Agribusiness & Applied Economics Report No. 791

June 2019

ECONOMIC IMPACTS
OF CLOUD SEEDING ON AGRICULTURAL CROPS IN NORTH DAKOTA

Dean Bangsund & Nancy Hodur

NDSU | AGRIBUSINESS AND APPLIED ECONOMICS

Acknowledgments

Special thanks are extended to Darin Langerud, Director, North Dakota Atmospheric Resource Board, for his efforts in securing insurance data and for his leadership throughout the study.

Thanks are extended to Edie Nelson, Department of Agribusiness and Applied Economics, NDSU, for document preparation and to our colleagues for reviewing this manuscript.

Financial support was provided by the North Dakota Atmospheric Resource Board.

This publication is available electronically at this web site: http://agecon.lib.umn.edu/.

Table of Contents

List of Tables

List of Figures

List of Appendix Tables

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 2008 through 2017 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.

North Dakota's cloud seeding program included Bowman, McKenzie, Mountrail, Slope, Ward, and Williams Counties from 2008 through 2017 and Burke County from 2015 through 2017. Average annual benefits from hail suppression were estimated at $6.9 million. The value of increased rainfall in the 5 percent rainfall scenario was estimated to average $21.2 million annually, while the value of increased growing season rainfall was estimated to average nearly $41.9 million annually in the 10 percent rainfall scenario. Total benefits for the nine crops would average $12.20 to $21.16 per planted acre for the 5 percent and 10 percent scenarios, respectively. Program costs were estimated at $909,000 per year while direct annual benefits to producers ranged from $28 million to $48 million, depending upon rainfall scenarios. Total statewide business activity, which includes producer benefits plus indirect and induced economic effects, ranged from $55 million to $96 million annually.

Statewide, cloud seeding would be estimated to save $117 million in annual hail damage to the nine crops in this study. The value of increased precipitation in the 5 percent rainfall scenario was estimated to average $182 million annually, while the value of increased growing season precipitation was estimated to average nearly $360 million annually in the 10 percent rainfall scenario. Including hail suppression, total direct benefits of cloud seeding would average nearly $300 million or $14.65 per planted acre annually from 2008 through 2017 under the 5 percent rainfall scenario and $477 million or $23.35 per planted acre annually under the 10 percent rainfall scenario.

For the 5 percent rainfall scenario, total direct impacts of $300 million from a statewide cloud seeding project were estimated to generate a gross business volume (direct plus secondary economic effects) of $590 million or $28.90 per planted acre annually over the period. For the 10 percent rainfall scenario, total direct impacts of $477 million would create a gross business volume of $940 million or $46 per planted acre annually.

A breakeven analysis revealed that program efficacy could range from 2 percent to 13 percent of anticipated outcomes and still generate producer benefits equal to program costs in the treatment counties. Considering the treatment counties had about 2.3 million acres planted annually to the nine study crops with a program cost of $909,000 per year, the value of hail suppression, added yield, or any combination of hail reduction and added yield would only need to be about $0.40 per planted acre for the program costs to equal program benefits.

The North Dakota Atmospheric Resource Board estimated the expected annual cost of implementing a statewide cloud seeding program to be $4 million, which would only require yield gains of one-tenth to one-quarter bushel per acre for program costs to match producer benefits. The potential benefit to the state could 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.

Assessment of the Economic Impacts of Cloud Seeding on Agricultural Crops in North Dakota

Dean A. Bangsund and Nancy M. Hodur*

Introduction

North Dakota is consistently among the top states for annual hail damage to agricultural crops (National Crop Insurance Services 2013, 2014, 2015, 2016, 2017; 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 NDCMP, 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 studies 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; Bangsund and Leistritz 2009).

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 Bangsund and Leistritz (2009). Since 2007, crops raised and their value have changed 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 and Bangsund and Leistritz studies, the economic impact of cloud seeding was estimated for both project counties and for the entire state, even though only a handful of counties in western North Dakota actually are part of the NDCMP.

* Research Scientist, Department of Agribusiness and Applied Economics and Director, Center for Social Research, North Dakota State University, Fargo.

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 (2008 through 2017) 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.

<u>Treatment Counties and Rain Enhancement Regions</u>

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). Burke County participated in the project from 2015 through 2017.

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.

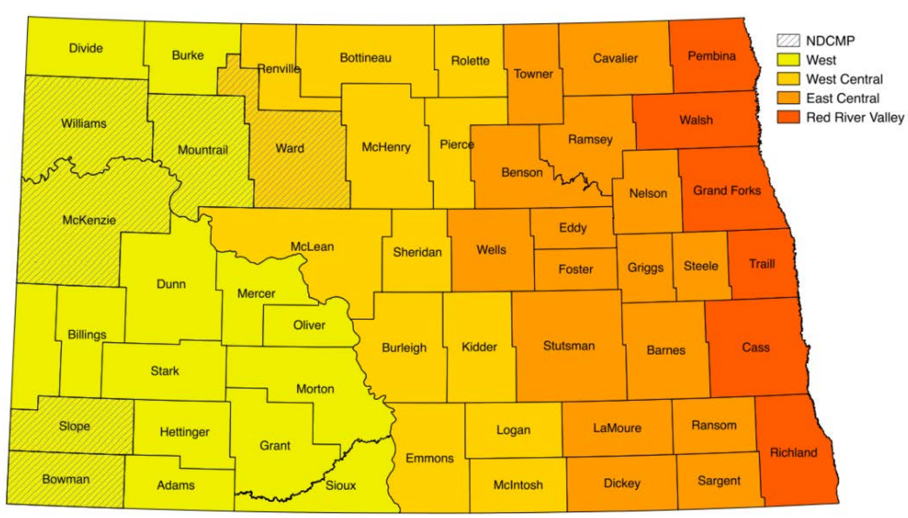

Figure 1. Cloud Modification Project Counties and Rain Enhancement Regions, North Dakota, 2008 through 2017
Source: North Dakota Atmospheric Resource Board (2019).

[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; Bangsund and Leistritz 2009). 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 in previous studies (Johnson et al. 1989; Sell and Leistritz 1998; Bangsund and Leistritz 2009). 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 (2009-2018). 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*), North Dakota Farm Services Agency, and NDSU Extension were used to estimate gross value of crop production in North Dakota.

(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 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 canola acreage exceeding oats and flax acreage in the state. Bangsund and Leistritz (2009) included alfalfa, barley, dry beans, canola, corn, flax, soybeans, sunflowers, and wheat.

The top eight crops in North Dakota, from 2008 through 2017, based on harvested acreage were wheat[1], soybeans, corn, canola, barley, sunflowers, dry edible beans, and flax (Table 1). Also included in this study was alfalfa. From 2008 through 2017, planted acreage for the eight crops, plus harvested acreage for alfalfa, averaged 20.4 million acres annually or about 96.5 percent of planted acreage in the state.

[1] Durum, spring, and winter wheat were combined to represent one crop

Table 1. Crop Production Statistics, North Dakota, 2008 through 2017

Area Crop	Acres Planted	Acres Harvested	Yield Per Harvested Acre	Units	Production	Price/Unit	Value
All Counties	---------- 000s ---------						--- 000s ---
Alfalfa	1,482.7	1,482.7	1.89	ton	2,799,667	$85.65	$239,789.9
Barley	861.9	783.8	64.94	bu	50,894,150	$4.98	$253,421.2
Canola	1,164.3	1,154.3	17.60	cwt	20,317,572	$18.93	$384,519.2
Corn	2,608.5	2,558.6	131.25	bu	335,826,809	$4.02	$1,349,178.5
Dry Edible Beans	611.4	586.8	16.87	cwt	9,896,287	$28.96	$286,616.3
Flax	276.1	270.9	20.70	bu	5,608,170	$10.88	$61,006.8
Soybeans	5,052.4	4,889.4	34.27	bu	167,570,864	$10.20	$1,709,634.3
Sunflowers	746.4	710.3	15.11	cwt	10,729,239	$21.00	$225,290.5
Wheat	7,623.1	7,436.6	44.43	bu	330,409,498	$6.15	$2,031,126.2
Totals	20,426.8	19,873.4					$6,540,582.9
Study Counties*							
Alfalfa	288.1	288.1	1.62	ton	467,844	$86.73	$40,576.1
Barley	120.8	110.2	57.96	bu	6,386,558	$4.90	$31,317.9
Canola	251.5	249.3	16.40	cwt	4,089,103	$18.59	$76,010.5
Corn	24.4	23.2	97.88	bu	2,274,110	$3.80	$8,641.9
Dry Edible Beans	2.0	1.8	14.26	cwt	25,644	$28.54	$731.8
Flax	101.1	99.7	21.31	bu	2,123,436	$10.65	$22,611.4
Soybeans	93.9	91.9	31.21	bu	2,868,710	$9.49	$27,229.3
Sunflowers	68.6	65.0	15.58	cwt	1,012,332	$20.52	$20,772.2
Wheat	1,717.1	1,658.8	37.17	bu	61,658,323	$6.34	$391,035.1
Totals	2,667.5	2,588.0					$618,926.2

* Project included Bowman, Burke, McKenzie, Mountrail, Slope, Ward, and Williams Counties. Represents data for all acreage in project counties, even though Slope County only had selected townships in the program. Also includes the ten-year average acreage for Burke County even though Burke County was only in the project from 2015 through 2017.

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 2019). 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 (Table 2). 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.

Table 2. Average Annual Crop-Loss Ratios, Cloud Modification Project Counties and All Counties, by Crop, North Dakota, 2008 through 2017

Crop	Cloud Modification Project Counties	All Counties
	----- Crop-loss Ratios (%) -----	
Alfalfa	8.1179	4.3046
Barley	7.0548	5.5090
Canola	5.9102	4.8148
Corn	2.1030	4.4342
Dry Edible Beans	8.9051	6.5982
Flax	2.0820	2.8419
Soybeans	4.9902	5.5084
Sunflowers	1.6546	3.4831
Wheat	4.2729	4.0546
Composite Average	4.4353	4.7736

Crop loss ratios represent insured losses divided by total insured liabilities for hail-only damages. Ratios for project counties do not have adjustments for reductions in losses due to cloud seeding.
Source: National Crop Insurance Services (various years).

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 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.

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)

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 (i.e., statewide) 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.

A potential 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)
$$\frac{\dfrac{AddYield_O}{AvgYield_O}}{Rain_O} = \frac{\dfrac{AddYield_N}{AvgYield_N}}{Rain_N}$$

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 2013 through 2017

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 2013 through 2017. Solving equation (1) for anticipated yield increases ($AddYield_N$) produced the following equation.

Equation (2) $$AddYield_N = AvgYield_N \times (Rain_N \times (Rain_O / (AddYield_O / AvgYield_O)))$$

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 (Table 3).

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 2018 (North Dakota Atmospheric Resource Board 2019). Two rainfall scenarios were used for the study (Table 3).

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.

For ND Cloud Modification Project counties, enhanced growing season rainfall represented slightly more than a ¼ inch of precipitation for small grains and over 1/3 inch of precipitation for row crops for the 5 percent scenario. Those values increased to over ½ inch for small grains and nearly 7 tenths of precipitation for row crops in the 10 percent scenario. Estimated enhanced rainfall amounts in the other regions of the state generally increased from west to east, and were higher than estimated rainfall amounts in the NDCMP counties (Table 3).

Table 3. Average Annual Change in Growing Season Rainfall, Five and Ten Percent Scenarios, North Dakota, 2008 through 2017

	5 Percent Rainfall Scenario		10 % Rainfall Scenario	
Region	**June-July**	**June-August**	**June-July**	**June-August**
	------------------------------------- rainfall (inches) -------------------------------------			
Statewide Cloud Seeding Scenario				
West	0.2893	0.3776	0.5682	0.7418
West Central	0.3328	0.4397	0.6620	0.8747
East Central	0.3590	0.4846	0.7180	0.9696
Red River Valley	0.3699	0.5034	0.7398	1.0078
NDCMP Counties*	0.2814	0.3633	0.5333	0.6884

*NDCMP counties from 2008 through 2017 were Bowman, McKenzie, Mountrail, Slope, Ward, and Williams. Burke County was in the project from 2015 through 2017.
Source: North Dakota Atmospheric Resource Board (2019).

Yield changes were estimated for all nine crops for each rain enhancement region (Table 4). 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.

Additional rainfall (5 percent scenario) was estimated to increase yields for alfalfa (0.04/tons/ac), barley (1.4 bu/ac), canola (80 lbs/ac), corn (2.4 bu/ac), dry edible beans (40 lbs/ac), flax (0.9 bu/ac), soybeans (1 bu/ac), sunflowers (80 lbs/ac), and wheat (1.5 bu/ac) in the NDCMP counties.

Table 4. Average Annual Increase in Yields per Harvested Acre, Five and Ten Percent Rainfall Scenarios, North Dakota, 2008 through 2017

Scenario and Region	Alfalfa	Barley	Canola	Corn	D. Edible Beans	Flax	Soybeans	Sunflower	Wheat
	--- tons/ac --	--- bu/ac --	--- lbs/ac --	--- bu/ac --	--- lbs/ac --	--- bu/ac --	--- bu/ac --	--- lbs/ac --	--- bu/ac --
Statewide Scenario – 5 percent Rainfall Scenario									
West	0.037	1.28	63.1	2.18	37.5	0.39	0.91	82.8	1.36
West Central	0.045	1.86	112.9	2.43	46.0	1.49	1.02	78.0	1.89
East Central	0.044	1.87	95.5	2.89	45.7	1.03	1.11	78.5	1.62
RRV	0.039	1.46	76.5	2.43	44.6	0.62	1.19	80.3	1.15
Statewide Scenario – 10 percent Rainfall Scenario									
West	0.073	2.51	123.9	4.27	74.9	0.76	1.81	162.7	2.67
West Central	0.090	3.69	224.6	4.84	91.9	2.96	2.03	155.1	3.75
East Central	0.087	3.73	190.9	5.78	91.5	2.07	2.22	157.1	3.24
RRV	0.078	2.92	153.1	4.85	89.3	1.25	2.37	160.7	2.31
NDCMP -- 5 Percent Rainfall Scenario									
All Counties*	0.038	1.44	79.73	2.37	39.76	0.88	0.996	80.34	1.47
NDCMP --10 Percent Rainfall Scenario									
All Counties*	0.074	2.85	157.55	4.71	75.51	1.75	1.99	158.81	2.90

*NDCMP counties included Bowman, McKenzie, Mountrail, Slope (selected townships), Ward and Williams from 2008 through 2017, and Burke County from 2015 through 2017.

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 85 percent of national production from 2008 through 2017 (Table 5). Other crops also represented a substantial portion of national production, such as barley (25 percent), dry edible beans (46 percent), sunflowers (41 percent), and flax (92 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.

Table 5. North Dakota Crop Production as Percentage of National Production, Average 2008 through 2017

Crop	Percentage
Alfalfa	4.6
Barley	25.5
Canola	85.1
Corn	2.6
Dry Edible Beans	45.6
Flax	92.4
Soybeans	4.4
Sunflower	41.0
All Wheat	14.7

Source: National Agricultural Statistics Service.

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 6). 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.

Table 6. Price Elasticities for Statewide Changes in Crop Supply, North Dakota

Crop	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%
All Wheat**	0.8560%

* Opposite average statewide price response to a 1 percent change in statewide supply.
** Johnson et al. (1998).

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 2 to 4 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 2008 through 2017, was estimated to represent less than a 1 percent change in state production for any of the nine crops included in the study (Table 7). Changes in state crop production from added rainfall in the NDCMP counties ranged from an average of 0.002 percent for dry beans to 0.80 percent for flax over the period. The largest crop in the NDCMP counties was wheat, which was expected to increase state supply by 0.34 percent annually in the 10 percent rainfall scenario. As a result, changes in statewide crop supply due to enhanced rainfall in the NDCMP counties were deemed insufficient to influence crop prices.

