The effects of surface water availability on corn production in Weld County, Colorado

by

Cortland Worrall

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Dr. Nathan Hendricks

ABSTRACT

The agriculture industry in Colorado relies heavily on the amount of snowpack and surface water to be successful and to be profitable. In Colorado they use reservoirs and ditches to disperse water to farmers and the rest to other uses and cities. The amount of water that is allocated to a single farmer can vary from year to year due to unpredictability of availability of water from snowpack and rainfall. In addition, the state has seen multiple years of population growth that has caused more of the surface water to be allocated to the rapidly growing cities instead of to farmers for agriculture use.

In this study, I focus on Weld County Colorado because it is the largest agriculture producing county in Colorado and one of the fastest growing counties in terms of population Colorado. This study will look at historical data of surface water used for irrigation and the effects it has on farmers and their decision to plant corn over the last thirty years. I study the impacts on corn because corn is a major crop in Weld County and needs significantly more water than some other crops. The surface water data will come from the Colorado's Decision Support System (CDSS) that provides all the historical and current water levels of all the reservoirs and ditches. Corn data was collected from the United State Department of Agriculture (USDA) National Agricultural Statistic Service (NASS).

This study examines the correlation between surface water available for agricultural irrigation use and the amount of corn planted that year and corn yield. A regression analysis is used in this study to see how the available surface water from year to year will affects farmers and their decision to plant corn and the yield. Other variables included in the

analysis to help understand the correlation between surface water and corn production are temperature and precipitation.

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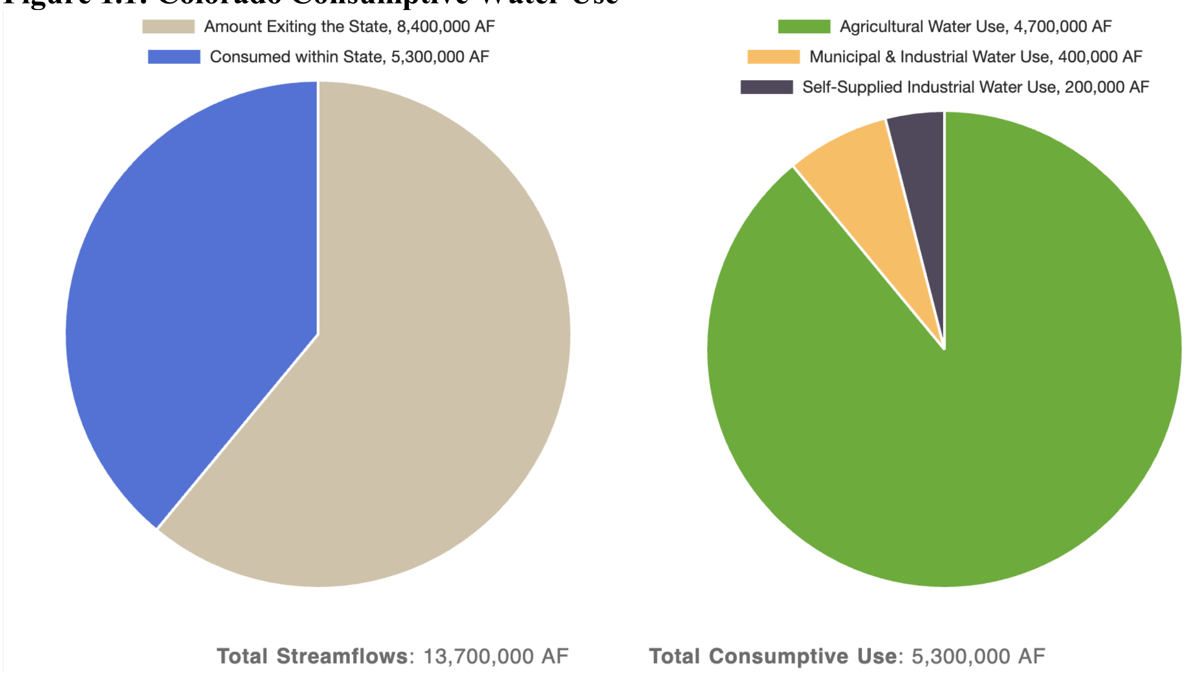
CHAPTER I: INTRODUCTION

We do not have enough water for everything, and we are stuck deciding where to allocate our water and trying to determine the amount of water there will be from year to year. Users cannot count on having the same amount of water from year to year and must account for periods of drought. The world of agriculture and the farmers a part of it greatly depend on groundwater that helps them produce our largest crops like rice, wheat, and corn. Groundwater accounts for 40% of all agriculture production in the world (Bhattarai, et al. 2021). With groundwater becoming depleted in major areas of the world, the optimization of surface water has become vital to areas that do not have the groundwater to fulfill their water needs.

Areas in the world that do not have the groundwater capacity to keep up with their agriculture production are also having to plan for rapidly rising populations (Dozier, et al. 2017). The rapidly growing populations in the western United States have caused an increase in demand for water that was originally allocated for crop production. States are having to plan for this increase in population and how they will allocate the water moving forward. States that do not have the groundwater capacity are having to look at other ways to get the water they need for their people and agriculture production. In Colorado, the water allocation is greatly impacted by the spring snowpack in the Rocky Mountains and not only does this show what the surface water allocation will be, but the behavioral response of agricultural producers in the surrounding areas in Colorado (Manning, Goemans and Maas 2017). Weld County farmers must make their crop decisions based on the snowpack that year because they do not have the luxury of ample groundwater that other areas of the United States have. With rapidly growing population in Weld County, farmers do not know what surface water availability will be in the future because domestic water use is favored over all other uses. The state of Colorado has been making plans for the increasing population and looking to efficiently increase their surface water collection and distribution. Metro Denver EDC shows that the Denver Metro in 2019 had an estimate population of 3,236,481 and Northern Colorado population of 680,701. By 2030 they are expecting the Denver Metro's population to increase to 3,639,091 and to 4,170,926 by 2050. Northern Colorado 2030 population is expected to be 842,492 and to 1,204,089 by 2050 (MetroDenverEDC 2024).

The total amount of water that originates in Colorado is 13.7 million acre-feet. Of those 13.7 million acre-feet there is only 40% or 5.3 million acre-feet that is consumed, approximately 83% of the consumption is supplied by surface water, and the remaining 17% is supplied by groundwater (State of Colorado 2016). Figure 1.1 shows the breakdown of water exiting the state at 8.4 million acre-feet and what is consumed in the state at 5.3 million acre-feet. Figure 1.1 also shows that agriculture uses 4.7 million acre-feet, municipal and industrial uses 400,000 acre-feet, and self-supplied industrial uses 200,000 acre-feet. This statistic shows the amount of reliance that Colorado has on their surface water because they do not have the ground water capacity to meet the need of the state or the farmers, and most of their water leaves the state. More specifically they rely on the spring snowpack in the Rocky Mountains for their surface water collection. Like many states, they are seeing the effects of the growing population in the state and the rising demand of more water for residential areas. As Colorado's Water Plan (State of Colorado 2016) points out, this population growth will create a significant need for an additional 600,000 to one million acre-feet of water annually to meet future municipal and industrial (including self-supplied industrial) demands. This means that the total Colorado consumed water supply will need to increase between 5.9 million and 6.3 million acre-feet, which is an increase of 11.3% to 18.9%. Ranchers and farmers account for 47 billion dollars of the economy in Colorado, and if no action is taken to resolve the future demand for water and rising population, the state is risking a decrease in the water in the state by 740,000 acre-feet (State of Colorado 2016). This will not only affect the agriculture industry, but also their water-based recreation which accounts for 19 billion dollars to Colorado's economy. For Colorado, its surface water is not only vital to the agriculture industry, but to the whole economy.

