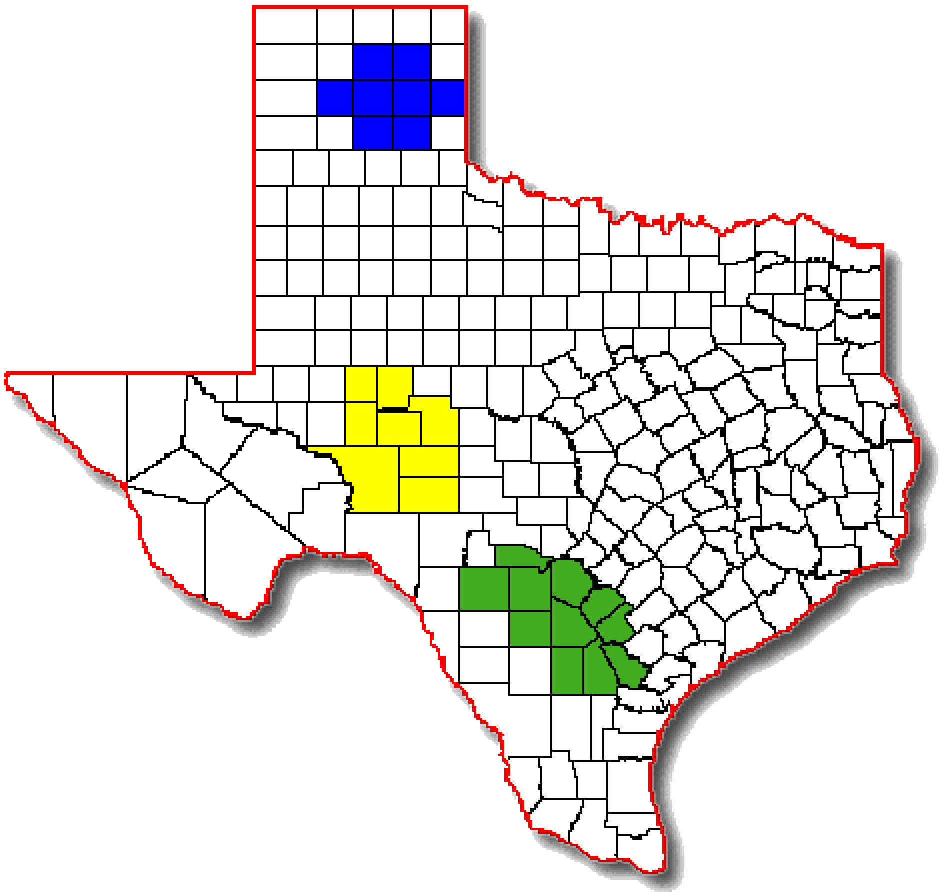
A Benefit-Cost Analysis of Texas Weather Modification Activities Resulting in an Additional One Inch of Rainfall Across a Region



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INTRODUCTION

A number of possible benefits from rainfall enhancement efforts have been identified as important to the citizens of Texas. Among the benefits listed include: 1) increased agricultural production to both crop and livestock producers, 2) decreased surface and ground water consumption, 3) improved opportunities for economic stability and future growth, 4) enhanced landscape appearance, 5) increased reservoir levels, 6) replenishment of aquifers, 7) improved habitat conditions for wildlife, 8) increased lake and river levels, and 9) fire suppression. While it is difficult to dispute the validity of the latter six beneficial impacts, this analysis will focus primarily on the first three. Environmental, aesthetic, and recreational benefits undoubtedly result from increased rainfall, but are difficult to quantify and are subjective. However, increased agricultural production, reductions in irrigation activity, and resulting economic impact can be objectively calculated. It is this process that will be described throughout the remainder of this study.

The purpose of this analysis was to provide the framework for an economic assessment to agriculture of a hypothetical one inch of additional rainfall in counties participating in selected weather modification programs. The economic impacts solely to agricultural activities were estimated at the county level for 31 participating counties in three active and one former weather modification programs. County level estimates were aggregated in clusters to report the expected direct and statewide economic impacts from an additional one inch of rainfall across the counties in the West Texas Weather Modification Association, Panhandle Groundwater and Conservation District program, South Texas Weather Modification Association, and the Southwest Texas Rainfall Enhancement Association. Operating cost data was provided by each of the associations to enable benefit-cost ratios to be calculated so the potential return on investment from increased agricultural production could be considered.

For the purpose of this analysis, the benefits of a weather modification program are calculated based on the 31 participating counties realizing one additional inch of timely rainfall as a result of program efforts. Since weather modification activities occur during the March through October period, consideration was given to evaluate the impact of additional rainfall during this timeframe on agricultural enterprises. The economic impact of additional rainfall to agriculture is directly determined by the prevailing crop and livestock grazing practices in the affected region. Across the study area counties, average precipitation levels ranged from approximately 14 to 30 inches annually. So, one additional inch of rainfall would be expected to have marginally different impacts between counties, especially to livestock grazing activities. The following sections detail the data and methods used to define the prevailing agricultural inventory, an assessment of the expected responses to additional rainfall on these enterprises, a quantification of the economic impacts on the affected counties, and finally an assessment of the clustered impacts of counties participating in the various weather modification programs.

