IMPROVING DATA AND UNDERSTANDING OF PUBLIC WATER SUPPLY IN NORTH DAKOTA THROUGH MUNICIPAL AND INDUSTRIAL WATER-USE INFORMATION SPECIFICALLY FOCUSING ON THE BAKKEN REGION 2000-2018

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

The Bakken oil boom 2005–2015 has dominated conversations on North Dakota's water use in the past two decades. This study focused on municipal and industrial water use across 83 different use categories for the Bakken and non-Bakken areas of the state. A phone survey was conducted to determine how industrial permit holders use their water. Additionally, water use databases from the North Dakota State Water Commission and Southwest Water Authority were analyzed to determine correlations between the oil boom and water use in municipal and industrial categories, and determine differences and similarities between water use in the Bakken and the rest of the state. Results show many industrial permit holders use their water for its intended purpose and sell the remaining water to other industries, such as oil, which made commercial water sales increase drastically. Information from this project is useful for future water projections and planning.

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DEDICATION

I dedicate this paper to my grandfather Eugene Hanley, and my brother Zachary Cleys.

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CHAPTER 1: LITERATURE REVIEW

Water is used in a variety of ways between municipal and industrial settings. Municipal water is used for a myriad of purposes such as drinking, bathing, cooking, cleaning and landscaping (Mayer et al. 1999; Blokker et al. 2009; Willis et al. 2013; Rathnayaka et al. 2015). Looking at industrial water, residential water use is the highest consumer for municipal water use and has led many researchers to focus on this sector (Kim and McCuen. 1979; Kostas and Chrysotomos 2006; Polebitski and Palmer 2009; Mini et al. 2014). Industrial and commercial use has been studied with less intensity, tending to focus on manufacturers (Kim and McCuen, 1979). A more recent study has aimed to determine how commercial and industrial water use is affected in the urban environment, such as heated building space (Morales et al. 2011) while other studies focus on non-residential water use (Zhang and Brown 2005; Wentz and Gober 2007; Blokker et al. 2009). A majority of studies still focus on residential use.

Often, the residential sector uses over one-half of all municipal water, and numerous studies have sought to determine where and how the water is used (Grimmond and Oke 1986; Mayer et al. 1999; Cole and Stewart 2013; Mini et al. 2014). End-use studies are often carried out to determine where to conserve water, as a pre-emptive measure or response to water stress, (Stewart et al. 2009). Hauber-Davidson and Iris (2006) stated “what you don’t measure, you can’t manage,” giving water conservation a justified basis for study.

Residential water use is commonly broken into two categories, indoor and outdoor use. Indoor water use includes toilets, showers, washing machines, and faucet taps, while outdoor use is dominated by irrigation for gardens and lawns (Vickers 2001). Total water use can vary depending on the season with outdoor water use seeing higher variations throughout the year (Willis et al. 2013; Attari 2014; Mini et al. 2014; Rathnayaka et al. 2015; Gnoisnsky 2017).

Water use data in North Dakota is often recorded with meters in urban areas but is still self-reported in rural areas (Ellingson et al. 2019). These meters vary on when they record water use data. Some meters collect data at a certain time every day while others record the data at the top of the month. Self-reported data is often collected once a year and is not accurate.

Within the last 20 years, the development of smart water metering technology has allowed real time data collection for water consumption (Hauber-Davidson and Idris 2006). These meters allow for the end use to determine how much water is consumed and when it is consumed (Cole and Stewart 2013). Over the last decade, this technology has aided indoor end use water research (Beal et al. 2013; Britton et al. 2013; Cole and Stewart 2013; Willis et al. 2013). Toilets are the largest use of residential water in North America (Vickers 2001) and Asia (Bradley 2004) whereas showers were the largest use in Australia. Power et al. (1981) approximated that 80% of all indoor water use is used by toilets, bathing, and washing clothes. This study did not factor in seasonality.

Rathnayakea et al. (2015) conducted a study in Australia to determine the impacts seasonality has on water use. While research shows that indoor water use remains approximately stable throughout the year, this study shows that the quantity of water varied with the seasons. Researchers found that the proportion of water that was used for showering was higher in the summer months for one district, and higher in the winter for another district. Although the reason for this is not known the researchers speculated that the higher winter use was due to longer showers and the higher summer use was due to a higher frequency in showers (Rathnayakea et al. 2015).

Irrigation is the most dominant and varied use of outdoor residential water (Vickers, 2001). Vickers (2001) found a vast range in outdoor water use spanning multiple climatic differences. Ontario, Canada makes up 10% of total water use was for residential purposes while residential purposes in Texas had use of 75% of its total water use. A study in Florida found that approximately 65% of total water use in residential areas was used for irrigation (Haley et al. 2007). Multiple studies have shown that outdoor water used for irrigation is higher in the summertime, periods of drought, and high temperatures when compared to the wintertime, with cooler temperatures and wetter conditions (Grimmond and Oke 1986; Zhou et al. 2000; Balling and Gober 2007; House-Peters et al. 2010; Mini et al. 2014; Rathnayaka et al. 2015).

Commercial Water Use

There is little research available regarding commercial water use. Of the studies available the majority are focused on the residential sector. One example is a report generated by the City of Santa Fe, New Mexico (CoSF 2001). This study, analyzed approximately 1,500 water use records, breaking them into 22 different commercial sub-categories. Researchers then compared their information to a single family home's use (in acre feet used per year) and found that other categories had double the use of a single family home or higher. Gas Stations with a carwash had the highest use (31.2 times the use of a single family home) and a motel with limited services had the least use (0.6 times the use of a single family home) (CoSF 2001). This is a rather unique report since most tend to focus on only one-specific sub-category (Brown 2002; O'Neill et al. 2002) and not multiple categories. Vickers (2001) published a book that provides the average daily water demand for 37 sub-categories of commercial, industrial and institutional water use. Seneviratne (2007) broke commercial water use in California down to nine categories, giving the percentage of total commercial water used for each category.

Florida's commercial sectors have been analyzed recently for trends in water use among different categories (Morales et al. 2009; Morales and Heaney 2010; Morales et al. 2011). The

Morales et al. (2009) and Morales et al. (2011) studies attempted to correlate the area of heated buildings to predict commercial, industrial, and institutional water use. Researchers found that seasonality and temperature (both outside a heated building space) could be used to predict the water usage of the study area. Morales and Heaney (2010) developed water use coefficients from a study looking at 24 different sub-categories of commercial use. Hotels and shopping centers were found to be the largest commercial water users utilizing, approximately 30% of all commercial water, and public school systems were the largest institutional user.

Endter-Wada et al. (2008) specifically studied the irrigation aspect of commercial water use in Utah. Researchers surveyed the plant life in the area and combined it with water billing and use data to create an index (in this case a "water budget") for water use. This index was then applied to the business in the area to determine if their water use fell into one of three categories (conservative, acceptable, or wasteful use). Researchers discovered that the type of irrigation system was a large factor in determining what category of use the business was in. Wasteful watering had many contributing factors but researchers implied that water conservation programs should be more site specific in recommendations to reduce water use (Endter-Wada et al. 2008).

Modeling and Forecasting Water Use

Models are created to forecast future water use to prepare for future needs. These models can forecast demand, hours, days, weeks or months in advance, allowing for better conservation and emergency management (Smith 1988; Shvartser et al. 1993; Altunkaynak et al. 2005; Ghiassi et al. 2008). Models forecasting water demand for shorter periods, periods lasting less than one year, create short term forecasts (Zhang et al. 2014). Models that forecast water demand for periods of greater than a year generate long term forecasts (Polebitski and Palmer 2009).

Short term forecasting allows for better planning and management (Yurdusev et al. 2009). These forecasts help to estimate water demand hours to weeks in advance, ensuring that there is enough water for the Municipalities to not run out during peak use times. This is especially helpful when determining if water has to be released or pumped in from reservoirs (Smith 1988; Bougadis et al. 2005). Short term forecasting can also give guidance on specific water regulations and effective water use reduction measures (Yuan et al. 2014). While short term forecasting aids in immediate planning and management, long term forecasting aids in identifying potential changes in demand.