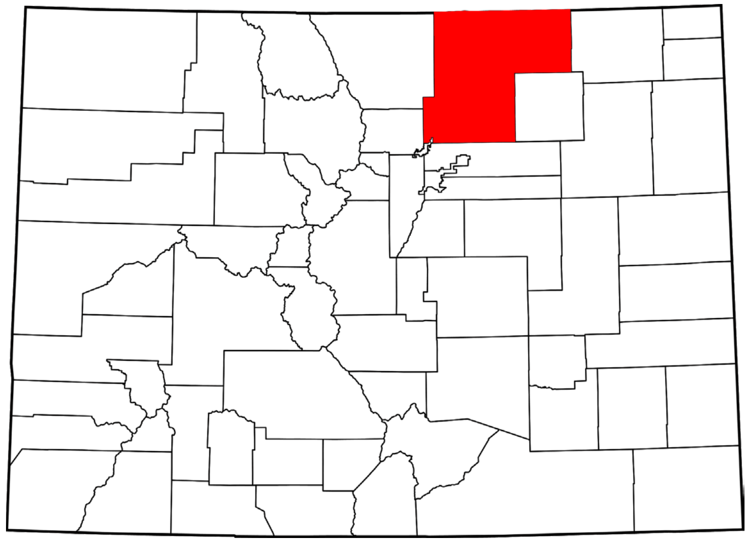
Figure 1.1: Colorado Consumptive Water Use



Source: CSU Colorado Water Knowledge

Weld County Colorado is like other semiarid regions in Colorado that must deal with the unpredictability of water year to year and farmers must predict if there will be enough water for them to produce their crops. Weld County is one of the largest counties in Colorado by land area with 2.5 million acres with 75% being used for agriculture and making it the 3rd largest county by land area in Colorado. Weld County is the largest agriculture producing county in the state with over 3,000 farms creating over one billion dollars in market value (Weld County, CO 2024). Looking at Figure 1.2 there is a map that shows the location of Weld County in Colorado, and the dimensions of the county compared to the other counties in the state. This study looks to see how the surface water affects corn production in the county. More specifically this study will be looking into surface water historically used for irrigation and corn acres planted to find from year-to-year how corn acres planted are affected by the amount of water that is available. Using a regression analysis, this study will look for a correlation between surface water and acres of corn planted. A regression analysis will also be used to see a correlation between yield and surface water. The data used is from Colorado's Decision Support System (CDSS) for all surface water data and United States Department of Agriculture (USDA) National Agricultural Statistic Service (NASS) provided corn data. This data will also show what you can expect to happen to the corn acres if the water levels are lower. This is important because with a county that continues to grow then more water will be allocated to the cities then the farmers. If there is no correlation found in this analysis, then it will show how farmers regardless of water availability will continue to plant corn instead of changing to another crop.

Figure 1.2: Weld County Colorado



Source: Uncover Colorado

When looking at the trends in this study, it will show that corn acres are trending down as surface water is also trending down. In addition, the analysis will show that the precipitation has a negative trend, and the temperature has a positive trend. Analysis will show that there is not a strong statistical correlation between surface water availability and corn production. There were other variables that were not used in analysis that could have affected the strength of the correlation. The study does show that there is a negative trend in corn acres and surface water, but there are many other variables that affect farmers in planting acres of corn. Other analyses were done with the SWSI which is the Drought and Surface Water Supply Index. This index is a measure of the water supply conditions of the major river basins in Colorado. SWSI analysis showed a stronger correlation compared to analysis using surface water data.

CHAPTER II: LITERATURE REVIEW

Colorado is a state that must collect surface water to be able to support the growing population and to be able to support its agriculture industry. The rainfall and snowpack are very crucial to the collection of water to be used by everyone in the state. With how unpredictable snow and rain can be year to year, farmers are faced with determining how they will grow crops when the amount of water available is uncertain from year to year. When periods of droughts occur, farmers find themselves with little to no water especially if the cities need more water for recreation and drinking water. As the population continues to grow and the more water needed for the cities to function, farmers are starting to see less and less water available to them. With corn being a crop that needs more water than other crops, farmers either must choose a drought tolerant corn, change to a crop that does not need as much water, or fallow the land when there is less water available or going through a drought period.

2.1 Weld County Corn

Corn is one of the largest agriculture commodities produced in Weld County and Colorado. Wheat is the only crop that is planted more than corn in the county and state. The USDA 2023 State Agriculture Overview shows that in Colorado there is 2.3 million acres of wheat, 1.33 million acres of corn, and 23,200 acres of sugar beets. Right to Farm - Agriculture in Weld County shows that there is over 875,000 acres of crops planted every year and over 300,000 is irrigated crops annually in Weld County. All the crops have different water requirements that are needed to produce a desired yield. There are crops that are more drought tolerant, meaning they do not need as much water to produce a good yield. "In the Greeley area, the seasonal water use of sugar beets is 27.1 in. while corn uses only 23.9 in" (Schneekloth and Andales 2017). Other crops in the area like wheat that uses

17.9 in and dry beans that use 15.7 in of water in season (Schneekloth and Andales 2017). With the average precipitation in Greeley being only 8.6 in annually and corn needing roughly 23.9 in of water, the gap is having to be supplemented by surface water that is collected from the snowpack. When there is not enough water to reach the recommended amount of water for the crop, producers must adopt a limited irrigation approach. Producers must decide whether to reduce their irrigated acres (i.e., fallow land or use for non-irrigated production), reduce the amount of irrigation that is applied to their field, or switch to different crops that require less irrigation and are more drought tolerant (Schneekloth and Andales 2017). For a lot of farmers in Weld County, fallowing acres is not an economical option because they rely on the silage or grain for their livestock.

2.2 Surface Water Rights

Having a semiarid climate that can be very unpredictable throughout the state and not having enough groundwater to support its agriculture industry leaves Colorado to rely on their surface water. "In rapidly urbanizing semi-arid regions, increasing amounts of historically irrigated cropland lies permanently fallowed due to water court policies as agricultural water rights are voluntarily being sold to growing cities" (Dozier, et al. 2017). With water allocation changing with rising populations in cities, farmers can get less water if cities need more sense domestic use outranks agriculture use. "Any water right not put to a beneficial use can be, according to law, taken away and available for others to use" (Dozier, et al. 2017). There is currently no incentive to use water efficient methods to save water because the water you do not use can be taken away and given to others and have a loss of water rights. This encourages farmers to use all the water even if it is not needed because of the fear of losing water rights and not having enough water in the future. With surface water availability changing from year-to-year, farmers will have to first determine if there will be enough water for them to produce certain crops like corn because of the amount of water that is needed to produce corn. Then, a farmer will have to determine if there will be enough water to reach desired yields and profitability that is needed.

2.3 The Colorado River Water Crises

Schmidt, Yackulic, & Kuhn (2023) discuss the water crisis that is occurring from the Colorado River. Figure 2.1 shows the borders of the Colorado River Basin, and what areas use the Colorado river. Weld County does use the Colorado River water through trans-basin diversion as shown in Figure 2.1. This means that water levels dropping in the Colorado River will have a direct impact on the county. Not only does this have a huge effect to Colorado and Weld County, but to surrounding states who also use this river for water. Farmers are having to fallow their crop land and are growing in frustration with state water managers. The Colorado River is broken into three sections which are Mexico, Lower Basin (Arizona, Nevada, California, Utah and New Mexico), and Upper Basin (Arizona, Colorado, Utah, Wyoming and New Mexico) that use water from the river. The Gulf of California has not seen any water flow for most of the years due to lack of water. "During the Millennium Drought (2000-2023), the average annual natural flow at Lees Ferry was 12.5 million af/yr. (15.4 billion m^3/yr.), 13% less than the average annual natural flow between 1930 and 1999 and 30% less than the annual flow between 1906 and 1929" (Schmidt, Yackulic and Kuhn 2023). The last 23 years has seen a drastic drop in water flow that has been affecting not only Colorado but all the states that are part of the Colorado River Basin. The Colorado River cannot keep up with the current consumptive use so use will have to decrease to match the decline in water flow. We are at the point where it is no feasible to rely on precipitation to refill the reservoirs and the river. "If Basin-wide long-term average water consumption is reduced by 13%-20%, reservoir storage could be maintained and potentially increased, providing the buffer against interannual variability in water supply that has supported economic and population growth in the Basin" (Schmidt, Yackulic and Kuhn 2023). If there would be a reduction in water consumption, then it would put even more strain on crop producers who must make decisions on what to plant or to fallow the land.