IMPACT OF ADDITIONAL RAINFALL TO DRYLAND CROP ACREAGE

The initial focus with respect to the economic impact of additional rainfall is targeted on dryland production acreage. The four predominant agricultural commodities produced among the 31 study area counties are corn, wheat, sorghum, and cotton. An estimate of the cropping acreages and production method (dryland or irrigated) for each of the counties were obtaining from the Certified Acreage Reports from the United States Department of Agriculture (USDA) Farm Service Agency. Five years of data covering 2009-2013 were used to calculate average crop acreages for each county. A five year average was used to smooth out any spikes or troughs in plantings devoted to an individual crop while also identifying the most likely alternative crops and capturing the shifts in acreage for each county. Table 1 shows the historical dryland production acreages for corn, wheat, sorghum and cotton for each county in the study area. Based on the USDA certified acreage reports, these counties planted a combined annual average of 163,544 corn acres (36.3% dryland), 418,404 wheat acres (82.5% dryland), 163,555 sorghum acres (88.0% dryland) and 372,582 cotton acres (66.7% dryland). Across the 1,118,086 acres dedicated to these four crops, 797,038 acres (71.3%) were classified as dryland production with a little more than 321,047 acres (28.7%) produced under irrigation.

Each agricultural commodity responds uniquely to additional water. For this analysis, information related to the expected agronomic response for dryland crops mirrored estimates from a previous 2000 Johnson study where Extension soil and crop specialists provided quantification of these levels. It was estimated that an additional inch of rainfall during the March to October period would conservatively provide the following per acre increases in yield to dryland production: 5 bushels of corn, 1 bushel of wheat, 150 pounds of sorghum, 35 pounds of cotton lint, and 56.7 pounds of cottonseed. The rather low estimate of yield response for wheat can be explained in large part by the timing of additional rain resulting from weather modification. This period does improve conditions for wheat, but to a lesser extent than would be realized if the rainfall occurred during more critical periods for this cool season crop. The value of the additional production was calculated using a six year Olympic average price for each commodity covering 2008-2013 as reported by the USDA National Agricultural Statistics Service. Specifically, the value of additional production was estimated using prices of: $5.31/bushel of corn; $6.58/bushel of wheat; $8.24/cwt. of sorghum; $0.72/pound of cotton lint; and $221/ton of cottonseed.

IMPACT OF ADDITIONAL RAINFALL TO IRRIGATED CROP ACREAGE

The effect of additional timely rainfall on irrigated acres is fairly obvious. An additional one inch of timely rainfall would reduce the need for irrigation during this time period proportionately (i.e. by one acre inch). Table 2 shows the 2011-2013 average USDA Farm Service Agency certified acres for all irrigated crops for each study area county. A three year period was used because detailed irrigated acreage figures for all crops prior to 2011 were not available. These figures represent the producer certified irrigated acres within each county and includes a wide spectrum of enterprises ranging from traditional row crops to vegetable crops, pecans, and hay. With 463,107 certified irrigated acres in the study area, an additional inch of rainfall would imply a decrease in irrigation application and expenses associated with 463,107 acre inches (or 38,592 acre feet) of water.

The incremental cost of applying one acre inch of irrigation water was taken from the Texas A&M AgriLife Extension Crop Enterprise Budgets (2013). These cost estimates are provided on an Extension District basis, so the costs used for counties within the same Extension District are identical. However across districts, the budgets recognize different prevailing technologies, labor requirements and application costs. In each case, the cost estimate used represents the marginal cost of applying one acre inch of irrigation water. Infrastructure and equipment investment costs are not included. Across the six different Extension Districts represented in this study, the irrigation cost estimates ranged from $3.30 to $7.00 per acre-inch.

Table 1. Average (2009-2013) USDA Farm Service Agency Certified Dryland Acres of Corn, Wheat, Sorghum, and Cotton for Counties Participating in a Weather Modification Program.

County	Dryland Corn Acres	Dryland Wheat Acres	Dryland Sorghum Acres	Dryland Cotton Acres
Armstrong	0	52,917	13,437	975
Atascosa	1,173	1,043	867	1,236
Bandera	0	49	24	0
Bee	13,796	1,812	18,405	5,172
Bexar	6,299	6,502	5,682	399
Carson	87	68,990	22,595	17,267
Crockett	0	360	0	0
Dimmit	66	386	604	200
Donley	0	9,000	774	5,362
Frio	379	4,339	2,084	396
Glasscock	83	8,851	4,316	62,528
Gray	75	34,293	10,414	14,597
Hutchinson	0	27,461	2,061	1,670
Irion	0	594	1	86
Karnes	8,801	3,212	2,313	3710
La Salle	621	218	75	53
Live Oak	6,823	573	2,767	1,823
McMullen	0	0	250	0
Medina	10,695	12,302	9,026	6,022
Potter	0	9,665	2,062	393
Reagan	0	8,320	2,369	20,412
Roberts	0	6,688	1,412	806
Schleicher	0	4,388	804	11,967
Sterling	0	4,674	0	0
Sutton	0	744	0	0
Tom Green	133	39,321	21,424	80,440
Uvalde	4,154	11,065	9,468	2,893
Webb	0	0	0	0
Wheeler	0	18,211	1180	6,573
Wilson	5,699	2,652	6185	1,372
Zavala	545	6,658	3279	2,092
TOTAL	**59,429**	**345,288**	**143,879**	**248,443**

Table 2. Average (2011-2013) USDA Farm Service Agency Certified Irrigated Cropland Acres and Estimated Irrigation Costs (per acre-inch).

