	11	405	2,088	1,199	188	543	120	533	-4	-9	5,066
1,961	1	-23	0	124	0	1,168	1,171	94	160	81	206	28	3,010
1,962	23	23	15	359	0	183	81	53	1,432	96	118	75	2,457
1,963	0	38	0	146	34	75	120	191	153	45	97	26	926
1,964	47	61	14	84	66	750	95	131	356	330	94	74	2,104
1,965	188	16	3	445	3,314	1,107	57	4	115	493	126	128	5,996
1,966	0	-11	0	397	983	184	0	136	491	78	0	0	2,257
1,967	0	0	20	18	174	59	86	60	1,206	190	180	9	2,000
1,968	28	0	0	595	907	938	226	0	310	96	114	248	3,461
1,969	61	84	51	1,140	1,227	511	2	42	195	359	35	66	3,772
1,970	0	1	2	504	1,443	118	0	84	952	488	0	0	3,593
1,971	0	25	1	25	227	197	67	1,626	1,097	756	612	107	4,739
1,972	2	23	0	38	81	107	147	458	171	133	194	0	1,354
1,973	107	95	12	1,535	271	1,164	2,919	304	1,799	-151	1	0	8,054
1,974	-16	-1	13	81	2,031	134	19	1,561	1,953	208	257	1	6,241
1,975	0	20	16	849	3,678	1,210	417	320	117	94	11	23	6,754
1,976	0	23	19	2,868	2,243	313	2,022	276	622	1,376	53	17	9,831
1,977	24	-19	0	2,563	518	324	0	0	0	2	13	0	3,426
1,978	0	26	42	117	162	431	31	269	2,249	24	1,051	-16	4,386
1,979	30	3	26	688	1,068	575	2,046	216	153	23	0	51	4,878
1,980	36	0	36	23	1,491	183	0	25	816	58	189	43	2,900
1,981	26	1	13	168	286	3,236	493	32	66	182	131	0	4,634
1,982	15	11	0	85	2,465	337	15	182	60	0	64	89	3,321
1,983	12	13	26	1	580	1,075	862	206	492	193	196	38	3,693
1,984	91	38	42	4	40	77	44	39	22	31	0	0	427
1,985	4	0	0	459	447	3,835	2,666	2	536	422	539	-12	8,897
1,986	23	-14	11	53	2,219	1,682	11	19	838	1,103	29	104	6,079
1,987	19	69	3	122	2,586	2,516	637	4	51	26	243	23	6,299
1,988	0	0	0	101	1,114	228	316	52	11	28	0	3	1,854
1,989	22	11	64	319	1,192	499	0	28	35	35	30	9	2,244
1,990	27	23	4	444	1,538	194	952	47	187	196	201	0	3,814
1,991	225	10	0	1,488	947	1,288	436	272	1,389	126	114	1,158	7,453
1,992	-112	-21	-35	533	2,626	1,364	251	120	36	0	43	27	4,832
1,993	15	0	19	284	1,356	1,197	0	0	0	26	0	0	2,898
1,994	46	0	0	215	1,473	358	0	49	483	902	2	74	3,601
1,995	2	0	0	753	3,393	324	101	11	429	71	190	11	5,285
1,996	1	6	10	92	101	531	118	1,594	1,299	219	381	232	4,581
1,997	19	102	42	1,731	1,239	4,554	38	210	61	216	124	79	8,414
1,998	66	-10	0	56	19	0	74	519	2,111	574	17	18	3,444
Average (1934-1998)	38	25	20	587	1,010	792	417	241	647	264	128	81	4,250
Drought Avg (1952-1956)	16	9	15	124	180	140	141	152	196	54	38	27	1,093

4C.29.3.4 Increase in Sustained Yield (attributable to Weather Modification)

The recharge enhancements attributable to weather modification for the Nueces and Blanco Recharge Basins were processed with GWSIM4 to determine increases in sustained yield from the Edwards Aquifer. Sustained yield of the Edwards aquifer is defined as the amount of pumpage from the Edwards such that a simulated minimum flow at Comal Springs is protected during the drought of record (in this case, 60 cfs). The additional water supply is based on increases in sustained yield from the Edwards Aquifer. Weather modification evaluated with 5 percent precipitation increase in the Nueces Recharge Basin and 6.5 percent precipitation increase in the Blanco Recharge Basin is calculated to increase sustained yield by 1,916 acft/yr and 488 acft/yr, respectively. The Nueces Basin has greater water supply benefits with a brush management program due to its higher average annual recharge as compared with the Blanco Basin.

4C.29.4 Environmental Effects of Weather Modification

Although cloud seeding weather modification is not a new technique, the effectiveness of weather modification has been difficult to measure. Since Texas has established a permit procedure, administered by TCEQ, data are being collected for a more scientific study of cloud seeding effectiveness and management. Originally conceived as a means to end droughts, weather modification is now considered a long-term water augmentation strategy for freshwater supplies.[17] The amount of silver iodide and calcium chloride used during a seeding event is negligible and too dispersed to have a measurable effect on the environment. Safe handling and storage of these materials prior to dispersal are a larger concern. Both are normally used in industrial applications and printing. Therefore, procedures for handling and storing silver iodide are well documented. Assuming that increased rainfall in the seeded area does not result in decreased rainfall elsewhere, it is difficult to see what adverse environmental impact would result. The benefits resulting from cloud seeding in the South Central Texas Region may include improvements in environmental and economic conditions. Environmental conditions in a stream, estuary, or lake can be improved by increased freshwater flows and the improvements can be measured using water quality parameters and aquatic life. Economic conditions can be improved by increasing crop production, by increasing animal production as a result of increasing the food supply, and by increasing ground and surface water supplies. Increasing water supplies can further improve economic conditions by affecting recreation, agriculture, municipal, and industrial activities in beneficial ways.