Table 7. Average Annual Change in State Crop Supply from Enhanced Rainfall as Share of Total State Production, Cloud Modification Project Counties and Statewide Scenario, North Dakota, 2008 through 2017

	Enhanced Rainfall Scenario			
	Cloud Modification Project Counties		Statewide Scenario	
Crop	5 Percent	10 Percent	5 Percent	10 Percent
	-------------------------- % of state crop production --------------------------			
Alfalfa	0.09	0.17	2.3	4.5
Barley	0.08	0.15	2.7	5.4
Canola	0.23	0.45	5.3	10.6
Corn	0.00	0.01	2.0	4.1
Dry Edible Beans	0.00	0.00	2.7	5.4
Flax	0.40	0.79	5.5	11.0
Soybeans	0.01	0.03	3.4	6.7
Sunflowers	0.11	0.22	5.4	10.7
Wheat	0.17	0.34	3.6	7.1

Note: Estimated production from enhanced rainfall in the NDCMP counties was removed from total state production when estimating percentages.

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

Input-output analysis is a mathematical representation of the production and consumption of goods and services within a given economy. The basic premise to input-output modeling can be traced to economic base theory, or the understanding that a given economy is comprised of both 1) economic sectors or industries which produce goods/services for export outside the economy (basic sectors) and 2) economic sectors which produce goods/services within the economy for use by those exporting industries (non-basic sector). However, most current I-O modeling platforms do not limit economic activity in non-basic sectors to be driven or determined entirely by basic sector output.

Input-output analysis is premised on the notion of inter-industry transactions, where industries use products/services from other industries to generate their output, and outputs from one industry usually represent inputs to another industry. The basis for the interdependence (linkages) within input-output analysis between consuming and producing industries forms the foundation for development of multiplier effects. Multiplier effects can then be used to estimate how initial changes in economic activity result in economy-wide changes in a given area and represent the core component of input-output analysis.

Economic impact assessments often use input-output analysis to measure the economic activity from a project, program, policy, or activity. Direct impacts are those changes in output, employment, or income that represent the initial or first-round effects of the economic question under study (i.e., project, program, policy, event, or activity).

Direct economic impacts are usually measured as injections (or reductions) of money into a specified economy. Direct impacts, whether changes in sales, employment, or income, therefore represent inputs into input-output models to trace linkages among sectors of an economy and calculate various forms of business activity resulting from a direct impact in an economic sector.

Input-output analysis is then used to estimate indirect and induced economic effects. Indirect economic effects arise from the additional consumption of goods and services triggered by businesses that supply inputs to firms in a given sector/industry. Indirect effects can be interpreted as the additional economic activity created through purchases by businesses. Induced economic effects arise from the additional spending by households from changes in personal income associated with direct effects and indirect effects. Changes in personal income can come from payrolls of businesses that are directly impacted, changes in payroll from businesses that supply goods and services to an impacted sector (induced effects), and proprietor income resulting from a change in business volume. Induced effects measure the additional business activity that is triggered as changes in personal income are translated into the purchase of goods and services for personal consumption.

Finally, the types of economic effects (i.e., direct, indirect, and induced) are used to define several economic metrics that measure the size or magnitude of an impact within a given economy. Those metrics often include value-added, economic output, employment, employment compensation, labor income, and government revenues (see Appendix C for additional discussion).

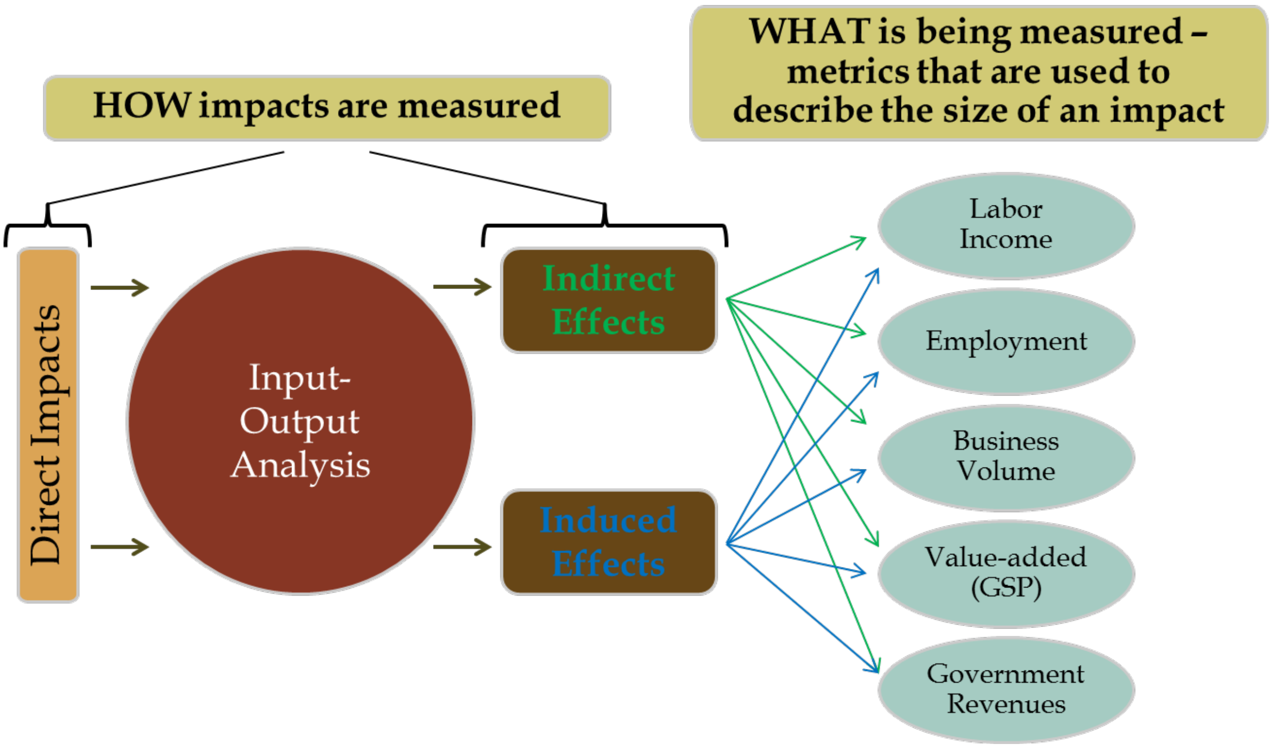

Figure 2. Impact Assessment Methodology
Source: DA Bangsund, Department of Agribusiness and Applied Economics NDSU.

Study Limitations and Omissions

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 2008 through 2017. 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 the state's top eight crops averaged 19.9 million acres annually over the study period. By contrast, harvest acreage of all crops in North Dakota, including alfalfa, averaged 21 million acres over the same period. Thus, the crops included in this study represented 94 percent of harvested crop acreage in the state from 2008 through 2017.

Adjustments to crop prices for increases in crop supply attributable to an increase in growing season rainfall were included in the statewide analysis. However, reducing hail damage also will result in an increase in crop supply. Changes in crop supply resulted from reduced hail damage was not included in this study.

Several coefficients linking cloudseeding to agricultural benefits are reliant on studies that are several decades old. While the refinement of those coefficients based on updated agricultural production characteristics (i.e., genetic enhancements to crop varieties) and any change in cloud seeding applications might result in a refinement of the economic estimates, it is unlikely that new coefficients would alter the conclusions of the economic study.

Conceptually, from an economic impact perspective, arguments could be made that funding for the NDCMP would probably be used in other government programs in the state in the absence of the project. Therefore, net economic benefits would require looking at how the $909,000 would be spent, and the subsequent secondary economic effects from that alternative. Examination into hypothetical alternatives from a government spending perspective were not addressed in this study. Project funding is extremely modest compared to estimated economic outcomes, and removing project funding (and also potential secondary impacts from the original $909,000) from the estimated economic benefits would not affect conclusions drawn in this study.

Results

Two assessments of the benefits of cloud seeding in North Dakota were performed. A statewide assessment included all counties in North Dakota and 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 2008 through 2017, the average annual crop-hail loss-cost ratio by county varied from 1.57 percent to 11.59 percent (Appendix A). Averaged across all counties, the crop-hail loss ratio was estimated at 4.71 percent. The average value of crop production for the nine crops in the study was estimated at about $6.5 billion annually. The total crop value lost to hail averaged about $299 million or about $14.65 per planted acre annually from 2008 through 2017. However, only about 40 percent of that damage was estimated to be savable through cloud seeding. Statewide, cloud seeding was estimated to save $117 million in hail damage to the nine crops in this study (Table 8). An annual statewide benefit of $117 million equates to $5.75 per planted acre over the period; an average for the nine crops in the study.

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 $299 million annually from 2008 through 2017 (Table 8). Total direct benefits averaged $14.65 per planted acre in the 5 percent rainfall scenario. In the 10 percent scenario, the total direct benefits to the state averaged $477 million annually from 2008 through 2017. Total direct benefits averaged $23.35 per planted acre in the 10 percent rainfall scenario.

The value of added growing season rainfall was estimated separately for the 5 percent and 10 percent scenarios (Table 8). In the 5 percent scenario, changes in the average annual gross value of crop production by county varied from $623,000 to $9.7 million (Appendix B). Collectively, the value of increased growing season rainfall was estimated to average $182 million annually over the period, which translated into benefits of $8.90 per planted acre or $9.15 per harvested acre.

In the 10 percent scenario, changes in the average annual gross value of crop production by county varied from $1.2 million to $19.2 million (Appendix B). Collectively, the value of increased growing season rainfall was estimated to average nearly $360 million annually over the period. The statewide benefits of increased growing season rainfall in the 10 percent scenario were estimated at $17.60 per planted acre or $18.08 per harvested acre.

The crops generating the largest gains in crop revenues from enhanced revenues were wheat and canola for the NDCMP counties (Table 9). In the statewide analysis, wheat, soybeans, and corn were the crops generating the largest gains in crop revenues.

Table 8. Direct Economic Benefits, Cloud Modification, Statewide Assessment, North Dakota, 2008 through 2017								
	Average Acreage*		Average Annual Estimates			Estimates per Planted Acre		
Scenario and Region	**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 $ ------------			------------ $ per acre ------------		
West	5,007,171	4,836,851	20,893	32,064	52,957	4.17	6.40	10.58
West Central	5,076,666	4,935,855	23,574	48,606	72,179	4.64	9.57	14.22
East Central	6,859,049	6,702,558	47,367	68,466	115,833	6.91	9.98	16.89
RRV	3,480,725	3,398,023	25,622	32,629	58,251	7.36	9.37	16.74
Total	20,423,611	19,873,299	117,456	181,765	299,220	5.75	8.90	14.65
10 Percent Rainfall Scenario			------------ 000s $ ------------			------------ $ per acre ------------		
West	5,007,171	4,836,851	20,893	62,345	83,238	4.17	12.45	16.62
West Central	5,076,666	4,935,855	23,574	95,818	119,391	4.64	18.87	23.52
East Central	6,859,049	6,702,558	47,367	136,373	183,740	6.91	19.88	26.79
RRV	3,480,725	3,398,023	25,622	64,865	90,487	7.36	18.64	26.00
Total	20,423,611	19,873,299	117,456	359,401	476,856	5.75	17.60	23.35

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

Table 9. Average Annual Change in Crop Value from Enhanced Rainfall, Cloud Modification Project Counties and Statewide Scenario, North Dakota, 2008 through 2017

	Enhanced Rainfall Scenario			
	Cloud Modification Project Counties		Statewide Scenario	
Crop	5 Percent	10 Percent	5 Percent	10 Percent
	----------------- net crop value (000s $) from enhanced rainfall -----------------			
Alfalfa	810.8	1,595.4	2,750.8	5,184.4
Barley	695.8	1,373.8	5,423.6	10,725.5
Canola	3,089.5	6,108.3	11,502.5	21,966.8
Corn	201.8	400.6	27,370.6	54,661.7
Dry Edible Beans	20.4	40.8	4,305.3	8,433.6
Flax	915.4	1,815.9	2,408.8	4,685.9
Soybeans	865.8	1,731.6	55,863.1	111,595.1
Sunflowers	933.6	1,847.1	7,591.6	14,611.2
Wheat	13,687.8	26,986.8	64,548.5	127,536.5
Total	21,220.8	41,900.3	181,764.8	359,400.7

Note: North Dakota Cloud Modification Counties scenario does not include price adjustments. Statewide scenario includes estimated changes in crop prices applied to all counties.

<u>Direct Impacts for North Dakota Cloud Modification Project Counties</u>

From 2008 through 2017, the North Dakota Cloud Modification Project operated in Bowman, McKenzie, Mountrail, Slope, Ward, and Williams Counties. Burke County participated in the project from 2015 through 2017. Cloud seeding in Slope County only covered 41 percent of cropland in that county over the 2008 through 2017 period. As a result of only partial cloud seeding coverage in Slope County, treated and non-treated cropland in the county were 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-project 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 project counties were deemed insufficient to materially influence regional crop prices.

The average annual crop-hail loss-cost ratio by treatment county varied from 2.7 percent to 9 percent (Table 10). Averaged across all treatment counties, the crop-hail loss ratio was estimated at 4.54 percent–numerically very similar to the overall average for the entire state (4.71 percent). The average value of crop production for the nine crops in the project counties was estimated at $619 million annually. The total crop value lost to hail averaged $28.1 million or about $10.55 per planted acre annually over the period. However, only about 41.4 percent of that damage was estimated to be savable through cloud seeding. Collectively, cloud seeding in the treatment counties was estimated to save $6.9 million annually in hail damage (Table 11). An annual benefit of $6.9 million equates to $3.00 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 11). In the 5 percent scenario, changes in the average annual gross value of crop production by county varied from $750,000 to $8.3 million (Appendix B). Collectively, the value of increased growing season rainfall was estimated at $21.2 million annually, which translated into benefits of $9.19 per planted acre or $9.48 per harvested acre.

In the 10 percent scenario, changes in the average annual gross value of crop production by county varied from $1.5 million to $16.6 million (Appendix B). Collectively, the value of increased growing season rainfall was estimated at $41.9 million annually, which translated into benefits of $18.15 per planted acre or $18.72 per harvested acre.

In the 5 percent rainfall scenario, the total direct benefits (hail reduction plus added yield) averaged $28.2 million annually from 2008 through 2017 (Table 11). Total direct benefits averaged $12.20 per planted acre in the 5 percent rainfall scenario. In the 10 percent scenario, the total direct benefits to the state averaged $48.8 million annually. Total direct benefits averaged $21.16 per planted acre in the 10 percent rainfall scenario.

Table 10. Average Annual County-wide Crop Loss-Cost Ratios, Cloud Modification Project Counties, Selected Crops, North Dakota, 2008 through 2017

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Avg
Bowman	0.0065	0.0885	0.1517	0.1036	0.0022	0.0281	0.0256	0.1088	0.0623	0.0000	0.0708
Burke	0.0125	0.0304	0.0965	0.0010	0.0593	0.1131	0.0153	0.0086	0.0289	0.0143	0.0363
McKenzie	0.0958	0.0047	0.0685	0.0096	0.0702	0.1699	0.0183	0.0385	0.0240	0.0282	0.0528
Mountrail	0.0297	0.0097	0.0679	0.0096	0.0249	0.0146	0.1195	0.0281	0.0688	0.0215	0.0426
Slope	0.0784	0.0261	0.0577	0.3400	0.0009	0.0394	0.0050	0.0971	0.2360	0.0266	0.0903
Ward	0.0246	0.0048	0.0493	0.0387	0.0221	0.0300	0.0184	0.0213	0.0492	0.0112	0.0267
Williams	0.0365	0.0253	0.0596	0.0313	0.0281	0.0264	0.1825	0.0327	0.0480	0.0286	0.0552
Ten Year Composite Average for NDCMP Treatment Counties											0.0455
State	0.0346	0.0137	0.0360	0.0888	0.0179	0.0383	0.0362	0.0478	0.0858	0.0607	0.0477

Source: National Crop Insurance Services (*various years*).