Long term forecasting not only allows for betting planning and management, but it also allows for a greater number of variable to be studied (Khatri and Variravamoorthy 2009; Maheswaran and Khosa 2013). Long term forecasting models can offer more clear results by utilizing short term data to generate patterns (Qi and Chang 2011; Zhou et al. 2000). Maheswaran and Khosa, (2013) utilized a wavelet model to predict groundwater levels. By compiling short term forecasting data into the model, they were able to produce accurate predictions for 18 months (Maheswarn and Khosa 2013). Long term forecasting can produce accurate results using data from short term forecasting.

Models can be categorized into short term and long term time frames, as well as split into groups based on the type of statistical analysis they perform (Qi and Chang 2011). Simple water forecasting models can use both regression analysis and time series analysis. Regression models assume that there is a past relationship between water demand and another variable that will continue (Qi and Chang 2011). Foster and Beattie (1979) used regression analysis to determine the impact of city size on water demand. Conversely, time series analysis focuses on trends in water use and how they contribute to changes in water demand over time. Zhou et al. (2000)

created a time series analysis forecast of the water demand for consumers in Melbourne, Australia 24 hours ahead of time by using past demand data and climatic variables. This was to ensure that enough water was released from the storage reservoirs to meet consumer demand. Both regression and time series analysis can be used for short and long term forecasting, but time series analysis is used almost exclusively for short term forecasting. The majority of studies use these methods to model within cities and urban areas and is variable based on input data that is not always reliable.

Other modeling approaches allow for more complex situational analysis based on computational intelligence techniques. The majority of research studies related to water use are represented by modeling and statistical design of those models. One of the most common types of computational intelligence techniques used in water demand forecasting is artificial neural networks (ANN) (Qi and Chang 2011). Generally, ANN contains at least three layers, (input layer, output layer, and hidden layer) and is purely driven by data. Ghiassi et al. (2008) developed DAN2, an ANN that could forecast water demand anywhere between 48 hours to 24 months in the future. DAN2 outperformed the most common ANN models, with a more accurate forecast (greater than 99% accurate) (Ghiassi et al. 2008). Regression models have been compared to ANN models for short term water demand modeling with ANN models producing more reliable results (Bouagdis et al. 2005). ANN models are trained with historical use data which narrows the model's window of error. This allows for more accurate, predictions based on past water use (Qi and Chang 2011).

There are also hybrid models that combine multiple models to create a hybrid that outperforms simple method models (Qi and Chang 2011). Shvartser et al. (1993) developed a demand behavioral model that used both time series analysis and pattern recognition to forecast hourly water demand. Wong et al. (2010) developed a statistical model for daily water consumption using general statistics. Their model performed fairly, when compared to the actual amount of water consumed, and showed stark differences in water use between weekdays and weekend days. These results gave an improved insight into Hong Kong's urban water use and allow for more effective water management practices (Wong et al. 2010). With the statistical techniques available to model water demand, the goals of the chosen model will influence what statistical technique is chosen.

Recently models have been developed that encompass the entire urban water cycle. Mitchell et al. (2001) developed Aquacycle, a model that combines indoor water use, climatic data, and physical characteristics of the urban environment to determine stormwater, wastewater, and water use. Aquacycle provides aims to reduce the amount of high quality (potable) water that is pumped into the urban environment by giving guidance on ways to use wastewater and stormwater that don't require potable water. The dynamic Urban Water Simulation Model (DUWSiM), developed by Willuweit and O'Sulliven (2013), looks at the major components of the urban water cycle, specifically runoff, water demand, water supply, and wastewater, and its long term demand in the urban environment. Researchers found that the model was able to predict water demand and stormwater runoff for the City of Dublin with relative accuracy (Willuweit and O'Sulliven 2013).

As beneficial as models are for forecasting, future water demand models are not always consistent or reliable. Additionally, data used in models is not always correct, reliable, or robust as one would like, leading to inappropriate and inaccurate models (Gleick 2003). This has led many professionals to shy away from using models or to partial acceptance of the models overall (Sampson et al. 2011). Other reasons that the use of models is not more widely practiced include:

their complex nature; they are time consuming to run; and policy makers generally have a limited understanding of models and what they can do (Maidment and Parzen 1984). Even though models have their drawbacks, the information they produce can be useful in the right context. Incorporating models into water planning can be useful in the right situation.

Variables Influencing Water Use

Climatic conditions and socioeconomic conditions are the variables generally associated with residential water use (Gleick 2003; Kenny and Juracek 2012). These variables leave researchers with conflicting results regarding the impacts climate and weather may have on commercial water consumption (Kim and McCuen 1979; Endter-Wada et al. 2008). Kim and McCuen (1979) stated that commercial water use does not vary seasonally or daily, but a study in Utah found that use varies throughout the year (Kim and McCuen 1979; Endter-Wada et al. 2008). Variation in commercial water use can be caused by the irrigation of business landscaping.

Socioeconomic Variables

Many different socioeconomic factors have been considered important when forecasting future water demand. Price of water and income are two factors that are often incorporated into models (Dziegiolewski and Boland 1989; Arbues et al. 2003; Polebitski and Palmer 2009). In general, as water prices increase, demand for water decreases (Foster and Beattie 1979). Similarly, as income increases demand for water generally increases (Willis et al. 2013). Population size is a common model variable (Gleicks 2003; Yurdusev et al. 2009). Yurdusev et al. (2009) found that an ANN based model including a population variable provided better results than models that didn't include population.

Structural factors such as building type, square footage, and building density have all been linked to water demand (Dziegielewski and Boland 1989; Polebski and Palmer 2009). Property factors such as lot size, lot value, presence of a pool, and landscaping investment, have also been shown to be related to water demand (Morgan and Smolen 1976; Wentz and Gober 2007).

Climatic Variables

Weather conditions have been considered an important factor to include when modeling water demand. The two weather variables most commonly considered are precipitation and temperature (Morgan and Smolen 1976; Aly and Wanakule 2004). Water demand generally decreases with an increase in precipitation, which is attributed to a shortterm decrease in outdoor use (Zhou et al. 2000; Balling and Gober 2007). Actual rainfall amounts and the number of days since the last precipitation event can improve forecasting more than the presence/absence of precipitation (Bougadis et al. 2005). On the other hand, as temperature increases, water demand and use generally increase as well (Grimmond and Oke 1986). The daily maximum temperature is considered the best temperature variable to use when forecasting water demand (Maidment and Miaou 1986; Zhang et al. 2014). Maidment and Miaou, (1986) conducted a study on the impacts of water use and temperature in cities in three different states. They found that a threshold (70F°) above which water use rises steadily with maximum daily temperature (Maidment and Miaou 1986). Including both precipitation and temperature in water use modeling generally provides better results than excluding climatic data all together. Of those two variables, the occurrence of precipitation seems to have a slightly larger impact on water use (Zhang et al. 2014).

Commercial Variables

In the past, commercial water use, which includes commercial, industrial, and governmental water uses, was forecasted as “water use per employee” (Mercer and Morgan 1974). In a Mercer and Morgan (1974) study the water use category “arboretum, botanical, and zoological gardens” used the most water per employee. This has been found to produce mediocre results, giving way to the need to use variables beyond water use per employee (Mercer and Morgan 1974).

Kim and McCuen (1979) conducted a study on retail stores that focused on determining what factors helped predict commercial water use, specifically for retail stores. Three general categories were utilized: the employee factor, the customer layout factor, and the customer water facility factor. All three groups of factors have multiple aspects within them; the final factors most appropriate are gross store area, length of display windows and number of drinking fountains (Kim and McCuen 1979). This data allows for better planning in commercial water use. Recently heated building area has been proposed as a new approach in estimating commercial water demand (Morales et al. 2009; Morales et al. 2011). Although the method appears to offer an improvement over the water use per employee factor, it can still be limited by the ability to obtain reliable data.

Trends in Water Use

Trends in water use are important to understand how water is used and provide a look into the future of water resources (Kenny and Juracek 2012). This information is vitally important due to the fact that water is a finite resource (Kostas and Chrysostomos 2006). Trends in water use can be identified by looking at past data on water use and varies by country and region. For example, during the oil boom from 2005 until 2015 trends in the Bakken (oil rich) region of North Dakota varied from the rest country and even eastern North Dakota (Carter et al. 2016; Horner et al. 2016; Lin et al. 2018).