County	Irrigated Cropland Acres	Per Acre-Inch Irrigation Cost
Armstrong	5,188	$5.50
Atascosa	19,288	$3.70
Bandera	0	$7.00
Bee	6,458	$3.70
Bexar	6,334	$7.00
Carson	70,432	$5.50
Crockett	0	$3.30
Dimmit	2,231	$3.70
Donley	24,385	$5.50
Frio	58,771	$3.70
Glasscock	26,346	$3.30
Gray	26,624	$5.50
Hutchinson	17,224	$5.50
Irion	12	$6.75
Karnes	511	$3.70
La Salle	4,688	$3.70
Live Oak	1,401	$3.70
McMullen	0	$3.70
Medina	38,301	$7.00
Potter	741	$5.50
Reagan	10,888	$3.30
Roberts	5,864	$5.50
Schleicher	468	$6.75
Sterling	386	$6.75
Sutton	119	$7.00
Tom Green	40,218	$6.75
Uvalde	50,695	$7.00
Webb	385	$3.70
Wheeler	12,279	$5.50
Wilson	8,926	$7.00
Zavala	23,943	$3.70
TOTAL	**463,107**	

IMPACT OF ADDITIONAL RAINFALL TO GRAZING LANDS

The impact of additional rainfall on livestock grazing is somewhat difficult to determine, but too important to ignore. According to the Texas Agricultural Statistics Service's 2013 County estimate reports, the 31 counties in the study area support 1,057,900 head of beef cows, 184,000 goats and 221,100 sheep. Intuitively, additional rainfall would provide moisture to produce increased grazing forages, which in turn would allow for increased stocking rates, higher daily gain rates for livestock, improved body condition scores for females leading to improved fertility, and/or heavier weaning/sale weights. In addition, the period of weather modification activities (March-October) coincides with the growing season for many of the warm season native grasses that serve as the foundation for rangeland production systems. In order to quantify the increased grazing value to pastures from an additional inch of rainfall, several important components of the grazing land economic environment were combined. First, the percentage that one additional inch of rainfall represents when compared to the average annual precipitation level was calculated for each county in the study area (using the county seat as a reference point). Monthly average rainfall and snowfall data for the 31 county seats were obtained from National Weather Service statistical reports. Average snowfall was converted to precipitation equivalents using a 10 to 1 conversion factor. Table 3 presents the percentage increase in annual precipitation corresponding to one inch of additional rainfall added to the combined rainfall and converted snowfall levels (i.e. marginal precipitation percentage). These figures was also computed to measure one additional inch of rainfall as a percentage of the average expected March - October precipitation levels. However, using the lower figure corresponding to annual rainfall was selected in order to remain more conservative in making a grazing land value estimate.

Second, the number of pastureland acres by county was obtained from the USDA 2012 Agricultural Census. USDA Farm Service Agency certified acreage reports were inappropriate as a source for this information since the majority of grazing land operators have little incentive to certify their grazing land acreage. For those 10-12 counties where a significant level of pastureland was certified with the Farm Service Agency, it was observed that this total ranged from 8 to 30 percent of the pastureland acres identified in the 2012 Agricultural Census and the majority of counties in the study certified little to no pastureland acres. Obviously, the actual number of pastureland acres used for productive livestock grazing (as opposed to a pure wildlife enterprise or other uses) lies below the total pastureland acres reported in the Agricultural Census and above the under-reported levels of the FSA certification reports. For this reason, this analysis uses 50 percent of the pastureland acres reported by the 2012 Agricultural Census (and reported in Table 3) to serve as a conservative estimate of the baseline area positively impacted by additional rainfall. In other words, of the 16.8 million acres of pastureland reported for study area counties in the census, 8.4 million acres were assumed to be used for livestock grazing activities and benefitting from the influence of additional rainfall.

Third, the baseline grazing value of grazing land was obtained using data from the USDA Risk Management Agency insurance program for Pasture, Rangeland and Forage. This Risk Management Agency program provides insurance coverage to grazing land producers through a rainfall index insurance program based on weather data collected and maintained by the National Oceanic and Atmospheric Administration's Climate Prediction Center. Through this program, agricultural producers enroll their acreage, pay an insurance premium, and are compensated based on precipitation shortfalls relative to the long-term average for a specified area and timeframe. As a baseline for compensation, a specific county base value for grazing lands is used. These county level grazing value baselines are used for this analysis and reported in Table 3 and represents the actual value that agricultural producers can use to insure against precipitation shortfalls. Multiplying the percentage increase in precipitation represented by one additional inch of rainfall for each county by the insurable grazing value of pastureland results in the per acre value increase from one additional inch of rainfall to livestock grazing enterprises. This additional value would be expected to manifest itself through additional livestock revenues resulting from the improved production and efficiency measures identified above.

Table 3. Marginal Precipitation, Pastureland Acres, Insurable Grazing Value, and Per Acre Value Increase from One Additional Inch of Rainfall for Counties Participating in a Weather Modification Program.

County	One Inch as a Percentage of Annual Precipitation	Pastureland Acres	Insurable Grazing Value of Pastureland	Per Acre Value Increase from One Additional Inch of Rainfall
Armstrong	5.77%	290,123	$8.11	$0.47
Atascosa	4.25%	445,709	$9.85	$0.42
Bandera	5.60%	289,753	$8.25	$0.46
Bee	4.08%	374,785	$16.15	$0.66
Bexar	3.39%	200,945	$16.15	$0.55
Carson	5.77%	208,372	$8.11	$0.47
Crockett	4.89%	1,513,576	$8.25	$0.40
Dimmit	6.09%	533,153	$9.85	$0.60
Donley	5.77%	502,270	$8.30	$0.48
Frio	6.09%	425,664	$9.85	$0.60
Glasscock	7.18%	275,321	$7.41	$0.53
Gray	6.99%	313,116	$8.11	$0.57
Hutchinson	6.99%	420,540	$8.11	$0.57
Irion	4.64%	474,101	$8.25	$0.38
Karnes	4.32%	326,084	$16.15	$0.70
La Salle	5.98%	468,091	$9.85	$0.59
Live Oak	4.33%	373,412	$9.85	$0.43
McMullen	5.98%	409,886	$9.85	$0.59
Medina	6.66%	567,326	$16.15	$1.08
Potter	5.77%	507,247	$8.11	$0.47
Reagan	4.79%	603,782	$8.25	$0.40
Roberts	6.99%	509,761	$8.11	$0.57
Schleicher	4.86%	797,807	$8.25	$0.40
Sterling	4.86%	570,990	$8.25	$0.40
Sutton	5.21%	862,169	$8.25	$0.43
Tom Green	4.64%	762,534	$8.25	$0.38
Uvalde	6.66%	779,548	$8.25	$0.55
Webb	5.99%	1,889,579	$9.85	$0.59
Wheeler	6.63%	409,757	$8.30	$0.55
Wilson	4.32%	253,952	$16.15	$0.70
Zavala	6.09%	505,581	$9.85	$0.60
TOTAL		**16,864,934**		

