Economic Impacts of Cloud Seeding on Agricultural Crops in North Dakota

Report prepared for the
North Dakota Atmospheric Resource Board
by
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Table of Contents

Page

List of Tables ii

List of Figures iii

List of Appendix Tables iii

Executive Summary iv

Introduction 1

Methods 2
- Treatment Counties and Rain Enhancement Regions 2
- Hail Suppression 3
- Enhanced Growing Season Rainfall 5
  - Yield Response 6
  - Price Effects 10
  - Combined Effects 12
- Input-Output Analysis 12
- Study Limitations 12

Results 13
- Direct Impacts for Statewide Assessment 13
- Direct Impacts for North Dakota Cloud Modification Project Counties 15
- Total Impacts for Statewide Assessment 18
- Total Impacts for North Dakota Cloud Modification Project Counties 20
- State Tax Revenues 20

Conclusions 22

References 23

Appendices:
- Appendix A: Average Crop-Loss Ratios, by County, North Dakota, 1998 through 2007 27
- Appendix B: Gross Value of Crop Production, Total Direct Impacts, and Gross Business Volume, North Dakota Cloud Modification Project Counties and Statewide Assessment, North Dakota, 1998 through 2007 31

List of Tables

Table | Page

1 Average Production, Selected Crops, North Dakota, 1998 through 2007 4

2 Change in Growing Season Rainfall, Five and Ten Percent Scenarios, North Dakota, Average Annual 1998 through 2007 8

3 Average Annual Changes in Yields, Five and Ten Percent Rainfall Scenarios, North Dakota, 1998 through 2007 9

4 Price Elasticities for Changes in Crop Supply, Statewide Assessment, North Dakota, 1998 through 2007 11

5 Direct Economic Benefits, Cloud Modification, Statewide Assessment, North Dakota, 1998 through 2007 14

6 Direct Economic Benefits, North Dakota Cloud Modification Project Counties, North Dakota, 1998 through 2007 17

7 Average Annual Total Economic Impacts, North Dakota Cloud Modification Project, Treatment Counties and Statewide Assessment, North Dakota, 1998 through 2007 19

8 Average Annual State Tax Collections, North Dakota Cloud Modification Project Counties and Statewide Assessment, North Dakota, 1998 through 2007 21

List of Figures

Figure | Page

1 Cloud Modification Counties and Rain Enhancement Regions, North Dakota 2

List of Appendix Tables

Table | Page

A1 Planted and Harvested Acreage, Crop Value, Crop-Hail Loss Factors, Hail Losses, Hail Reduction Factors, and Avoided Hail Losses, by County, North Dakota, Averages 1998 through 2007 29

B1 Value of Enhanced Growing Season Rainfall, Five and Ten Percent Rainfall Scenarios, Statewide Assessment, by County, North Dakota, Averages 1998 through 2007 33

B2 Direct Impacts and Gross Business Volume, Five and Ten Percent Rainfall Scenarios, Statewide Assessment, by County, North Dakota, Averages 1998 through 2007 35

B3 Value of Enhanced Growing Season Rainfall, Five and Ten Percent Rainfall Scenarios, North Dakota Cloud Modification Project, North Dakota, Averages 1998 through 2007 37

B4 Direct Impacts and Gross Business Volume, Five and Ten Percent Rainfall Scenarios, North Dakota Cloud Modification Project, North Dakota, Averages 1998 through 2007 37

Executive Summary

North Dakota is consistently among the top states for annual hail damage to agricultural crops and historically high rates of hail damage are one of the key reasons for implementing the North Dakota Cloud Modification Project (NDCMP). Cloud seeding, in an attempt to mitigate the hail damage inflicted on agricultural crops, has been implemented in various capacities in the state since the early 1950s.

The annual economic effects of cloud seeding were based on estimating the value of hail suppression and enhanced growing season rainfall from 1998 through 2007 on the top eight crops based on harvested acreage. Alfalfa was added as a ninth crop. Data on crop insurance losses and liabilities and crop production statistics were combined with data on hail suppression from cloud seeding to estimate the amount of crop hail losses potentially savable through cloud seeding. The value of increased crop production resulting from added growing season rainfall was based on changes in crop yields and corresponding changes in crop prices. A 5 percent and a 10 percent change in growing season rainfall were modeled.

Statewide, cloud seeding would be estimated to save $53.3 million in annual hail damage to the nine crops in this study. The value of increased rainfall in the 5 percent rainfall scenario was estimated to average $42.1 million annually, while the value of increased growing season rainfall was estimated to average $81 million annually in the 10 percent rainfall scenario. Including hail suppression, total direct benefits of cloud seeding averaged $95.4 million or $4.87 per planted acre annually from 1998 through 2007 under the 5 percent rainfall scenario and $134.5 million or $6.86 per planted acre annually under the 10 percent rainfall scenario.

For the 5 percent rainfall scenario, total direct impacts of $95.4 million from a statewide cloud seeding program would generate a gross business volume (direct plus secondary economic effects) of $294 million or $14.99 per planted acre annually over the period. For the 10 percent rainfall scenario, total direct impacts of $134.5 million would create a gross business volume of $414.2 million or $21.13 per planted acre annually.

The North Dakota Atmospheric Resource Board estimated the expected annual cost of implementing a statewide cloud seeding program to be about $3 million. The most conservative of the two scenarios evaluated in this study indicated that collections of state taxes would be nearly double the anticipated cost ($3 million cost versus $6 million in state revenues). The benefit to the state would be substantial, especially considering the economic impacts in this study did not include all crops or increased forage production from grazing lands, nor did the impacts include avoided hail losses to personal, commercial, and industrial property. The state could reap tremendous economic benefits from a modest investment if the North Dakota Cloud Modification Project was implemented statewide.

Economic Impacts of Cloud Seeding on Agricultural Crops in North Dakota

Dean Bangsund and F. Larry Leistritz

Introduction

North Dakota is consistently among the top states for annual hail damage to agricultural crops (National Crop Insurance Services 2005, 2006, 2007, 2008, 2009; Changnon 1977, 1984) and some areas in southwestern North Dakota have historically had some of the highest ratios of claims paid to insured liabilities in the United States (Miller and Fuhs 1987). The historically high rates of hail damage to crops are one of the key reasons for implementing the North Dakota Cloud Modification Project (NDCMP). Cloud seeding, in an attempt to mitigate the hail damages inflicted on agricultural crops, has been implemented in various capacities in the state since the early 1950s.

Experimental trials to test the hypothesis of hail reduction from cloud seeding produced mixed results during the 1970s (Miller et al. 1975; Crow et al. 1979). However, more recent analyses of cloud seeding effects, along with improvements in technology for delivering and targeting of cloud treatments, produced scientific evidence that the North Dakota Cloud Modification Project has been effective in reducing hail damage in target areas (Smith et al. 1987, 1992, 1997). Early in the development of the North Dakota Cloud Modification Project, questions regarding the economic effects of added growing season rainfall were examined (Johnson et al. "ARE Study" 1974; Enz et al. 1982; Schaffner et al. 1983). Economic analyses of the benefit of reduced hail damage followed (Johnson et al. 1989). The most recent study addressing economics of cloud modification activities in North Dakota included both the value of hail suppression and added growing season rainfall (Sell and Leistritz 1998).

The goal of this study is to update the analysis of the value of hail suppression and enhanced growing season rainfall in North Dakota conducted by Sell and Leistritz (1998). Since 1998, the crops raised and their value have changed considerably in some regions of the state. As crop values continue to increase, the benefits of hail suppression and added rainfall would also be expected to change. In the Sell and Leistritz study, the economic impact of cloud seeding was estimated for the entire state, even though only a handful of counties in western North Dakota actually were part of the NDCMP.

Methods

The economic effects of cloud seeding were based on estimating the value of hail suppression and enhanced growing season rainfall. Consistent with previous research, this study used data over a ten-year period (1998 through 2007) and selected the top eight crops based on harvested acreage over the study period.[1] Due in part to the availability of insurance coverage for forage crops, and the regional importance of forage crops in the state, alfalfa was included as an additional crop. The following sections discuss the data, methods, and procedures used in each component of the study.

Treatment Counties and Rain Enhancement Regions

Cloud seeding has been conducted in selected counties in western North Dakota since the early 1950s. Over the past ten years, the North Dakota Cloud Modification Project (NDCMP) has been operating in Bowman County and parts of Slope County in the southwestern corner of the state, and in Williams, McKenzie, Mountrail, and Ward Counties in northwestern North Dakota (Figure 1).

The state was divided into four rain enhancement regions in past studies. The four regions largely divide the state into sections that extend from the Canadian border to the South Dakota border (Figure 1). Changes in rainfall were expected to differ from east to west across the state.