Figure 2.1: Colorado River Basin

Source: (Schmidt, Yackulic and Kuhn 2023)

2.4 Water Productivity of Maize in The US High Plains

Trout & DeJonge (2017) examine the effects of the declining water available for crop production and how it will affect corn yields. They are running a four-year trial where they look at the effects of different irrigation applications and how it effects the corn yield. The experiment will be done right outside of Greeley Colorado in Weld County. This study will show how corn is affected by different amounts of irrigation applied and what farmers can expect will happen to their yield if they must apply less irrigation. This experiment was done because the groundwater use has been used to a point of exceeding sustainable amounts that will lead to the aquifer to deplete. Additionally, the snowpack in the mountains, as a result of higher temperatures due to climate change, is causing a higher watershed evaporation and in turn less water for irrigated crops. In past studies, they have found that when irrigation is reduced by 30%, yield decreases by 10% (Zang 2003). Results in their 4-year trial showed a decreasing yield with a decreasing estimated crop water requirement. When the reduction of irrigation is 25%, crop yields stay consistent, but greater than a 25% irrigation reduction shows a decline in corn yield. Trout & DeJonge (2017) states that "Genetic improvements in maize varieties have resulted in an average 1 to 2% annual increase in maize yields with little or no increase in water use." Water deficit increasing in the western states will continue unless there are changes to the water management (Trout and DeJonge 2017). Planning for the future of irrigated crops is vital, especially with rising populations in the west and water must be able to accommodate the increasing population.

2.5 Reduced Irrigation and Crop Production

As the state's water supply continues to not meet farmers water needs, the total number of irrigated acres is expected to start decline by 2050 (State of Colorado 2016). Even though agriculture is going to still be the main user of Colorado's water, irrigated acres are expected to decline by 15-20% by 2050. The State of Colorado also states that there needs to be an additional 2 million acre-foot of water now to be considered fully irrigated. With the state currently not considered to have enough water to be fully irrigated, farmers are not reaching maximum yield potential for their crops.

Manning et al. (2017) states, “we use the U.S. Department of Agriculture Natural Resource Conservation Service’s Surface Water Supply Index1 (SWSI) as a measure of surface water expectations and confirm that eastern Colorado producers plant more acres of irrigated corn in years when a high-water supply is expected during the irrigation season.” The Manning et al. (2017) model looks at how expected surface water and actual surface water affect farmers’ decision in planting, irrigation, and harvesting. Their model also takes weather, costs, and climate change into consideration, because irrigation is a decision made daily based off weather, costs, and climate change. Results from this study showed that, for planting decisions, when they went from extreme drought years to expected surface water supplies, there was an additional 760 acres planted. This proves that expected surface water has a significant impact on farmers’ decision to plant.

CHAPTER III: METHODS

3.1 Overview of Regression Analysis

For this study, I decided to use a regression analysis to see how the surface water collected annually would affect the amount of corn acres planted in Weld County Colorado. I decided to use a regression analysis because a regression will show me if there is a correlation between my variables and how strong the correlations is. Additionally, it will show the decrease in the number of acres planted for every ACFT decrease in water available. In this regression, I will also be including annual rainfall, bushel per acre, and temperature to help explain the conditions of that growing year and help explain why certain years produced more than others but had less surface water available.

I used Gretl statistical for my regression analysis and to create graphs for this study. The variable that will be used are corn acres planted, total acre-feet, bushel per acre, precipitation, temperature, and time. Corn acres planted or yield will be my dependent variable in most of my models, because this study is looking at how surface water availability affects the amount of corn acres planted from year to year. Precipitation and temperature will be used to see how it affected the surface water and the corn acres planted. They will also show what that year was like for corn farmers.

SWSI ratings were collected to run analysis instead of surface water data when the dependent variable was either corn acres or yield. April water conditions ratings were collected for the last 30 years to see how it would influence farmer's decision to plant. I used the South Platte River Basin water conditions because it is the river basin that is used in Weld County.

3.2 Regression Equations

The first equation below was used for the regression analysis in Table 5.1. The data that was used for this analysis was the corn acres planted, total surface water used for agriculture irrigation, rainfall during that year, and the average temperature in year. The corn acres were set as my dependent variable and the rest were independent variable. The regression also included an error term. This equation is important in telling me how water available for agriculture use and weather would affect the amount of corn acres planted.

$$CornAcres_t = b0 + b1*TotalACFT_t + b2*Precipitation_t + b3*AVG\ Temp_t + e_t$$

The next equation below is what was used for the regression analysis in Table 5.2. The data that was used for this analysis was the average corn yield, total surface water used for agriculture irrigation, rainfall during that year, the average temperature, and a linear time trend. The average yield was set as my dependent variable and the rest were independent variables. This equation is important in telling me how well the acres that were planted performed from year to year and shows how the independent variables affect the corn yield. Corn yield may decline with less irrigation water if farmers are not able to apply water as intensively due to limited supplies.

$$TotalBuperAcre_t = b0 + b1*TotalACFT_t + b2*Precipitation_t + b3*AVG\ Temp_t + b4*t + e_t$$

The next equation below is what was used for the regression analysis in Table 5.3. Data was used for this analysis was the total surface water used for agriculture irrigation, rainfall during that year, and the average temperature. Total surface water used for agriculture irrigation was set as my dependent variable and the rest were independent variable. The equation below was used to help see how much the weather would affect the total amount of surface water.

$$\boldsymbol{TotalACFT_t = b0 + b1*Precipitation_t + b2*AVG\ Temp_t + e_t}$$

CHAPTER IV: DATA

For this analysis, thirty years of surface water and corn acres produced in the Weld County data will be collected from 1993 to 2022. Data that is collected is the total amount of surface water and corn acres planted and yield for that year. These two data sets will be used in the regression analysis looking for a correlation between the two, and to see how much the surface water levels from year-to-year affect corn acres planted and yield. Also, data for precipitation and temperature was collected to help explain the conditions for that growing year. All data collected is in the Appendix section of the paper. When looking at the data the year 2011 was not included. This was because when collecting surface water data there was a significant amount of data not recorded for a majority of the locations. If a location's water is not used for irrigation, then it will not show up on the records and since the water was not used for irrigation, then I cannot use it for my data. In 2011, there were many structures that had been used for irrigation in past years now being used for other uses other than irrigation.

4.1 Surface Water

There was 30 years of data collected for all variables, so I could see a trend over the last three decades. The surface water that was collected for Weld County will come from the Colorado's Decision Support Systems Diversion Records that keeps all records of water diversions in the state of Colorado. In this system it will be filtered down by water division and county. Weld County is in division one which includes the South Platte River basin, Republican River basin, and Laramie River basin. Records were filter for Weld County to avoid getting data for the whole division. The data that was collected came from the irrigation year which is November to October. The reason why the irrigation year is collected instead of the calendar year is because corn seed will start being sold before January of the year that corn is planted. The reason people buy corn before January is because seed companies will give discounts for buying from them early. The surface water collected is in Acre-feet (ACFT) which is the amount of water to cover one acre of land with one-foot depth of water. One ACFT is equivalent to 325,851 gallons of water. The reason I chose to use acre-feet for the unit of measurement is because the diversion records showed the water in acre-feet. Acre-feet has been a measurement that is not only used in these records but a form a measurement used throughout the country for water diversion records.