Table 11. Direct Economic Benefits, Cloud Modification Project Counties, North Dakota, 2008 through 2017

	Average Acreage*		Average Annual Estimates			Estimates per Planted Acre		
Scenario and Region	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 $ ---------------------------			------------------------- $ per acre -------------------------		
West	1,622,794	1,572,831	5,307	12,877	18,184	3.27	7.94	11.21
West Central	685,342	664,836	1,623	8,344	9,967	2.37	12.17	14.54
Total	2,308,135	2,237,667	6,930	21,221	28,151	3.00	9.19	12.20
10 Percent Rainfall Scenario								
West	1,622,794	1,572,831	5,307	25,296	30,603	3.27	15.59	18.86
West Central	685,342	664,836	1,623	16,604	18,227	2.37	24.23	26.60
Total	2,308,135	2,237,667	6,930	41,900	48,830	3.00	18.15	21.16

* 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

Direct impacts were allocated as a change in personal income based on three selected classes of income within the IMPLAN modeling system which represent low through high income classes: $30k-$40k (20%), $50k-$70k (60%), and $100K-$150k (20%).

For the 5 percent rainfall scenario, total annual direct impacts from a statewide cloud seeding project were estimated to average $299 million from 2008 through 2017. An additional $299 million in net revenues to producers would generate secondary economic activity of $290 million annually. The gross business volume (direct plus secondary effects) was estimated at $590 million over the period. In the 5 percent rainfall scenario, the total economic effects were estimated at $28.90 per planted acre (Table 12).

For the 10 percent rainfall scenario, total annual direct impacts from a statewide cloud seeding project were estimated to average $477 million from 2008 through 2017. An additional $477 million in net revenues to producers would generate secondary economic activity of $463 million annually. The gross business volume (direct plus secondary effects) was estimated at $940 million over the period. In the 10 percent rainfall scenario, the total economic effects were estimated at $46 per planted acre (Table 12).

Table 12. Average Annual Total Economic Impacts, Cloud Modification Project Counties and Statewide Assessment, North Dakota, 2008 through 2017

Scenario and Region	Average Annual Effects: Total Direct Impacts	Average Annual Effects: Gross Business Volume	Average Annual Effects per Planted Acre: Total Direct Impacts	Average Annual Effects per Planted Acre: Gross Business Volume
	---------------------- 000s $	----------------------	------------------- $ per Acre	-------------------
Statewide Assessment – 5 Percent Rainfall Scenario				
West	52,957	104,409	10.58	20.85
West Central	72,179	142,307	14.22	28.03
East Central	115,833	228,373	16.89	33.30
RRV	58,251	114,846	16.74	33.00
Total	299,220	589,935	14.65	28.89
Statewide Assessment – 10 Percent Rainfall Scenario				
West	83,238	164,109	16.62	32.78
West Central	119,391	235,389	23.52	46.37
East Central	183,740	362,257	26.79	52.82
RRV	90,487	178,401	26.00	51.25
Total	476,856	940,156	23.35	46.03
NDCMP Counties – 5 Percent Rainfall Scenario (no price effects)				
West	18,184	35,851	11.21	22.09
West Central	9,967	19,650	14.54	28.67
Total	28,151	55,502	12.20	24.05
NDCMP Counties – 10 Percent Rainfall Scenario (no price effects)				
West	30,603	60,336	18.86	37.18
West Central	18,227	35,936	26.60	52.44
Total	48,830	96,273	21.16	41.71

*Gross business volume was distributed among counties based on dollar volume of direct impacts within each 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 $28 million from 2008 through 2017 (Table 12). An additional $28.1 million in net revenues to producers would generate secondary economic activity of $27.4 million annually. The gross business volume (direct plus secondary effects) was estimated at $55.5 million over the period. In the 5 percent rainfall scenario, the total economic effects were estimated at $24.05 per planted acre (Table 12).

For the 10 percent rainfall scenario, total direct impacts from a statewide cloud seeding project were estimated to average $48.8 million from 2008 through 2017. An additional $48.8 million in net revenues to producers would generate secondary economic activity of $47.4 million annually. The gross business volume (direct plus secondary effects) was estimated at $96.2 million over the period. In the 10 percent rainfall scenario, the total economic effects were estimated at $41.71 per planted acre (Table 12).

An important clarification is that the secondary economic effects primarily accrue to the economic sectors represented by spending profiles in IMPLAN. Because economic benefits of cloud seeding are interpreted to represent additional personal income, the link between the additional personal income and secondary economic activity occurs through the personal spending or consumption of consumer goods and services by the producer. An alternative interpretation might be that the extra income would be translated into more crop production inputs, and require the spending to represent the consumption of farm production services and goods. Gross business volumes, when expressed as dollars per acre, do not represent the total economic effect felt by producers. The economic effect felt by producers is represented only by the direct impacts.

The distribution of personal spending within the IMPLAN modeling system was aggregated to represent rather large economic units, or groupings of a number of smaller, individual economic sectors. The economic areas of the North Dakota economy most affected would be trade (retail and wholesale) and services (Figure 3).

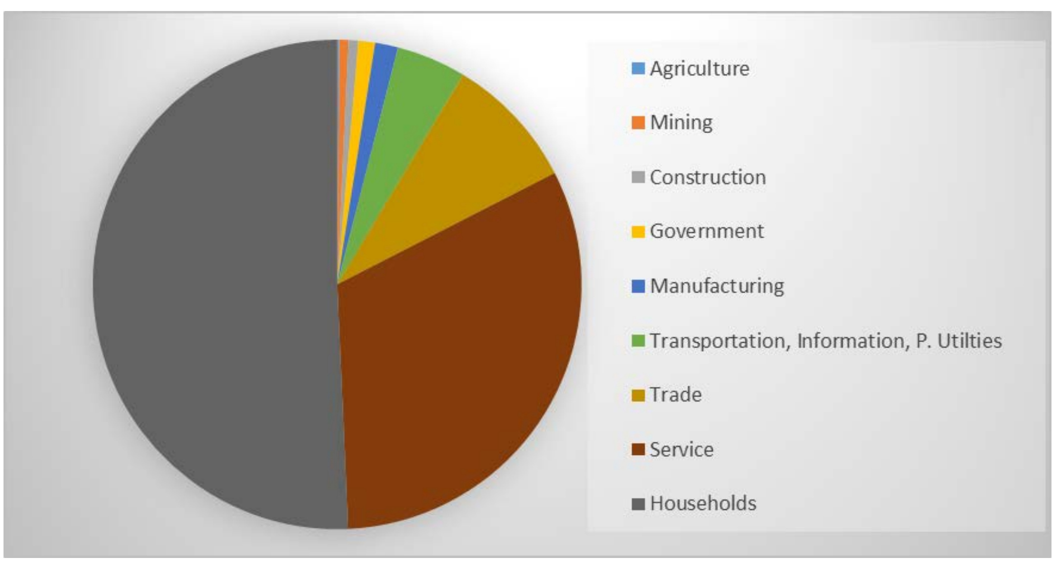

Figure 3. Average Annual Distribution of Direct and Secondary Economic Effects of Cloud Seeding, By Major Economic Groupings, North Dakota, 2008 through 2017

State Tax Revenues

Governmental revenues, usually based on tax collections, are another important measure of economic impacts. The IMPLAN modeling system estimates the value of various government revenues that are likely to result from the spending and respending of the direct impacts. Since the direct impacts were treated as personal income, the spending of that income would generate tax revenue streams to the state and local government from the business activity created by the first and subsequent rounds of spending.

IMPLAN's primary tool for estimating taxes is the comparison of business output in the economy with levels of local and state revenues. The model then uses relationships between economy-wide output and the business volume derived from the specific impact assessment to provide estimates of government revenues.

In the statewide assessment, annual collections from tax and non-tax revenues were estimate at $6.1 million and $9.7 million for the 5 percent and 10 percent rainfall scenarios, respectively (Table 13). In the evaluation of the NDCMP, annual collections of government revenues were estimated at $576,000 and $1 million for the 5 percent and 10 percent rainfall scenarios, respectively (Table 13).

Table 13. Average Annual State Tax Collections, Cloud Modification Project Counties and Statewide Assessment, North Dakota, 2008 through 2017

	Cloud Modification Project Counties		Statewide Assessment	
State and Local Government Revenues	5 Percent Rainfall Scenario	10 Percent Rainfall Scenario	5 Percent Rainfall Scenario	10 Percent Rainfall Scenario
	$			
Sales Tax	409,500	710,300	4,352,400	6,936,200
Personal Income	50,000	86,700	531,100	846,300
Other Non-tax Revenues	34,000	58,900	360,900	575,100
Other taxes	28,800	49,900	305,600	487,100
Fines, Fees, Licenses	22,200	38,500	235,600	375,500
Corporate Income	16,400	28,400	174,100	277,400
Dividends	15,000	25,900	158,900	253,200
Totals	575,900	998,600	6,118,600	9,750,800

Breakeven Threshold Analysis

The North Dakota Cloud Modification Project was evaluated in previous economic assessments using an implied assumption that cloud seeding accomplished the stated reduction in hail losses and generated enhanced rainfall, albeit at two potential levels. While the science of cloud seeding has established a strong causality between treatments and modified local weather behavior, quantifying modified weather behavior remains difficult due to the variability of weather-related factors and crop growing season conditions.

A breakeven analysis was conducted to equate project benefits to program costs. The project has two direct economic benefits to producers; a reduction in hail losses and additional growing season rainfall. An efficacy factor was used to adjust the hail reduction coefficients and the amount of added growing season rainfall. For example, if program effectiveness was 25 percent less than expected, then a hail loss factor of 0.45 would be reduced to 0.3375 [0.45 x (1-reduction rate)]. The same process was applied to levels of enhanced rainfall. For example, if enhanced rainfall was 25 percent less than expected, then the amount of expected additional growing season rainfall was decreased accordingly. The decreased amount of rainfall translates into a lower yield gain, relative to a higher amount of additional rainfall.

Depending upon which combination of benefits was included, program efficacy only needed to range from 2 percent to 13 percent of expected outcomes to generate producer benefits equal to program costs for the treatment counties (Table 14). Program costs were estimated at $909,000 annually (North Dakota Atmospheric Resource Board 2019). With program costs averaging less than $1 million per year, the program would only need to reduce hail losses slightly and/or generate a small amount of additional rainfall to create an equivalent amount of producer revenues. Considering the treatment area averaged about 2.3 million planted acres (i.e., acreage planted to the state's top eight crops, including alfalfa), a benefit of $0.40 per acre would largely equate project benefits to program costs. The NDCMP would only need to improve yields, from reduced hail damage, increased growing season rainfall, or a combination of reduced hail and additional rainfall, by about one-tenth to one-quarter of a bushel per acre for most crops. The NDCMP appears to require an extremely low threshold of efficacy to match program costs to added producer benefits.

A quartile analysis also was performed on program effectiveness. At a level of 25 percent of expected outcomes (with a 5 percent rainfall scenario), the NDCMP would produce benefits of $3 per planted acre (Table 15). Alternatively, if the program operates at 100 percent of expected benefits (with a 10 percent rainfall scenario) producer revenues were estimated at $21 per planted acre.

Table 14. Breakeven Efficacy for Cloud Modification Project, Project Operating Costs and Economic Benefits, Treatment Counties, North Dakota, 2008 through 2017

Scenario Parameters*				Annual Benefits to Crop Producers within Cloud Modification Counties						Annual Statewide Economic Benefits		
				Total (000s $)			Per Harvested Acre ($/ac)					
Program Costs** Set to Equal	Include Reduced Hail Loss	Added Rain-fall	Program Efficacy (%)	Reduced Hail Loss	Enhanced Yields	Combined Benefits	Reduced Hail Loss	Enhanced Yields	Combined Benefits	Added Jobs	Gross Business Volume (000s $)	State and Local Govt Revenues
Combined Benefits	Yes	5%	3.22	223	685	909	0.10	0.30	0.39	6.3	1,792	18,600
Combined Benefits	Yes	10%	1.86	129	780	909	0.06	0.34	0.39	6.3	1,792	18,600
Combined Benefits	Yes	No	13.11	909	0	909	0.39	0	0.39	6.3	1,792	18,600
Reduced Hail	Yes	5%	13.11	909	2,783	3,692	0.39	1.21	1.60	25.4	7,278	75,500
Reduced Hail	Yes	10%	13.11	909	5,494	6,403	0.39	2.38	2.77	44.1	12,624	130,900
Reduced Hail	Yes	No	13.11	909	0	909	0.39	0	0.39	6.3	1,792	18,600
Enhanced Yields	Yes	5%	4.28	296	909	1,206	0.13	0.39	0.52	8.3	2,376	24,600
Enhanced Yields	Yes	10%	2.17	150	909	1,059	0.07	0.39	0.46	7.3	2,088	21,600
Enhanced Yields	Yes	No	Not applicable									
Enhanced Yields	No	5%	4.28	0	909	909	0	0.39	0.39	6.3	1,791	18,600
Enhanced Yields	No	10%	2.17	0	909	909	0	0.39	0.39	6.3	1,792	18,600

*Excludes price adjustments.
**Cloud Modification Project operating costs averaged $909,000 annually from 2008 through 2017.

Table 15. Quartile Evaluation for Cloud Modification Project, Producer and Statewide Economic Benefits, Treatment Counties, North Dakota, 2008 through 2017

Scenario Parameters*			Annual Benefits to Crop Producers within Cloud Modification Counties						Annual Statewide Economic Benefits		
			Total (000s $)			Per Planted Acre ($/ac)					
Program Efficacy (%)	Include Reduced Hail Loss	Added Rain-fall	Reduced Hail Loss	Enhanced Yields	Combined Benefits	Reduced Hail Loss	Enhanced Yields	Combined Benefits	Added Jobs	Gross Business Volume (000s $)	State and Local Govt Revenues
25	Yes	5%	1,733	5,306	7,038	0.75	2.30	3.05	48	13,876	144,000
50	Yes	5%	3,465	10,609	14,074	1.50	4.60	6.10	97	27,749	288,000
75	Yes	5%	5,198	15,916	21,114	2.25	6.90	9.15	145	41,628	432,000
100	Yes	5%	6,930	21,221	28,151	3.00	9.19	12.20	194	55,502	576,000
25	Yes	10%	1,733	10,475	12,208	0.75	4.54	5.29	84	24,069	250,000
50	Yes	10%	3,465	20,949	24,414	1.50	9.08	10.58	168	48,135	499,000
75	Yes	10%	5,198	31,426	36,623	2.25	13.62	15.87	252	72,205	749,000
100	Yes	10%	6,930	41,900	48,830	3.00	18.15	21.16	336	96,273	998,000

*Excludes price adjustments.

Conclusions

The economic impacts of cloud seeding in North Dakota were evaluated from 2008 through 2017. 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.