COUNTY LEVEL ESTIMATED IMPACTS

The county level economic impacts from one additional inch of rainfall accruing to dryland crops (corn, wheat, sorghum, and cotton only), cost savings to irrigated acres (of all certified crops), and grazing land values were estimated for each county and are presented in Table 4. This information represents the estimated impacts assuming the entire county participated realized one additional inch of rainfall. While several counties in the study area participated at a less than 100 percent level, this information provides useful information on which to evaluate the potential economic benefits. Adjustments to account for

Table 4. Estimated Revenue and Cost Savings from One Additional Inch of Rainfall based on 100 Percent County Coverage.

County	Increased Dryland Crop Revenues	Cost Savings to Irrigated Acreage	Increased Grazing Land Value	Direct Economic Impact
Armstrong	$545,203	$28,534	$67,846	$641,583
Atascosa	$87,683	$71,366	$93,302	$252,351
Bandera	$617	$0	$66,922	$67,539
Bee	$768,958	$23,896	$123,375	$916,229
Bexar	$292,941	$44,338	$54,991	$392,270
Carson	$1,280,025	$387,374	$48,728	$1,716,128
Crockett	$2,371	$0	$305,216	$307,587
Dimmit	$18,080	$8,255	$159,816	$186,150
Donley	$237,825	$134,119	$120,209	$492,153
Frio	$76,883	$217,451	$127,596	$421,930
Glasscock	$2,084,673	$86,943	$73,275	$2,244,891
Gray	$816,563	$146,434	$88,771	$1,051,768
Hutchinson	$258,875	$94,734	$119,226	$472,834
Irion	$6,641	$79	$90,767	$97,486
Karnes	$400,461	$1,891	$113,757	$516,109
La Salle	$20,520	$17,346	$137,962	$175,828
Live Oak	$276,653	$5,182	$79,613	$361,449
McMullen	$3,096	$0	$120,807	$123,903
Medina	$666,479	$268,109	$305,004	$1,239,593
Potter	$101,490	$4,077	$118,621	$224,188
Reagan	$727,440	$35,932	$119,362	$882,733
Roberts	$86,874	$32,252	$144,521	$263,647
Schleicher	$416,032	$3,161	$160,019	$579,212
Sterling	$30,765	$2,603	$114,526	$147,894
Sutton	$4,896	$831	$185,280	$191,007
Tom Green	$3,062,661	$271,474	$145,988	$3,480,123
Uvalde	$391,401	$354,863	$214,090	$960,354
Webb	$0	$1,423	$557,590	$559,013
Wheeler	$341,648	$67,536	$112,817	$522,001
Wilson	$288,529	$62,480	$88,593	$439,601
Zavala	$164,774	$88,590	$151,551	$404,916
TOTAL	**$13,461,057**	**$2,461,273**	**$4,410,140**	**$20,332,470**

partial county participation are provided later when clustered county groupings and the respective weather modification associations are examined. Additionally, these estimates are perfectly scalable, meaning that the impact of an additional half inch of rainfall would be expected to produce one half of the economic impacts presented in Table 4. Likewise, higher levels of additional rainfall (above one inch) would result in proportionately higher estimated economic impacts.

Differences in the magnitude of county-level estimates can be entirely explained by the presence of dryland corn, wheat, sorghum and cotton acreage, irrigation activity, and pastureland acres in each county. Of the counties included in the study area, the top three potential beneficiaries from additional rainfall for each impact category were: Tom Green, Glasscock, and Carson for dryland crop revenues;

Carson, Uvalde, and Tom Green for cost savings to irrigated acres; and Webb, Crockett, and Medina for increased grazing land value. In terms of combined direct economic impact, the top five beneficiaries were determined to be Tom Green, Glasscock, Carson, Medina, and Gray counties with each county estimated to receive over $1 million in direct economic benefits accruing to agriculture from one additional inch of rainfall.

ESTIMATED ASSOCIATION LEVEL IMPACTS and BENEFIT-COST RATIOS

The estimated economic impacts to individual counties can be aggregated to arrive at a collaborative impact for each of the various weather modification programs. For counties that participated in a partial participation/coverage capacity, the estimated county level impacts presented in Table 4 were adjusted to account for partial participation/coverage. The estimate of direct economic impact provides the combined estimates accruing from dryland crop revenues, cost savings to irrigated acreage, and increased grazing land revenues. These estimates are useful for considering county level potential benefits from participating in a program that results in one additional inch of rainfall. These estimates represent the most direct and immediate benefit from increased agricultural production.