[17] Bomar, George, TCEQ Senior Meteorologist, Austin, Texas.

4C.29.5 Engineering and Costing of Weather Modification

According to Mike Mahoney at Evergreen UWCD, the total cost of the program for STWMA's 10-county region (6,603,520 acres) was $428,067 in 2003, including $215,387 in initial capital costs and $212,680 Operations and Maintenance costs, or $0.065 per acre. For 2004, the Edwards Aquifer Authority contracted SWTREA as part of their Precipitation Enhancement Program to perform cloud-seeding over Uvalde County at an annual cost of $37,951 or $0.04 per acre. The Authority also contracted STWMA to perform cloud seeding in Bandera, Bexar, and Medina Counties at an annual cost of $86,825 or approximately $0.04 per acre.

For the Nueces Recharge Basin, the total annual cost for a weather modification program for Edwards, Real, Kinney, and Uvalde Counties (3,693,440 acres) is estimated at $147,740, assuming an annual cost of $0.04 per acre. For an increased sustained yield of 1,916 acft/yr from the Edwards Aquifer (Section 4C.29.3.4), the unit cost is estimated at $77 per acft. This cost is based on increases in sustained yield from the Edwards Aquifer and is not necessarily applicable to other basins.

For the Blanco Recharge Basin, the total annual cost for a weather modification program for Blanco and Hays Counties (901,120 acres) is estimated at $36,050, assuming an annual cost of $0.04 per acre. For an increased sustained yield of 488 acft/yr from the Edwards Aquifer (Section 4C.29.3.4), the unit cost is estimated at $74 per acft. This cost is based on increases in sustained yield from the Edwards Aquifer and is not necessarily applicable to other basins.

4C.29.6 Implementation Issues

Weather modification in the form of cloud seeding is a beneficial, but uncertain, source of usable water. However, data are not adequate to quantify firm yield in terms of a measurable and dependable regional water supply option.

One important potential benefit of cloud seeding is that a part of the agricultural water supply needs (irrigated and dryland crops and rangelands) could be met. For example, higher rainfall would lower the quantities of irrigation water that has to be withdrawn from the aquifers and streams of the South Central Texas Region, and dryland production would benefit from increased rainfall. This could be a significant water supply option for agricultural uses. Over a sufficient period, agricultural production data could be developed to demonstrate that crop yield, animal production, and other measurable agricultural parameters have increased as compared to the same data prior to beginning the cloud seeding program. For a relatively minor cost, cloud seeding could meet some of the agricultural needs, as well as contribute to aquifer recharge and streamflows of the region.

Evaluations of this regional water management option for the Nueces and Blanco Recharge Basins are provided in Tables 4C.29-8 and 4C.29-9.

Table 4C.29-8.
Evaluation Summary of Weather Modification to Enhance Water Supply Yield-Nueces Recharge Basin

Impact Category	***Comment(s)***
a. Water Supply 1. Quantity 2. Reliability 3. Cost of Treated Water	 1. Sustained yield increase of 1,916 acft/yr from Edwards Aquifer 2. Good reliability, if good timing is achieved. 3. Low cost; $77 per acft
b. Environmental factors 1. Instream flows 2. Bay and Estuary Inflows 3. Wildlife Habitat 4. Wetlands 5. Threatened and Endangered Species 6. Cultural Resources 7. Water Quality	 1. May slightly increase instream flows. 2. May slightly increase bay and estuary flows. 3. None or low impact. 4. None or low impact. 5. None or low impact. 6. None or low impact. 7. None or low impact.
c. Impacts to State water resources	• No apparent negative impacts on other water resources • Benefit to Edwards Aquifer water resources due to increased water for recharge.
d. Threats to agriculture and natural resources in region	• Potential benefit to farmers and ranchers through increased rainfall • Potential threats due to limited risk of increased flooding
e. Recreational impacts	• None
f. Equitable Comparison of Strategies	• Cost based on weather modification programs in South Central Texas Region
g. Interbasin transfers	• Not applicable
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Improvement over existing conditions
j. Effect on navigation	• None
k. Consideration of water pipelines and other facilities used for water conveyance	• None

Table 4C.29-9.
Evaluation Summary of Weather Modification to Enhance Water Supply Yield-Blanco Recharge Basin

Impact Category	***Comment(s)***
a. Water Supply	
1. Quantity	1. Sustained yield increase of 488 acft/yr from Edwards Aquifer
2. Reliability	2. Good reliability, if good timing is achieved.
3. Cost of Treated Water	3. Low cost; $74 per acft
b. Environmental factors	
1. Instream flows	1. May slightly increase instream flows.
2. Bay and Estuary Inflows	2. May slightly increase bay and estuary flows.
3. Wildlife Habitat	3. None or low impact.
4. Wetlands	4. None or low impact.
5. Threatened and Endangered Species	5. None or low impact.
6. Cultural Resources	6. None or low impact.
7. Water Quality	7. None or low impact.
c. Impacts to State water resources	• No apparent negative impacts on other water resources • Benefit to Edwards Aquifer water resources due to increased water for recharge.
d. Threats to agriculture and natural resources in region	• Potential benefit to farmers and ranchers through increased rainfall • Potential threats due to limited risk of increased flooding
e. Recreational impacts	• None
f. Equitable Comparison of Strategies	• Cost based on weather modification programs in South Central Texas Region
g. Interbasin transfers	• Not applicable
h. Third party social and economic impacts from voluntary redistribution of water	• Not applicable
i. Efficient use of existing water supplies and regional opportunities	• Improvement over existing conditions
j. Effect on navigation	• None
k. Consideration of water pipelines and other facilities used for water conveyance	• None

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