"The WDID is a unique number, which means there is only one designated WDID number for each structure or specific aspect of a structure" (Division of Water Resources 2018). With every structure there are diversion codes that represent source, from, use, type, group, to, and observation. The River Operations & Compact Coordinator at Colorado Division of Water Resources for Weld County explained that to identify the water used for agriculture irrigation would require examining the sources and use codes. Tables 2.1 and 2.2 explain how to identify which water diversions will be used for agricultural irrigations. Both tables were used to determine what water diversion records would be used for my analysis. Table 2.1 shows the different type of natural sources of water in Colorado and all water must first have a source before it has a use. The source that would be used for irrigation was the natural stream flow source. So, the first thing to look for in the diversion record is that there is a Source code of 1 for natural stream flow. When choosing structures to use, the River Operations & Compact Coordinator stated that the natural stream flow source would be what is used for irrigation use and is why I do not use any other sources.

In Table 2.2 there are all the different use codes for water diversion. The use code that was used for the analysis was use code 1 for irrigation. In the table, it states that the use code 1 is for application of water for the growth of beneficial vegetation. Diversion records sources and uses can be different from year to year so, any records that had more than 10 years of different sources or uses would be excluded from the data and analysis. Some records would not date far enough back or are no longer being used in the last decade. There were 23 structures that were identified and met all requirements to be used as my data for surface water.

Table 4.1: SOURCE Codes

1	Natural Stream Flow	Waters of the state that are part of the natural stream.
2	Reservoir Storage	Water released from storage in a reservoir; not flow through water.
3	Ground Water	Includes tributary and non-tributary water.
4	Trans basin Water	Water imported from another basin, the drainage from which does not combine with drainage from the importing basin within the state of Colorado. Trans basin water is considered "foreign water" to the receiving basin and is, therefore, generally fully consumable.[21]
5	Non-Stream Flow	Direct flow from springs, localized run-off, etc. before water enters stream; may also include diversions of water that is "futile" to the call or otherwise considered non-tributary, such as adit drainage, etc.
8	Re-usable Water	The unconsumed portion of fully consumable water that has been quantified and maintained under dominion and control after previous diversion, USE and release.
X[22]	Unspecified	Water of an unspecified nature or water associated with multiple SOURCEs used for "total through head gate" kinds of diversion records for administrative purposes. **(TYPE must equal "0").**

Table 4.2: USE Codes

0	Storage	Stored in a Reservoir or Reservoir System for later release to beneficial USE.
1	Irrigation	Application of water for the growth of beneficial vegetation.
2	Municipal	Urban uses by a municipality or quasi-governmental entity legally responsible for distribution of water.
3	Commercial	Ordinary non-manufacturing businesses such as hotels, campgrounds, retail stores, restaurants and stock yards.
4	Industrial	Manufacturing, mining, steam production, etc.
5	Recreation	Generally non-consumptive (except evaporation) uses for such things as aesthetics, acoustical, etc.
6	Fishery	Generally non-consumptive (except evaporation) where only use is production of fish.
7	Fire	As needed for emergencies or training.
8	Domestic	Residential use for inside uses and lawn and garden irrigation; see also "H", for household use only diversion records.
9	Stock	Livestock watering; no record required to document incidental access to water diverted for other uses.
A	Augmentation	Replacement supply; must include the associated plan of augmentation in the GROUP.
B	Sub-basin export	Diverted from one sub-basin to another that is in the same river system. (Typically involves moving water from one water district to another water district within the same water division.)
C	Change of Use Return Flows	Water released to replace historic return flow obligations as a result of diverting changed water.
E	Evaporation	Evaporative loss, generally from storage or recharge area impoundment.

F	Federal reserved	U.S. Government claimed uses in existence at statehood, typically associated with springs for stock and domestic or public campground wells.
G	Geothermal	Non-consumptive, thermal energy exchange.
H	Household use only	Generally associated with single dwelling, exempt wells; no uses outside the home or for more than basic sanitary and residential consumption.
K	Snow making	Water turned into snow.
M	Minimum stream flow/lake level	Defined in statute and used in decrees granted to the CWCB.
P	Power generation	Non-consumptive, hydroelectric operation.
Q	Quantification of amount	Denotes a quantification of a volume of water simply being carried by the structure.
R	Recharge	Released underground or delivered to a recharge structure for later USE in accordance with a decree or approval of the State Engineer.
S	Export from State	Released out of state.
T	Trans basin export	Released from one basin to another basin, the drainage from which does not combine with drainage from the releasing basin within the State of Colorado. (Typically involves moving water from one water division to another, with the general exception of transfers between the Colorado and Gunnison Rivers.)
W	Wildlife	Habitat and wildlife watering.
Z	Other	Use is something other than a USE specified in this table. (Comment required describing "use".)

Source: (Division of Water Resources 2018)

The Surface Water Supply Index (SWSI) compares the total amount of available water in the basins and sub-basins for each month compared to the amount of water for the same month in previous years. The SWSI ratings were collected to see what water conditions were prior to the growing season. The SWSI scale ranges from -4 (severe drought) to +4 (abundant supply) with 0 (near normal supply) in the middle. The rating is determined by the historical data recorded for different basins and subbasins. April ratings were collected to see how water conditions were the month before planting would start. South Platte River Basin ratings were used, because Weld County is in the South Platte River water division. The SWSI ratings were used in the regression analysis to see how they would influence a farmers' decision to plant corn acres.

4.2 Corn Production

The planted corn acres for the last thirty years in Weld County was collected through USDA Agricultural Statistics Service. This data is what I am looking to see how it changes based on the available surface water. The average yield (measured in bushel per acre) was collected as well through this site and will be used to show how well the planted acres produced that year. The reason the total acres planted is used instead of acres that was harvested is because this study wants to find how the surface water affects farmer to buy and plant corn or switch to a less water intensive crop. Also, yield was collected to see how the acres planted perform that year with the amount of surface water that was used.

4.3 Weather

The weather data that was collected from the Reno Gazette Journal and they use the National Centers for Environmental Information (NCEI) for their weather data in Weld County. This data will help with explaining the planting conditions that year and how it may have affected acres, yield, and surface water. The temperature collected was average temperature in Fahrenheit through the months of April to October and precipitation was the total amount of precipitation in inches through April to October in Weld County, Colorado for the last thirty years. This data will help look at the conditions for a certain growing year and help explain why some years look better than others when that year doesn’t have a lot of surface water available. The weather data will provide a better explanation to my regression analysis and show how not only surface water affects the corn production in the county.

CHAPTER V: RESULTS

5.1 Discussion of Data Visualization

Figure 5.1 shows the data and trend for surface water used for agriculture in Weld County for the last 30 years. The 2011 data was excluded from all data tables and graphs due to the lack of data collected for surface water that year. Surface water for agriculture use has been trending down over the last 30 years. The most surface water that was allocated for agriculture use was in 1998 at 330,925 ACFT and the lowest was in 2002 at 209,197 ACFT. The average surface water for the last 15 years (2008-2022) was 256,477 ACFT while the first 15 years (1993-2007) collected was an average of 292,201 ACFT. That is a drop of 12.3% of surface water used for agriculture irrigation from the first decade of data to the last decade of data. This is a significant drop in water used for agriculture, because this comes out to 35,724 ACFT less water or 11,640,701,124 less gallons of water on average. One reason for this trend is the rising population that the entire state has caused cities to claim more water from other agriculture use and other industries in the state. Another reason for the decline in surface water amounts is the precipitation in the state has had a slight decline over the last 30 years that is shown in figure 5.2. In 2002 the surface water was at an all-time low for agriculture use in Weld County. One explanation for this low year would be that the precipitation that same year and the year before was heading toward an all-time low in the last 30 years in the county. Not only was the precipitation very low, but the corn acres planted was also near the lowest it has been in the last 30 years. Precipitation and surface water being toward the lowest points in the last 30 years help explain why corn acres were near the lowest they have been in 30 years in 2002. Figure 5.3 shows the average temperatures for the last 30 years. The temperatures show a rise in the temperature in the county for the last 30 years. While warm temperatures are needed for corn growth, there is a risk when temperatures keep rising can cause more surface water evaporation, which mean less surface water available.