In addition, a statewide impact estimate is provided using Impact Analysis for Planning (IMPLAN) output multipliers. These multipliers estimate the state economic impact of the relevant agricultural commodities from farm gate through the supply chain and account for the processing, transportation and value added impacts of increased production in the region. These secondary impacts can be viewed as a proxy for increased economic stability and growth; benefits that are not confined to the agricultural community. The specific multipliers used for this estimate were 2.02 for corn, wheat, and sorghum; 2.1662 for cotton lint and cottonseed; and 2.2495 for increased grazing values which is the assigned multiplier for beef production (which comprised 94% of the animal unit livestock composition of the study area in 2013). No multiplier impact was associated with cost savings to irrigated acreage. This resulting statewide impact estimate is especially relevant to state level entities considering return on investment from a broader state-level perspective as opposed to the county-level focus.

For each association, a five-year operating history of expenses was provided accounting for operating activities during 2009 through 2013. The five year history was used to account for a range of operating activities acknowledging that some years provide more opportunities for cloud seeding activities than others and results in higher operating expenses. This information also served as a basis for calculating the benefit-cost ratios (i.e. the return on investment for every dollar invested in the program) if one additional inch of rainfall were realized. The highest operating expense level observed over the five year period for each association was used to calculate the benefit-cost estimates. This concession recognizes that high cloud seeding activity levels would likely be necessary to produce one additional inch of rainfall across the region. Specifically, the expense levels used were: $375,526 for the West Texas Weather Modification Association (incurred in both 2012 and 2013); $219,741 for the Panhandle Groundwater Conservation District (incurred in both 2012 and 2013); and $274,598 for the South Texas Weather Modification Association (incurred in 2011). Additionally, during this period the Southwest Texas Rainfall Enhancement Association operated as a five county association from 2009 - 2011 (incurring the highest expense of $244,388 in 2010) and as a two county alliance of Uvalde and Webb counties in 2012 (with operating expenses of $196,840). In 2013, Uvalde county joined the South Texas Weather Modification Association.

Figure 1 provides a map of the eight participating counties in the West Texas Weather Modification Association. Table 5 presents the estimated impacts resulting from an additional one inch of rainfall across each of the participating counties. The direct economic impact estimates range from

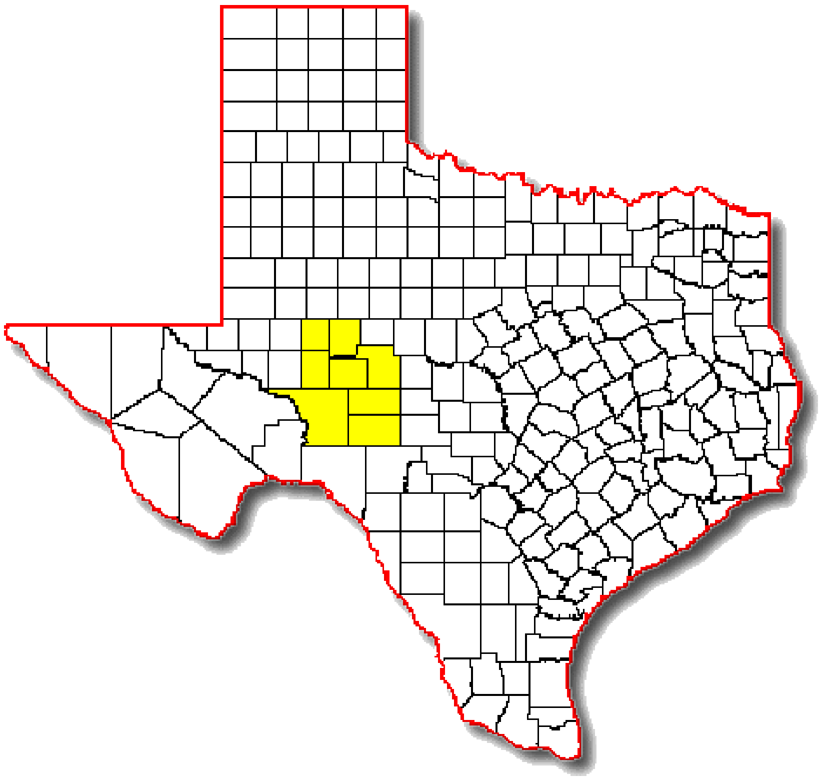

Figure 1. Counties in the West Texas Weather Modification Association.

Table 5. Estimated Economic Impacts of an Additional One Inch of Rainfall Across Counties Participating in the West Texas Weather Modification Association.

Participating Counties	Increased Dryland Crop Revenues	Cost Savings to Irrigated Acreage	Increased Grazing Land Revenues	Direct Economic Impact	Statewide Impact
Crockett	$2,371	$0	$305,216	$307,587	$691,373
Glasscock	$2,084,673	$86,943	$73,275	$2,244,891	$4,750,952
Irion	$6,641	$79	$90,767	$97,486	$218,070
Reagan	$727,440	$35,932	$119,362	$882,733	$1,867,927
Schleicher	$436,032	$3,161	$160,019	$579,212	$1,258,655
Sterling	$30,365	$2,603	$114,526	$147,894	$322,374
Sutton	$4,896	$831	$185,280	$191,007	$427,508
Tom Green*	$1,378,197	$122,163	$65,695	$1,566,055	$3,220,707
TOTAL	**$4,651,015**	**$251,712**	**$1,114,139**	**$6,016,866**	**$12,757,566**
Benefit-Cost Ratio for the Association's Activities				**16.02**	**33.97**

* The coverage area of Tom Green County was estimated to be 45% of acreage. Numbers provided represent 45% of the estimated impact of complete Tom Green County coverage.