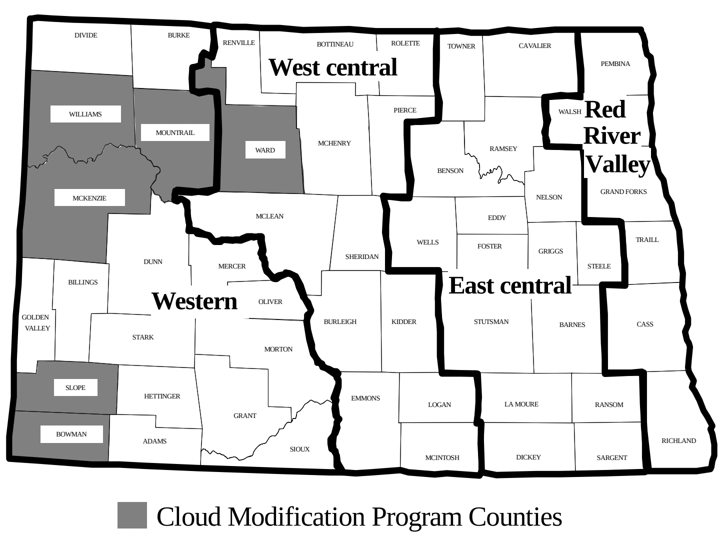

Figure 1. Cloud Modification Counties and Rain Enhancement Regions, North Dakota

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[1] Using only the top eight crops based on harvested acreage was a methodology carried forward from previous economic studies (Johnson et al. 1989; Sell and Leistritz 1998). Previous economic studies were reliant on using 'hail-loss reduction factors' from Smith et al. (1997), which influenced the selection of crops included in those studies.

Hail Suppression

The economic impact of crop-hail reduction predominantly followed the methodology established by Johnson et al. (1989) and Sell and Leistritz (1998). The general procedures for estimating the value of reducing hail damage on agricultural crops included:

(1) calculating an overall annual crop-hail loss-cost ratio per county. Crop insurance data for all crops in North Dakota, by county, by year, were obtained from National Crop Insurance Services (2008). Crop-hail loss-cost ratios represented insured losses divided by insured liabilities, and an average loss ratio was estimated for each county over the period (Appendix A).

(2) computing a ten-year average gross value of crop production per county based on the nine selected crops. Data from the North Dakota Agricultural Statistics Service (*various years*) was used to estimate gross value of crop production in North Dakota. Marketing year average prices were multiplied by crop production to estimate gross value of production.

(3) multiplying crop-hail loss-cost ratios (1) by gross value of crop production (2) to estimate total hail losses.

(4) multiplying the total hail losses by hail reduction factors to determine the portion of crop hail losses potentially savable through cloud seeding. Hail reduction factors were largely based on information from Smith et al. (1997).

The number and type of crops included in previous economic studies have changed due to evolving crop patterns in the state. Johnson et al. (1989) included spring wheat, durum, barley, oats, flax, sunflowers, and corn in their analysis, which corresponded with data from Smith et al. (1987). Sell and Leistritz (1998) included the six crops[2] used in the Johnson study, but added soybeans and dry edible beans. During the 1990s, soybean and dry edible bean production increased substantially in the state, easily ranking among the top eight crops based on harvested acreage. Sell and Leistritz (1998) did not include canola, despite the fact that canola acreage had expanded to exceed oats and flax acreage in the state. The top eight crops in North Dakota, from 1998 through 2007, based on harvested acreage were wheat, soybeans, corn, barley, canola, sunflower, flax, and dry edible beans (Table 1). Also included in this study was alfalfa. From 1998 through 2007, planted acreage for the eight crops, plus harvested acreage for alfalfa, averaged 19.6 million acres annually or about 86 percent of planted acreage in the state. When alfalfa was included, total planted acreage in the state averaged 22.9 million acres annually.

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[2]Durum and spring wheat were combined to represent one crop in the Sell and Leistritz study. A single category for wheat was used in this study.

Table 1. Average Production, Selected Crops, North Dakota, 1998 through 2007

Crop	Planted Acreage	Harvested Acreage	Units	Production
Wheat	9,119,000	8,648,000	bu	285,479,000
Soybeans	2,637,000	2,578,000	bu	81,036,000
Barley	1,577,000	1,459,500	bu	79,567,000
Corn	1,386,000	1,138,000	bu	129,817,000
Sunflowers	1,266,000	1,221,000	cwt	16,420,600
Canola	953,500	926,000	cwt	12,583,600
Dry Edible Beans	630,000	576,000	cwt	8,189,000
Flax	541,000	523,600	bu	9,903,000
Alfalfa	not applicable	1,490,000	tons	2,706,000

Source: North Dakota Agricultural Statistics Service.

Smith et al. (1997) provided a 'hail reduction factor' based on statistical analysis of hail suppression data in North Dakota. Hail reduction factors represent the average annual portion of hail damage that is expected to be mitigated from cloud seeding activities. Based on hail data for spring wheat, durum, barley, oats, flax, sunflowers, and corn (grain) in western North Dakota, Smith et al. (1997) concluded that cloud seeding in North Dakota reduced hail damage by 45 percent (0.45). The Sell and Leistritz study used a hail reduction factor of 0.30 for soybeans and dry edible beans. The 0.30 factor was based on a reasonably conservative derivative of the Smith reduction factor for the original six crops. The reduction factor used by Sell and Leistritz for soybeans and dry edible beans was used in this study. A hail reduction factor for alfalfa was based on 50 percent of the 0.45 factor for the original six crops. Since alfalfa generally has more than one harvest during the season and has the capacity for re-growth during the season, the likelihood of losing an entire season's harvest from hail damage is lessened for any particular weather occurrence. A weighted average hail reduction factor was estimated for each county based on average annual acreage of each crop over the period (Appendix A).

As discussed earlier, crop-hail loss-cost ratios for each county, year, and crop were used to develop a 10-year weighted loss-cost ratio for each county (National Crop Insurance Services 2008). The loss-cost ratio is estimated by dividing total insured losses by total insured liability. The ratio represents the dollar loss per dollar of insured liability. County loss-cost ratios were multiplied by the average annual value of crop production to determine the county-wide losses due to hail for the nine crops in the study. The above approach is used because producers do not insure 100 percent of crop acreage or 100 percent of crop gross value each year, and hail losses reported by National Crop Insurance Services do not represent all of the hail losses associated with an individual crop or collectively across crops for any county.

Possible crop output savable due to cloud modification involved multiplying estimated total losses due to hail by the weighted-average hail reduction factor for each county. The product of this approach is an estimate of the direct economic impact of hail suppression attributable to cloud modification. Separate equations were used for the treated and non-treated counties in North Dakota. The equations for each are shown below.

Non-treated counties were based on the following:

Average Gross Value of Crop Production
x
Average Loss-cost Ratio
x
Adjusted Reduction Factor

Treated counties were based on the following:

[(Average Gross Value of Crop Production x Loss-cost Ratio)
/ (1.0 - Adjusted Reduction Factor)]
minus (Average Gross Value of Crop production x Loss-cost Ratio)

Treated counties were handled differently since actual reductions in hail losses due to cloud seeding were inherently embedded in the National Crop Insurance Services data. In other words, the reduction in hail losses associated with cloud modification were already represented in the insurance data, and thus the value of hail suppression was estimated differently than non-treatment counties.

Enhanced Growing Season Rainfall

The economic impact of enhanced growing season rainfall predominantly followed the methodology established by Schaffner et al. (1983) and Sell and Leistritz (1998). The general procedures for estimating the value of enhanced growing season rainfall included:

(1) estimating yield increases associated with additional growing season rainfall.

(2) adding incremental yield increase to existing yields, and multiplying enhanced yields by crop acreage to estimate rain enhanced crop supply. Under both the statewide assessment and NDCMP assessment, estimated yield increases were used to

adjust baseline yield data for the NDCMP counties since reported yield data for those counties already contained the yield effects of enhanced growing season moisture.

(3) estimating the percentage change in crop supply due to enhanced growing season rainfall.

(4) calculating anticipated price response to changes in production (i.e., crop supply) and adjusting prices received by estimated price response.

(5) using adjusted prices with enhanced crop supply to estimate rain enhanced gross crop revenue.

(6) estimating the difference between gross crop revenues with and without enhanced growing season rainfall.

Yield Response

Schaffner et al. (1983) based yield changes associated with enhanced growing season rainfall on statistical relationships developed by Johnson et al. (1974). Sell and Leistritz (1998) adopted both the yield responses and anticipated enhanced growing season rainfall amounts presented in the Schaffner study. The primary analysis of yield response to added growing season rainfall for both the Schaffner and Sell and Leistritz studies came from the relationships developed in the Johnson et al. (1974) study. The Johnson study looked at yield response to a variety of growing season conditions over a 50-year period.