Interesting trends in water use have emerged, especially when examined in relation to population and population growth. In general, as affluence increases, more water is consumed, especially in less urbanized areas (Fry 2006). When the population grows and urbanization increases, more water is demanded by municipalities (Molden and Sakthivadival 1999). These two factors aid in explaining that regions with the fastest growth in domestic water use tend to be those that have had low water consumption levels in the past (Portnov and Meir 2008).

Other trends displayed a more stable or decreased water use (Bradley 2004; Franczyk and Chang 2009; Maupin et al. 2014). In many countries across the world, such as Korea, the US and the UK, there have been reports of reduced water use per capita (Bradley 2004). While there are many different contributing factors, one explanation is that households with higher incomes are more likely and able to purchase more efficient appliances (Stewart et al. 2009). More accurate reporting practices and the increasing trend toward conservation could be impacting the long term demands (Konieczki and Heilman 2004).

The USGS is the main federal agency in the United States (U.S.) that studies water use. They publish a report every five years, going back 60 years (Dieter and Maupin 2017). To breakdown total water use, USGS looks at eight separate categories: public supply, domestic, irrigation, livestock, aquaculture, industrial, mining, and thermoelectric power (Maupin et al. 2014). The USGS reports provide data sets for examining the connection between population growth and trends in water use. In 2010, the estimated average daily withdrawal for all eight categories combined was at its lowest level since 1970 (Maupin et al. 2014). In 2010 the public water supply category saw its first decline since 1950 (Dieter and Maupin 2017). This was a 5%

decrease even though the total U.S. population increased 4 %, between 2010 and 2015 the population again increased by 4% while public supply withdrawal decreased 7% (Dieter and Maupin 2017). This means that overall water withdrawal continues to increase as our water use increases but there is less use per capita.

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CHAPTER 2: SURVEYS OF MUNICIPAL AND INDUSTRIAL PERMIT HOLDERS (2000-2018) IN THE BAKKEN AND NON-BAKKEN REGIONS OF NORTH DAKOTA

Abstract

The oil boom in North Dakota brought with it a need to better understand the differences between municipal and industrial water use. There is little known about the way industrial water use categories influence each other in the state of North Dakota. There is also no standard use amount for what determines a municipal use permit from an industrial use permit. To help determine this a phone survey was conducted of all municipal and industrial permit holders in the state of North Dakota 2000 to 2018. The goal of the survey was to determine from permit holders the reasons for obtaining a permit, how water on the permit is used, and what the category of use for the permit. All municipalities with 1,000 or more residents in the state, or 500 or more in the Bakken region were surveyed (n=59). There were a total of 206 industrial permit holders 2000-2018 in the state, 61 of them successfully completed the survey. Results show that most industries in city limits use municipal water. The majority of industrial permit holders surveyed (50%) were located in the Bakken region and used their water for oil field purposes. In total 77% of respondents reported using 90% of their water for its intended purpose (ex. making a product), while 46% of respondents reported selling their excess water. This information is useful for water mangers helps in understanding where and how industrial water is being used and sold. It also allows water managers to better estimate future water needs.

Introduction

Industrial uses for water have not been studied as extensively as municipal water (Maupin et al. 2014; Lin et al. 2018). While municipal water focuses on city water used for domestic purposes, industrial water has a wide variety of uses including oil, coal, and energy production, manufacturing, and many other commercial uses. Water use in the Bakken region of North Dakota increased with the recent oil boom, but as the boom has slowed and entered a post boom time period, the effects on the water use need to be explored to better understand the effect the boom has had on the state (North Dakota State Water Commission 2020).

While municipal water has been assessed in multiple studies, industrial water use has only become a focus more recently (Maupin et al. 2014; Lin et al. 2018). Maupin et al. (2014) reported on water use in eight residential and commercial categories focusing on trends across the United States (US) in the past 60 years. They found overall water use in 2010, in all categories, were lower than 2005, and the lowest they had been since 1970. This reduction in industrial use was attributed to more efficient systems that helped recycle water used.. North Dakota also saw a reduction in overall use as a part of the Maupin et al. (2014) study. In the Bakken region, this reduction makes sense as the oil boom in the area was not going strong until 2005 when the oil boom happened. From 2005 to 2015, the length of the boom, water use was at a steady increase until the post boom began in 2015 (Lin et al. 2018). Lin et al. (2018) assessed industrial water in the Bakken region of North Dakota over time by utilizing state permit data. They found that the increase in industrial use had little overall effect on water use in the region but impacted the way permits were given and managed (Lin et al. 2018). This allowed some users to change their permit use type and others to get a temporary permit to provide the industry with water.

The goal of this study is to determine the differences and similarities between municipal and industrial use permits in North Dakota that are held by the NDSWC water use permit holders from 2000-2018. Determining is there a threshold of “normal commerce” for municipal and industrial use permits that determines how a permit is defined? The survey will separate permits in the industrial use categories between the Bakken and non-Bakken regions determine if a difference exists between industrial use types in these areas. Specifically, researchers assessed the initial reason permits were obtained, how they are being used, and what category of use the reported water use falls into. While data has been recorded on water use for these permits, this study is the first of its kind to compare and contrast all water use permits for industrial and municipal water use in the state. This information is vital for water managers as it gives insight into why companies would either fall under a municipal permit or seek their own industrial permit. This information is necessary for improving the current state permitting system, as well as assisting in planning for future needs.

Materials and Methods

The state of North Dakota, US was the study area for this project (Figure 2.1). Two questionnaires were developed to assess differences between industrial and municipal water use within the state. One questionnaire was specifically tailored to municipalities, while the other was designed for industrial water permit holders in the state (Appendix A and B, respectively). Questions focused on the history of the permit(s), permit use, and if permit holders were willing to share monthly use data. Researchers initially contacted all municipal and industrial permit holders over the phone, if requested permit holders were sent a digital copy via email to fill out.

Permit holders who had an industrial or municipal water use permit with the NDSWC, and used water between 2000-2018, were the study population for this project. A total of 59 municipalities were assessed, similar to Ellingson (2018) and Ellingson et al. (2019) all municipalities in the state with over 1,000 residents were assessed, but in the Bakken region municipalities with 500 or more residents were assessed. The Bakken area for this study was defined similarly to Ellingson et al. (2019), as north of interstate 94 to the Canadian border, and west of state highway 83 to the Montana border (Figure 2.1). The same municipal populations and delineation of the Bakken were selected to allow comparisons to past studies. This area was selected because it is where growth occurred that impacted water use, not just where the oil well concentrations are.

A total of 206 industrial water use permits used water between 2000-2018. The NDSWC does provide basic contact information for permit holders when permits are initially obtained. Researchers attempted to contact all permit holders utilizing this information, if contact information was no longer valid researchers used Google and the internet to search for up to date contact information. In total, 105 of the permit holders could not be contacted. Of the 105, 101 did not have valid contact information, and four permit holders were deceased. There were also 14 permit holders who were initially contacted but asked researchers to call back, and researchers were unable to successfully reach them again. The remaining 87 remaining permit holders were all contacted but however 26 permit holders refused to take the survey, therefore a total of 61 industrial permit holders completed the survey.

There were 59 municipal permit holders, based on population sizes utilized in the study, and 58 out of the 59 municipalities participated in the study. The one city that failed to complete a survey was contacted multiple times but never returned the survey. All permit holders, industrial and municipal, included in the study were contacted a minimum of three times over an approximately six week period. Permit holders were initially contacted and left a phone message if they didn’t answer. If they didn’t respond they were contacted again 10-14 days after the initial call. Again they were left a message and if they didn’t respond they contacted again 10-14 days after the second call. If after three attempts permit holders did not respond researchers marked them as “unable to be reached”.