Even after correcting for inflation, project benefits estimated in previous studies are less than estimated in this study. That condition was also present in that the last study also demonstrated more benefits than the preceding study. Several factors have changed the estimates of the benefits of cloud seeding over the past four studies; 1) the number of crops included in the studies has increased, 2) the crop mix has shifted from lower value small grains to higher value row crops, 3) yield increases have created corresponding increases in crop value, and 4) crop acreage has increased as enrollment in the Conservation Reserve Program has decreased. Also, over the past four studies, price adjustments to the statewide analysis have been added and additional rainfall due to cloud seeding has been revised downward. With these changes the value of cloud seeding remains strongly linked to the value of crops in each study.

From a producer's perspective, the direct economic value of cloud seeding, averaged across the state, was estimated to range from $14 to $23 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 project to be nearly $4 million. The most conservative of the two scenarios evaluated in this study indicated that collections of state taxes would clearly exceed the anticipated cost ($4 million cost versus $6 million in government revenues). The benefit to the state would be substantial, approximately $119 in direct benefits to $1 dollar of program costs.

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Appendix A

Average Crop-Loss Ratios, by County, North Dakota, 2008 through 2017

Appendix Table A1. Average Annual County-wide Crop Loss-Cost Ratios, Study Crops, North Dakota, 2008 through 2017

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Adams	0.2809	0.1502	0.1178	0.0699	0.0377	0.0210	0.0464	0.0349	0.1822	0.0166
Barnes	0.0225	0.0039	0.0549	0.0684	0.0174	0.0351	0.0566	0.0826	0.1067	0.0685
Benson	0.0954	0.0139	0.0109	0.0421	0.0102	0.0178	0.0044	0.0661	0.1791	0.0809
Billings	0.3861	0.0006	0.3613	0.0241	0.0000	0.0541	0.0440	0.0924	0.3118	0.0539
Bottineau	0.0231	0.0067	0.0153	0.0070	0.0205	0.0401	0.0014	0.0242	0.0437	0.0424
Bowman	0.0065	0.0885	0.1517	0.1036	0.0022	0.0281	0.0256	0.1088	0.0623	0.0000
Burke	0.0125	0.0304	0.0965	0.0010	0.0593	0.1131	0.0153	0.0086	0.0289	0.0143
Burleigh	0.0783	0.0156	0.0221	0.0841	0.0073	0.0412	0.1238	0.0220	0.0401	0.0076
Cass	0.0055	0.0012	0.0114	0.0403	0.0093	0.0161	0.0324	0.0777	0.0444	0.0788
Cavalier	0.0201	0.0151	0.0493	0.0079	0.0475	0.0142	0.0647	0.0401	0.0779	0.0969
Dickey	0.0084	0.0114	0.0126	0.3151	0.0253	0.0865	0.0221	0.0325	0.0935	0.0571
Divide	0.0000	0.0136	0.0090	0.0000	0.0091	0.0311	0.0649	0.0199	0.0084	0.0075
Dunn	0.3083	0.0844	0.1232	0.1545	0.0270	0.0948	0.1222	0.0040	0.1381	0.0632
Eddy	0.0031	0.0001	0.0101	0.0529	0.0006	0.0013	0.0015	0.0557	0.1149	0.0045
Emmons	0.1163	0.0153	0.1787	0.1285	0.0071	0.0252	0.0037	0.0341	0.1439	0.0165
Foster	0.0524	0.0041	0.0038	0.1518	0.0044	0.0005	0.0197	0.0614	0.0383	0.2292
Golden Valley	0.0499	0.0200	0.0055	0.0582	0.0000	0.0071	0.0000	0.0148	0.0045	0.0000
Grand Forks	0.0103	0.0050	0.0079	0.0333	0.0090	0.0226	0.0259	0.0459	0.1134	0.0303
Grant	0.0541	0.0089	0.1130	0.0668	0.0099	0.0479	0.0162	0.0542	0.1526	0.1117
Griggs	0.0306	0.0000	0.0012	0.0501	0.0011	0.0043	0.0136	0.0813	0.1033	0.1626
Hettinger	0.1385	0.0118	0.0595	0.0738	0.0588	0.0360	0.0125	0.0276	0.0762	0.0072
Kidder	0.0080	0.0003	0.0547	0.0899	0.0325	0.0508	0.0186	0.0446	0.0983	0.0238
La Moure	0.0132	0.0134	0.0380	0.2024	0.0237	0.0494	0.0164	0.0329	0.0103	0.0905
Logan	0.0204	0.0011	0.0368	0.1091	0.0090	0.0095	0.0062	0.0145	0.1582	0.1301
McHenry	0.0276	0.0143	0.0763	0.0310	0.0153	0.0091	0.0053	0.0472	0.0151	0.0366
McIntosh	0.1334	0.0208	0.0012	0.0932	0.0267	0.1014	0.0116	0.1044	0.1184	0.0697
McKenzie	0.0958	0.0047	0.0685	0.0096	0.0702	0.1699	0.0183	0.0385	0.0240	0.0282
McLean	0.1158	0.0176	0.0645	0.0176	0.0172	0.0065	0.0994	0.0858	0.0494	0.0216
Mercer	0.2654	0.0046	0.0289	0.1620	0.0085	0.0430	0.0773	0.0221	0.0753	0.0208
Morton	0.0830	0.0027	0.0617	0.0646	0.0002	0.1080	0.0275	0.0306	0.1657	0.0137
Mountrail	0.0297	0.0097	0.0679	0.0096	0.0249	0.0146	0.1195	0.0281	0.0688	0.0215
Nelson	0.0188	0.0256	0.0065	0.0325	0.0049	0.0371	0.0249	0.0437	0.1194	0.0027
Oliver	0.1467	0.0074	0.1057	0.0328	0.0001	0.0419	0.1769	0.0780	0.0268	0.0085
Pembina	0.0474	0.0243	0.0543	0.0111	0.0687	0.0558	0.0522	0.0318	0.1282	0.1387
Pierce	0.0468	0.0458	0.0162	0.0279	0.0145	0.0260	0.0278	0.0562	0.1351	0.1009
Ramsey	0.0179	0.0090	0.0285	0.0235	0.0226	0.0721	0.0161	0.0381	0.1292	0.0387
Ransom	0.0052	0.0129	0.0710	0.1411	0.0213	0.0508	0.0089	0.0687	0.0445	0.0067
Renville	0.0387	0.0122	0.0709	0.0265	0.0201	0.0281	0.0157	0.0216	0.0342	0.0311
Richland	0.0427	0.0243	0.0046	0.0994	0.0026	0.0786	0.0101	0.0820	0.0225	0.0099
Rolette	0.0372	0.0041	0.0324	0.0049	0.0364	0.0335	0.0159	0.0350	0.1702	0.0125
Sargent	0.0061	0.0013	0.0031	0.2304	0.0064	0.0213	0.0344	0.0076	0.0471	0.0164
Sheridan	0.0110	0.0413	0.0057	0.0215	0.0161	0.0002	0.0700	0.0281	0.0341	0.0213
Sioux	0.0601	0.0073	0.0334	0.0722	0.0102	0.0048	0.0583	0.0564	0.2042	0.0722
Slope	0.0784	0.0261	0.0577	0.3400	0.0009	0.0394	0.0050	0.0971	0.2360	0.0266
Stark	0.1003	0.0236	0.0765	0.0293	0.0030	0.0679	0.0194	0.0147	0.0443	0.0283
Steele	0.0710	0.0037	0.0088	0.1761	0.0032	0.0141	0.0284	0.0511	0.1099	0.0922
Stutsman	0.0205	0.0053	0.0198	0.1467	0.0216	0.0103	0.0113	0.0402	0.1198	0.0086
Towner	0.0207	0.0155	0.0529	0.0051	0.0054	0.0174	0.0077	0.0352	0.0669	0.0478
Traill	0.0105	0.0085	0.0055	0.0499	0.0177	0.1238	0.0514	0.0486	0.3204	0.1481
Walsh	0.0065	0.0097	0.0455	0.0236	0.0190	0.0099	0.0142	0.0658	0.1406	0.0607
Ward	0.0246	0.0048	0.0493	0.0387	0.0221	0.0300	0.0184	0.0213	0.0492	0.0112
Wells	0.0138	0.0077	0.0257	0.1106	0.0065	0.0076	0.0608	0.0344	0.1131	0.0815
Williams	0.0365	0.0253	0.0596	0.0313	0.0281	0.0264	0.1825	0.0327	0.0480	0.0286
State	0.0346	0.0137	0.0360	0.0888	0.0179	0.0383	0.0362	0.0478	0.0858	0.0607

Source: National Crop Insurance Services (*various years*).

Appendix Table A2. Average Annual Planted and Harvested Acreage, Crop Value, Crop-Hail Loss Factors, Hail Losses, Hail Reduction Factors, and Avoided Hail Losses for Statewide Implementation Scenario, by County, North Dakota, 2008 through 2017

Counties	Planted Acreage	Harvested Acreage	Value of Crop Production	Crop-Hail Loss Ratio	Total Hail Losses	Reduction Factors	Avoided Hail Losses
Adams	173,162	167,635	$35,517,589	8.62%	$3,059,999	40.4%	$1,235,141
Barnes	636,112	626,088	$254,131,233	5.50%	$13,968,534	36.2%	$5,062,280
Benson	444,872	435,198	$152,748,638	5.46%	$8,334,485	38.2%	$3,186,990
Billings	166,262	157,831	$25,789,668	11.59%	$2,989,536	38.0%	$1,137,109
Bottineau	590,105	576,753	$177,658,382	2.47%	$4,391,186	42.3%	$1,857,963
Bowman	162,754	158,084	$31,921,573	7.08%	$2,259,422	37.4%	$506,306
Burke	302,976	297,775	$75,153,498	3.63%	$2,725,422	42.9%	$1,147,529
Burleigh	310,564	300,365	$84,225,955	4.65%	$3,917,893	39.1%	$1,530,598
Cass	889,168	874,977	$380,095,590	3.30%	$12,535,911	36.4%	$4,557,181
Cavalier	709,490	698,849	$247,037,842	5.01%	$12,373,905	42.8%	$5,296,216
Dickey	381,435	369,954	$168,133,765	7.62%	$12,806,483	36.7%	$4,700,594
Divide	316,773	307,485	$66,160,211	2.00%	$1,320,136	42.9%	$566,560
Dunn	292,792	284,321	$57,473,840	9.75%	$5,605,026	38.7%	$2,168,290
Eddy	174,300	170,176	$57,237,517	2.76%	$1,582,557	36.8%	$581,956
Emmons	413,126	397,564	$128,778,825	6.71%	$8,641,774	40.7%	$3,512,901
Foster	279,746	272,841	$99,001,960	6.09%	$6,024,977	36.9%	$2,220,235
G. Valley	252,448	242,391	$53,309,540	1.57%	$838,025	41.8%	$350,210
G. Forks	566,819	549,464	$221,274,198	3.35%	$7,421,013	37.7%	$2,798,879
Grant	318,015	309,003	$68,873,422	5.75%	$3,960,555	38.7%	$1,532,974
Griggs	249,663	245,838	$89,327,277	4.93%	$4,404,025	36.4%	$1,603,592
Hettinger	348,520	333,769	$82,036,833	4.71%	$3,862,905	43.0%	$1,660,030
Kidder	247,220	242,933	$57,951,416	4.58%	$2,656,372	34.8%	$925,118
La Moure	490,545	474,268	$208,940,864	5.18%	$10,817,562	36.1%	$3,900,634
Logan	277,401	268,126	$78,424,600	5.16%	$4,050,580	36.2%	$1,467,010
McHenry	408,274	400,417	$111,249,954	2.66%	$2,958,008	40.1%	$1,186,519
McIntosh	292,395	283,624	$81,298,322	6.87%	$5,587,640	36.4%	$2,036,577
McKenzie	267,529	257,953	$49,506,908	5.28%	$2,613,925	40.3%	$712,340
McLean	662,392	640,156	$190,088,970	4.91%	$9,330,314	42.4%	$3,957,347
Mercer	186,540	179,232	$42,110,134	6.44%	$2,711,012	38.9%	$1,054,051
Morton	361,872	348,896	$81,000,594	5.43%	$4,396,122	40.4%	$1,774,909
Mountrail	465,388	452,921	$110,158,897	4.26%	$4,692,764	42.3%	$1,455,579
Nelson	327,863	319,880	$108,093,186	3.40%	$3,680,479	38.0%	$1,398,191
Oliver	138,083	133,143	$35,410,199	6.03%	$2,136,477	39.6%	$845,405
Pembina	456,241	444,505	$172,711,200	6.80%	$11,743,636	38.1%	$4,468,935
Pierce	320,553	314,312	$99,246,918	5.29%	$5,252,945	39.4%	$2,068,793
Ramsey	465,138	453,258	$160,896,371	4.12%	$6,621,186	39.7%	$2,630,648
Ransom	280,209	271,398	$120,461,919	4.33%	$5,218,254	36.7%	$1,913,605
Renville	363,722	351,253	$105,476,974	2.83%	$2,980,654	43.1%	$1,284,178
Richland	656,223	636,561	$299,325,051	3.83%	$11,473,164	37.5%	$4,296,945
Rolette	245,744	241,685	$74,896,049	4.27%	$3,198,075	41.1%	$1,313,875
Sargent	332,127	321,396	$146,427,535	3.93%	$5,748,174	36.8%	$2,116,730
Sheridan	259,828	253,831	$73,164,847	2.75%	$2,014,562	40.2%	$809,832
Sioux	130,004	123,850	$24,037,313	6.08%	$1,460,990	37.1%	$541,374
Slope	268,951	258,116	$53,321,973	9.03%	$4,816,716	40.9%	$1,798,509
Stark	340,563	326,121	$69,083,291	3.56%	$2,457,306	40.9%	$1,005,823
Steele	351,985	346,042	$147,436,438	5.64%	$8,314,829	36.4%	$3,023,069
Stutsman	779,171	761,196	$282,831,544	4.13%	$11,670,532	35.6%	$4,152,505
Towner	423,614	415,723	$142,078,746	2.99%	$4,242,218	41.3%	$1,751,982
Traill	433,016	425,764	$189,810,885	9.17%	$17,414,037	37.0%	$6,451,483
Walsh	479,258	466,766	$179,201,376	4.37%	$7,827,330	38.9%	$3,048,307
Ward	685,342	664,836	$192,046,415	2.67%	$5,130,945	42.6%	$1,623,049
Wells	532,779	520,454	$191,189,647	5.27%	$10,084,455	38.0%	$3,827,703
Williams	514,538	498,325	$106,817,029	5.52%	$5,893,404	43.4%	$1,964,683
State Total	20,423,611	19,873,299	$6,540,582,922	4.77%	$312,218,434	37.8%	$118,019,240