The problem with estimating yield increases in this study was that previously published estimates of yield increases were considered outdated, especially when examining the change in crop yields that has occurred over the past 25 years. Another problem was the ND Atmospheric Resource Board considered the estimated added growing season rainfall amounts used in previous studies also to be outdated.

For purposes of estimating yield changes to enhanced growing season rainfall, the general relationship between crop yields and added growing season rainfall developed by Johnson et al. (1974) was considered valid, despite the elapsed time since the relationships were developed. However, the relationships were perceived to require adjustment to account for substantial changes in average yields observed over the past 25 years. An additional consideration was that any new estimation of added yield required the ability to use alternative values for additional growing season rainfall. An equation was developed to compare past yields and incremental yield increases, and previous changes in growing season rainfall to current yields and anticipated yield increases, and updated growing season rainfall estimates. The relationships are defined in equation 1 and were estimated separately for each crop in the four rain enhancement regions.

Equation (1)

$$\frac{\left(\frac{AddYield_O}{AvgYield_O}\right)}{Rain_O} = \frac{\left(\frac{AddYield_N}{AvgYield_N}\right)}{Rain_N}$$

where: AddYield = Additional yield obtained from added growing season rainfall
AvgYield = Five-year average crop yield
Rain = Added growing season rainfall
$_O$ = Values from Schaffner et al. (1983) and average yield for 1977 through 1981
$_N$ = Values for current study and average yield for 2003 through 2007

Average yields from 1977 through 1981 were estimated from North Dakota Agricultural Statistics Service (*various years*) and used for $AvgYield_O$. $AddYield_O$ and $Rain_O$ values were obtained from Schaffner et al. (1983). $AvgYield_N$ represented average yields from 2003 through 2007. Solving equation (1) for anticipated yield increases ($AddYield_N$) produced the following equation.

Equation (2)

$$AddYield_N = AvgYield_N \times \left(Rain_N \times \left(Rain_O / \left(AddYield_O / AvgYield_O\right)\right)\right)$$

Equation 2 produces an estimated yield increase ($AddYield_N$) when entering current values for $Rain_N$. Current values for $Rain_N$ were obtained from the Atmospheric Resource Board Cooperative Observer Network database.

Combining past data on average yields, yield increases, and changes in growing season rainfall with current data provided updated estimates of yield increases that account for changes in average yields over the past 25 years given alternative estimates of added growing season rainfall. Updated estimates of added growing season rainfall were based on the Cooperative Observer Network database, which contained data on actual rainfall received throughout the state from 1977 to 2006 (North Dakota Atmospheric Resource Board 2009). Two rainfall scenarios were used for the study (Table 2). The first scenario assumed statewide cloud seeding would result in a 5 percent increase in growing season rainfall, based on historic data from the Cooperative Observer Network database. A second scenario was based on a 10 percent change in growing season rainfall. Consistent with Schaffner et al. (1983), added growing season rainfall was modeled to occur from June through July for small grains and from June through August for row crops.

Yield changes were estimated for all nine crops for each rain enhancement region (Table 3). Sell and Leistritz (1998) included dry edible beans in their analysis for hail damage, but did not estimate a yield increase attributable to added growing season rainfall. Changes in yields for dry edible beans were based on relationships between reported dry edible bean yields and soybean yields in each of the four study regions. Similar approaches were used for estimating yield changes for alfalfa and canola, two crops not used in previous studies.

Table 2. Change in Growing Season Rainfall, Five and Ten Percent Scenarios, North Dakota, Average Annual 1998 through 2007

	5 Percent Rainfall Scenario		10 Percent Rainfall Scenario	
Region	June-July	June-August	June-July	June-August
	-------------------------------- rainfall in inches		--------------------------------	
Statewide Cloud Seeding Program				
West	0.2819	0.3666	0.5558	0.7231
West Central	0.3177	0.4263	0.6326	0.8488
East Central	0.3444	0.4722	0.6889	0.9443
Red River Valley	0.3469	0.4874	0.6937	0.9743
NDCMP Counties*	0.2772	0.3570	0.5291	0.6815

* NDCMP counties from 1998 through 2007 were Bowman, McKenzie, Mountrail, Slope, Ward, and Williams.
Source: ND Atmospheric Resource Board (2009).

Table 3. Average Annual Changes in Yields, Five and Ten Percent Rainfall Scenarios, North Dakota, 1998 through 2007

Region	Alfalfa tons/acre	Barley bu/acre	Canola lbs/acre	Corn bu/acre	Edible Beans cwt/acre	Flax bu/acre	Soybeans bu/acre	Sunflower lbs/acre	Wheat bu/acre
5 Percent Rainfall Scenario – Statewide Program									
West	0.029	1.010	45.333	1.630	0.261	0.286	0.569	60.170	0.956
West Central	0.038	1.456	79.046	2.361	0.335	1.214	0.707	68.897	1.310
East Central	0.042	1.501	66.462	2.360	0.409	0.864	0.922	63.597	1.095
Red River Valley	0.038	1.086	55.462	1.820	0.425	0.610	0.929	63.101	0.848
10 Percent Rainfall Scenario – Statewide Program									
West	0.057	1.992	89.407	3.214	0.521	0.565	1.138	118.673	1.885
West Central	0.075	2.898	157.369	4.700	0.670	2.417	1.415	137.171	2.608
East Central	0.083	3.002	132.928	4.720	0.818	1.728	1.843	127.195	2.189
Red River Valley	0.075	2.172	110.920	3.641	0.850	1.220	1.858	126.202	1.695
5 Percent Rainfall Scenario – NDCMP Counties*									
West	0.028	0.993	44.236	1.587	0.254	0.282	0.554	58.586	0.940
West Central	0.031	1.270	67.609	1.977	0.326	1.059	0.689	57.690	1.143
10 Percent Rainfall Scenario – NDCMP Counties*									
West	0.054	1.896	84.453	3.030	0.491	0.538	1.072	111.847	1.794
West Central	0.060	2.424	129.070	3.774	0.631	2.022	1.333	110.135	2.182

* NDCMP counties from 1998 through 2007 were Bowman, McKenzie, Mountrail, Slope, Ward, and Williams.

Price Effects

Generally, as supply of agricultural commodities increases commodity prices usually decrease, albeit price and supply movements are not necessarily proportional. Annual increases in growing season rainfall would be expected to change the supply of nearly all commodities in North Dakota over the study period. For some crops included in this study, production in North Dakota represents a considerable portion of national production. For example, canola production in North Dakota represented 87 percent of national production from 1998 through 2007. Other crops also represented a substantial portion of national production, such as barley (31 percent), dry edible beans (32 percent), sunflowers (50 percent), and flax (93 percent). Thus, considering the relative proportion of national supply represented by production in North Dakota, changes in North Dakota production could have noticeable effects on national supply and might influence market prices.

Sell and Leistritz (1998) used a ‘flexibility coefficient’ to adjust the price of wheat for changes in supply due to added growing season rainfall. The flexibility coefficient used in the Sell and Leistritz study was developed from an analysis of wheat markets by Johnson et al. (1998). However, flexibility coefficients for the remaining eight crops in this study were not available, and study limitations prevented replicating the market analyses performed by Johnson et al. (1998).

To address the price response issue, natural logs of both crop prices and state crop production were regressed over the 1998 to 2007 period. That approach provided price elasticity coefficients for alfalfa, barley, canola, dry edible beans, flax, and sunflowers (Table 4). The price elasticity coefficients mean that for every one percent change in supply crop price can be expected to change by a given percentage in the opposite direction. For example, the coefficient for flax was estimated at 0.2438 percent. When supply of flax increases by 1 percent, price of flax is expected to decrease by 0.2438 percent. The price elasticities estimated in this analysis represent ‘ballpark’ estimates of price response to changes in supply, and were not expected to substitute for the market analyses performed by Johnson et al. (1998). Nevertheless, the inclusion of some price effects was deemed appropriate to provide a more conservative estimate of the benefits of enhanced growing season rainfall. Alternatively, ignoring price effects would knowingly inflate estimates of the value of enhanced rainfall.

Price effects were not observed for changes in the state production of corn and soybeans over the period. The lack of observable price effects associated with changes in the supply of corn and soybeans in North Dakota was not surprising since North Dakota represented about 3 percent of national production of those crops over the period.