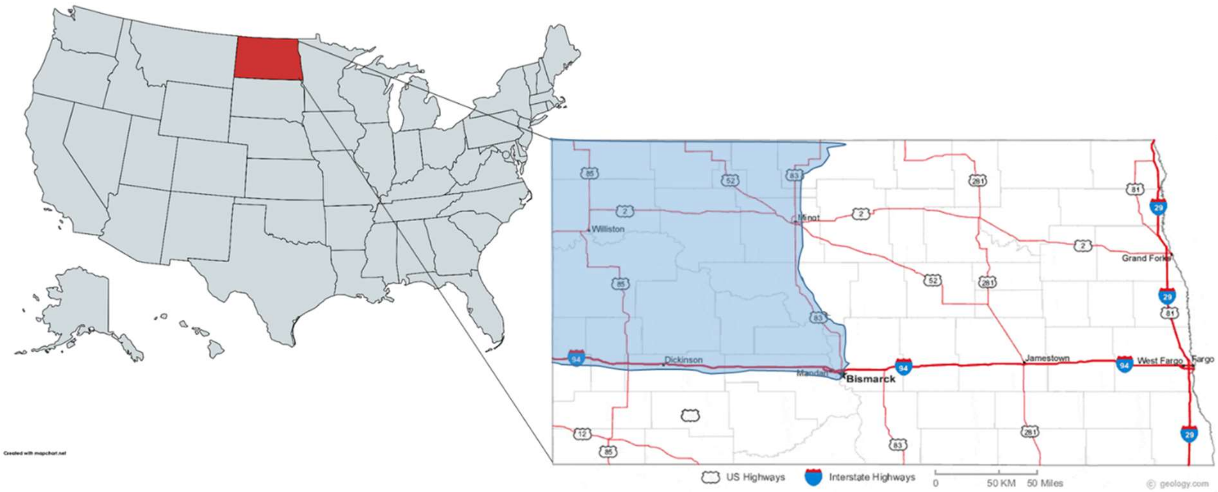

Figure 2.1. United States with North Dakota in red and projected out to show the Bakken area highlighted in blue.

Permit use type was categorized by combing the classification system used by Ellingson (2018) and the 13 categories used by the Water Research Foundation (Water Research Foundation 2015). While all 59 cities (Appendix C) were categorized as municipal water use for analysis, industrial water use was split into more specific types for a stronger and more accurate analysis. After the completion of the surveys, responses were aggregated and coded for analysis. The response rate was 93% for municipalities and 63% for industrial permit holders. Due to the high response rate, generalized interpretations were made for the results in the categories for both regions.

Results and Discussion

Industrial Permits

The industrial survey was given to all industrial water use permit holders in North Dakota between 2000-2018. The survey had a response rate of 63% for all permit holders for which we were able to obtain contact information. The response rate on municipal surveys was 93%, with all but one survey being completed for this population, making this a full population survey. As established by Brauch and Holton (2008), any survey response with a response rate of over 50%

is considered a full population response Due to the high rate of response, which is above the recommended rate by Baruch and Holton (2008), there will be no need to adjust survey statistics based on response rate.

Number and Location of Permits

The following questions were asked of industries about the number and location of permits:

- Question 1: How many industrial permits do you currently have? (Table 2.1)
    - Question 1a: If multiple permits, are these for multiple sites?
    - Question 1b: If multiple permits, what was the reason for obtaining multiple permits? (Table 2.2)

The majority of respondents had one permit, with most permit holders in the Bakken region (Table 2.1). Only 35% of respondents had two permits or more, and again these permit holders were mostly located in the Bakken region. In general, if industries held multiple permits, this was done to have permits for multiple sites, as when asked if they held multiple permits for multiple sites (Questions 1b) 33% responding yes, 5% responding no, and 62% responding not applicable (not holding multiple permits). The industrial permit holders that had multiple permits had a variety of reasons for obtaining multiple permits (Question 1b). Table 2.2 provides a breakdown of reasons provided to researchers for obtaining multiple permits. In general, most of the time multiple permits were obtained for more water, to draw from multiple sources or locations, or to increase water use for production.

Table 2.1. Industrial permit holder responses to number of permits currently held (n=61), n for each parameter is in parenthesis. *Note: all permit holders held an industrial permit sometime between 2000-2018, though they may not have a current permit.

Questions	Percent of Total Respondents	Percent of Total in Bakken	Percent of Total in non-Bakken
Respondents with zero or one permit	65% (40)	85% (34)	15% (6)
Respondents with multiple permits	35% (21)	86% (18)	14% (3)

Table 2.2. Industrial permit holder reasons for holding multiple permits (n=56), n for each parameter is in parenthesis.

Reasons	Percent of Multiple Permit Holders	Percent of Total in Bakken with this Reason	Percent of Total in non-Bakken with this Reason
To draw from different water sources	7% (4)	75% (3)	25% (1)
One permit was not enough allotted water	5% (3)	100% (3)	0%
Location	5% (3)	100% (3)	0%
Production or processing reasons	13% (7)	71% (5)	29% (3)
Other	7% (4)	75% (3)	25% (1)
Not applicable	63% (35)	86% (30)	14% (5)

Location of Permit/Choice of Industrial Permit

The second set of questions in the survey addressed the location of the industry. These questions were asked to reference if there was municipal water available to the permit holder or if they chose to obtain a permit separate from a municipality. Additionally, these questions hoped to assess where permitted water was being used (i.e. within or outside city limits). The questions are summarized as follows:

- Question 2a: Are you located within or outside city limits, and if so what city (summarized below into Bakken and non-Bakken)? (Table 2.3)
- Question 2b: Why did you choose to get an industrial permit vs. fall under a municipal water permit from the NDSWC? (Table 2.4)

- Question 2c: Did you have the option of using water from a municipal permit? (Table 2.5)

A summary of responses for question 2a can be found in Table 2.3. It should be mentioned, that the data for this question may be skewed for respondents that took the survey by paper or email, as permit holders may have reported their office location or their permit(s) location. The intent of the question was to determine where permits are being used, however it is plausible that some respondents interpreted the question incorrectly. Surveys that were answered on the phone did not have this problem. A small percentage of permit holders (5%) had permits both inside and outside the Bakken region. In general, the majority of industrial permit respondents held permits outside of city limits and were located in the Bakken region. Multiple reasons were cited as to why permit holders chose to get an industrial permit instead of falling under a municipal water permit (Question 2b). A summary of the responses can be found in Table 2.4. For a large portion (36%) of respondents, they didn't fall under a municipal permit because it was not an option for them. However, an additional 36% of respondents gave an "other" answer. Some of the popular (two more respondents gave this answer) "other" responses included: they needed more water than municipal water would allow, it was going to be used and/or sold for fracking, and potable water wasn't needed.

Table 2.3. Industrial permit holder information on where permit is located (n=55), n for each parameter is in parenthesis.

Questions	**Percent of Total Respondents**	**Percent of Total in Bakken**	**Percent of Total in non-Bakken**
Inside city limits	15% (8)	88% (7)	12% (1)
Outside city limits	80% (44)	84% (37)	16% (7)
Both inside and outside	5% (3)	67% (2)	33% (1)

Table 2.4. Industrial permit holder reasons for choosing an industrial vs. a municipal permit (n=56), n for each parameter is in parenthesis.

Reasons	Percent of Permit Holders	Percent of Total in Bakken with this Reason	Percent of Total in non-Bakken with this Reason
Was their only option	36% (20)	75% (15)	25% (5)
Took over an existing permit to use	12% (7)	86% (6)	14% (1)
Not close enough to city or other supplier	11% (6)	83% (5)	17% (1)
Other	36% (20)	90% (18)	10% (2)
Didn't answer question	5% (3)	100% (3)	0%

Survey respondents were also asked if they had access to municipal sources of water (Question 2c). This question was asked to better understand if permit holders would choose to use municipal water if they had the option. This could also help to identify anyone who might be "double dipping" (i.e. using water from both industrial and municipal water). A summary of the answers is found in Table 2.5. In general, respondents chose the industrial permit because they were not given another option (63%). As shown in Table 2.3, a majority of permit holders had permits that were outside of city limits (80%), which excludes them from using municipal water. Therefore, distance from the municipal source was a limiting factor for many permit holders, leading to their choice of an industrial permit.

Table 2.5. Industrial permit holder access to municipal water (n=56), n for each parameter is in parenthesis.