Figure 5.1: Surface Water

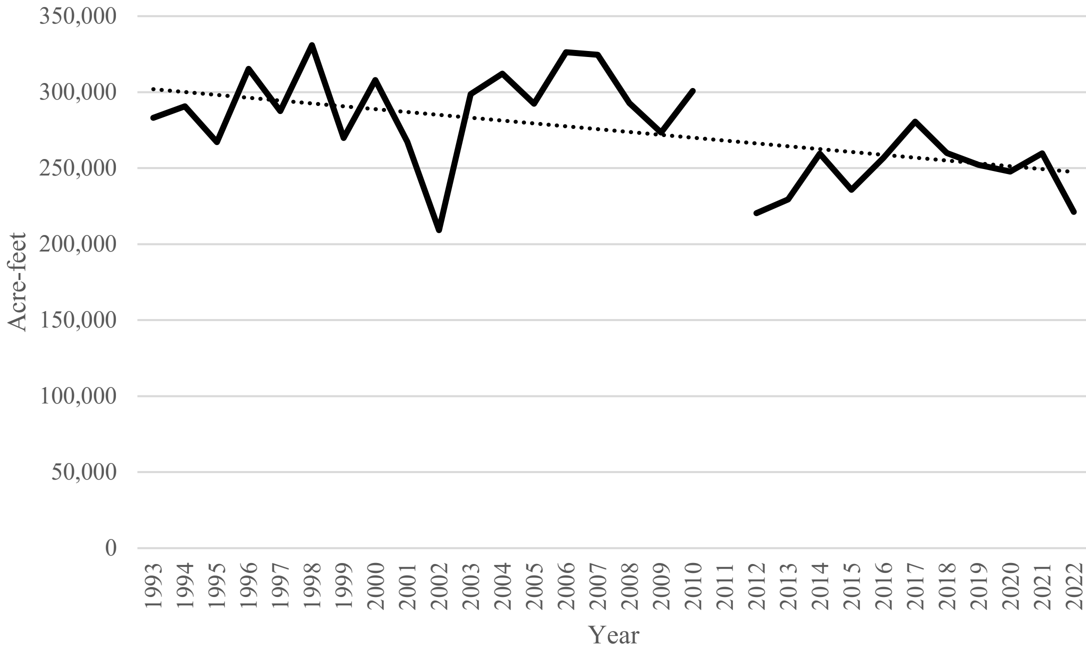


Figure 5.2: Precipitation

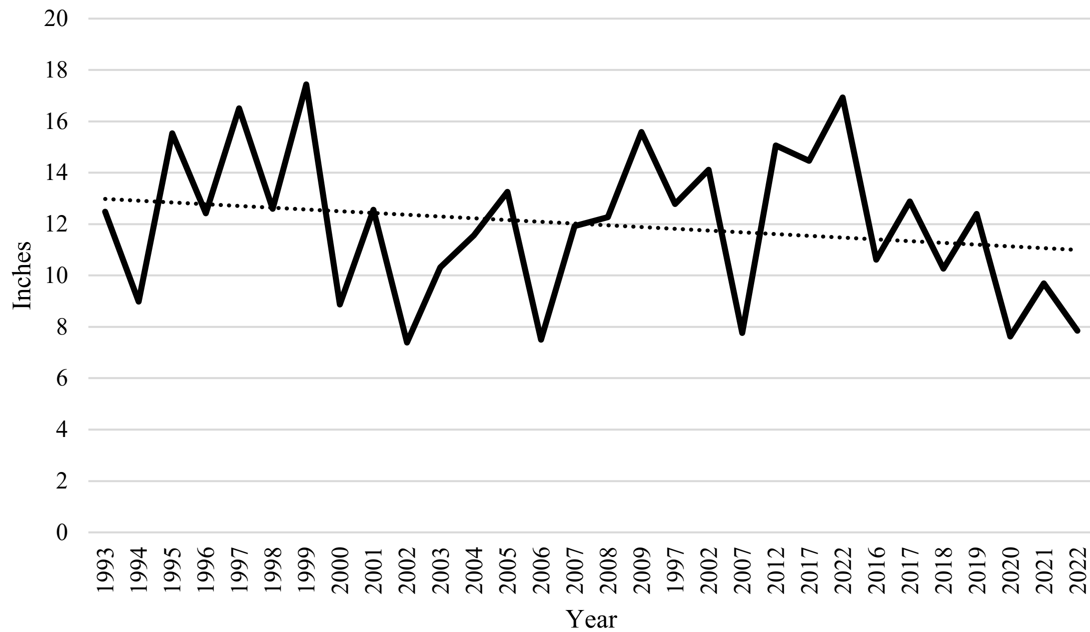
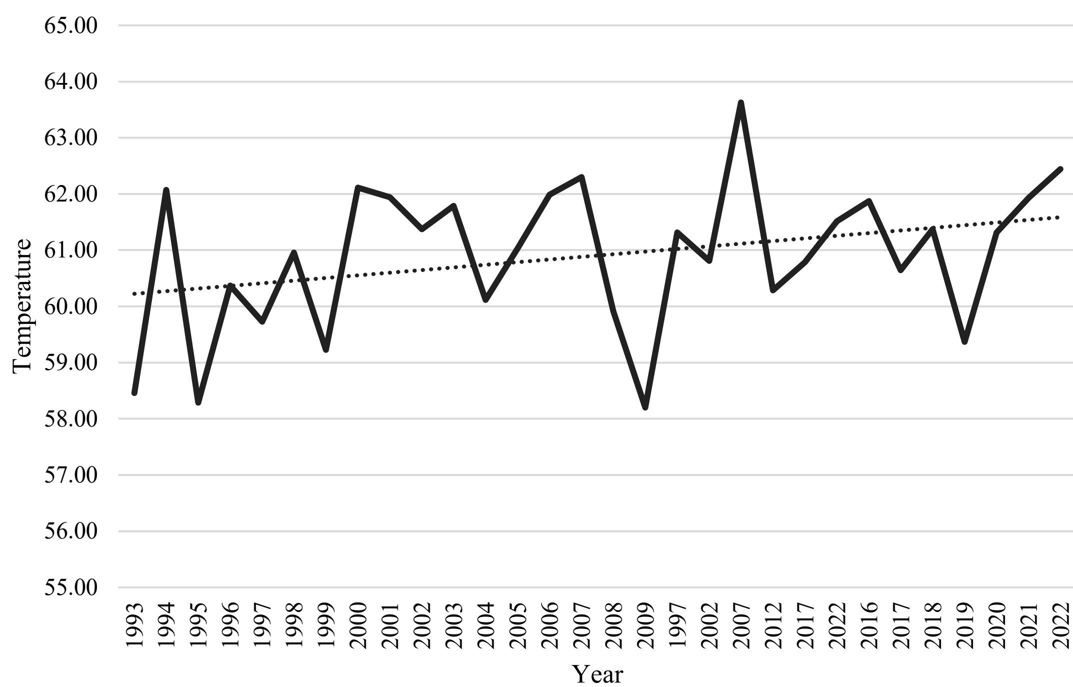
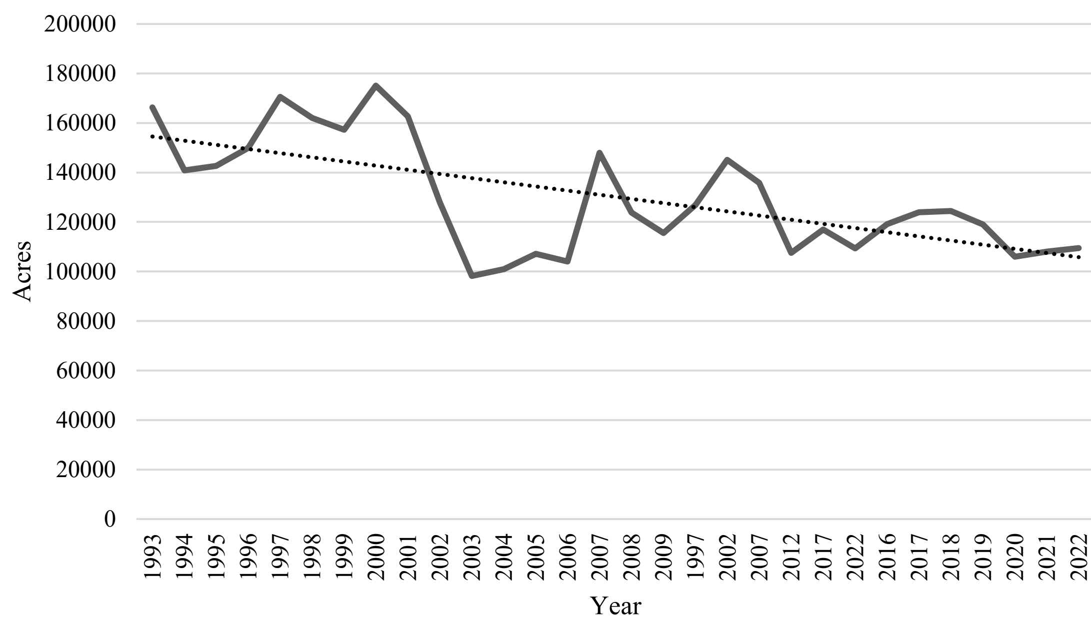