Price effects for all crops except corn and soybeans were included for all counties in North Dakota when evaluating the statewide effects of cloud seeding. However, price effects were omitted when only evaluating the economic effects of cloud seeding on the NDCMP counties. Collectively, the change in crop production in the NDCMP counties due to enhanced rainfall, averaged from 1998 through 2007, was estimated to represent less than a 1 percent change in state production for any of the nine crops included in the study. Changes in state crop production from added rainfall in the NDCMP counties ranged from an average of 0.01 percent for soybeans to 0.84 percent for flax over the period. The largest crop in the NDCMP counties was wheat, which was expected to increase state supply by 0.52 percent annually. As a result, changes in statewide crop supply due to enhanced rainfall in the NDCMP counties were deemed insufficient to influence crop prices.

Table 4. Price Elasticities for Changes in Crop Supply, Statewide Assessment, North Dakota, 1998 through 2007

Crop	Price Elasticity Coefficient*
Alfalfa	0.4884 %
Barley	0.1912 %
Canola	0.4134 %
Corn	not available
Dry Edible Beans	0.4258 %
Flax	0.2438 %
Soybeans	not available
Sunflowers	0.3465 %
Wheat**	0.8560 %

* Opposite price response to a 1 percent change in supply.

** Obtained from Johnson et al. (1998).

Combined Effects

After estimating the change in crop production (supply), changes in crop prices (price elasticity coefficient multiplied by percentage change in supply) were estimated. Changes in crop prices were then subtracted from actual prices received by producers over the period. Adjusted prices were then multiplied by crop production to estimate a new gross value of crop production. The gross value of crop production without added growing season rainfall was subtracted from the gross value of crop production with added growing season rainfall to estimate the economic benefits of additional growing season rainfall.

Changes in the gross value of crop production (i.e., value without and value with added growing season rainfall) were estimated separately for each crop, county, and year. The changes were then summed by year for all crops by county, and then annual changes by county were averaged over the ten-year period.

Input-Output Analysis

Economic activity from a project, program, policy, or activity can be categorized into direct and secondary impacts. Direct impacts are those changes in output, employment, or income that represent the initial or first-round effects of the project, program, policy, or activity. Secondary impacts (sometimes further categorized into indirect and induced effects) result from subsequent rounds of spending and respending within the economy. This process of spending and respending is sometimes termed the multiplier process, and the resultant secondary effects are sometimes referred to as multiplier effects (Leistritz and Murdock 1981).

Input-output (I-O) analysis traces linkages (i.e., the amount of spending and respending) among sectors of an economy and calculates the total business activity resulting from a direct impact in a basic sector (Coon et al. 1985). An economic sector is a group of similar economic units (e.g., communications and public utilities, retail trade, construction). The North Dakota I-O Model has 17 economic sectors, is closed with respect to households (households are included in the model), and was developed from primary (survey) data from firms and households in North Dakota. Empirical testing has shown the North Dakota Input-Output Model is sufficiently accurate in estimating gross business volume, personal income, retail activity, and gross receipts in major economic sectors in North Dakota (Coon and Leistritz 2008).

Study Limitations

Reducing the severity and/or frequency of hail would generate benefits from more than just mitigated damage to agricultural crops. Value of reduced hail to personal, commercial, and industrial property was not included. Considerable damage occurs annually to those properties, and the value of reducing those damages was not included. Also, enhanced growing season rainfall could influence forage production on grazing lands in North Dakota. The value of increased forage from pasture and range land on beef production in the state was not included.

This study focused on the top eight crops in North Dakota based on harvested acreage from 1998 through 2007. Alfalfa was added as a ninth crop in this study. However, potatoes, sugarbeets, peas, lentils, rye, safflower, millet, oats, among other crops, were not included. Hail reduction and enhanced growing season rainfall would generate benefits for all of the crops raised in the state. Harvested acreage for alfalfa and planted acreage for the state's top eight crops averaged 19.6 million acres annually over the study period. By contrast, planted acreage of all crops in North Dakota, including harvested acreage of alfalfa, averaged 22.9 million acres over the same period. Thus, the crops included in this study represented 86 percent of planted crop acreage in the state from 1998 through 2007.

Results

Two assessments of the benefits of cloud seeding in North Dakota were performed. A statewide assessment included all counties in North Dakota. The statewide assessment assumed cloud modification efforts would include the entire surface area of North Dakota. The second assessment focused only on the counties currently enrolled in the North Dakota Cloud Modification Project (see Figure 1).

Direct Impacts for Statewide Assessment

From 1998 through 2007, the average annual crop-hail loss-cost ratio by county varied from 1.67 percent to 9.53 percent (Appendix A). Averaged across all counties, the crop-hail loss ratio was estimated at 4.8 percent. The average value of crop production for the nine crops in the study was estimated at about $2.66 billion annually. The total crop value lost to hail averaged about $134.3 million or about $6.85 per planted acre annually from 1998 through 2007. However, only about 40 percent of that damage was estimated to be savable through cloud seeding. Statewide, cloud seeding would be estimated to save $53.3 million in hail damage to the nine crops in this study (Table 5). An annual statewide benefit of $53.3 million equates to $2.72 per planted acre over the period; an average for the nine crops in the study.

Table 5. Direct Economic Benefits, Cloud Modification, Statewide Assessment, North Dakota, 1998 through 2007

Region	Average Acreage*		Average Annual Estimates			Estimates per Planted Acre		
	Planted	Harvested	Value of Reduced Hail	Value of Enhanced Rainfall	Total Direct Impacts	Value of Reduced Hail	Value of Enhanced Rainfall	Total Direct Impacts
5 Percent Rainfall Scenario			---------------------- 000s $ ----------------------					
West	4,844,797	4,490,510	7,747	4,336	12,083	$1.60	$0.90	$2.49
West Central	4,937,844	4,685,760	10,570	13,254	23,824	$2.14	$2.68	$4.83
East Central	6,600,107	6,304,794	23,567	17,726	41,294	$3.57	$2.69	$6.26
Red River Valley	3,217,251	3,079,536	11,403	6,823	18,225	$3.54	$2.12	$5.67
Totals	19,600,000	18,560,600	53,287	42,139	95,427	$2.72	$2.15	$4.87
10 Percent Rainfall Scenario								
West	4,844,797	4,490,510	7,747	7,787	15,534	$1.60	$1.61	$3.21
West Central	4,937,844	4,685,760	10,570	25,513	36,083	$2.14	$5.17	$7.31
East Central	6,600,107	6,304,794	23,567	34,593	58,161	$3.57	$5.24	$8.81
Red River Valley	3,217,251	3,079,536	11,403	13,359	24,762	$3.54	$4.15	$7.70
Totals	19,600,000	18,560,600	53,287	81,252	134,539	$2.72	$4.15	$6.86

* Limited to alfalfa, barley, canola, corn, dry edible beans, flax, soybeans, sunflowers, and all wheat.

The value of added growing season rainfall was estimated separately for the 5 percent and 10 percent scenarios (Table 5). In the 5 percent scenario, changes in the average annual gross value of crop production by county varied from $97,000 to $2.2 million (Appendix B). Collectively, the value of increased growing season rainfall was estimated to average $42 million annually over the period, which translated into benefits of $2.15 per planted acre or $2.27 per harvested acre.

In the 10 percent scenario, changes in the average annual gross value of crop production by county varied from $168,000 to $4.3 million (Appendix B). Collectively, the value of increased growing season rainfall was estimated to average $81 million annually over the period. The statewide benefits of increased growing season rainfall in the 10 percent scenario were estimated at $4.15 per planted acre or $4.38 per harvested acre.

The value of reduced hail damage was combined with the benefits of enhanced growing season rainfall to generate total direct benefits. In the 5 percent rainfall scenario, the total direct benefits (hail reduction plus added yield less price effects) to the state averaged $95.4 million annually from 1998 through 2007 (Table 5). Total direct benefits averaged $4.87 per planted acre in the 5 percent rainfall scenario. In the 10 percent scenario, the total direct benefits to the state averaged $134.5 million annually from 1998 through 2007. Total direct benefits averaged $6.86 per planted acre in the 10 percent rainfall scenario.

Direct Impacts for North Dakota Cloud Modification Project Counties

From 1998 through 2007, the North Dakota Cloud Modification Project operated in Bowman, McKenzie, Mountrail, Slope, Ward, and Williams Counties. However, cloud seeding in Slope County varied from 100 percent coverage in 1998 to zero coverage in 1999. From 2000 through 2007, the townships enrolled in the program represented about 41 percent to 50 percent of the cropland in the county. As a result of only partial cloud seeding coverage in Slope County, treated and non-treated cropland in the county was handled differently. The percentage of cropland receiving cloud seeding was handled in the same manner as other project counties. The remaining percentage of cropland that represented untreated areas was evaluated using the same methods as those used with non-program counties. In addition to treating Slope county differently, price effects were ignored in estimating the benefits of added growing season rainfall. Changes in crop production from the program counties were deemed insufficient to materially influence regional crop prices.