Reasons	Percent of Permit Holders	Percent of Total in Bakken	Percent of Total in non-Bakken
Not given the option	63% (35)	91% (32)	9% (3)
Given the option but decided to get own industrial permit	5% (3)	67% (2)	33% (1)
Unsure if they were given an option	7% (4)	25% (1)	75% (3)
Other	2% (1)	0%	100% (1)
Did not respond to question	23% (13)	92% (12)	8% (1)

How Water is Used

Once researchers had an understanding of why an industrial permit was obtained, questions were asked to understand the category of use for the permit, and the amount of water used for creating products or providing services vs. other uses. These questions were asked to understand the variety of ways industrial water is utilized in the state. Additionally, a series of questions were asked to see if permit holders utilized the water themselves or if they sold the water to outside entities. The summarized questions are below:

- Q3. What category of use does the water for the permit fall under? (Table 2.6)
- Q4. What percent of water do you use in making a product/providing a service? (Figure 2.2)
- Q5. Do you sell water to other entities? (Table 2.7). If so,
    - Q5a. To whom do you sell it? (Table 2.8)
    - Q5b. How is the water that is sold transported? (Table 2.9)
    - Q5c. How do you determine to whom you sell water (distance, need, other)? (Table 2.10)

- Q5ci. What criteria do you use to determine this (distance range, provide water over a certain amount)? (Table 2.11)

Question three sought to understand the categories of water use and how they were similar and/or different between the Bakken and non-Bakken. Results of question three are summarized in Table 2.6. Varied categories of use were represented, but oilfield represented 50% of the responses, with 96% of those located within the Bakken. There are oil development areas in North Dakota outside the Bakken region and the Bakken region as defined by this study, specifically farther south of Interstate 94 in the southwest part of the state, and near the city of Bottineau the north central portion of the state. The other most represented water use category was multiple use, permit holders that identified this category most often cited oilfield and agriculture as their multiple uses.

Table 2.6. Category of water use for industrial permit holders (n=56), n for each parameter is in parenthesis

Categories of Use	**Percent of Total Respondents**	**Percent of Total in Bakken**	**Percent of Total in non-Bakken**
Oilfield	50% (28)	96% (27)	4% (1)
Manufacturing	4% (2)	100% (2)	0%
Agriculture	5% (3)	67% (2)	33% (1)
Mining	5% (3)	100% (3)	0%
Construction/Contracting	9% (5)	80% (4)	20% (1)
Multiple use	13% (7)	71% (5)	29% (2)
Other	9% (5)	20% (1)	80% (5)
Did not answer question	5% (3)	100% (3)	0%

After the water use type was recorded, permit holders were asked what percentage of their water use is used in making their product or service, as compared to other uses such as restrooms and water fountains (Figure 2.2). The large majority (64%) of respondents use 100% of their water to make their product or service, and of these, 83% are in the Bakken and 17% in the non-Bakken area. Overall, respondents generally use a majority of their water for making their product or conducting their service, as 77% of respondents use 90% or more of their water for this purpose.

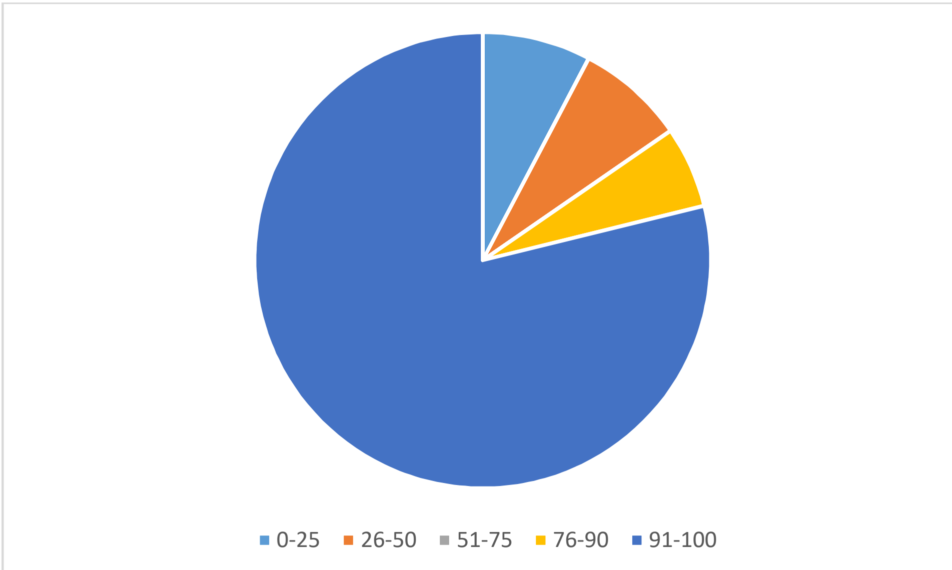

Figure 2.2. Amount of water use as a percent of 100% possible, used to create a product or provide a service (n=56). Each number represents the percent of the water used for permits to make products or provide services.

The next set of questions (5a-c) focused on selling water (Table 2.7). These questions were asked to determine how many permit holders sell water, who they are selling it to, how they are selling it, and how permit holders transport the water. It should be noted that industrial permit holders are allowed to sell excess water from their permit under North Dakota Century Code, as long as the water is used for a beneficial use. A beneficial use is any use that generates a product or service that benefits the state of North Dakota financially. Approximately 46% of respondents sell their excess water, and of those 81% are in the Bakken region (Table 2.7). Of the industrial permit holders that sell water, a majority sell to multiple buyers (62%), though oil companies and third-party sellers represent 15% and 19% of places water is sold (Table 2.8). In all groups to which permit holders sell water, the Bakken was the most common place that excess water from permits is sold.

Table 2.7. Industrial permit holders who sell excess water (n=56), n for each category is in parenthesis.

Responses	**Percent of Total Respondents**	**Percent of Total in Bakken**	**Percent of Total in non-Bakken**
Yes	46% (26)	81% (21)	19% (5)
No	50% (28)	86% (24)	14% (4)
Did not answer question	4% (2)	100% (2)	0%

Table 2.8. Places industrial permit holders sell excess water (n=26), n for each category is in parenthesis.

Responses	**Percent of Total Respondents**	**Percent of Total in Bakken**	**Percent of Total in non-Bakken**
Oil Companies	15% (4)	100% (4)	0%
Third Party that handled sale	19% (5)	60% (3)	40% (2)
Farmers	4% (1)	100% (1)	0%
Multiple Buyers	62% (16)	87.5% (14)	12.5% (2)

Researchers next sought to understand how the sold water was transported and what criteria were used to determine who could buy the water under a specific permit. The transport modes included truck (31%), pipe (23%), water depot (11%), and combination (35%) (Table 2.9). For each of these categories over 80% of permit holders that sell water are located in the Bakken region. In general, the majority of permit holders are willing to sell to anyone reputable (25%). The other most common responses were that they sell water to a third party who then sells the water themselves (17%), or they have an application/bid process (17%) in place to determine to whom they sell water (Table 2.10). When asked about specific criteria used to decide who to sell water to (Table 2.11), the most common response was by application or bid process (35%), followed by open to anyone (22%), and a third party contractor (17%).

Additionally, there were 13% of respondents that chose other, the "other" responses often included water being sold to a particular entity or being part of a prior or master agreement plan for selling of water.

Table 2.9. Transport mechanism for sold water for industrial use permits (n=26), n for each category is in parenthesis.

Transport Mechanisms	Percent of Total Respondents	Percent of Total in Bakken	Percent of Total in non-Bakken
Truck	31% (8)	87.5% (7)	12.5% (1)
Pipe	23% (6)	83% (5)	17% (1)
Water Depot	11% (3)	100% (3)	0%
Combination	35% (9)	89% (8)	11% (1)

Table 2.10. Industrial permit holders response on determining to whom they sell water (n=24), n for each category is in parenthesis.

Responses	Percent of Total Respondents	Percent of Total in Bakken	Percent of Total in non-Bakken
Third Party	17% (4)	75% (3)	25% (1)
Application/Bid	17% (4)	100% (4)	0%
Distance	8% (2)	50% (1)	50% (1)
Need	12.5% (3)	100% (3)	0%
Distance and Need	8% (2)	100% (2)	0%
Open to anyone reputable	25% (6)	83% (5)	17% (1)
Other	12.5% (3)	67% (2)	33% (1)

Table 2.11. Specific criteria used to determine who gets the water that is sold (n=23), n for each category is in parenthesis.