Figure 5.3: Average Temperature



The corn acres planted in figure 5.4 show a downward trend over the last 30 years. The highest amount of corn acres came in 2000 at 175,100 acres of corn and the lowest was in 2003 at 98,200 acres. The last 15 years average (2008-2022) was 117,564 acres planted and the first 15 years of data (1993-2007) was 140,927 acres. This a drop of 16.6% of acres planted in Weld County, which is a drop of 23,363 acres on average. In 2007 there is a surge in acres of corn and the main reason besides corn prices were slightly higher was that the amount of surface water that was available for corn use. The total decline of the planted corn acres has decreased from crop land being sold for residential areas to support the growing population in the county and the whole state. Another reason for the decline in corn acres is the decline in the total surface water available for agriculture use in the county.

Figure 5.4: Corn Acres Planted



The corn yield in figure 5.5 shows a positive trend as the bushel per acre increased over the last 30 years. The greatest yield was in 2010 at 194 Bu/acre and the lowest was in

1995 at 117 Bu/acre. The average yield for the last 15 years is 168 Bu/acre, and the first 15 years of data is 151 Bu/acre. This is an increase of 10.1% on average and an increase of 17 Bu/acre. Compared to the rest of the United States, the corn yield in Colorado is under the average and has not increased at the same rate. Figure 5.6 shows the national average corn yield, and it shows a positive trend line that looks to continue increasing in the future. In the U.S., the average yield from 1994-2007 was 138 Bu/acre and from 2008-2022 it increased to 165 Bu/acre. This an increase of 16.4% Bu/acre and on average 27 Bu/acre increase. Weld county Colorado has seen an increase of 10% while the rest of the country is seeing a higher increase at 16.4%. Weld County does have an average yield that is higher than the national average, but is starting to plateau, whereas the rest of the country is still trending toward higher yields. Yields are plateauing in Weld County due to the dryer climate and less water available for crops. Genetics and farming improvements can only increase the yields by so much when water is essential to corn production.