The average annual crop-hail loss-cost ratio by county varied from 2.3 percent to 9.5 percent (Appendix A). Averaged across all counties, the crop-hail loss ratio was estimated at 4.8 percent–numerically very similar to the overall average for the entire state. The average value of crop production for the nine crops in the program counties was estimated at $251.5 million annually. The total crop value lost to hail averaged $11.1 million or about $4.75 per planted acre annually over the period. However, only about 42.9 percent of that damage was estimated to be savable through cloud seeding. Collectively, cloud seeding in the treatment counties was estimated to save $3.7 million annually in hail damage (Table 6). An annual benefit of $3.7 million equates to $1.57 per planted acre over the period.

The value of added growing season rainfall was estimated separately for the 5 percent and 10 percent scenarios (Table 6). In the 5 percent scenario, changes in the average annual gross value of crop production by county varied from $560,000 to $3.3 million (Appendix B). Collectively, the value of increased growing season rainfall was estimated at $8.4 million annually, which translated into benefits of $3.58 per planted acre or $3.77 per harvested acre.

In the 10 percent scenario, changes in the average annual gross value of crop production by county varied from $1.1 million to $6.2 million (Appendix B). Collectively, the value of increased growing season rainfall was estimated at $16 million annually, which translated into benefits of $6.84 per planted acre or $7.19 per harvested acre.

In the 5 percent rainfall scenario, the total direct benefits (hail reduction plus added yield) averaged $12 million annually from 1998 through 2007 (Table 6). Total direct benefits averaged $5.16 per planted acre in the 5 percent rainfall scenario. In the 10 percent scenario, the total direct benefits to the state averaged $19.7 million annually. Total direct benefits averaged $8.41 per planted acre in the 10 percent rainfall scenario.

Table 6. Direct Economic Benefits, North Dakota Cloud Modification Project Counties, North Dakota, 1998 through 2007

Region	Average Acreage*		Average Annual Estimates			Estimates per Planted Acre		
	Planted	Harvested	Value of Reduced Hail	Value of Enhanced Rainfall	Total Direct Impacts	Value of Reduced Hail	Value of Enhanced Rainfall	Total Direct Impacts
5 Percent Rainfall Scenario			---------------------- 000s $ ----------------------					
West	1,632,837	1,540,660	2,194	5,111	7,305	$1.34	$3.13	$4.47
West Central	704,352	681,963	1,485	3,260	4,744	$2.11	$4.63	$6.74
Totals	2,337,188	2,222,624	3,679	8,370	12,049	$1.57	$3.58	$5.16
10 Percent Rainfall Scenario								
West	1,632,837	1,540,660	2,194	9,757	11,951	$1.34	$5.98	$7.32
West Central	704,352	681,963	1,485	6,224	7,709	$2.11	$8.84	$10.94
Totals	2,337,188	2,222,624	3,679	15,982	19,660	$1.57	$6.84	$8.41

* Limited to alfalfa, barley, canola, corn, dry edible beans, flax, soybeans, sunflowers, and all wheat.

Total Impacts for Statewide Assessment

Secondary economic impacts result from subsequent rounds of spending and respending of direct economic impacts within an economy. In this study, the reduction in hail losses and the increase in gross revenue linked to added growing season rainfall constituted the direct economic impacts from cloud seeding efforts. As those direct impacts are worked through the North Dakota economy, additional economic activity is created. The combination of direct and secondary economic activity is often called gross business volume or total economic activity.

Reduction in hail damage and increased crop revenues from enhanced growing season rainfall were both expected to increase retained revenues for producers. These additional revenues were treated as an increase in personal income, and allocated to the *Households* sector of the North Dakota Input-Output Model. The North Dakota Input-Output Model traces linkages (i.e., the amount of spending and respending) among sectors of an economy and calculates the total business activity resulting from a direct impact in a basic sector (Coon et al. 1985).

For the 5 percent rainfall scenario, total annual direct impacts from a statewide cloud seeding program were estimated to average $95.4 million from 1998 through 2007. An additional $95 million in net revenues to producers would generate secondary economic activity of $198 million annually. The gross business volume (direct plus secondary effects) was estimated at $293.8 million over the period. In the 5 percent rainfall scenario, the total economic effects were estimated at $14.99 per planted acre (Table 7).

For the 10 percent rainfall scenario, total annual direct impacts from a statewide cloud seeding program were estimated to average $134.5 million from 1998 through 2007. An additional $134.5 million in net revenues to producers would generate secondary economic activity of $279.6 million annually. The gross business volume (direct plus secondary effects) was estimated at $414.2 million over the period. In the 10 percent rainfall scenario, the total economic effects were estimated at $21.13 per planted acre (Table 7).

Table 7. Average Annual Total Economic Impacts, North Dakota Cloud Modification Project, Treatment Counties and Statewide Assessment, North Dakota, 1998 through 2007

	Average Annual Effects (000s $)		Annual Effects per Planted Acre	
Region	Total Direct Impacts	Gross Business Volume*	Total Direct Impacts	Gross Business Volume*
5 Percent Rainfall Scenario – Statewide Program				
West	12,083	37,196	$2.49	$7.68
West Central	23,824	73,337	$4.83	$14.85
East Central	41,294	127,115	$6.26	$19.26
R. River Valley	18,225	56,104	$5.67	$17.44
Totals	95,427	293,752	$4.87	$14.99
10 Percent Rainfall Scenario – Statewide Program				
West	15,334	47,817	$3.21	$9.87
West Central	36,083	111,074	$7.31	$22.49
East Central	58,161	179,035	$8.81	$27.13
R. River Valley	24,762	76,225	$7.70	$23.69
Totals	134,539	414,151	$6.86	$21.13
5 Percent Rainfall Scenario – NDCMP Counties				
West	7,305	22,486	$4.47	$13.77
West Central	4,744	14,604	$6.74	$20.73
Totals	12,049	37,090	$5.16	$15.87
10 Percent Rainfall Scenario – NDCMP Counties				
West	11,951	36,790	$7.32	$22.53
West Central	7,709	23,729	$10.94	$33.69
Totals	19,660	60,519	$8.41	$25.89

* Gross business volume was distributed among counties based on dollar volume of direct impacts by county. Actual generation of secondary economic impacts is likely to primarily occur in local and regional trade centers and may not be proportional to direct impacts within any county or rainfall enhancement region.

Total Impacts for North Dakota Cloud Modification Project

For the 5 percent rainfall scenario, total direct impacts from the North Dakota Cloud Modification Project were estimated to average $12.0 million from 1998 through 2007 (Table 7). An additional $12 million in net revenues to producers would generate secondary economic activity of $25 million annually. The gross business volume (direct plus secondary effects) was estimated at $37.1 million over the period. In the 5 percent rainfall scenario, the total economic effects were estimated at $15.87 per planted acre (Table 7).

For the 10 percent rainfall scenario, total direct impacts from a statewide cloud seeding program were estimated to average $19.7 million from 1998 through 2007. An additional $19.7 million in net revenues to producers would generate secondary economic activity of $40.9 million annually. The gross business volume (direct plus secondary effects) was estimated at $60.5 million over the period. In the 10 percent rainfall scenario, the total economic effects were estimated at $25.89 per planted acre (Table 7).

State Tax Revenues

Governmental revenues, usually based on tax collections, are another important measure of economic impacts. State collections from personal income, corporate income, and sales and use taxes were estimated based on the secondary economic activity generated by the reduction in hail losses and revenues associated with added growing season rainfall. Secondary economic impacts in the *Retail Trade* sector were used to estimate revenue from sales and use taxes. Economic activity in the *Households* sector (which represents economy-wide personal income) was used to estimate personal income tax collections. Secondary economic impacts in other sectors of the economy (e.g., business and personal services, communications and public utilities, construction, transportation) were used to estimate corporate income tax collections. In the statewide assessment, annual collections from personal income, corporate income, and sales and use taxes arising from secondary economic activity were estimated at $5.9 million and $8.3 million for the 5 percent and 10 percent rainfall scenarios, respectively (Table 8). In the evaluation of the NDCMP, annual collections from personal income, corporate income, and sales and use taxes arising from secondary economic activity were estimated at $745,000 and $1.2 million for the 5 percent and 10 percent rainfall scenarios, respectively (Table 8).