Criteria Used	Percent of Total Respondents	Percent of Total in Bakken	Percent of Total in non-Bakken
Third Party Decides	17% (4)	75% (3)	25% (1)
Application/Bid	35% (8)	100% (8)	0%
Distance	13% (3)	67% (2)	33% (1)
Open to anyone with payment	22% (5)	80% (4)	20% (1)
Other	13% (3)	100% (3)	0%

Availability of Data

The last question asked of industrial permit holders was asked to determine how accessible monthly water use data is for researchers to obtain for possible future studies. Results are summarized in Table 2.12, however it should be noted that even though entities say they are willing to share data, they don't always follow through with the request (Ellingson 2018). A total of 11% of respondents said yes they would be willing to provide data while 29% said no. Interestingly, 30% said that the NDSWC has the data. However, the NDSWC clarified that while they do record information about the permit on a monthly basis, they do not record monthly water use. Additionally, while the data exists within NDSWC it is not in an accurate form that is useful to outside entities. There were 13% of respondents that chose other, and while they did not give a clear answer on how to obtain the monthly use data, they assured researchers that it was possible to get. This question indicates that most users do wish not to share their monthly use data, are unable to access it themselves, or believe it is already provided for public consumption and don't need to provide additional data.

Table 2.12. Willingness of industrial permit holders to share data (n=56), n for each category is in parenthesis.

Responses	**Percent of total respondents**	**Percent of Total in Bakken**	**Percent of Total in non-Bakken**
Yes	11% (6)	67% (4)	33% (2)
No	29% (16)	81% (13)	19% (3)
Maybe	7% (4)	75% (3)	25% (1)
NDSWC has it	30% (17)	88% (15)	12% (2)
Public request required	5% (3)	100% (3)	0%
Other	2% (1)	100% (1)	0%
Did not answer question	16% (9)	89% (8)	11% (1)

Municipal Permits

There were a total of 59 cities contacted to complete the municipal survey, and 58 participated for a response rate of 96%. Due to the high response rate, further statistical analysis is not needed and interpretations can be applied using summary statistics (Baruch and Holton 2008). In general, the municipal survey followed the same structure as the industry survey with changes to address municipal water use information.

Numbers and Types of Permits

The first questions focused on the number and types of permits held by the municipality. Keep in mind everyone contacted in this survey was a municipality that held a municipal permit. However, researchers were checking to see if the municipality also held other permits, specifically industrial permits. Below are questions 1, 1a, and 2 from the survey.

- Q1. How many permits does your city have from the NDSWC? (Table 2.13)
  - Q1a. Are these industrial or municipal permits? (Table 2.14)
- Q2. If you have multiple permits, what was the reason for obtaining the additional permits? (Table 2.15)

The majority of municipalities have one permit (48%), though it was a close split as 40% of municipalities had multiple permits (Table 2.13). The majority of municipalities hold multiple municipal permits (76%), though 14% hold both municipal and industrial permits, and 3% hold municipal and another type of permit (Table 2.14). It should be noted that within the municipal survey questions, opposite of industrial permits, the majority were in the non-Bakken area as opposed to the Bakken. When asked the reason they obtained multiple permits, 30% of municipalities indicated the multiple permits were used to pull water from multiple sources and/or locations of the same source, while 35% didn't give any answers at all.

Table 2.13. The number of permits held by municipalities (n=58), n for each category is listed in 17% said for oilfields, and 13% responded to support industry (Table 2.15). Overall, the results of these questions indicate that the majority of municipalities in the state have one permit, though some municipalities pull other permits to support the industry in their area. In general, this would encourage industries to fall under municipal permits rather than pull their own permit.

Table 2.13. Number of permits held by municipalities (n=58), n for each category is listed in parenthesis.

Number of permits	**Percent of total respondents**	**Percent of Total in Bakken**	**Percent of Total in non-Bakken**
One	48% (28)	36% (10)	64% (18)
More than one	40% (23)	52% (12)	48% (11)
Unsure	10% (6)	17% (1)	83% (5)
Didn’t answer question	2% (1)	100% (1)	0%

Table 2.14. Types of permits held by municipalities (n=58), n for each category is listed in parenthesis.

Type of permits	**Percent of Total respondents**	**Percent of Total in Bakken**	**Percent of Total in non-Bakken**
Municipal	76% (44)	34% (16)	66% (29)
Both municipal and industrial	14% (8)	50% (4)	50% (4)
Municipal and other permit type (ex. Irrigation)	3% (2)	100% (2)	0%
Didn’t answer question	7% (4)	75% (3)	25% (1)

Table 2.15. Reason for obtaining additional permits (n=23), n for each category is listed in parenthesis.

Reasons	Percent of Total respondents	Percent of Total in Bakken	Percent of Total in non-Bakken
Oil industry	17% (4)	100% (4)	0%
Support Industry	13% (3)	33% (1)	67% (2)
Increased water need	4% (1)	0%	100% (1)
Multiple sources/locations	30% (7)	43% (3)	57% (4)
Other	4% (1)	0%	100% (1)
Did not answer	35% (8)	50% (4)	50% (4)

To help researchers better understand why an industrial permit was taken out within a municipality, question three asked cities the purpose of the permit. Only eight cities gave answers, which included: energy production (n=1), oilfield (5), wastewater (1), and irrigation (1). All of these cities were in the Bakken, except energy production was located in the non-Bakken region. In question four, municipalities were asked what percent of water is used in making a product or conducting a service for the industrial permit held by the city. Again there were eight answers and they were varied, including: "200,000 gallons for refinery", "low percentage", "100% for fracking" (n=2), "100% in office", "large percent for oil and agriculture", "sold at water depot", and "20% sold". All responses came from the Bakken region except the "low percentage" response. Similar to the question asked of industrial permit holders on the percent of water used to make a product or provide a service, municipalities found varied answers with some groups using all or a high majority of the water for the product/service and others not. It is important to mention that only 14% of municipalities surveyed answered this question as it solely pertains to those municipal permit holders who also have an industrial permit.

What Municipal Permit Holders Know About Industrial Permits in Their City

The last set of questions was asked of municipal permit holders to find out what they know about industries in their town on why they may or may not choose to have their own permit. As you read through this section you will quickly see the answers to what cities know about industry permits held in their town is minimal. Question five and the subsections to that question are laid out below. It should be noted that not one single municipality answered or had an answer to questions 5ai, 5aii, 5aiii, 5bi, 5bii, or 5biii, therefore the results of these questions will not be discussed.

- Q5. How many industries in town pull water from their own permit?
  - Q5a. How many industries pull water from a combination of their own permit and the city's water?
    - Q5ai. Why do the industries pull water from their own permits and not the cities?
    - Q5aii: Do other similar industries have their own permit or fall under the cities' municipal permit?
    - Q5aiii. What are the criteria used in your area/by industries to make the decision to pull an industrial permit or fall under the municipal permit?
  - Q5bi. What criteria do industries use for pulling water from different permits?
  - Q5bii. If more than one industry in city limits is doing this, do they use the same criteria?
  - Q5biii. If the criteria are different, how so?

Question five was designed to gauge the number of industries that are situated in city limits that are using industrial water. There were 82% (n=47) municipalities that said no or were unsure, 12% (7) did not answer the question, the four remaining municipalities answered: "one for an energy company", "well water classified as bulk water", "ten", and "I think there are a few". For question 5a when asked how many industries pull from both an industrial and municipal permit all municipalities either did not answer the question or said none. The one city that answered, responded an "industrial plant(s) pull from Hillsboro and Mayville" water. These answers are estimates of what the city knew of industries in their area. Many cities informed researchers that they would have no idea what the industries in town do but when pressured said they would give their best guess as comfortable. From answers given, researchers could tell that very few industries in the town are using a combination of permit types, relying on either all municipal or their own industrial permit water.

Conclusion

Both the industrial survey and municipal survey gave insight into North Dakota water use and aided researchers in completing the study objectives. It is apparent from both the municipal and industrial survey that in general if industries fall inside city limits they pull water from the municipal permit, and if they fall outside of city limits they pull water from their own industrial permit. A few industries indicated that they didn't pull from municipal water as they used more water than a municipal permit can provide, but this was only a handful of industries. Researchers are not sure if this is a city by city rule for municipal permits or a general municipal expectation, as based on past research in the state (Ellingson 2018) there were a handful of industries in larger cities that used extremely large amounts of municipal water each year.