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, 2008 through 2017

Appendix Table B1. Average Annual Value of Enhanced Growing Season Rainfall, Five and Ten Percent Rainfall Scenarios, Statewide Assessment, by County, North Dakota, 2008 through 2017						
	5 Percent Rainfall Scenario			10 Percent Rainfall Scenario		
Counties	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	$1,251,506	$6.79	$6.50	$2,428,187	$13.17	$12.61
Barnes	$7,029,756	$11.19	$11.02	$14,018,651	$22.32	$21.97
Benson	$4,248,178	$9.78	$9.57	$8,469,421	$19.50	$19.07
Billings	$891,169	$6.27	$5.99	$1,696,870	$11.94	$11.40
Bottineau	$6,037,163	$10.53	$10.29	$11,856,533	$20.69	$20.22
Bowman	$1,035,446	$5.98	$5.76	$2,028,983	$11.72	$11.28
Burke	$2,058,412	$6.95	$6.83	$3,952,393	$13.35	$13.11
Burleigh	$2,997,096	$9.21	$8.82	$5,908,393	$18.16	$17.40
Cass	$9,668,177	$11.04	$10.86	$19,187,680	$21.91	$21.56
Cavalier	$6,250,752	$9.18	$9.04	$12,276,061	$18.02	$17.76
Dickey	$4,257,152	$11.14	$10.80	$8,563,616	$22.40	$21.72
Divide	$2,343,456	$7.68	$7.45	$4,562,279	$14.94	$14.50
Dunn	$1,788,570	$6.23	$6.05	$3,461,277	$12.07	$11.70
Eddy	$1,632,857	$9.63	$9.40	$3,268,650	$19.28	$18.82
Emmons	$3,945,564	$9.63	$9.24	$7,771,601	$18.97	$18.21
Foster	$2,936,090	$10.74	$10.47	$5,824,939	$21.30	$20.77
Golden Valley	$1,750,336	$7.55	$7.26	$3,383,989	$14.59	$14.03
Grand Forks	$4,921,020	$8.92	$8.66	$9,794,076	$17.76	$17.23
Grant	$1,942,701	$6.47	$6.25	$3,791,414	$12.63	$12.20
Griggs	$2,487,777	$10.08	$9.92	$4,976,212	$20.16	$19.85
Hettinger	$2,420,106	$7.16	$6.84	$4,679,336	$13.84	$13.22
Kidder	$1,972,136	$8.15	$8.02	$3,866,761	$15.99	$15.72
La Moure	$5,523,158	$11.34	$10.96	$11,048,823	$22.69	$21.92
Logan	$2,249,996	$9.26	$8.96	$4,449,356	$18.31	$17.72
McHenry	$3,963,503	$9.97	$9.78	$7,807,602	$19.65	$19.27
McIntosh	$2,782,792	$9.62	$9.33	$5,488,325	$18.98	$18.41
McKenzie	$1,785,074	$6.87	$6.60	$3,501,238	$13.47	$12.94
McLean	$6,968,610	$10.96	$10.57	$13,689,116	$21.53	$20.76
Mercer	$1,113,977	$6.20	$5.93	$2,170,639	$12.09	$11.56
Morton	$2,529,189	$7.05	$6.75	$4,910,854	$13.69	$13.11
Mountrail	$3,127,189	$6.95	$6.76	$6,111,310	$13.58	$13.21
Nelson	$3,142,644	$9.77	$9.53	$6,248,885	$19.42	$18.95
Oliver	$919,524.7	$6.86	$6.60	$1,769,303	$13.21	$12.70
Pembina	$3,606,065	$8.11	$7.90	$7,210,729	$16.22	$15.81
Pierce	$3,251,451	$10.41	$10.21	$6,433,658	$20.60	$20.19
Ramsey	$4,463,009	$9.87	$9.62	$8,853,234	$19.58	$19.08
Ransom	$2,965,590	$10.96	$10.61	$5,905,235	$21.82	$21.14
Renville	$3,726,262	$10.67	$10.30	$7,316,251	$20.96	$20.22
Richland	$7,076,295	$11.11	$10.78	$13,973,899	$21.94	$21.28
Rolette	$2,522,640	$10.66	$10.48	$4,942,675	$20.88	$20.52
Sargent	$3,719,126	$11.54	$11.17	$7,421,189	$23.02	$22.28
Sheridan	$2,627,917	$10.41	$10.16	$5,178,479	$20.51	$20.03
Sioux	$623,048.4	$6.07	$5.91	$1,193,072	$11.63	$11.32
Slope	$1,833,909	$7.04	$6.73	$3,592,701	$13.78	$13.19
Stark	$2,293,135	$6.92	$6.60	$4,438,800	$13.40	$12.78
Steele	$3,692,264	$10.65	$10.47	$7,380,260	$21.29	$20.93
Stutsman	$8,283,302	$10.88	$10.63	$16,566,868	$21.75	$21.26
Towner	$3,860,290	$9.43	$9.25	$7,601,618	$18.56	$18.21
Traill	$4,199,012	$9.84	$9.68	$8,447,250	$19.80	$19.47
Walsh	$3,645,884	$7.81	$7.61	$7,228,077	$15.49	$15.09
Ward	$7,327,294	$11.13	$10.79	$14,567,977	$22.13	$21.46
Wells	$5,156,581	$9.90	$9.67	$10,322,183	$19.82	$19.37
Williams	$4,124,631	$8.26	$8.00	$8,086,796	$16.20	$15.58
State Total	$186,968,782			$369,623,724		

Appendix Table B2. Average Annual Direct Impacts and Gross Business Volume, Five and Ten Percent Rainfall Scenarios, Statewide Assessment, by County, North Dakota, 2008 through 2017

	5 Percent Rainfall Scenario				10 Percent Rainfall Scenario			
Counties	Total Direct Impacts	Gross Business Volume	Direct Impacts	Gross Business Volume	Total Direct Impacts	Gross Business Volume	Direct Impacts	Gross Business Volume
	------------ 000s $ ------------		$ per Planted Acre		------------ 000s $ ------------		$ per Planted Acre	
Adams	$3,061,362	$6,035,697	$10.10	$19.92	$4,838,598	$9,539,645	$15.97	$31.49
Barnes	$2,794,260	$5,509,084	$8.82	$17.39	$4,904,052	$9,668,692	$15.48	$30.52
Benson	$4,336,899	$8,550,509	$9.32	$18.37	$7,086,446	$13,971,439	$15.23	$30.02
Billings	$4,896,865	$9,654,522	$13.46	$26.54	$8,379,181	$16,520,158	$23.04	$45.42
Bottineau	$8,611,067	$16,977,339	$12.56	$24.77	$15,517,052	$30,592,985	$22.64	$44.64
Bowman	$5,861,472	$11,556,314	$11.39	$22.46	$9,604,668	$18,936,294	$18.67	$36.80
Burke	$7,428,479	$14,645,782	$16.70	$32.92	$11,641,811	$22,952,668	$26.17	$51.59
Burleigh	$7,699,496	$15,180,111	$13.05	$25.72	$13,337,333	$26,295,512	$22.60	$44.56
Cass	$5,038,641	$9,934,044	$12.34	$24.33	$8,776,542	$17,303,585	$21.50	$42.38
Cavalier	$5,209,645	$10,271,190	$16.25	$32.04	$8,284,904	$16,334,285	$25.85	$50.96
Dickey	$3,749,812	$7,393,025	$15.26	$30.08	$6,087,770	$12,002,477	$24.77	$48.84
Divide	$11,734,256	$23,134,931	$16.54	$32.61	$17,945,803	$35,381,443	$25.29	$49.87
Dunn	$7,695,279	$15,171,797	$13.58	$26.77	$12,543,499	$24,730,412	$22.13	$43.63
Eddy	$4,508,765	$8,889,354	$13.75	$27.11	$7,582,329	$14,949,108	$23.13	$45.60
Emmons	$8,070,752	$15,912,069	$17.69	$34.88	$11,671,192	$23,010,596	$25.58	$50.44
Foster	$7,082,161	$13,962,990	$15.23	$30.02	$11,460,961	$22,596,110	$24.64	$48.58
G. Valley	$5,683,916	$11,206,249	$13.42	$26.45	$9,495,957	$18,721,962	$22.42	$44.20
G. Forks	$6,710,488	$13,230,211	$14.00	$27.61	$10,308,572	$20,324,093	$21.51	$42.41
Grant	$3,866,547	$7,623,175	$13.21	$26.04	$5,454,402	$10,753,747	$18.63	$36.73
Griggs	$2,399,215	$4,730,226	$8.97	$17.68	$4,021,020	$7,927,730	$15.03	$29.63
Hettinger	$10,763,038	$21,220,105	$16.25	$32.04	$17,331,756	$34,170,806	$26.17	$51.59
Kidder	$2,105,213	$4,150,580	$11.29	$22.25	$3,104,141	$6,120,037	$16.64	$32.81
La Moure	$1,714,560	$3,380,379	$12.42	$24.48	$2,517,548	$4,963,527	$18.23	$35.95
Logan	$2,206,893	$4,351,049	$12.66	$24.96	$3,834,540	$7,560,071	$22.00	$43.37
McHenry	$5,099,090	$10,053,224	$18.23	$35.94	$7,930,067	$15,634,699	$28.35	$55.89
McIntosh	$2,850,112	$5,619,201	$11.53	$22.73	$4,699,401	$9,265,207	$19.01	$37.48
McKenzie	$3,374,743	$6,653,549	$12.99	$25.61	$5,865,026	$11,563,321	$22.57	$44.50
McLean	$12,225,102	$24,102,668	$15.69	$30.93	$20,297,778	$40,018,532	$26.05	$51.36
Mercer	$8,955,143	$17,655,710	$16.81	$33.14	$14,090,837	$27,781,100	$26.45	$52.14
Morton	$11,893,434	$23,448,762	$18.70	$36.86	$18,683,370	$36,835,609	$29.37	$57.91
Mountrail	$13,990,517	$27,583,312	$15.73	$31.02	$23,274,413	$45,887,182	$26.18	$51.61
Nelson	$4,045,783	$7,976,553	$16.20	$31.95	$6,488,574	$12,792,691	$25.99	$51.24
Oliver	$6,629,864	$13,071,254	$18.84	$37.14	$10,232,201	$20,173,520	$29.07	$57.31
Pembina	$10,576,313	$20,851,962	$24.42	$48.16	$14,749,941	$29,080,572	$34.06	$67.16
Pierce	$2,307,417	$4,549,239	$13.33	$26.27	$3,316,422	$6,538,566	$19.15	$37.76
Ramsey	$2,116,116	$4,172,075	$12.73	$25.09	$3,004,180	$5,922,958	$18.07	$35.62
Ransom	$1,411,055	$2,781,997	$8.67	$17.09	$2,279,178	$4,493,564	$14.00	$27.61
Renville	$2,047,954	$4,037,689	$8.11	$15.99	$3,632,854	$7,162,432	$14.39	$28.37
Richland	$3,935,076	$7,758,286	$11.29	$22.26	$6,062,875	$11,953,395	$17.40	$34.30
Rolette	$2,957,846	$5,831,606	$11.00	$21.68	$4,600,841	$9,070,889	$17.11	$33.73
Sargent	$3,176,247	$6,262,199	$9.33	$18.39	$5,208,247	$10,268,434	$15.29	$30.15
Sheridan	$4,220,296	$8,320,618	$13.59	$26.79	$6,833,049	$13,471,847	$22.00	$43.38
Sioux	$7,230,123	$14,254,709	$17.50	$34.50	$10,835,202	$21,362,382	$26.23	$51.71
Slope	$3,469,399	$6,840,171	$10.91	$21.51	$5,319,545	$10,487,866	$16.73	$32.98
Stark	$4,117,031	$8,117,022	$11.38	$22.43	$6,322,660	$12,465,580	$17.47	$34.45
Steele	$1,279,560	$2,522,744	$9.84	$19.41	$1,960,166	$3,864,609	$15.08	$29.73
Stutsman	$8,708,241	$17,168,924	$22.83	$45.01	$12,765,158	$25,167,428	$33.47	$65.98
Towner	$9,130,094	$18,000,639	$18.61	$36.70	$14,361,878	$28,315,476	$29.28	$57.72
Traill	$3,865,898	$7,621,897	$13.94	$27.48	$6,215,685	$12,254,672	$22.41	$44.18
Walsh	$4,669,741	$9,206,731	$15.97	$31.49	$7,228,454	$14,251,418	$24.72	$48.74
Ward	$4,789,613	$9,443,068	$17.09	$33.70	$7,639,028	$15,060,894	$27.26	$53.75
Wells	$11,207,489	$22,096,373	$17.08	$33.67	$17,938,989	$35,368,008	$27.34	$53.90
Williams	$5,712,019	$11,261,656	$17.20	$33.91	$9,290,132	$18,316,164	$27.97	$55.15
State Total	$299,220,400	$589,934,570	$14.65	$28.88	$476,856,229	$940,156,401	$23.35	$46.03

Appendix Table B3. Average Annual Value of Enhanced Growing Season Rainfall, Five and Ten Percent Rainfall Scenarios, Statewide Assessment, by County, North Dakota, 2008 through 2017

	5 Percent Rainfall Scenario			10 Percent Rainfall Scenario		
Counties	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	$1,110,538	$7.02	$6.82	$2,181,227	$13.80	$13.40
Burke	$752,212	$7.58	$7.39	$1,478,377	$14.90	$14.53
McKenzie	$1,962,683	$7.61	$7.34	$3,854,731	$14.94	$14.41
Mountrail	$3,788,524	$8.36	$8.14	$7,443,394	$16.43	$15.99
Slope	$844,858	$7.94	$7.62	$1,659,334	$15.60	$14.97
Ward	$8,343,786	$12.55	$12.17	$16,604,177	$24.97	$24.23
Williams	$4,418,211	$8.87	$8.59	$8,679,013	$17.42	$16.87
Total	$21,220,812	$9.48	$9.19	$41,900,252	$18.72	$18.15

Appendix Table B4. Average Annual Direct Impacts and Gross Business Volume, Five and Ten Percent Rainfall Scenarios, Statewide Assessment, by County, North Dakota, 2008 through 2017

	5 Percent Rainfall Scenario				10 Percent Rainfall Scenario			
Counties	Total Direct Impacts	Gross Business Volume*	Direct Impacts	Gross Business Volume	Total Direct Impacts	Gross Business Volume	Direct Impacts	Gross Business Volume
	------------ 000s $ ------------		$ per Planted Acre		------------ 000s $ ------------		$ per Planted Acre	
Bowman	$1,616,844	$3,187,725	$9.93	$19.59	$2,687,533	$5,298,665	$16.51	$32.56
Burke	$856,635	$1,688,917	$8.42	$16.59	$1,582,799	$3,120,603	$15.55	$30.66
McKenzie	$2,675,023	$5,274,000	$10.00	$19.71	$4,567,071	$9,004,309	$17.07	$33.66
Mountrail	$5,244,103	$10,339,127	$11.27	$22.22	$8,898,973	$17,544,966	$19.12	$37.70
Slope	$1,408,575	$2,777,107	$12.71	$25.06	$2,223,051	$4,382,905	$20.06	$39.55
Ward	$9,966,835	$19,650,334	$14.54	$28.67	$18,227,226	$35,936,288	$26.60	$52.44
Williams	$6,382,894	$12,584,335	$12.41	$24.46	$10,643,696	$20,984,814	$20.69	$40.78
Total	$28,150,909	$55,501,545	$12.20	$24.05	$48,830,349	$96,272,550	$21.16	$41.71

*Gross business volume was distributed among counties based on dollar volume of direct impacts within each 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.