Table 8. Average Annual State Tax Collections, North Dakota Cloud Modification Project Counties and Statewide Assessment, North Dakota, 1998 through 2007

State Tax	Statewide Assessment		ND Cloud Modification Project Counties	
	5 Percent Rainfall Scenario	10 Percent Rainfall Scenario	5 Percent Rainfall Scenario	10 Percent Rainfall Scenario
Sales and Use	$3,290,000	$4,639,000	$415,000	$678,000
Personal Income	$2,222,000	$3,133,000	$281,000	$458,000
Corporate Income	$392,000	$552,000	$49,000	$81,000
Totals	$5,904,000	$8,324,000	$745,000	$1,217,000

Conclusions

The economic impacts of cloud seeding in North Dakota were evaluated from 1998 through 2007. Two separate assessments were conducted: a statewide assessment assuming the entire state was included in a cloud seeding effort and an assessment of the North Dakota Cloud Modification Project counties. Within each major assessment, two scenarios were used to evaluate the economic effects of different assumptions on the amount of additional growing season rainfall attributable to cloud seeding.

The last study to examine the economic impacts of the North Dakota Cloud Modification Project was conducted in 1998 (Sell and Leistritz 1998). In that study, a statewide cloud seeding program was estimated to have an average annual gross business volume of $332 million in real terms (2007 dollars), based on eight of the state's top nine crops. By comparison, the statewide assessment in this study estimated an average annual gross business volume of $294 million to $414 million, depending upon assumptions for added growing season rainfall. Some notable differences exist between the two studies. First, the Sell and Leistritz study was based on eight crops, with one of the state's largest crops omitted (i.e., canola) – this study contained the state's largest eight crops and included alfalfa as a ninth crop. Second, price adjustments related to increased production were only included for wheat in the Sell and Leistritz report – this study included price adjustments for all crops except soybeans and corn. Adding price adjustments produced more conservative estimates of the value of added growing season precipitation. The added growing season rainfall estimates in the Sell and Leistritz study would approximate a 15 percent increase in actual growing season rainfall – by contrast, the largest change in growing season rainfall used in this study was a 10 percent increase. Considering the differences between the two studies, the value of cloud seeding efforts in the state would appear to have increased substantially from the assessments conducted 10 years ago. Despite using more conservative estimates for added growing season rainfall, the value of a statewide cloud seeding effort appears to have paralleled changes in the overall value of the state's top eight crops.

From a producer's perspective, the direct economic value of cloud seeding, averaged across the state, was estimated to range from $4.87 to $6.86 per planted acre. Those values would represent a meaningful boost in revenues to producers.

The North Dakota Atmospheric Resource Board estimated the expected annual cost of implementing a statewide cloud seeding program to be nearly $3 million. The most conservative of the two scenarios evaluated in this study indicated that collections of state taxes would be nearly double the anticipated cost ($3 million cost versus $6 million in state revenues). The benefit to the state would be substantial, especially considering the economic impacts in this study did not include all crops, nor did the impacts include avoided hail losses to personal, commercial, and industrial property. The state could reap tremendous economic benefits from a modest investment if the North Dakota Cloud Modification Project was implemented statewide.

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APPENDIX A

Average Crop-Loss Ratios, by County, North Dakota, 1998 through 2007

Appendix Table A1. Planted and Harvested Acreage, Crop Value, Crop-Hail Loss Factors, Hail Losses, Hail Reduction Factors, and Avoided Hail Losses, by County, North Dakota, Averages 1998 through 2007

County	Planted Acreage	Harvested Acreage	Value of Crop Production	Crop-Hail Loss Ratio	Total Hail Losses	Hail Reduction Factors	Avoided Hail Losses
Adams	229,439	204,433	$18,587,332	7.32%	$1,360,255	41.22%	$560,750
Barnes	626,379	609,626	$106,580,920	4.26%	$4,539,457	39.16%	$1,777,646
Benson	405,125	382,615	$50,289,829	5.65%	$2,841,475	41.84%	$1,188,880
Billings	103,256	93,389	$8,648,465	4.18%	$361,517	34.51%	$124,772
Bottineau	566,160	535,590	$73,377,463	2.95%	$2,168,235	44.06%	$955,318
Bowman	204,292	182,639	$17,809,793	9.49%	$1,690,884	40.32%	$460,667
Burke	320,725	308,125	$34,438,107	3.48%	$1,197,850	43.94%	$526,365
Burleigh	294,531	267,685	$29,935,479	3.19%	$955,855	39.12%	$373,909
Cass	830,261	806,899	$139,272,974	6.70%	$9,328,296	36.26%	$3,382,904
Cavalier	715,830	683,237	$103,328,652	9.53%	$9,842,908	44.19%	$4,349,416
Dickey	323,642	309,569	$58,574,675	6.09%	$3,566,745	38.43%	$1,370,667
Divide	316,249	303,971	$33,942,270	1.67%	$566,306	43.92%	$248,730
Dunn	289,254	270,293	$25,981,342	4.06%	$1,054,050	37.68%	$397,146
Eddy	188,304	173,553	$24,329,704	2.61%	$636,192	40.87%	$260,017
Emmons	333,947	298,526	$37,837,697	3.53%	$1,335,614	41.23%	$550,632
Foster	259,640	246,226	$35,616,851	5.17%	$1,840,630	41.11%	$756,711
Golden Valley	107,600	96,436	$10,438,870	7.27%	$759,152	41.58%	$315,659
Grand Forks	526,079	495,230	$83,438,176	4.60%	$3,834,257	38.74%	$1,485,528
Grant	267,618	229,326	$21,638,103	6.42%	$1,388,630	39.82%	$552,925
Griggs	279,960	267,941	$49,917,207	5.00%	$2,495,220	40.68%	$1,015,167
Hettinger	410,548	386,396	$47,429,926	4.57%	$2,165,181	43.37%	$939,134
Kidder	220,162	206,883	$24,749,452	2.91%	$720,606	35.41%	$255,142
La Moure	471,557	455,089	$81,523,202	6.92%	$5,643,661	38.50%	$2,172,767
Logan	284,618	270,377	$45,030,921	5.31%	$2,392,229	41.20%	$985,551
McHenry	398,700	381,785	$44,990,569	3.28%	$1,477,634	41.53%	$613,599
McIntosh	314,644	298,468	$50,371,642	5.86%	$2,949,768	41.05%	$1,210,958
McKenzie	281,209	260,720	$26,083,792	2.89%	$752,679	41.48%	$221,231
McLean	638,631	614,886	$75,759,703	3.82%	$2,896,640	43.46%	$1,258,767
Mercer	178,869	165,570	$17,484,400	1.99%	$348,537	40.02%	$139,484
Morton	355,915	314,632	$31,657,048	6.25%	$1,979,140	39.96%	$790,844
Mountrail	484,044	469,118	$50,359,894	2.26%	$1,137,769	43.46%	$380,094
Nelson	323,436	310,600	$47,843,676	4.55%	$2,177,346	41.57%	$905,213
Oliver	145,031	136,000	$16,161,076	3.26%	$527,473	39.99%	$210,932
Pembina	431,996	408,022	$73,530,168	7.08%	$5,206,089	39.96%	$2,080,336
Pierce	299,380	285,490	$37,119,513	5.68%	$2,109,688	42.89%	$904,743
Ramsey	426,590	400,300	$53,096,101	6.25%	$3,318,886	42.08%	$1,396,509
Ransom	294,636	285,593	$61,689,830	2.60%	$1,605,687	38.80%	$623,033

- continued -

Appendix Table A1. Continued

County	Planted Acreage	Harvested Acreage	Value of Crop Production	Crop-Hail Loss Ratio	Total Hail Losses	Hail Reduction Factors	Avoided Hail Losses
Renville	406,793	391,961	$48,946,938	3.93%	$1,925,018	44.49%	$856,392
Richland	527,959	513,745	$89,878,969	5.04%	$4,531,430	35.90%	$1,626,770
Rolette	227,345	216,660	$31,262,402	4.42%	$1,383,101	42.21%	$583,835
Sargent	328,190	311,776	$60,697,844	5.13%	$3,115,815	37.96%	$1,182,775
Sheridan	248,582	235,488	$30,783,687	4.08%	$1,255,811	42.74%	$536,685
Sioux	135,443	108,781	$11,935,333	2.99%	$356,274	38.30%	$136,437
Slope*	184,682	166,320	$17,613,103	4.71%	$829,754	41.25%	$351,583
Stark	352,013	332,497	$36,633,549	4.09%	$1,499,232	40.67%	$609,713
Steele	368,531	355,823	$68,217,305	6.56%	$4,471,923	38.59%	$1,725,498
Stutsman	657,072	630,786	$91,093,008	5.63%	$5,127,036	38.75%	$1,986,650
Towner	414,365	391,507	$56,901,489	5.25%	$2,988,506	43.52%	$1,300,672
Traill	432,493	416,726	$77,646,727	3.24%	$2,515,467	37.25%	$937,028
Walsh	468,464	438,915	$75,329,377	6.23%	$4,689,656	40.31%	$1,890,307
Ward	704,352	681,963	$88,411,495	4.90%	$4,331,064	43.86%	$1,484,528
Wells	516,850	490,555	$76,802,783	4.88%	$3,747,984	41.51%	$1,555,694
Williams	478,608	461,864	$51,239,877	4.60%	$2,355,594	43.33%	$780,424
State Total	19,600,000	18,560,600	$2,662,258,708	4.799%	$134,296,206	39.68%	$53,287,140

Note: County-level estimates of crop hail losses avoidable due to cloud seeding remained unchanged between the statewide assessment and the NDCMP analysis.