Based on data available through the NDSWC website and interviews of municipalities and industries, it is impossible to determine what constitutes "normal commerce" for industrial permits. The more pertinent question, based on the data, is how much water is used on industrial water use permits vs. industrial water used under municipal permits. Without pulling monthly and/or yearly account information for each industry, in each municipality, that uses over 12.5 acre feet per year on their billing, it is impossible to determine normal commerce. If the NDSWC is interested in determining this in the future, it can be done, but not with the research questions and data analyzed as part of this study.

Overall, most industrial permit holders only have one permit. Whether permit holders had one or multiple permits, the majority of permits were utilized for the oilfields (50%) and were located in the Bakken region. The industrial permit holders also use a majority of the water they are permitted to make the product or provide the main service of their industry, as 77% of respondents indicated they use 90% or more of their water for these purposes. However, almost half of respondents (46%) also indicated that they sell excess water from their permit to different entities including oil companies, farmers, individuals, and third party contractors or a combination of these.

One finding that researchers found very interesting in the data is the fact that many industries feel that the NDSWC is recording accurate monthly and annual water use for their permit, while NDSWC says the information is not in an accurate/useful format. It may be worth the NDSWC taking the time to look at this data or categorize it differently as they receive it to have it in a useful form for research and analysis. Information from this study is useful to water managers both within North Dakota and nationally as they continue to improve water permitting systems, plan for the future, and seek to understand the water use data that currently exists.

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CHAPTER 3: ANALYSIS OF INDUSTRIAL AND MUNICIPAL WATER USE BETWEEN THE BAKKEN REGION AND NORTH DAKOTA 2000-2018

Abstract

The Bakken region is an oil rich, semiarid region that has experienced exponential growth and development in 21st Century. Water use information in this region is highly needed, but not readily available. This study sought to improve understanding of water use in the Bakken 2000-2018 including pre-oil boom, boom, and post-boom periods. Databases of water use for municipal and industrial state permit holders was utilized for the study, as well as one rural water supplier, Southwest Water Authority. Data was disaggregated into categories of use and organized into Bakken and non-Bakken regions based on geographical location. Commercial water use in the Bakken had the largest growth, while oil and gas stayed relatively uniform despite huge increases in oil development during this time frame. Water use for oil and gas purposes saw a decrease in the Bakken region, but an increase in the non-Bakken region. Municipal water use in the Bakken saw a small increase over time, while the non-Bakken showed a slight decrease in water use. These results were surprising, but it appears due to infrastructure not keeping up with water needs, and switching to regional water suppliers, permits are not wholly reflective of actual water use. Results from this study will aid water managers in planning for long term municipal and industrial use in areas that experience quick and drastic growth.

Introduction

Water use within the Bakken region has experienced extreme change since the oil boom of the 21st century rocked the area (Maupin et al. 2014; NDIC 2020a). This area saw growth in not only water use but also population increases and commercial expansion. Ellingson (2018) notes that the boom brought approximately 84,000 people to the sparsely populous rural area and created an estimated 70,000 jobs between 2010 and 2015 (USCB 2020; Munasib and Rickman 2015; Ellingson 2018). This generated a large scale change in the socioeconomic system of the Bakken region and its fringes (Fernando and Cooley 2016; Junod et al. 2018). With the increase in population and industry came the need for increased water use (Lin et al. 2018), which in turn affected the number of permits granted in the area and increased the amount of water used per permit. The post boom period in oil production, starting around 2015, is when large scale oil production started to curtail (NDIC 2020a). While production spiked to its highest point in 2018, this has been followed by a sharp and constant decrease ever since. The drop in production was due to significant decreases in the price of oil, as oil in the Bakken is shale oil and expensive to extract (NDIC 2020b).

Past studies of water use in the Bakken have focused on end use categories, water conservation, and the industrial expansion of fracking and its impact (Stewart et al. 2009; Ellingson 2018; Lin et al. 2018; Ellingson et al. 2019). Lin et al. (2018) focused on industrial water use related to fracking and its trends between 2008 and 2014. This information is useful, however, the study focused primarily on industrial water use for fracking, and due to the timing of the study, it failed to encompass the entire pre boom, boom, post boom cycle in the Bakken. More recently, Ellingson (2018) analyzed municipal water use for similarities across different residential and commercial categories across different size municipalities but focused only on municipal water over a small snapshot of time. Additionally, Ellingson et al. (2019) sought to understand municipal categorization of data and conservation measures in Bakken vs. non-Bakken areas, however again the data focused on a short time period. To the authors knowledge, there are no studies to date that have explored both municipal and industrial water use in Bakken, nor have any studies assessed the full boom bust cycle of the 21st century to understand changes in water use over time in an oil region.

A case study was initiated to determine how the oil boom has affected water use in both the Bakken and non-Bakken regions of North Dakota between 2000 and 2018. The objectives of this study were to: 1) assess industrial and municipal water use and how they have changed due to oil development in the pre-boom, boom, and bust cycles between 2000 and 2018; and 2) evaluate potential thresholds of industrial water use vs. normal commerce. Results from this study will aid water managers in planning for long term industrial and municipal use in areas that may experience sudden and drastic development and population growth and/or subsequent decline. This is important because it will let water managers know if there is a relationship between different use categories inside of greater industrial use and if those relationships are region specific.

Materials and Methods

The state of North Dakota, USA was used as the study area for the project to keep permitting regulations the same across the entire study area. Data was obtained from the North Dakota State Water Commissions (NDSWC) online permit database (NDSWC 2020) and the Southwest Water Authority (SWA), the largest rural water district in the state. The NDSWC is the water permitting authority in the state and their database holds yearly water use records of all permitted users of water. The SWA holds water use permits through the NDSWC but provides water to rural consumers including individuals, municipalities, and businesses in the southwest part of the state. SWA allocates the water used on their NDSWC permit(s) to sub-permit water users in the water district. In the current study, the SWA sub-permits for industrial, commercial, and municipal users were categorized in the same way as the NDSWC permit to compare differences in use and trends. Data was checked to confirm there were no double entries between the two databases.

While these databases hold more detailed information, researchers focused solely on total water use per year, specifically focused on industrial and municipal water use per permit between 2000 and 2018. The data was further categorized by geographical area, either being affected by oil development 2000-2018, “Bakken”; or not affected by oil development during the same time frame, “non-Bakken” (Figure 3.1). The Bakken area for this study is defined similarly to Ellingson et al. (2019), as the area north of interstate highway 94 to the Canadian border, and west of state highway 83 to the Montana border. This area was selected because it is similar to the area defined by Ellingson et al. (2019) and because it is where population growth occurred due to the oil activities that impacted water use, not just where the oil wells are concentrated.

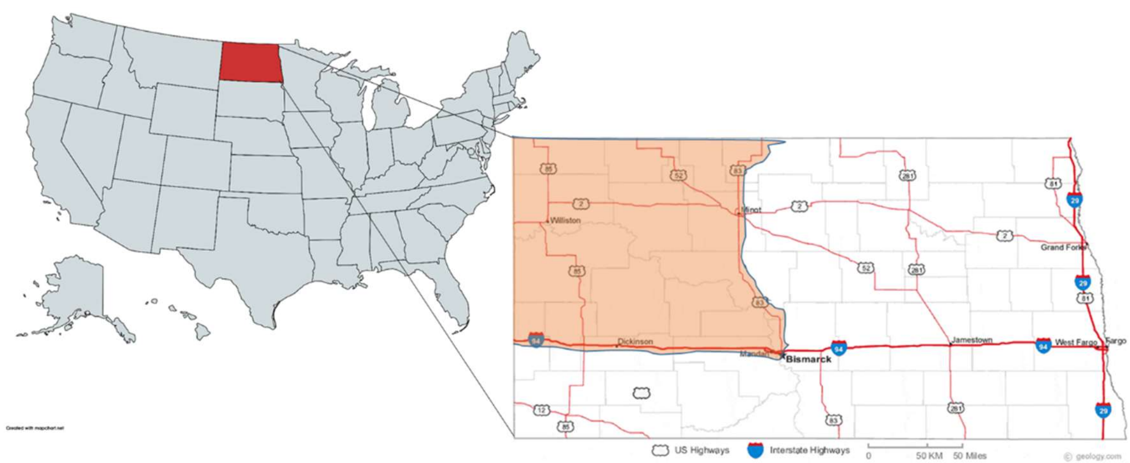

Figure 3.1. Map of the United States with North Dakota in red and projected out to show the Bakken region highlighted in light red.