$97,000 (for Irion County) to $2.2 million (for Glasscock County). Collectively, the estimated direct impact is over $6.0 million with statewide impact estimated to be $12.7 million. One common technique used to evaluate a potential investment expenditure is to examine the benefit-cost ratio, which is simply the dollar value of the expected benefits divided by the dollar costs of the project. Using the operating cost figures provided by the association, the benefit-cost ratio for direct economic impacts was estimated to be 16.02, which can be interpreted as a $16.02 return for every $1 invested. Again, these benefit-cost ratios quantify benefits from an additional one inch of rainfall which represents an average increase of 5.13% in rainfall for the eight participating counties. Accounting for the statewide impacts, the benefit-cost ratio increases to 33.97 assuming that the additional rainfall is realized.

Figure 2 provides a map of the eight participating counties in the Panhandle Groundwater Conservation District program. Table 6 presents the estimated impacts resulting from an additional one inch of rainfall across each of the participating counties. The direct economic impact estimates range from $18,800 (for Hutchinson County that participates at a nominal level) to $1.7 million (for Carson County). Collectively, the estimated direct impact is over $4.8 million with statewide impact estimated to be $9.4 million. The benefit-cost ratio for direct economic impacts was estimated to be 22.20, implying a $22.20 return for every $1 invested. These benefit-cost ratio estimates quantify benefits from an additional one inch of rainfall which represents an average increase of 6.34% in rainfall for the eight participating counties. Accounting for the statewide impacts, the benefit-cost ratio increases to 42.81.

Figure 3 provides a map of the eleven participating counties in the South Texas Weather Modification Association. Table 7 presents the estimated impacts resulting from an additional one inch of rainfall across each of the participating counties. The direct economic impact estimates range from $67,500 (for Bandera County) to $1.2 million (for Medina County). Collectively, the estimated direct impact is over $5.6 million with statewide impact estimated to be $10.9 million. The benefit-cost ratio for direct economic impacts was estimated to be 20.73, which implies a $20.73 return for every $1 invested. These benefit-cost ratio estimates quantify benefits from an additional one inch of rainfall which represents an average increase of 5.06% in rainfall for the eleven participating counties. Accounting for the statewide impacts, the benefit-cost ratio increases to 39.51.

Table 8 presents the estimated impacts resulting from an additional one inch of rainfall across each of the counties that participated in the Southwest Texas Rain Enhancement Association. For the program that operated through 2011, the five county coalitions depict a direct economic impact estimate range from $175,800 (for La Salle County) to $960,300 (for Uvalde County). Collectively, the estimated direct impact from the five county program is over $2.2 million with statewide impact estimated to be $4.4 million. The benefit-cost ratio for direct economic impacts was estimated to be 9.36, implying a $9.36 return for every $1 invested. These benefit-cost ratio estimates quantify benefits from an additional one inch of rainfall which represents an average increase of 6.16% in rainfall for the five participating counties. Accounting for the statewide impacts, the benefit-cost ratio increases to 18.18. Finally, Table 9 shows the estimated impacts and benefit-cost ratios of the abbreviated two county program consisting of Uvalde and Webb counties that operated in 2012.

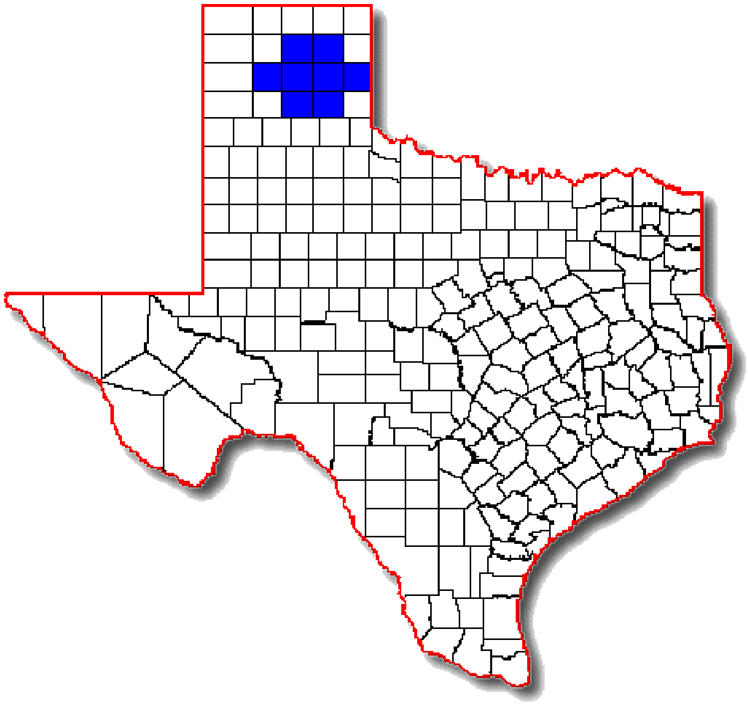

Figure 2. Counties in the Panhandle Groundwater and Conservation District Program.

Table 6. Estimated Economic Impacts of an Additional One Inch of Rainfall Across Counties Participating in the Panhandle Groundwater Conservation District Program.