Figure 5.5: Bushel per Acre

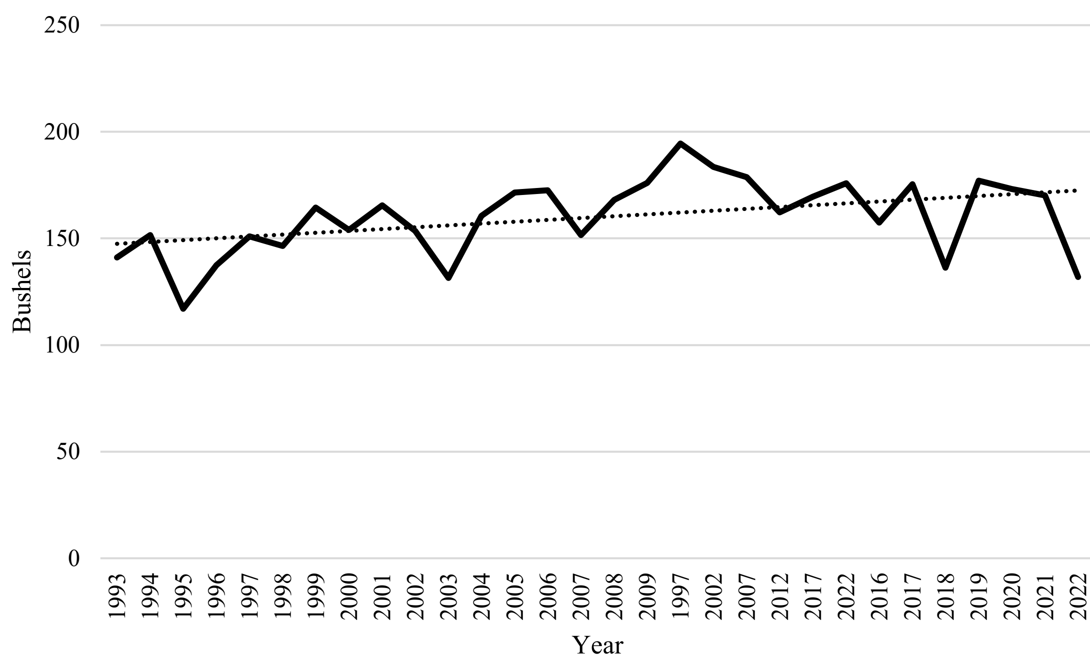


Figure 5.6: U.S. Bushel per Acre

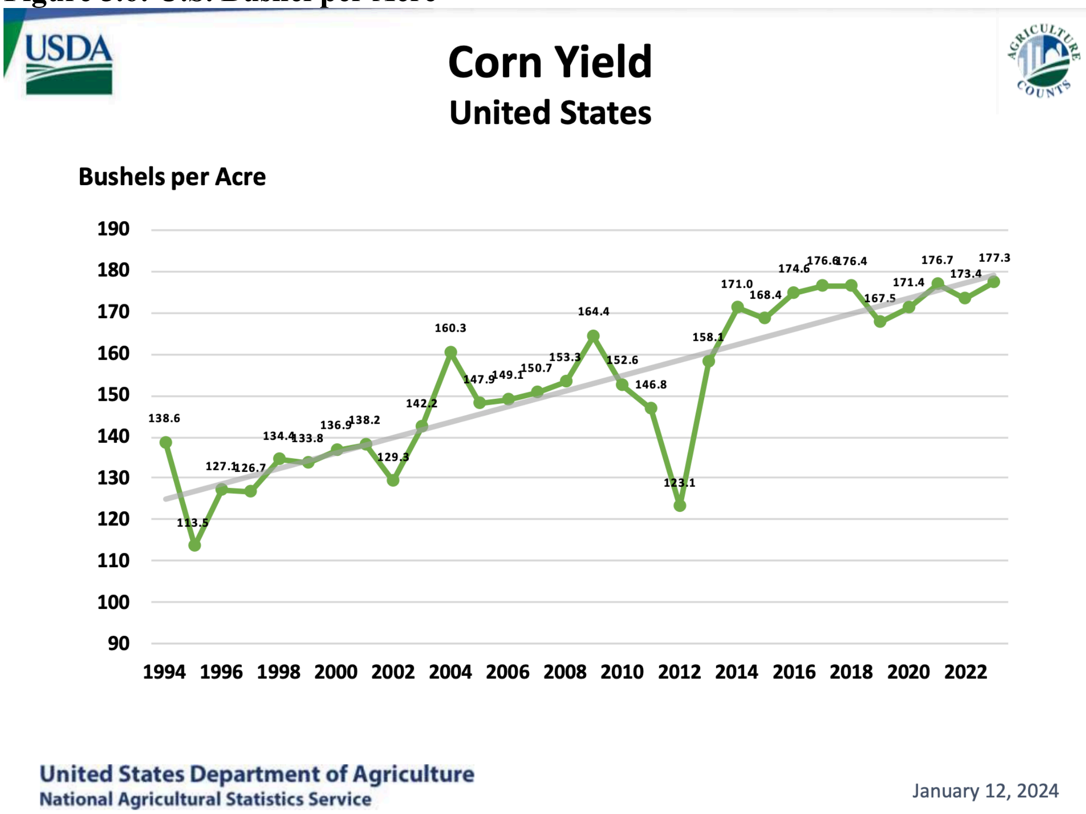
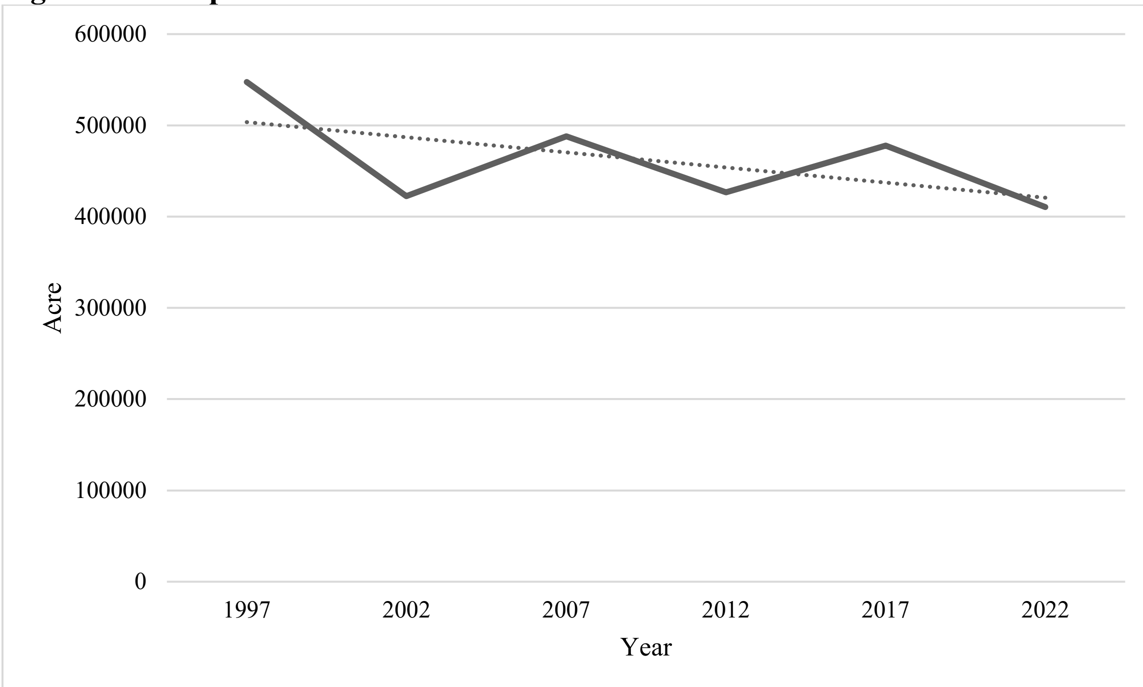


Figure 5.7 below shows the cropland harvested in Weld County from 1997 to 2022. This data was collected from the USDA Census of Agriculture. A report for the state is made every five years showing the agriculture statistics for that year and will include stats specifically from the counties in the state. From 1997 to 2022 there has been a negative trend in total crops harvested. 1997 shows the highest cropland harvested at 547,532 acres and the lowest in 2022 at 410,514 acres harvested. This graph shows that in Weld County there is less crops making it to harvest and has been trending negatively. This trend can be from there being less acres due to urbanization and or there is not enough water for crops to make it to harvest.

Figure 5.7: Cropland Harvested



5.2 Regression Analysis

In Table 5.1, I used total acre-feet, precipitation, and average temperature as my independent variables and corn acres as my dependent. In this regression analysis, I was looking for how surface water, rainfall, and the temperature would affect the corn acres planted by farmers. I am wanting to see if less available water for farmers will causes them to plant less acres of corn. This is the main question of this thesis, and this model will show if there is a direct correlation between the amount of surface water available and the amount of corn acres planted. Looking at the p-value in my regression analysis I do not see a strong correlation. I am looking for a p-value the is equal to or less than .05, because any p-value greater than .05 is considered to be statistically insignificant due to it being higher in random variations or by chance. With all the independent variables being from .17 to .997 as their p-value, I can determine that they are not statistically significant. Now looking at the R-squared, I am looking for a higher R-squared to represent that the model explains more variation in the dependent variable corn acres. In this regression analysis, I only had a R-squared value of .11, meaning that only 11% of the dependent variable is explained by the variance of the independent variables. I was expecting a higher correlation between my dependent and independent variables. Years that showed lower amounts of surface water and rainfall would result in less corn acres being planted in the county.

The coefficients will show how the independent variables will affect the dependent variable. So, when the independent variables increase or decrease then it will increase or decrease the dependent variable by what the coefficient represents. The surface water coefficient is the main premise of this study and will show how additional or less available surface water affects corn acres planted. The surface water sign was about what I expected with 0.19 acres for every acre-foot increased. For example, an additional 100,000 acre-feet of surface water would only increase corn acres by 19,000 acres.

Other variables that were not included that would likely have an effect is corn prices. If corn prices are high enough, farmers are incentivized to produce a corn crop even in years when growing conditions are not ideal. Another factor that can affect corn acres is the improvement of crop genetics and water optimization technology or drought traits. Farmers can produce the same or more corn with less water than they could 30 years ago.

Table 5.1: Regression Results with Dependent Variable Corn Acres

	Coefficient	**Std. Error**	**t-ratio**	**p-value**
Const	61983	288104	0.21	0.83
TotalACFT	0.19	0.13	1.43	0.17
Precipitation	1421.82	1967.27	0.72	0.48
AVGTemp	−18.65	4392.13	−0.0042	0.997
R-squared	0.11			

In Table 5.2, I used total acre-feet, precipitation, average temperature, and time as my independent variables and corn yield as my dependent. Time was added to the independent variable to account for improvements in crop genetics over time. This analysis was used to help see the correlation of bushels of corn produced per acre and how surface water, precipitation, and temperature. This would help tell how the corn acres performed in relation to the water available and weather. Looking at the p-value in my regression analysis I did not see any p-values that showed any significance except for time with a p-value of 0.03. The Time variable showed that as the years continued, we could expect the yield to increase by 0.99 Bu/acre each year. The rest of the independent variables had p-values that ranged from 0.24 to 0.48 and are not statistically significant. R-squared was very low as well at 0.24, meaning that 24% of the dependent variable is explained by the variance of the independent variables. I was expecting years that had high surface water and rainfall would have more yield and vice versa when years were low. Warmer temperatures are needed for corn growth, but constant rising temperature will cause more surface water evaporation and in turn leave less water for corn casing lower yields. Surface water coefficient had a very a lot lower effect on corn yield then expected in the model. I was expecting higher yields when the surface water variable increased and vice versa when it decreased. 100,000 acre-feet increase of surface water to increase yield by 8.03 Bu/acre.

Factors that could affect yield and were not included would be the amounts of fertilizer that was applied to the fields. Not only that, but the cost of fertilizers and other inputs would have an effect on the yield. When costs per acre increase, the yield can be affected to save money especially on years when corn prices are down. Also, just like in Table 5.1 the improvement of corn genetics has improved greatly over the last 30 years showing a positive trend. Looking at Figure 5.3 you can see the positive trend line over the last 30 years.