Appendix Table B5. Total Crop Revenue (Baseline), Five Percent Enhanced Rainfall Scenario, Statewide Assessment, North Dakota, 2008 through 2017

County	Alfalfa	Barley	Canola	Corn	D.E. Beans	Flax	Soybeans	Sunflower	Wheat	Total
	----------------	----------------	----------------	----------------	---------------- 000s $	----------------	----------------	----------------	----------------	
Adams	4,421.8	647.2	2,529.0	1,659.2	0.0	339.8	26.4	3,923.4	22,223.6	35,770.5
Barnes	2,346.8	3,352.6	72.9	87,543.4	2,860.1	1.0	123,220.3	1,654.5	33,087.0	254,138.5
Benson	1,943.4	12,792.9	4,532.8	25,655.2	17,511.8	432.3	47,910.8	984.8	40,937.2	152,701.3
Billings	6,679.9	1,084.0	747.5	518.7	0.0	150.6	44.3	2,021.3	14,618.1	25,864.4
Bottineau	2,021.4	28,804.4	22,607.9	7,280.2	147.3	2,744.8	26,811.8	17,975.0	70,337.7	178,730.6
Bowman	7,416.2	693.6	1,039.8	156.3	0.0	509.0	0.0	1,327.8	18,712.0	29,854.7
Burke	3,798.9	4,188.3	17,856.2	7.7	0.0	3,188.3	589.8	1,423.6	45,128.3	76,181.1
Burleigh	9,822.6	5,036.6	2,544.7	14,780.4	1,675.1	1,751.4	10,233.0	10,850.3	27,786.3	84,480.4
Cass	2,166.8	3,751.0	0.0	149,760.3	3,737.4	133.6	179,869.8	4,232.5	36,444.2	380,095.6
Cavalier	389.5	12,182.4	91,267.5	1,902.7	7,298.9	1,474.9	23,456.9	2,779.1	108,950.1	249,702.1
Dickey	3,970.2	724.0	0.0	87,328.0	2,512.4	0.0	65,110.9	718.3	7,770.0	168,133.8
Divide	3,694.2	1,593.8	5,274.2	70.8	0.0	2,539.5	1,054.5	486.3	51,852.6	66,566.0
Dunn	12,052.7	1,521.5	1,666.1	2,726.8	9.1	355.1	0.0	4,549.8	34,718.3	57,599.3
Eddy	2,436.1	4,671.7	748.8	10,722.6	3,006.4	164.1	22,196.3	944.0	12,314.6	57,204.5
Emmons	7,842.7	3,961.5	476.8	37,931.0	811.0	225.4	20,011.7	26,140.3	31,426.0	128,826.5
Foster	1,419.0	6,341.8	624.3	25,823.0	1,460.1	121.3	45,299.4	859.2	16,993.9	98,942.1
G. Valley	4,619.4	615.4	6,037.3	737.1	0.0	553.3	0.0	3,750.4	37,010.5	53,323.3
G. Forks	1,305.9	3,597.3	576.0	52,112.5	40,415.8	10.4	60,205.6	3,871.2	59,237.2	221,331.8
Grant	12,404.9	1,375.2	1,163.9	9,853.9	75.9	593.7	4,758.0	11,629.2	27,135.1	68,989.8
Griggs	2,581.3	3,363.3	198.9	16,217.2	5,456.8	0.0	38,595.4	914.7	22,019.5	89,347.2
Hettinger	3,855.6	1,331.7	12,904.9	4,637.0	0.0	863.7	228.0	4,802.8	54,681.7	83,305.4
Kidder	12,704.1	2,988.3	810.5	7,336.1	85.1	2,029.5	13,608.0	3,551.3	14,844.9	57,957.9
La Moure	2,649.9	1,068.1	0.0	90,644.4	3,193.9	0.1	96,214.6	1,080.7	14,089.1	208,940.9
Logan	8,084.5	2,899.1	126.3	19,846.2	378.3	202.3	28,071.5	4,285.5	14,543.8	78,437.2
McHenry	7,144.1	7,221.9	11,911.6	14,778.7	679.4	2,522.0	20,485.3	8,067.8	38,840.3	111,651.1
McIntosh	8,517.3	1,763.3	104.9	15,949.4	0.0	145.3	28,734.0	6,402.8	19,691.8	81,308.8
McKenzie	7,737.9	3,045.8	1,815.9	140.9	23.3	565.9	0.0	584.2	31,892.2	45,806.0
McLean	4,220.6	6,342.3	24,042.8	19,179.4	10,448.0	7,747.3	16,684.6	11,987.4	90,753.8	191,406.2
Mercer	7,259.2	3,286.1	3,638.1	4,652.7	400.0	780.9	1,133.2	4,845.5	16,391.6	42,387.4
Morton	12,691.3	4,278.1	1,016.1	9,826.7	0.0	679.9	2,034.6	12,042.7	38,532.7	81,102.2
Mountrail	6,482.4	4,669.6	21,309.2	565.0	67.5	5,939.1	2,341.4	2,209.9	60,400.5	103,984.7
Nelson	2,420.1	5,460.2	5,844.6	11,259.6	9,775.2	206.1	35,775.2	822.7	36,580.4	108,144.1
Oliver	4,785.6	1,472.0	1,179.6	5,085.8	1,234.8	463.7	1,857.8	3,870.5	15,546.3	35,496.2
Pembina	780.6	2,571.1	1,769.1	14,430.2	33,602.9	0.0	44,450.2	1,646.2	73,637.7	172,888.1
Pierce	2,897.3	6,740.9	9,306.2	10,490.8	2,326.6	698.7	28,628.0	2,530.2	35,896.9	99,515.5
Ramsey	371.6	17,042.8	18,616.0	25,480.2	16,178.9	504.9	38,217.1	1,169.0	43,963.1	161,543.6
Ransom	3,629.4	201.0	0.0	50,945.3	3,825.7	0.0	47,012.5	762.5	14,085.6	120,461.9
Renville	1,016.8	16,334.0	17,719.5	1,843.5	0.0	2,993.0	10,662.4	7,093.9	48,031.9	105,694.9
Richland	1,658.3	445.5	0.0	156,399.8	1,009.4	0.0	117,972.2	1,945.3	19,894.5	299,325.1
Rolette	3,277.2	6,272.1	19,408.7	1,776.5	394.0	795.7	9,829.6	2,144.6	31,370.2	75,268.6
Sargent	1,141.5	110.4	0.0	70,623.2	865.7	0.0	62,708.5	232.9	10,745.4	146,427.5
Sheridan	2,749.2	6,854.3	4,934.9	6,646.0	520.8	3,126.5	16,846.8	4,067.5	27,646.8	73,392.8
Sioux	6,956.0	182.9	89.3	2,141.8	0.0	75.9	894.4	5,001.0	8,705.0	24,046.2
Slope	6,466.0	1,009.5	2,732.1	457.3	0.0	374.4	0.0	2,352.7	36,481.2	49,873.1
Stark	8,086.4	1,373.8	3,838.4	3,852.5	0.0	473.0	81.3	5,851.4	45,910.3	69,467.1
Steele	712.9	2,633.8	120.8	44,859.5	20,464.5	20.3	56,839.7	1,124.5	20,672.6	147,448.5
Stutsman	6,216.8	3,970.4	624.2	89,247.4	5,232.3	545.1	142,229.9	2,342.6	32,390.6	282,799.3
Towner	599.4	7,809.6	32,014.1	4,560.2	7,913.8	1,166.3	25,652.9	1,559.3	61,518.5	142,794.2
Traill	475.9	4,068.2	2.1	63,148.4	16,620.6	0.0	72,447.8	1,797.6	31,250.5	189,811.1
Walsh	661.6	4,294.7	8,208.2	20,892.5	41,433.0	334.2	32,040.0	1,999.6	69,805.5	179,669.3
Ward	3,001.3	9,717.4	23,591.5	6,761.8	154.6	9,155.6	21,721.6	10,263.2	91,381.7	175,748.7
Wells	1,531.8	7,670.2	1,197.6	37,379.8	22,323.3	429.8	62,259.6	3,206.1	55,207.8	191,206.0
Williams	4,185.3	6,600.4	5,595.3	135.5	445.6	1,116.1	901.8	644.5	78,973.8	98,598.3
State	238,301.6	252,028.0	394,436.8	1,348,761.1	286,575.4	59,243.8	1,707,959.6	223,324.1	2,003,060.8	6,513,691.2

Appendix Table B6. Average Annual Change in Crop Revenues, Five Percent Enhanced Rainfall Scenario with Price Effects, Statewide Assessment, North Dakota, 2008 through 2017

County	Alfalfa	Barley	Canola	Corn	D.E. Beans	Flax	Soybeans	Sunflower	Wheat	Total
	-- 000s $ --									
Adams	66.0	16.3	50.6	44.5	0.0	2.7	1.1	153.5	742.7	1,077.4
Barnes	14.5	73.1	3.8	1,825.8	39.3	0.0	3,983.4	54.2	837.4	6,831.5
Benson	28.8	287.4	160.0	624.8	276.0	15.3	1,615.2	41.2	1,188.6	4,237.3
Billings	127.7	26.1	34.4	25.8	0.0	1.3	2.2	77.0	687.9	982.4
Bottineau	28.5	648.6	939.8	166.2	2.8	145.2	783.8	599.6	2,553.7	5,868.1
Bowman	105.3	16.6	30.6	6.7	0.0	3.0	0.0	63.0	682.6	907.8
Burke	44.6	77.2	258.3	0.2	0.0	21.8	26.6	53.1	1,429.2	1,911.1
Burleigh	116.9	115.1	99.5	353.1	28.2	120.8	316.5	377.1	1,172.4	2,699.6
Cass	2.9	48.1	0.0	2,553.2	50.4	1.0	6,076.9	105.3	595.4	9,433.3
Cavalier	5.7	249.6	2,210.9	46.2	129.9	41.4	870.5	100.3	2,815.9	6,470.4
Dickey	24.5	16.2	0.0	1,809.4	28.4	0.0	1,894.6	19.6	214.9	4,007.6
Divide	43.8	27.6	110.4	1.9	0.0	18.1	49.3	24.6	1,958.7	2,234.3
Dunn	151.4	31.6	35.1	74.3	0.1	3.6	0.0	166.2	1,237.3	1,699.7
Eddy	21.7	98.4	26.2	255.5	52.3	6.3	749.0	32.4	382.5	1,624.4
Emmons	76.1	90.5	24.2	882.4	12.0	18.9	582.8	689.5	1,343.0	3,719.5
Foster	18.8	145.9	25.2	586.0	22.7	5.3	1,554.9	30.1	488.0	2,876.9
G. Valley	77.6	13.4	85.7	21.8	0.0	5.3	0.0	130.5	1,348.0	1,682.2
G. Forks	12.0	63.0	18.6	944.9	630.5	0.3	2,080.8	159.0	989.2	4,898.2
Grant	95.9	28.7	24.9	222.0	0.3	5.2	119.5	390.0	1,052.3	1,938.9
Griggs	7.5	70.5	6.8	379.0	70.6	0.0	1,295.3	25.9	587.2	2,442.8
Hettinger	64.4	21.8	227.3	116.8	0.0	6.0	9.8	163.1	1,687.7	2,297.0
Kidder	215.2	86.3	46.8	187.5	1.9	163.5	447.7	122.7	653.5	1,925.0
La Moure	14.6	23.0	0.0	1,826.0	44.9	0.1	2,917.3	39.4	364.3	5,229.4
Logan	94.2	74.6	10.2	451.2	6.5	19.1	953.2	176.1	614.8	2,399.9
McHenry	94.4	182.6	512.7	336.8	11.6	139.2	632.7	290.4	1,658.9	3,859.3
McIntosh	94.0	45.3	7.1	385.7	0.0	13.2	1,058.4	220.8	809.3	2,633.8
McKenzie	95.2	62.9	46.7	3.4	0.4	4.7	0.0	20.3	1,458.7	1,692.3
McLean	60.5	153.5	1,012.6	417.6	166.2	460.8	500.6	366.0	3,668.5	6,806.2
Mercer	58.3	56.7	66.7	112.8	3.9	4.5	34.2	172.3	542.7	1,052.0
Morton	93.6	78.9	29.0	267.3	0.0	3.8	59.8	429.8	1,382.7	2,344.9
Mountrail	86.3	86.9	374.5	12.7	0.8	39.4	76.4	91.4	2,170.6	2,939.1
Nelson	16.8	119.5	202.7	273.0	151.1	6.5	1,286.9	45.8	1,007.2	3,109.5
Oliver	52.6	26.7	17.6	97.6	10.2	3.3	50.6	130.0	481.5	870.1
Pembina	4.7	35.1	32.1	272.1	501.6	0.0	1,534.5	58.9	1,166.0	3,605.0
Pierce	40.8	155.2	368.2	232.5	40.7	40.9	892.6	86.2	1,288.4	3,145.4
Ramsey	5.2	357.3	559.5	600.1	270.1	18.3	1,369.3	55.8	1,235.3	4,470.9
Ransom	7.1	5.6	0.0	1,013.4	52.4	0.0	1,410.2	19.3	368.0	2,876.0
Renville	17.8	367.4	726.9	42.7	0.0	140.1	332.0	238.1	1,741.2	3,606.3
Richland	5.0	6.6	0.0	2,615.6	11.6	0.0	3,854.0	62.6	355.2	6,910.5
Rolette	48.0	145.1	706.0	40.7	8.1	35.5	316.3	88.5	1,059.3	2,447.4
Sargent	5.4	2.1	0.0	1,424.2	10.1	0.0	1,872.4	7.5	273.7	3,595.3
Sheridan	38.5	160.0	217.2	147.5	10.8	201.3	550.9	133.2	1,107.2	2,566.6
Sioux	74.2	5.6	4.0	61.9	0.0	1.0	28.4	195.9	367.6	738.6
Slope	79.5	23.1	51.3	15.3	0.0	2.5	0.0	111.5	1,447.3	1,730.6
Stark	133.7	24.9	70.5	96.3	0.0	3.5	3.3	215.7	1,629.6	2,177.5
Steele	3.1	49.7	3.2	936.9	264.8	1.9	1,793.4	31.2	522.9	3,607.1
Stutsman	45.3	98.4	22.8	1,956.5	73.5	24.2	4,774.6	88.9	985.1	8,069.4
Towner	7.2	176.4	899.3	107.6	129.3	35.4	866.1	64.2	1,660.0	3,945.4
Traill	1.8	51.3	0.2	1,078.1	202.2	0.0	2,290.3	41.3	459.6	4,124.8
Walsh	5.1	73.0	149.6	393.6	606.0	4.5	1,167.8	75.8	1,194.5	3,670.0
Ward	48.2	236.6	1,213.5	169.5	4.5	589.9	723.3	322.8	3,850.2	7,158.4
Wells	17.1	157.7	45.5	850.8	372.7	20.3	2,014.5	103.8	1,543.9	5,126.1
Williams	52.9	130.3	157.4	3.1	5.6	9.8	39.5	29.9	3,486.3	3,914.8
State	2,750.9	5,423.6	11,925.9	27,370.6	4,305.3	2,408.8	55,863.1	7,591.5	64,548.4	182,188.1

Appendix Table B7. Total Crop Revenue (Baseline), Ten Percent Enhanced Rainfall Scenario, Statewide Assessment, North Dakota, 2008 through 2017