Participating Counties	Increased Dryland Crop Revenues	Cost Savings to Irrigated Acreage	Increased Grazing Land Revenues	Direct Economic Impact	Statewide Impact
Armstrong*	$508,129	$26,594	$63,232	$597,955	$1,199,445
Carson	$1,280,025	$387,374	$48,728	$1,716,128	$3,162,207
Donley	$237,825	$134,119	$120,209	$492,153	$909,644
Gray	$816,563	$146,434	$88,771	$1,051,768	$2,062,844
Hutchinson*	$10,303	$3,770	$4,745	$18,819	$35,563
Potter*	$97,542	$3,919	$114,007	$215,467	$459,149
Roberts	$86,874	$32,252	$144,521	$263,647	$536,550
Wheeler	$341,648	$67,536	$112,817	$522,001	$1,041,737
TOTAL	**$3,378,910**	**$801,998**	**$697,030**	**$4,877,938**	**$9,407,140**
Benefit-Cost Ratio for the District's Activities				**22.20**	**42.81**

* The estimated coverage area of Armstrong County was 93.20%, Hutchinson County was 3.98%, and Potter County was 96.11% of acreage. Numbers provided represent this same proportional estimated impact to Armstrong, Hutchinson, and Potter counties compared to complete county coverage.

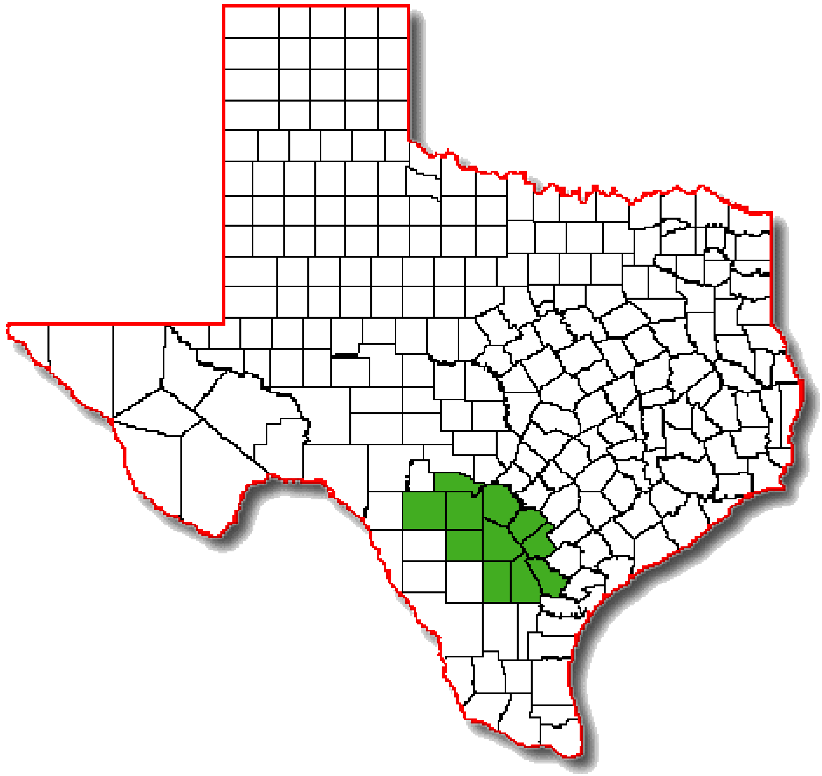

Figure 3. Counties in the South Texas Weather Modification Association.

Table 7. Estimated Economic Impacts of an Additional One Inch of Rainfall Across Counties Participating in the South Texas Weather Modification Association.

Participating Counties	Increased Dryland Crop Revenues	Cost Savings to Irrigated Acreage	Increased Grazing Land Revenues	Direct Economic Impact	Statewide Impact
Atascosa	$87,683	$71,366	$93,302	$252,351	$464,062
Bandera	$617	$0	$66,922	$67,539	$151,788
Bee	$768,958	$23,896	$123,375	$916,229	$1,878,557
Bexar	$292,941	$44,338	$54,991	$392,270	$761,621
Frio	$76,883	$217,451	$127,596	$421,930	$661,607
Karnes	$400,461	$1,891	$113,757	$516,109	$1,083,814
Live Oak	$276,653	$5,182	$79,613	$361,449	$751,510
McMullen	$3,096	$0	$120,807	$123,903	$278,010
Medina	$666,479	$268,109	$305,004	$1,239,593	$2,328,255
Uvalde	$391,401	$354,863	$214,090	$960,354	$1,640,418
Wilson	$288,529	$62,480	$88,593	$439,601	$850,919
TOTAL	**$3,253,702**	**$1,049,576**	**$1,388,050**	**$5,691,327**	**$10,850,560**
Benefit-Cost Ratio for the Association's Activities				**20.73**	**39.51**

Table 8. Estimated Economic Impacts of an Additional One Inch of Rainfall Across Counties Participating in the Southwest Texas Rain Enhancement Association through 2011.

Participating Counties	Increased Dryland Crop Revenues	Cost Savings to Irrigated Acreage	Increased Grazing Land Revenues	Direct Economic Impact	Statewide Impact
Dimmit	$18,080	$8,255	$159,816	$186,510	$405,205
La Salle	$20,520	$17,346	$137,962	$175,828	$369,384
Uvalde	$391,401	$354,863	$214,090	$960,354	$1,640,418
Webb	$0	$1,423	$557,590	$559,013	$1,255,722
Zavala	$164,774	$88,590	$151,551	$404,916	$771,988
TOTAL	**$594,775**	**$470,477**	**$1,221,010**	**$2,286,261**	**$4,442,717**
Benefit-Cost Ratio for the Association's Activities				**9.36**	**18.18**

Table 9. Estimated Economic Impacts of an Additional One Inch of Rainfall Across Counties Participating in the Southwest Texas Rain Enhancement Association, 2012.