Table 5.2: Regression Results with Dependent Variable Corn Yield

	Coefficient	Std. Error	t-ratio	p-value
Const	−40.80	208.83	−0.195	0.85
TotalACFT	8.03E-05	0.00011	0.73	0.47
Precipitation	1.69	1.42	1.19	0.24
AVGTemp	2.34	3.25	0.72	0.48
Time	0.99	0.43	2.32	0.03
R-squared	0.24			

In Table 5.3, I used precipitation and average temperatures for my independent variables and total acre-feet for my dependent variable. This regression analysis shows the relationship between weather characteristics and water deliveries. Looking at the p-value in my regression analysis I did not see any strong correlation with my lowest p-value being the average temperature at .74 and my other p-value showing .92 for precipitation. The R-squared was very low as well at .012, meaning that 1.2% of the dependent variable is explained by the variance of the independent variables. In this model, I was expecting a lot stronger correlation between my independent variables and my dependent variable. This model was supposed to show how precipitation and temperature would affect the surface water collected.

What was not accounted for was the surface water that was not used in the previous year and was available for the next growing season. The data accounts for water that went through structures that were used for agriculture use, but the water that was never used that year was not accounted for. In addition, snow melt that occurs from precipitation in the previous winters causing a low correlation was not accounted for. Another thing that was not accounted for was the amount of water the cities would request and take from year to year with the constant change in population from year to year.

Table 5.3: Regression Result with Dependent Variable Surface Water

	Coefficient	Std. Error	t-ratio	p-value
Const	404787	420312	0.9631	0.34
Precipitation	304.89	2920.16	0.1044	0.92
AVGTemp	−2191.26	6506.73	−0.3368	0.74
R-squared	0.012			

Table 5.4 is the same as Table 5.1, but instead of using surface water as an independent variable the SWSI rating is used. The reason the SWSI rating is used is because the rating shows the water supply condition is the month before planting. The SWSI coefficient is what I was expecting at 8315.4 acres increase when the rating increases. The p-value is at .02 which shows that there is a strong correlation between SWSI and corn acres. This shows that the SWSI rating does have some influence on a farmer's decision to plant corn. The R-squared for the analysis was not great at 0.24 meaning that 24% of the dependent variable is explained by the variance of the independent variables. Table 5.5, like Table 5.2, has the dependent variable as corn yield, but instead of using surface water data the SWSI rating was used. SWSI was not what I was expecting with yield only increasing by 2.16 and the p-value at 0.41. Additionally, the R-squared was not great at 0.26 meaning that 26% of the dependent variable is explained by the variance of the independent variables. This shows farmers will reduce corn acres instead of applying less water which in turn will lower corn yields.

Table 5.4: Regression Results with SWSI & Dependent Variable Corn Acres

	Coefficient	Std. Error	t-ratio	p-value
Const	191104	258278	0.74	0.47
SWSI	8315.4	3200.2	2.6	0.02
Precipitation	−499.5	1953.31	−0.26	0.80
AVGTemp	−1046.1	3993.1	−0.26	0.80
R-squared	0.24			

Table 5.5: Regression Results with SWSI & Dependent Variable Corn Yield

	Coefficient	Std. Error	t-ratio	p-value
Const	−18.15	209.15	−0.09	0.93
SWSI	2.16	2.60	0.83	0.41
Precipitation	1.40	1.55	0.90	0.38
AVGTemp	2.37	3.26	0.73	0.47
Time	0.94	0.38	2.48	0.02
R-squared	0.26			

CHAPTER VI: CONCLUSION

Looking at the trends in my figure indicates that the allocation of water does appear to have some impact on corn acres planted and yields. Considering all the analysis and data that was collected, there is not a strong correlation between that the amount of surface water and the corn acres planted and its yields in Weld County Colorado. Even though the total corn acres and surface water show a negative trend, there was not a statistically significant correlation between these two variables. The SWSI shows a stronger correlation with corn acres and yield than surface water did. This stronger correlation between SWSI and corn acres shows that SWSI is a better indicator of water availability than my other variables. The correlation between SWSI rating and yield was still not strong statistically even though it was stronger statistically than the surface water variable. Farmers in Weld County, Colorado have shown they would rather switch to more dry land acres instead of reducing water on irrigated acres. Perez-Quesada, Hendricks, and Steward (2024) found similar results when the High Plains aquifer had low ground water there would be a decrease in irrigated acres. This shows that when groundwater or surface water availability is low, farmers will plant less irrigated acres.

One limitation I found in my regression analysis is that there are many other factors that have an impact on corn acres and yield that are omitted from the analysis. One factor I think made the correlation weak was the improvement of corn genetics, technology, and corn management. Corn genetics has made great advancements in the last three decades and have developed new corn hybrids that are more drought tolerant and improve water optimization. With corn hybrids able to produce as much corn yield with less water than corn in the past, farmers can choose hybrids that can withstand a year without as much surface water available. Another factor that has encouraged farmers to grow on years that surface water availability is low is the price for corn that year. Cost of inputs like fertilizer and pesticides is another factor that will affect farmers' decision to plant less acres of corn or to switch to a crop that has less input requirements. Not only is price a big factor for farmers to choose to grow corn, but crop insurance has become a big factor in a farmer deciding to take a risk on years of low water. Population increase is another variable that could have made the correlation stronger. As the population increases so does urbanization which leads to corn acres to decrease due to development and surface water goes toward municipal use.

Companies like Syngenta have programs set up for farmers to get money back if they have adverse weather conditions like flooding and or drought during the growing season. Syngenta has a program called Agriclime that farmers can sign up for when they buy bags of corn seeds and with purchases of other qualifying products like pesticide or fertilizer. This program will pay back a percentage of the cost of each bag up to 20% when rainfall falls under certain precipitation levels on their fields that are under the twenty-year historical rainfall data for that region.

With improved water optimization genetics, crop insurance, corn prices, input costs and companies backing farmers, finding a strong correlation between surface water and corn acres planted is difficult. There are many other variables that were not used in my analyses that could have strengthened the correlation of corn acres and yields with surface water.

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APPENDIX A

Year	Total ACFT	Corn Acres	Bu/Acre	AVG Temp	Precipitation
1993	283,024	166300	141	58.46	12.48
1994	290,750	140900	151.5	62.07	8.98
1995	267,034	142700	117	58.29	15.54
1996	315,355	149900	137.5	60.37	12.42
1997	287,620	170500	151	59.73	16.51
1998	330,925	162100	146.5	60.96	12.59
1999	269,750	157200	164.5	59.23	17.44
2000	307,859	175100	154	62.11	8.87
2001	267,410	162700	165.5	61.94	12.56
2002	209,197	128000	153.5	61.37	7.39
2003	298,776	98200	131.5	61.79	10.31
2004	312,168	101000	160.5	60.11	11.56
2005	292,298	107200	171.5	61.03	13.26
2006	326,296	104100	172.5	61.99	7.5
2007	324,550	148000	151.5	62.30	11.92
2008	292,837	123800	168	59.91	12.27
2009	273,429	115600	176	58.20	15.59
2010	300,789	126900	194.5	61.31	12.78
*2011	*108,021	*145,100	*183.6	*60.81	*14.12
2012	220,374	135800	178.7	63.63	7.76
2013	229,347	107500	162.2	60.29	15.06
2014	259,588	116900	169.5	60.79	14.47
2015	235,836	109300	175.8	61.51	16.93
2016	256,773	119200	157.4	61.87	10.62
2017	280,619	123900	175.4	60.64	12.88
2018	260,037	124500	136.2	61.37	10.27
2019	252,264	119000	177.1	59.37	12.4
2020	247,753	106000	173.2	61.31	7.63
2021	259,714	108000	170.1	61.93	9.69
2022	221,318	109500	131.9	62.44	7.85

Note: * denotes that data for 2011 were omitted from the analysis.