APPENDIX B

Gross Value of Crop Production, Total Direct Impacts, and Gross Business Volume, North Dakota Cloud Modification Project Counties and Statewide Assessment, North Dakota, 1998 through 2007

Appendix Table B1. Value of Enhanced Growing Season Rainfall, Five and Ten Percent Rainfall Scenarios, Statewide Assessment, by County, North Dakota, Averages 1998 through 2007

County	5 Percent Rainfall Scenario			10 Percent Rainfall Scenario		
	Change in Gross Crop Revenues	Value per Harvested Acre	Value per Planted Acre	Change in Gross Crop Revenues	Value per Harvested Acre	Value per Planted Acre
Adams	$275,845	$1.35	$1.20	$498,870	$2.44	$2.17
Barnes	$1,882,907	$3.09	$3.01	$3,703,172	$6.07	$5.91
Benson	$962,348	$2.52	$2.38	$1,863,896	$4.87	$4.60
Billings	$106,981	$1.15	$1.04	$196,900	$2.11	$1.91
Bottineau	$1,583,506	$2.96	$2.80	$3,018,805	$5.64	$5.33
Bowman	$208,777	$1.14	$1.02	$401,534	$2.20	$1.97
Burke	$260,286	$0.84	$0.81	$437,427	$1.42	$1.36
Burleigh	$659,455	$2.46	$2.24	$1,261,573	$4.71	$4.28
Cass	$2,196,810	$2.72	$2.65	$4,341,815	$5.38	$5.23
Cavalier	$1,306,867	$1.91	$1.83	$2,457,705	$3.60	$3.43
Dickey	$1,022,373	$3.30	$3.16	$2,020,264	$6.53	$6.24
Divide	$212,768	$0.70	$0.67	$340,628	$1.12	$1.08
Dunn	$273,955	$1.01	$0.95	$486,160	$1.80	$1.68
Eddy	$473,291	$2.73	$2.51	$923,863	$5.32	$4.91
Emmons	$797,156	$2.67	$2.39	$1,529,898	$5.12	$4.58
Foster	$699,556	$2.84	$2.69	$1,365,525	$5.55	$5.26
Golden Valley	$97,071	$1.01	$0.90	$168,098	$1.74	$1.56
Grand Forks	$954,951	$1.93	$1.82	$1,846,901	$3.73	$3.51
Grant	$302,802	$1.32	$1.13	$557,402	$2.43	$2.08
Griggs	$845,196	$3.15	$3.02	$1,662,264	$6.20	$5.94
Hettinger	$247,704	$0.64	$0.60	$383,422	$0.99	$0.93
Kidder	$494,029	$2.39	$2.24	$950,164	$4.59	$4.32
La Moure	$1,490,629	$3.28	$3.16	$2,942,312	$6.47	$6.24
Logan	$894,982	$3.31	$3.14	$1,749,545	$6.47	$6.15
McHenry	$1,087,362	$2.85	$2.73	$2,084,748	$5.46	$5.23
McIntosh	$1,010,558	$3.39	$3.21	$1,974,619	$6.62	$6.28
McKenzie	$259,184	$0.99	$0.92	$495,802	$1.90	$1.76
McLean	$1,595,240	$2.59	$2.50	$3,013,675	$4.90	$4.72
Mercer	$153,987	$0.93	$0.86	$275,819	$1.67	$1.54
Morton	$401,045	$1.27	$1.13	$730,723	$2.32	$2.05
Mountrail	$446,094	$0.95	$0.92	$846,844	$1.81	$1.75
Nelson	$762,292	$2.45	$2.36	$1,473,203	$4.74	$4.55
Oliver	$143,041	$1.05	$0.99	$258,063	$1.90	$1.78
Pembina	$404,197	$0.99	$0.94	$753,610	$1.85	$1.74
Pierce	$821,630	$2.88	$2.74	$1,572,739	$5.51	$5.25
Ramsey	$1,069,993	$2.67	$2.51	$2,074,724	$5.18	$4.86

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Appendix Table B1. Continued

County	5 Percent Rainfall Scenario			10 Percent Rainfall Scenario		
	Change in Gross Crop Revenues	Value per Harvested Acre	Value per Planted Acre	Change in Gross Crop Revenues	Value per Harvested Acre	Value per Planted Acre
Ransom	$979,914	$3.43	$3.33	$1,935,526	$6.78	$6.57
Renville	$1,101,788	$2.81	$2.71	$2,089,438	$5.33	$5.14
Richland	$1,531,452	$2.98	$2.90	$3,039,675	$5.92	$5.76
Rolette	$631,239	$2.91	$2.78	$1,205,009	$5.56	$5.30
Sargent	$1,047,559	$3.36	$3.19	$2,073,572	$6.65	$6.32
Sheridan	$741,703	$3.15	$2.98	$1,426,756	$6.06	$5.74
Sioux	$197,572	$1.82	$1.46	$369,701	$3.40	$2.73
Slope	$161,734	$0.97	$0.88	$293,796	$1.77	$1.59
Stark	$252,429	$0.76	$0.72	$418,409	$1.26	$1.19
Steele	$1,092,079	$3.07	$2.96	$2,148,395	$6.04	$5.83
Stutsman	$1,841,887	$2.92	$2.80	$3,609,340	$5.72	$5.49
Towner	$930,999	$2.38	$2.25	$1,784,264	$4.56	$4.31
Traill	$1,186,199	$2.85	$2.74	$2,343,951	$5.62	$5.42
Walsh	$548,981	$1.25	$1.17	$1,033,263	$2.35	$2.21
Ward	$1,835,188	$2.69	$2.61	$3,635,883	$5.33	$5.16
Wells	$1,318,605	$2.69	$2.55	$2,555,374	$5.21	$4.94
Williams	$335,176	$0.73	$0.70	$627,282	$1.36	$1.31
State Total	$42,139,373	$2.27	$2.15	$81,252,349	$4.38	$4.15

Appendix Table B2. Direct Impacts and Gross Business Volume, Five and Ten Percent Rainfall Scenarios, Statewide Assessment, by County, North Dakota, Averages 1998 through 2007