County	Alfalfa	Barley	Canola	Corn	D.E. Beans	Flax	Soybeans	Sunflower	Wheat	Total
	------	------	------	------	000s $	------	------	------	------	------
Adams	4,421.8	647.2	2,529.0	1,659.2	0.0	339.8	26.4	3,923.4	22,223.6	35,770.5
Barnes	2,346.8	3,352.6	72.9	87,543.4	2,860.1	1.0	123,220.3	1,654.5	33,087.0	254,138.5
Benson	1,943.4	12,792.9	4,532.8	25,655.2	17,511.8	432.3	47,910.8	984.8	40,937.2	152,701.3
Billings	6,679.9	1,084.0	747.5	518.7	0.0	150.6	44.3	2,021.3	14,618.1	25,864.4
Bottineau	2,021.4	28,804.4	22,607.9	7,280.2	147.3	2,744.8	26,811.8	17,975.0	70,337.7	178,730.6
Bowman	7,597.0	713.1	1,093.2	162.8	0.0	517.6	0.0	1,415.1	19,431.9	30,930.8
Burke	3,798.9	4,188.3	17,856.2	7.7	0.0	3,188.3	589.8	1,423.6	45,128.3	76,181.1
Burleigh	9,822.6	5,036.6	2,544.7	14,780.4	1,675.1	1,751.4	10,233.0	10,850.3	27,786.3	84,480.4
Cass	2,166.8	3,751.0	0.0	149,760.3	3,737.4	133.6	179,869.8	4,232.5	36,444.2	380,095.6
Cavalier	389.5	12,182.4	91,267.5	1,902.7	7,298.9	1,474.9	23,456.9	2,779.1	108,950.1	249,702.1
Dickey	3,970.2	724.0	0.0	87,328.0	2,512.4	0.0	65,110.9	718.3	7,770.0	168,133.8
Divide	3,694.2	1,593.8	5,274.2	70.8	0.0	2,539.5	1,054.5	486.3	51,852.6	66,566.0
Dunn	12,052.7	1,521.5	1,666.1	2,726.8	9.1	355.1	0.0	4,549.8	34,718.3	57,599.3
Eddy	2,436.1	4,671.7	748.8	10,722.6	3,006.4	164.1	22,196.3	944.0	12,314.6	57,204.5
Emmons	7,842.7	3,961.5	476.8	37,931.0	811.0	225.4	20,011.7	26,140.3	31,426.0	128,826.5
Foster	1,419.0	6,341.8	624.3	25,823.0	1,460.1	121.3	45,299.4	859.2	16,993.9	98,942.1
G. Valley	4,619.4	615.4	6,037.3	737.1	0.0	553.3	0.0	3,750.4	37,010.5	53,323.3
G. Forks	1,305.9	3,597.3	576.0	52,112.5	40,415.8	10.4	60,205.6	3,871.2	59,237.2	221,331.8
Grant	12,404.9	1,375.2	1,163.9	9,853.9	75.9	593.7	4,758.0	11,629.2	27,135.1	68,989.8
Griggs	2,581.3	3,363.3	198.9	16,217.2	5,456.8	0.0	38,595.4	914.7	22,019.5	89,347.2
Hettinger	3,855.6	1,331.7	12,904.9	4,637.0	0.0	863.7	228.0	4,802.8	54,681.7	83,305.4
Kidder	12,704.1	2,988.3	810.5	7,336.1	85.1	2,029.5	13,608.0	3,551.3	14,844.9	57,957.9
La Moure	2,649.9	1,068.1	0.0	90,644.4	3,193.9	0.1	96,214.6	1,080.7	14,089.1	208,940.9
Logan	8,084.5	2,899.1	126.3	19,846.2	378.3	202.3	28,071.5	4,285.5	14,543.8	78,437.2
McHenry	7,144.1	7,221.9	11,911.6	14,778.7	679.4	2,522.0	20,485.3	8,067.8	38,840.3	111,651.1
McIntosh	8,517.3	1,763.3	104.9	15,949.4	0.0	145.3	28,734.0	6,402.8	19,691.8	81,308.8
McKenzie	7,915.0	3,122.4	1,902.1	144.2	24.1	577.2	0.0	613.7	33,408.0	47,706.7
McLean	4,220.6	6,342.3	24,042.8	19,179.4	10,448.0	7,747.3	16,684.6	11,987.4	90,753.8	191,406.2
Mercer	7,259.2	3,286.1	3,638.1	4,652.7	400.0	780.9	1,133.2	4,845.5	16,391.6	42,387.4
Morton	12,691.3	4,278.1	1,016.1	9,826.7	0.0	679.9	2,034.6	12,042.7	38,532.7	81,102.2
Mountrail	6,637.7	4,777.8	22,148.1	577.3	69.3	6,052.4	2,417.8	2,342.3	62,700.7	107,723.4
Nelson	2,420.1	5,460.2	5,844.6	11,259.6	9,775.2	206.1	35,775.2	822.7	36,580.4	108,144.1
Oliver	4,785.6	1,472.0	1,179.6	5,085.8	1,234.8	463.7	1,857.8	3,870.5	15,546.3	35,496.2
Pembina	780.6	2,571.1	1,769.1	14,430.2	33,602.9	0.0	44,450.2	1,646.2	73,637.7	172,888.1
Pierce	2,897.3	6,740.9	9,306.2	10,490.8	2,326.6	698.7	28,628.0	2,530.2	35,896.9	99,515.5
Ramsey	371.6	17,042.8	18,616.0	25,480.2	16,178.9	504.9	38,217.1	1,169.0	43,963.1	161,543.6
Ransom	3,629.4	201.0	0.0	50,945.3	3,825.7	0.0	47,012.5	762.5	14,085.6	120,461.9
Renville	1,016.8	16,334.0	17,719.5	1,843.5	0.0	2,993.0	10,662.4	7,093.9	48,031.9	105,694.9
Richland	1,658.3	445.5	0.0	156,399.8	1,009.4	0.0	117,972.2	1,945.3	19,894.5	299,325.1
Rolette	3,277.2	6,272.1	19,408.7	1,776.5	394.0	795.7	9,829.6	2,144.6	31,370.2	75,268.6
Sargent	1,141.5	110.4	0.0	70,623.2	865.7	0.0	62,708.5	232.9	10,745.4	146,427.5
Sheridan	2,749.2	6,854.3	4,934.9	6,646.0	520.8	3,126.5	16,846.8	4,067.5	27,646.8	73,392.8
Sioux	6,956.0	182.9	89.3	2,141.8	0.0	75.9	894.4	5,001.0	8,705.0	24,046.2
Slope	6,526.8	1,020.7	2,777.5	472.0	0.0	381.5	0.0	2,508.3	38,003.6	51,690.4
Stark	8,086.4	1,373.8	3,838.4	3,852.5	0.0	473.0	81.3	5,851.4	45,910.3	69,467.1
Steele	712.9	2,633.8	120.8	44,859.5	20,464.5	20.3	56,839.7	1,124.5	20,672.6	147,448.5
Stutsman	6,216.8	3,970.4	624.2	89,247.4	5,232.3	545.1	142,229.9	2,342.6	32,390.6	282,799.3
Towner	599.4	7,809.6	32,014.1	4,560.2	7,913.8	1,166.3	25,652.9	1,559.3	61,518.5	142,794.2
Traill	475.9	4,068.2	2.1	63,148.4	16,620.6	0.0	72,447.8	1,797.6	31,250.5	189,811.1
Walsh	661.6	4,294.7	8,208.2	20,892.5	41,433.0	334.2	32,040.0	1,999.6	69,805.5	179,669.3
Ward	3,085.3	10,003.7	25,379.6	6,929.5	161.0	9,877.4	22,444.8	10,788.9	95,517.7	184,187.9
Wells	1,531.8	7,670.2	1,197.6	37,379.8	22,323.3	429.8	62,259.6	3,206.1	55,207.8	191,206.0
Williams	4,284.6	6,759.7	5,872.9	138.5	457.0	1,139.0	941.3	686.0	82,607.8	102,886.8
State	239,059.0	252,689.1	397,526.4	1,348,968.6	286,595.8	60,128.8	1,708,798.7	224,296.2	2,016,889.2	6,534,951.8

Appendix Table B8. Average Annual Change in Crop Revenues, Ten Percent Enhanced Rainfall Scenario with Price Effects, Statewide Assessment, North Dakota, 2008 through 2017										
County	Alfalfa	Barley	Canola	Corn	D.E. Beans	Flax	Soybeans	Sunflower	Wheat	Total
	------------ 000s $ ------------									
Adams	128.5	31.5	92.7	87.2	0.0	5.1	2.2	292.1	1,451.4	2,090.6
Barnes	27.0	144.2	7.2	3,667.8	76.9	0.1	7,924.7	105.3	1,668.5	13,621.6
Benson	48.0	567.1	307.2	1,256.5	540.9	30.5	3,247.9	80.2	2,368.4	8,446.7
Billings	207.8	53.0	64.4	51.1	0.0	2.7	4.4	146.2	1,343.9	1,873.5
Bottineau	59.5	1,274.9	1,797.1	328.6	5.6	283.6	1,565.5	1,156.3	5,059.0	11,529.9
Bowman	206.9	32.6	59.1	13.1	0.0	5.6	0.0	123.0	1,338.5	1,778.8
Burke	82.1	144.6	463.3	0.4	0.0	33.3	53.3	100.8	2,791.5	3,669.3
Burleigh	228.8	227.4	189.9	702.8	55.4	234.9	632.0	727.4	2,322.6	5,321.2
Cass	5.5	95.5	0.0	5,101.5	98.8	1.9	12,023.2	204.5	1,186.2	18,717.1
Cavalier	8.8	503.4	4,221.4	95.3	254.8	83.4	1,737.6	195.3	5,610.8	12,710.9
Dickey	47.3	32.1	0.0	3,605.7	55.5	0.0	3,857.5	38.1	428.2	8,064.5
Divide	81.8	53.9	202.1	3.7	0.0	35.5	98.6	47.0	3,827.1	4,349.6
Dunn	276.5	62.7	64.5	146.2	0.2	6.2	0.0	315.0	2,417.4	3,288.7
Eddy	45.4	192.9	50.3	508.4	102.6	12.6	1,513.9	63.1	762.2	3,251.5
Emmons	144.2	175.5	46.3	1,751.4	23.6	36.9	1,162.1	1,325.9	2,660.3	7,326.2
Foster	31.0	287.1	48.4	1,175.4	44.5	9.6	3,079.2	58.7	972.2	5,706.1
G. Valley	144.8	26.1	152.7	42.4	0.0	7.7	0.0	246.7	2,632.2	3,252.5
G. Forks	17.5	123.2	35.5	1,895.5	1,235.3	0.5	4,160.1	309.7	1,970.8	9,747.9
Grant	204.9	58.6	45.6	437.8	0.6	9.3	239.0	739.1	2,055.9	3,790.9
Griggs	21.8	139.9	13.0	756.4	138.2	0.0	2,596.5	50.3	1,170.0	4,886.2
Hettinger	118.2	44.3	413.7	229.6	0.0	11.2	19.6	309.6	3,297.0	4,443.1
Kidder	391.9	170.8	89.8	373.0	3.8	319.8	893.8	236.7	1,294.6	3,774.3
La Moure	29.4	45.4	0.0	3,649.7	87.9	0.2	5,846.2	76.5	725.7	10,461.2
Logan	164.2	149.1	19.6	896.6	12.8	37.3	1,912.8	340.2	1,217.9	4,750.5
McHenry	181.2	363.9	979.3	672.2	22.7	271.2	1,266.6	560.0	3,286.5	7,603.5
McIntosh	160.4	87.5	13.7	771.6	0.0	25.7	2,105.0	425.8	1,603.2	5,193.0
McKenzie	189.1	122.9	90.0	6.7	0.9	8.9	0.0	39.6	2,861.1	3,319.2
McLean	116.6	304.6	1,934.4	829.0	325.9	890.3	1,001.3	704.4	7,267.3	13,373.7
Mercer	128.3	109.4	121.3	221.8	7.6	7.9	68.5	326.5	1,060.0	2,051.3
Morton	175.6	157.0	53.7	524.5	0.0	6.8	119.3	814.8	2,701.1	4,552.8
Mountrail	171.0	169.9	715.8	25.0	1.6	73.5	152.7	178.4	4,255.8	5,743.8
Nelson	33.1	239.5	390.1	550.1	296.0	12.5	2,564.6	89.4	2,007.0	6,182.3
Oliver	86.6	52.3	31.6	190.4	19.8	5.4	101.1	246.1	940.3	1,673.6
Pembina	7.1	71.6	60.9	547.6	982.2	0.0	3,100.9	114.7	2,323.0	7,208.1
Pierce	75.2	306.6	702.4	464.6	79.8	80.0	1,797.8	166.0	2,552.2	6,224.5
Ramsey	8.6	714.7	1,070.4	1,210.6	529.5	35.9	2,727.7	108.7	2,461.4	8,867.5
Ransom	14.8	11.1	0.0	2,017.7	102.5	0.0	2,808.3	37.7	733.3	5,725.4
Renville	33.8	724.6	1,391.7	85.0	0.0	275.3	663.8	459.3	3,449.4	7,082.9
Richland	8.5	13.1	0.0	5,202.6	22.7	0.0	7,565.6	121.8	707.6	13,641.9
Rolette	88.3	287.2	1,346.1	83.1	16.0	70.3	635.8	170.9	2,098.2	4,795.9
Sargent	11.0	4.1	0.0	2,839.0	19.7	0.0	3,739.6	14.7	545.3	7,173.4
Sheridan	74.2	319.8	415.4	291.4	21.2	388.0	1,098.1	256.7	2,193.4	5,058.2
Sioux	131.7	10.2	7.4	121.1	0.0	1.9	56.7	372.3	718.2	1,419.5
Slope	159.2	45.0	95.3	30.1	0.0	4.7	0.0	217.8	2,838.1	3,390.3
Stark	240.1	50.9	128.1	189.9	0.0	6.4	6.6	409.3	3,184.0	4,215.3
Steele	5.7	98.0	6.1	1,881.5	518.0	3.6	3,594.1	60.8	1,041.8	7,209.6
Stutsman	97.2	193.0	43.8	3,933.7	144.1	47.5	9,543.9	173.2	1,962.7	16,139.0
Towner	14.0	346.7	1,716.6	212.1	253.3	66.5	1,728.0	125.2	3,307.7	7,770.1
Traill	3.1	102.8	0.4	2,160.8	395.3	0.0	4,640.4	80.1	915.6	8,298.4
Walsh	8.4	142.2	283.1	785.8	1,186.6	8.6	2,333.1	147.6	2,379.8	7,275.1
Ward	98.6	470.2	2,404.6	337.3	9.0	1,170.1	1,446.4	641.4	7,655.7	14,233.2
Wells	35.6	316.2	87.0	1,694.4	730.7	38.4	4,080.1	201.6	3,076.3	10,260.4
Williams	105.6	254.7	303.9	6.1	11.2	18.5	79.1	58.3	6,837.5	7,675.0
State	5,184.5	10,725.6	22,777.1	54,661.7	8,433.6	4,686.0	111,595.1	14,610.4	127,535.7	360,209.6

Appendix C

Economic Impact Methods and Models

Overview

Economic impact assessments measure the economic activity from a project, program, policy, or activity. Economic activity is 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 a project, program, or event. Secondary impacts result from subsequent rounds of spending and re-spending within an economy.

Direct economic impacts are usually measured as injections (or reductions) of money into a specified economy. Direct impacts therefore represent inputs into an economic model to trace linkages among sectors of an economy and calculate various forms of business activity resulting from a direct impact in an economic sector.

Input-Output Analysis

Input-output analysis is a mathematical representation of the production and consumption of goods and services within a given economy. The basic premise to input-output modeling can be traced to economic base theory, or the understanding that a given economy is comprised of both 1) economic sectors or industries which produce goods/services for export outside the economy (basic sectors) and 2) economic sectors which produce goods/services within the economy for use by those exporting industries (non-basic sector). However, current I-O modeling platforms do not limit economic activity in non-basic sectors to be driven or sustained entirely by basic sector output.

Input-output analysis is premised on the notion of inter-industry transactions, where industries use products/services from other industries to generate their output, and outputs from one industry usually represent inputs to another industry. The basis for the interdependence (linkages) within input-output analysis between consuming and producing industries forms the foundation for development of multiplier effects. Multiplier effects can then be used to estimate how initial changes in economic activity result in economy-wide changes in a given area and represent the core component of input-output analysis.

While input-output analysis is a popular methodology used by a host of different stakeholders, the methodology has a number of fundamental assumptions or limitations. Key assumptions in input-output methodologies include 1) the economy is in equilibrium, 2) any expansion or contraction is linear, constant, and fixed, 3) no price and substitution effects, and 4) no supply constraints. This means that I-O models are a static representation of an economy and do not provide for dynamic adjustments that are likely to occur in an economy, especially those relating to large, fundamental changes in the size or structure of an area's key industries.

Since I-O models are widely available and used, output from those models is often accepted without much scrutiny. Despite development and use of other modeling processes (e.g., general equilibrium models) to mitigate the limitations and shortcomings of I-O modeling, I-O analysis remains the most widely used approach to conducting economic impact and contribution assessments.