Participating Counties	Increased Dryland Crop Revenues	Cost Savings to Irrigated Acreage	Increased Grazing Land Revenues	Direct Economic Impact	Statewide Impact
Uvalde	$391,401	$354,863	$214,090	$960,354	$1,640,418
Webb	$0	$1,423	$557,590	$559,013	$1,255,722
TOTAL	**$391,401**	**$356,286**	**$771,680**	**$1,519,367**	**$2,896,140**
Benefit-Cost Ratio for the Association's Activities				**7.72**	**14.71**

Table 10 summarizes the combined estimated impacts of the three active weather modification programs assessed in this study; West Texas Weather Modification Association, Panhandle Groundwater and Conservation District, and the South Texas Weather Modification Association. This aggregated portrayal pulls directly from the individual association level estimates provided in Tables 5, 6 and 7 but permits a framework for conveying the potential merits of the combined efforts of all three weather modification programs. For the 27 counties included in these three programs, one additional inch of rainfall represents an average increase of 5.46%. Collectively, the estimated direct economic impact is over $16.5 million with a statewide impact of $33 million. The benefit-cost ratio estimates imply a return on investment of $19.07 at the county level for every dollar invested or $37.95 for every dollar invested using the broader statewide perspective.

Table 10. Estimated Economic Impacts an Additional One Inch of Rainfall Across Counties Participating in Three Texas Weather Modification Programs.

Weather Modification Programs	Increased Dryland Crop Revenues	Cost Savings to Irrigated Acreage	Increased Grazing Land Revenues	Direct Economic Impact	Statewide Impact
West Texas Weather Modification Assn.	$4,651,015	$251,712	$1,114,139	$6,016,866	$12,757,566
Panhandle Groundwater Conservation District	$3,378,910	$801,998	$697,030	$4,877,938	$9,407,140
South Texas Weather Modification Assn.	$3,253,702	$1,049,576	$1,388,050	$5,691,327	$10,850,560
TOTAL	**$11,283,626**	**$2,103,286**	**$3,199,219**	**$16,586,131**	**$33,015,266**
Benefit-Cost Ratio for the Combined Activities				**19.07**	**37.95**

CONCLUSION

This paper was intended solely as an educational resource to provide a framework for assessing the potential benefits and costs of weather modification efforts and as a portion of the evidence needed to assess the relative merits of these types of activities. With every step in this analysis, a conservative stance was used in order to avoid overstating the potential benefits. This should only serve to add confidence that if an additional inch of rainfall can be realized, the benefits will meet or exceed expectations. While this study treats an additional inch of rainfall as producing predetermined impacts, which is clearly a fallacy. An additional inch of rainfall in a dry year is undoubtedly more valuable to agricultural enterprises than an additional inch of rainfall in a wet year. The approach of this study was to consider the value of additional rainfall as an addition to "normal" precipitation expected. As such, the impacts could be expected to be magnified when precipitation was at or below "normal" and somewhat less in years when precipitation levels exceeded their averages.

It should be noted that the dollar estimate of benefits include only economic impacts from increased dryland production of corn, wheat, sorghum, and corn, the cost savings accruing to irrigated cropland acres, and the increased grazing values accruing to pastureland enterprises (primarily cattle). Among the three economic impact categories for the study area counties/regions, dryland crop revenues (of corn, wheat, sorghum and cotton) were estimated to be the greatest beneficiary from additional rainfall, followed by grazing land values and finally irrigated acreage cost savings. The implication of this information suggests that any adjacent counties characterized with large acreages of dryland cropping activities and/or vast areas of grazing land could be promising beneficiaries and potentially good collaborators to recruit in the activities of an adjacent association.

While the estimates provided in this assessment quantify the direct and statewide benefits accruing from increased agricultural production by county, they do not recognize the possibility that a large portion of the secondary effects may migrate to adjacent areas. In other words, it could be expected that much of the direct economic impacts would be initially realized within the county, the secondary effects would likely find their way to more urban counties or regional processing hubs. As these dollars circulate and are exchanged for goods and services, they will naturally find their way to the places where goods and services are readily available. In this regard, a regional perspective about coordinated activities aimed at increasing rainfall appears to be constructive.

Not included in this analysis are dollar estimates for the other positive results from additional rainfall: enhanced landscape appearance, increased lake and river levels, benefits to municipalities including opportunities for growth or support of new business ventures, urban and recreational uses, etc.. The task of assigning values to these benefits has been left up to the reader to include as appropriate. What becomes fairly evident is that the benefits from increased agricultural production alone prove to be significant and are simply the result of a more favorable production environment. It is the responsibility of the reader to assign value to public benefits not quantified and to draw their own conclusions about the technical feasibility of efforts, activities, and programs targeting the realization of additional rainfall.

The estimates provided in the analysis examine the expected impacts from increased agricultural production resulting from a hypothetical one inch of additional rainfall. This additional inch or rainfall represents a 3.4-7.2 percent increase in average precipitation for the various study area counties. The likelihood of achieving these results is debatable, but documented rainfall resulting from weather modification efforts can now be easily quantified from an economic perspective. Further, these estimates are scalable, meaning that an additional one-half inch of rain across a region would be expected to produce half of the estimated impacts and/or an additional two inches of rain across a region would be expected to produce twice the estimated impacts. This is useful because it permits pairing the framework of this analysis with actual rainfall related research quantifying the precipitation results of weather modification efforts to provide more specific and realized documented impacts. Since the framework of this analysis is prepared at the county level, any geographically based rainfall result details that can be verified and documented can be quantified economically providing assessments of association activities on an annual basis or even rainfall event basis. Given that the potential economic impacts to agriculture alone show to be substantial, this type of paired documentation would likely result in compelling evidence to potential funding entities as they consider the best use of their limited resources among competing projects.

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