	5 Percent Rainfall Scenario				10 Percent Rainfall Scenario			
County	Total Direct Impacts	Gross Business Volume*	Total Direct Impacts	Gross Business Volume*	Total Direct Impacts	Gross Business Volume*	Total Direct Impacts	Gross Business Volume*
			---- per planted acre ---				---- per planted acre ---	
Adams	$836,595	$2,575,296	$3.65	$11.22	$1,059,621	$3,261,815	$4.62	$14.22
Barnes	$3,660,554	$11,268,304	$5.84	$17.99	$5,480,819	$16,871,526	$8.75	$26.94
Benson	$2,151,228	$6,622,137	$5.31	$16.35	$3,052,776	$9,397,316	$7.54	$23.20
Billings	$231,753	$713,407	$2.24	$6.91	$321,673	$990,201	$3.12	$9.59
Bottineau	$2,538,825	$7,815,279	$4.48	$13.80	$3,974,123	$12,233,488	$7.02	$21.61
Bowman	$669,444	$2,060,754	$3.28	$10.09	$862,201	$2,654,100	$4.22	$12.99
Burke	$786,651	$2,421,552	$2.45	$7.55	$963,791	$2,966,825	$3.01	$9.25
Burleigh	$1,033,364	$3,181,011	$3.51	$10.80	$1,635,482	$5,034,480	$5.55	$17.09
Cass	$5,579,714	$17,176,067	$6.72	$20.69	$7,724,719	$23,778,892	$9.30	$28.64
Cavalier	$5,656,283	$17,411,770	$7.90	$24.32	$6,807,121	$20,954,263	$9.51	$29.27
Dickey	$2,393,040	$7,366,510	$7.39	$22.76	$3,390,931	$10,438,256	$10.48	$32.25
Divide	$461,497	$1,420,630	$1.46	$4.49	$589,358	$1,814,211	$1.86	$5.74
Dunn	$671,102	$2,065,857	$2.32	$7.14	$883,307	$2,719,071	$3.05	$9.40
Eddy	$733,308	$2,257,346	$3.89	$11.99	$1,183,881	$3,644,323	$6.29	$19.35
Emmons	$1,347,788	$4,148,905	$4.04	$12.42	$2,080,530	$6,404,467	$6.23	$19.18
Foster	$1,456,267	$4,482,836	$5.61	$17.27	$2,122,236	$6,532,850	$8.17	$25.16
Golden Valley	$412,729	$1,270,507	$3.84	$11.81	$483,757	$1,489,142	$4.50	$13.84
Grand Forks	$2,440,479	$7,512,541	$4.64	$14.28	$3,332,429	$10,258,170	$6.33	$19.50
Grant	$855,727	$2,634,191	$3.20	$9.84	$1,110,327	$3,417,905	$4.15	$12.77
Griggs	$1,860,363	$5,726,768	$6.65	$20.46	$2,677,432	$8,241,900	$9.56	$29.44
Hettinger	$1,186,838	$3,653,450	$2.89	$8.90	$1,322,556	$4,071,205	$3.22	$9.92
Kidder	$749,171	$2,306,178	$3.40	$10.47	$1,205,306	$3,710,277	$5.47	$16.85
La Moure	$3,663,396	$11,277,053	$7.77	$23.91	$5,115,079	$15,745,676	$10.85	$33.39
Logan	$1,880,533	$5,788,855	$6.61	$20.34	$2,735,096	$8,419,407	$9.61	$29.58
McHenry	$1,700,961	$5,236,077	$4.27	$13.13	$2,698,347	$8,306,282	$6.77	$20.83
McIntosh	$2,221,515	$6,838,504	$7.06	$21.73	$3,185,577	$9,806,116	$10.12	$31.17
McKenzie	$480,415	$1,478,864	$1.71	$5.26	$717,032	$2,207,230	$2.55	$7.85
McLean	$2,854,007	$8,785,507	$4.47	$13.76	$4,272,443	$13,151,800	$6.69	$20.59
Mercer	$293,471	$903,393	$1.64	$5.05	$415,303	$1,278,421	$2.32	$7.15
Morton	$1,191,889	$3,668,999	$3.35	$10.31	$1,521,566	$4,683,816	$4.28	$13.16
Mountrail	$826,189	$2,543,261	$1.71	$5.25	$1,226,938	$3,776,866	$2.53	$7.80
Nelson	$1,667,505	$5,133,090	$5.16	$15.87	$2,378,416	$7,321,445	$7.35	$22.64
Oliver	$353,973	$1,089,636	$2.44	$7.51	$468,995	$1,443,700	$3.23	$9.95
Pembina	$2,484,534	$7,648,154	$5.75	$17.70	$2,833,946	$8,723,696	$6.56	$20.19
Pierce	$1,726,373	$5,314,303	$5.77	$17.75	$2,477,481	$7,626,396	$8.28	$25.47

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Appendix Table B2. Continued

	5 Percent Rainfall Scenario				10 Percent Rainfall Scenario			
County	Total Direct Impacts	Gross Business Volume*	Total Direct Impacts	Gross Business Volume*	Total Direct Impacts	Gross Business Volume*	Total Direct Impacts	Gross Business Volume*
			---- per planted acre ---				---- per planted acre ---	
Ramsey	$2,466,501	$7,592,646	$5.78	$17.80	$3,471,233	$10,685,448	$8.14	$25.05
Ransom	$1,602,948	$4,934,363	$5.44	$16.75	$2,558,559	$7,875,976	$8.68	$26.73
Renville	$1,958,180	$6,027,878	$4.81	$14.82	$2,945,830	$9,068,107	$7.24	$22.29
Richland	$3,158,221	$9,721,971	$5.98	$18.41	$4,666,445	$14,364,650	$8.84	$27.21
Rolette	$1,215,075	$3,740,372	$5.34	$16.45	$1,788,845	$5,506,576	$7.87	$24.22
Sargent	$2,230,334	$6,865,651	$6.80	$20.92	$3,256,347	$10,023,967	$9.92	$30.54
Sheridan	$1,278,389	$3,935,271	$5.14	$15.83	$1,963,441	$6,044,032	$7.90	$24.31
Sioux	$334,009	$1,028,181	$2.47	$7.59	$506,139	$1,558,039	$3.74	$11.50
Slope*	$513,317	$1,580,147	$2.78	$8.56	$645,380	$1,986,663	$3.49	$10.76
Stark	$862,142	$2,653,936	$2.45	$7.54	$1,028,122	$3,164,854	$2.92	$8.99
Steele	$2,817,577	$8,673,364	$7.65	$23.53	$3,873,892	$11,924,948	$10.51	$32.36
Stutsman	$3,828,537	$11,785,408	$5.83	$17.94	$5,595,990	$17,226,058	$8.52	$26.22
Towner	$2,231,672	$6,869,768	$5.39	$16.58	$3,084,936	$9,496,315	$7.44	$22.92
Traill	$2,123,227	$6,535,943	$4.91	$15.11	$3,280,979	$10,099,793	$7.59	$23.35
Walsh	$2,439,289	$7,508,877	$5.21	$16.03	$2,923,570	$8,999,585	$6.24	$19.21
Ward	$3,319,716	$10,219,102	$4.71	$14.51	$5,120,411	$15,762,090	$7.27	$22.38
Wells	$2,874,299	$8,847,972	$5.56	$17.12	$4,111,069	$12,655,044	$7.95	$24.48
Williams	$1,115,600	$3,434,158	$2.33	$7.18	$1,407,706	$4,333,321	$2.94	$9.05
State Total	$95,426,513	$293,752,000	$4.87	$14.99	$134,539,489	$414,151,000	$6.86	$21.13

* Gross business volume was distributed among counties based on dollar volume of direct impacts by county. Actual generation of secondary economic impacts is likely to primarily occur in local and regional trade centers throughout the state and may not be proportional to direct impacts in any individual county.

Appendix Table B3. Value of Enhanced Growing Season Rainfall, Five and Ten Percent Rainfall Scenarios, North Dakota Cloud Modification Project, North Dakota, Averages 1998 through 2007

County	5 Percent Rainfall Scenario			10 Percent Rainfall Scenario		
	Change in Gross Crop Revenues	Value per Harvested Acre	Value per Planted Acre	Change in Gross Crop Revenues	Value per Harvested Acre	Value per Planted Acre
Bowman	$584,393	$3.20	$2.86	$1,115,675	$6.11	$5.46
McKenzie	$813,431	$3.12	$2.89	$1,553,021	$5.96	$5.52
Mountrail	$1,586,871	$3.38	$3.28	$3,029,683	$6.46	$6.26
Slope	$557,274	$3.35	$3.02	$1,063,934	$6.40	$5.76
Ward	$3,259,733	$4.78	$4.63	$6,224,225	$9.13	$8.84
Williams	$1,568,612	$3.40	$3.28	$2,995,107	$6.48	$6.26
Totals	$8,370,314	$3.77	$3.58	$15,981,644	$7.19	$6.84

Appendix Table B4. Direct Impacts and Gross Business Volume, Five and Ten Percent Rainfall Scenarios, North Dakota Cloud Modification Project, North Dakota, Averages 1998 through 2007

	5 Percent Rainfall Scenario				10 Percent Rainfall Scenario			
County	Total Direct Impacts	Gross Business Volume*	Total Direct Impacts	Gross Business Volume*	Total Direct Impacts	Gross Business Volume*	Total Direct Impacts	Gross Business Volume*
			---- per planted acre ---				---- per planted acre ---	
Bowman	$1,045,060	$3,217,013	$5.12	$15.75	$1,576,342	$4,852,382	$7.72	$23.75
McKenzie	$1,034,662	$3,185,004	$3.68	$11.33	$1,774,252	$5,461,597	$6.31	$19.42
Mountrail	$1,966,966	$6,054,919	$4.06	$12.51	$3,409,777	$10,496,160	$7.04	$21.68
Slope	$908,858	$2,797,740	$4.92	$15.15	$1,415,517	$4,357,321	$7.66	$23.59
Ward	$4,744,261	$14,604,279	$6.74	$20.73	$7,708,753	$23,729,499	$10.94	$33.69
Williams	$2,349,035	$7,231,045	$4.91	$15.11	$3,775,530	$11,622,041	$7.89	$24.28
Totals	$12,048,841	$37,090,000	$5.16	$15.87	$19,660,171	$60,519,000	$8.41	$25.89

* Gross business volume was distributed among counties based on dollar volume of direct impacts by county. Actual generation of secondary economic impacts is likely to primarily occur in local and regional trade centers and may not be proportional to direct impacts within NDCMP counties.