Types of Economic Evaluations

Input-output analysis provides a tool for economists to perform ***economic impact*** and ***economic contribution*** analyses. These analyses can be applied to programs, projects, developments, industries, and other economic activities. Key macro-economic indicators such as employment compensation, labor income, value-added output, total business activity, secondary economic business activity (indirect and induced), selected government tax collections, and secondary (indirect and induced) employment can be estimated using input-output analysis.

Economic impact analysis estimates the change in key economic indicators resulting from the 'new' dollars (either gained or lost) from a specific project or development within a given economy. An economic impact analysis measures the *net effect* of two possible situations– often these situations would be the presence or absence of some type of economic activity, development, or program. Direct, indirect, and induced economic effects are estimated for all sectors of the economy in economic impact figures.

Economic contribution analysis differs in that it includes all relevant revenues and expenditures in the generation of the amount of economic activity created in an economic unit. Economic contribution analyses attempt to capture all economic activity without regard to the net change or value of alternative economic activities; therefore, economic contribution assessments provide measures of the *gross effects*. Typically, an economic contribution analysis will show more economic activity than found in an economic impact study for the same industry or activity. Direct, indirect, and induced economic effects are estimated for all sectors of the economy in economic impact figures.

Key Definitions

Direct Economic Effects: Direct economic impacts represent the first-round of payments for services, labor, and materials. Direct effects can be interpreted to represent jobs, labor income, and business activity that comprise the Agriculture Industry.

Indirect Economic Effects: Indirect economic effects arise from the additional consumption of goods and services triggered by businesses that supply inputs to firms in a given sector/industry. Indirect effects can be interpreted as the additional economic activity created through purchases by businesses.

Induced Economic Effects: Induced economic effects arise from the additional spending by households from changes in personal income associated with direct effects and indirect effects. Changes in personal income can come from payrolls of businesses that are directly impacted, changes in payroll from businesses that supply goods and services to an impacted sector (induced effects), and proprietor income resulting from a change in business volume. Induced effects measure the additional business activity that is triggered as changes in personal income are translated into the purchase of goods and services for personal consumption.

Value-added Effects: Value-added economic activity is a measure of the payment to labor and capital, and includes labor income, business taxes, and business/proprietor income (profit). This economic effect is sometimes referred to a measure of the value that is added to purchased inputs by a business or industry, and is analogous to gross state product. The use or consumption of goods and services in the production of another good or service is not included in value-added measures.

Total Economic Output: Total output is a measure of the business activity created by summing direct economic effects, indirect economic effects, and induced economic effects. This economic measure is sometimes called gross business volume. Total output therefore represents the sum of gross receipts of all economic sectors.

Employment and Employment Compensation: Employment is perhaps one of the most important economic measures associated with impact assessments. Direct employment represents the jobs employed by the business or economic sector for which the activity or event is being modeled. I-O analysis also estimates employment associated with indirect and induced economic effects. Changes in employment compensation include wages, salaries, and employment benefits linked to changes in employment levels.

Government Revenue: Changes in revenues to state and local governments are another important measure in most contribution studies. I-O models estimate changes in selected government revenues such personal income, sales and use, corporate income, severance, and property taxes, and a variety of miscellaneous revenues such as permits, fees, licenses, and dividends. Government revenues are not generally additive to economic effects, as most government revenues are either imputed internally or directly comprise a component of an industry balance sheet.

Selection of Input-output Model

The Department of Agribusiness and Applied Economics at NDSU developed an I-O model for North Dakota during the 1960s and was an important tool examining energy development in the state during the 1970s. The basic data for the model came from surveys of firms and businesses in the state, and key economic statistics included a corresponding data set defining state-level net exports (economic base), employment productivity ratios, and tax coefficients. The model and supporting economic data were widely-used for examining economic impact and economic contribution effects in the region. Finally, maintenance and use of the North Dakota Input-output Model was discontinued in 2018 as personnel and resources were no longer available to support the model.

A number of commonly used input-output models are available for conducting impact assessments for North Dakota. Publicly available models include RIMS II (Regional Input-Output Modeling System), IMPLAN (Impact Analysis for Planning), REMI (Regional Economic Models Inc.), and EMSI Analytics (Economic Modeling Specialists). There are other commercial models that are 1) not available for state-level analysis (e.g., REdyn, which combines I-O factors with computable general equilibrium (CGE) processes but is only used for the U.S. national economy), 2) specialized in fiscal effects and do not provide the same degree of impact assessment as the more common I-O models (e.g., LOCI, which only examines government costs of various types of impacts), and 3) built with varying degrees of sophistication primarily targeting subject-matter issues (e.g., JEDI-NREL that examines some economic impacts of constructing and/or operating energy-based facilities).

REMI was considered the best option from an empirical capacity, but the cost of acquiring the model and subscribing to annual baseline data updates was prohibitive. RIMs II is inexpensive, but the analytical capacity is substantially limited, and does not have any baseline or supporting data sets. IMPLAN was chosen as the modeling system because it is supported with detailed baseline data, and cost was not prohibitive.

IMPLAN Data Sources

IMPLAN modeling system uses a variety of data sets to construct the I-O model. In general, those data sets begin with federal data, work through regional and state-level economic statistics, and if available, attempt to combine information for counties or other smaller geographic units. [see www.implan.com for more detail regarding data sets used to construct the model]. Some of the key data sets for IMPLAN include the following:

-) U.S. Bureau of Labor Statistics Covered Employment and Wages data (CEW) (ES202)
-) Bureau of Economic Analysis
    : Benchmark I/O Accounts of the U.S. and Output Estimates
    : Regional Economic Accounts (REA)
-) U.S. Census Bureau
    : Consumer Expenditure Survey (CES)
    : County Business Patterns (CBP)
    : Decennial Census and Population Surveys
-) U.S. Department of Agriculture, National Agricultural Statistics Service
-) U.S. Geological Survey.
-) Information is also collected on military and non-military federal activities, railroads, personal consumption patterns based on various income levels, local and state tax collections, state and local government purchases and expenditures, and transfers among inter-institutional entities.

IMPLAN Economic Impact Methodology

IMPLAN modeling system is a popular input-output methodology because of its flexibility and customizability for structuring economic scenarios and ease of access to key data sets used in the modeling process (IMPLAN Group LLC 2016). IMPLAN can be structured to evaluate economic effects through a number of model operations. Those operations range from a change in sales for an entire industry to personal spending patterns for households with a specific income level. The flexibility to structure an assessment using multiple economic criteria, along with customization of baseline data, allow IMPLAN to be tailored to most economic conditions.

IMPLAN uses a variety of mechanisms, or economic triggers, to introduce a direct impact into a specified economy. Using a variety of mechanisms is one of the key attributes of the model that provide substantial flexibility in tailoring assessments to match expected economic activity.

An ***Industry Change*** represents adjusting the demand for the goods and services produced by an economic sector by varying that sector's revenue. Within this context, changes in sector gross revenues automatically result in changes in required labor, goods and services used to produce the sector's output (intermediate inputs), taxes on production and inputs (e.g., sales tax, property tax), and sector income. After setting the level of revenue change for an economic sector, IMPLAN allows custom values for employment, employment compensation, and sector income to be entered if default values are not desired.

Industry Spending Patterns can be used to change an economic sector's use of intermediate inputs without triggering changes in revenues, labor expenses or requirements, or sector income. The specific input is the sum of the total expenses that are expected to be purchased by that economic sector.

Labor Income Change is not specific to an economic sector, rather it introduces an increase in the payment for labor inputs within an economy. This approach also by-passes the need to change other aspects of an industry's balance sheet to achieve a change in labor income; however, the *Labor Income Change* requires a manual (i.e., calculated outside of the IMPLAN model) estimate of the change in direct employment based on assumptions for payroll expenses per job.

Household Income Change is used when personal spending capacity within an economy is increased, but there is not necessarily any direct link to output changes in any particular economic sector or when personal spending capacity is not directly linked changes in labor income. These types of changes in household income might be represented by income from royalties, trusts, easements, gifts, inheritances, lotteries, and social transfer payments.

Institutional Spending Patterns are used to estimate how changes in public sector revenues influence the consumption of goods and services by government entities, educational institutions, non-profits and other non-governmental organizations. *Institutional Spending Patterns* also provide options for use of household spending patterns by income levels, which can be used to approximate the consumption of goods and services by households.

IMPLAN Fiscal Analysis Methodology

IMPLAN estimates fiscal impacts by examining total government revenues from a variety of data sources. The model then estimates the share of government revenues based on the individual source of revenue (e.g., sales tax, income tax, severance tax, fees, and licenses). IMPLAN compares total government revenues, from all sources, with total industry output from all sectors in the economy. That process produces an estimate of tax revenue per unit of average industry output (e.g., gross sales, state gross product). The model does not estimate tax collections stemming from individual economic sectors or industries. Therefore, to estimate the fiscal impacts of a project, program, or activity, IMPLAN estimates the change in economy-wide business output, and then estimates the fiscal effects by multiplying that change in business output by the ratio of government revenues to economy-wide output. This process produces a direct relationship between expected new government revenues and a change in industrial or economic output.

Shortcomings and limitations of IMPLAN's fiscal impact methodology in North Dakota include.

A. IMPLANs fiscal impact methodology is locked to the premise that all government revenues are intrinsically linked to changes in economy-wide economic output. This relationship is embedded within IMPLANs default tax ratios and leads IMPLAN to generate large changes in some tax revenues even when direct causation is not contained in the economic assessment (i.e., without linking an economic impact to a specific change in a tax base or tax rate, or linking tax revenues on a per-sector basis). For some tax revenues, such as severance taxes, that methodology produces erroneous estimates. For other tax revenues, general economic output is a reasonable proxy for estimated changes in tax revenues.

B. IMPLAN's fiscal impact methodology cannot be adjusted internally to reflect state rules and stipulations affecting the specific taxes relating to unique conditions or special treatment that adjusts the tax base or tax rate.

IMPLAN Fiscal Data Sources

The following discussion of data sources is provided by IMPLAN Group LLC (2018).

IMPLAN's tax impact report values are based on the existing relationships of the data found in the IMPLAN database. The sources for these data are listed below, followed by description of each data element in the tax impact report.

- **NIPA Tables.** All items in the IMPLAN data sets are ultimately controlled to the U.S. level values from the Bureau of Economic Analysis' (BEA) National Income and Product Accounts (NIPA). Section 3 of the NIPA tables covers Government Current Receipts and Expenditures.

- **Consumer Expenditure Survey (CES).** The U.S. Census Bureau through the Consumer Expenditure Survey annually conducts surveys and diary samplings of household expenditure patterns. The survey data are reported for nine different categories of household income, which we control to the NIPA's Personal Consumption Expenditure (PCE) totals (which are not split out by income category). From these data, we can establish the tax-to-income relationships for the nine different household income categories. It is based on these relationships that we can distribute many of the national-level tax data to states and state-level tax data to counties, using the number of households in each of the nine household categories in the state or county.

- **Annual Survey of State and Local Government Finances (SLGF).** The U.S. Census Bureau also collects annual State/Local Government receipts and expenditures data. These data act as preliminary controls for state-level values (subject to controlling to the national NIPA values). That data also provides the proportional split of the Tax on Production and Inputs (TOPI) value amongst the various types (sales, property, etc.). The actual value of total TOPI (at the state level) comes from the BEA's REA series.
    - The annual survey also provides local government collections by tax type. These data are used to estimate, for the total state/local tax receipts, the share of each type of tax that belongs to local government. The data for each local

government is then used to apportion that local total (at the state level) to each county. Since the local total for each county is estimated, the model can distinguish between the state and local tax revenue in the tax impact report. In IMPLAN Online, the tax impact report includes 4 types of governments that compose State/Local Government:
    - State government
    - County government
    - Sub-county general government, which includes city and township governments, for example
    - Sub-county special government, which includes fire and public school districts, for example
  - IMPLAN supplements gaps in the SLGF with 5-year Census of Governments data, and supplements the SLGF state tax revenue with current-year state tax collections data from the Census.

- **Regional Economic Accounts (REA).** The Bureau of Economic Analysis collects and reports income, wealth, tax, and employment data on a regional, state and county basis. The REA data from these two tables are used to distribute the U.S. NIPA values to states and counties:
    - Table CA05 -- Personal Income by Major Source and Earnings by Industry
    - Table SA50 -- Personal Tax and Non-tax Payments

Definition of Government Revenues Produced by IMPLAN	
Government Revenues	Definition
State and Local Government	
Dividends	State and Local government dividends represent dividend payments to government by corporations from investments.
Social Insurance Taxes: Employee Contribution	The social insurance contributions paid by state employees towards State sponsored pensions, in lieu of social security.
Social Insurance Taxes: Employer Contribution	The social insurance contributions paid by the State towards State sponsored pensions, in lieu of social security.
Indirect Business Tax: Sales Tax	Sales taxes paid to State and Local government.
Indirect Business Tax: Property Tax	Real estate-based property taxes paid by firms to State and Local governments. Because of the special situation encountered with Sector 361, this includes payments of property taxes made on homes.
Indirect Business Tax: Motor Vehicle	Motor vehicle license taxes paid by firms to State and Local governments.
Indirect Business Tax: Severance Tax	Taxes imposed by a State on the extraction of natural resources.
Indirect Business Tax: Other Taxes	Other taxes paid to State and Local governments include business licenses, documentary and stamp taxes.
Indirect Business Tax: S/L Non-taxes	IBT state and local non-tax payments include fines (such as parking and speeding tickets), fees (State and County park passes or day fees) and donated funds.
Corporate Profits Tax	Corporate profits taxes paid to State and Local governments.
Personal Tax: Income Tax	Income taxes paid by individuals to State and Local Government through withholding, declarations and final settlement, less refunds.
Personal Tax: Non-taxes (fines and fees)	Household personal nontax payments to State and Local governments include fines, donations, passport and immigration fees, and migratory bird-hunting stamps.
Personal Tax: Motor Vehicle Licenses	Household personal motor vehicle fee payments to State and Local governments.
Personal Tax:	Household personal property tax payments to State and Local

Property Taxes	governments. Dividend, interest, and rental income of persons with capital consumption adjustment are sometimes referred to as property income.
Personal Tax: Other Tax (Fishing/Hunting)	Other taxes consist of miscellaneous fees and licenses (such as hunting and fishing licenses, marriage licenses, registration of pleasure boats, and licenses for pets) to State and Local governments.
Federal Government	
Social Insurance Taxes: Employee Contribution	The employee paid portion for Federal social insurance. These contributions include payments by employees, the self-employed, and other individuals who participate in the following government programs: Old-age, survivors, and disability insurance (social security, FICA); hospital insurance; supplementary medical insurance; unemployment insurance; railroad retirement; veterans life insurance; and temporary disability insurance.
Social Insurance Taxes: Employer Contribution	The employer paid portion for Federal social insurance. This includes social security, unemployment insurance, medical and retirement plans.
Indirect Business Tax: Excise Taxes	Includes Federally levied excise taxes on alcohol, tobacco, telephones, coal, fuels, air transportation, vehicles, etc.
Indirect Business Tax: Custom Duty	Custom duties are gross collections net refunds.
Indirect Business Tax: Non-Taxes	IBT Federal non-tax payments include petroleum royalties, fines, regulatory fees, forfeitures and donated funds.
Corporate Profits Tax:	Corporate profits taxes paid to Federal governments.
Personal Tax: Income Tax	Income taxes paid by individual to the Federal Government through withholding, declarations and final settlement, less refunds.
Source: IMPLAN Group LLC (2018).	