All municipal and industrial permits held in the state 2000-2018 were assessed for this study, including 59 municipal permits and 206 industrial permits including the 89 accounts from SWA. Municipal permits were included for cities with over 1,000 residents in the non-Bakken region and over 500 residents in the Bakken region to more easily relate the results to past studies. Industrial water use was classified into 9 categories based on the 15 categories used by The Water Research Foundation (2015), to better analyze data across the different industrial permit types. The dominant end use of industrial water was analyzed over four subcategories: landscape irrigation, oil and gas, coal, and power generation. These were the subcategories with the largest use in both the Bakken and non-Bakken areas. Manufacturing was analyzed over two subcategories: heavy manufacturing and other manufacturing because only one source of manufacturing existed inside the Bakken, but the non-Bakken had a large amount of use in both types. Commercial water use was large in both the Bakken and non-Bakken areas, and instead of separating into categories was analyzed as "commercial". There is the possibility that other manufacturing entities water use could be included under municipal permits/water use due to how SWA and NDSWC manage their permits and data systems. While these permits would not be included in the analysis of industrial permits, they are included in the municipal permit analysis.

Data was analyzed using simple linear regression to assess water use categories to determine trends and changes over the 18 year time period. All graphs report water use in acre feet, (1 acre foot is equal to 325,851 gallons of water). All linear regression graphs report a R^2 value that determines the strength of the relationship. The closer to 1.0 the value is, the stronger the relationship represented on the graph is.

Results and Discussion

Results and discussion below are split between the North Dakota State Water Commission (NDSWC) data and the Southwest Water Authority (SWA) data. The split is to highlight comparisons on how the different datasets track water use and their respective water use trends. Comparisons between the two datasets are made for those categories where similarities occur. The following figures are a graphical representation of the data. They are not to be used for prediction purposes.

Industrial

North Dakota State Water Commission Data

Bakken Region

The dominant end use of permitted water over time in the Bakken region was analyzed in four categories: landscape irrigation, oil and gas, coal, and power generation. This was done because these four categories are often lumped together and called dominant end use in other studies. Landscape irrigation in the Bakken had an increasing relationship over time, increasing six fold by 2018 (Figure 3.2). The positive, upward trend between water use and time is similar to what Ellingson (2018) found, as they reported an increase over time for landscape irrigation. The increase in water use for landscape irrigation is most likely attributed to the increase in population in the region leading to irrigation needed for personal landscaping, as well as increased businesses needing landscape irrigation. When the oil boom occurred in North Dakota, the Bakken area saw a spike in population as oil field workers and service personal moved to the area (Horner et al. 2016). This resulted in more homes and overall more people per home living in the area. It is speculated that there were also people already living in the Bakken that financially benefited from the oil boom who were able to upgrade homes and lawn/landscape irrigation systems. Fry (2006) showed that as less urbanized areas increase in affluence, their water use increases also. This is not uncommon, as Portnov and Meir (2008) point out that regions with fast water use growth often tend to be those that have had low water consumption in the past, which would be true of the Bakken region. Molden and Sakthivadival (1999) also demonstrate that as an area's population grows, and urbanization increases, so does the demand for water. Therefore, the increased population and the upgraded irrigation systems in the Bakken likely lead to an increase in water use for landscape irrigation.

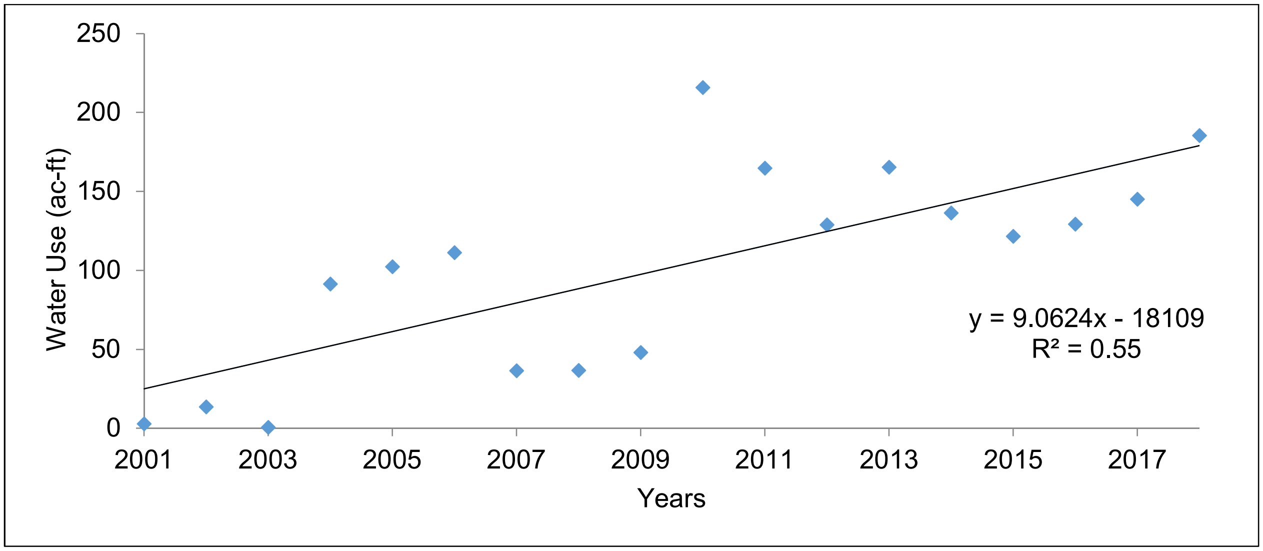

Figure 3.2. Linear regression of the sum of Bakken landscape irrigation water use over time from North Dakota State Water Commission permits. Shown is the trend line, linear equation and R^2 value.

Oil and gas water use based on the NDSWC permits in the Bakken did not increase over time (Figure 3.3). There were fluctuations over time, but no discernable increase. It was anticipated that there would be some increase in water use for oil and gas classified water permits. There could be several explanations for why there was no increase: 1) the existing permits could be at their maximum use so an overall increase was not permissible; 2) there might not have been any new permits issued to oil and gas entities and so no ability to increase water use; and 3) permit holders may have switched their water provider from the NDSWC to a different provider in the state. While the new providers may receive their water from the NDSWC, the specific type of permit that providers use is not clear. The increased demand for water due to increased oil and gas activity in the Bakken could have been met from other permitted sources like water depots as found by Lin et al. (2018). Figure 3.4 shows the relationship between Bakken oil and gas total use per year and the total appropriated water use per year. While use for oil and gas remained steady to a slight increase, appropriated use greatly increased, but the appropriated water was not actually utilized. This could be due to reporting error or false reporting which has been shown to happen in water use in other areas (Wong 1972; Shipton et al. 2009; Averyt et al. 2013). There is also evidence that suggests that some permit holders are obtaining water from other sources, like regional water providers. This was reported in the survey (Chapter 2), as well as points in the database where permits have steady use that suddenly ceases (Figure 3.29 and 3.30). Further investigation found that these permits had switched water providers to regional or other water suppliers in the state, instead of obtaining water on their designated NDSWC permit. If the NDSWC, the appropriating agency for all water use in the state, isn't able to accurately track water use, this greatly affects future planning, as the lack of accurate reporting would skew projections and plans and policy based on these projections.

Figure 3.4 shows an increase in recorded and appropriated water use after 2010. Oil in the Bakken region is held in shale and fracking is needed to extract the oil. The development of horizontal drilling and improvements in fracking methods in recent years have increased oil production, but also increased water used in the process (Norris et al. 2015). Traditional fracking of shales involved vertical drilling, but more recent technologies utilizing horizontal wells are utilizing slick-fracks and super-fracks to produce more oil. Slick-fracks are desirable as they reduce the resistance to flow by chemically changing the viscosity of the water, while super-fracks allows for more flow by causing more distributed damage to the shale using water (Norris et al., 2015). While both methods are becoming more utilized in the Bakken region, they both also require more water per frack and allow more fracks per well than traditional fracking

(Norris et al. 2015; Lin et al. 2018), likely at least partially contributing to the increased water use shown in Figure 3.4.

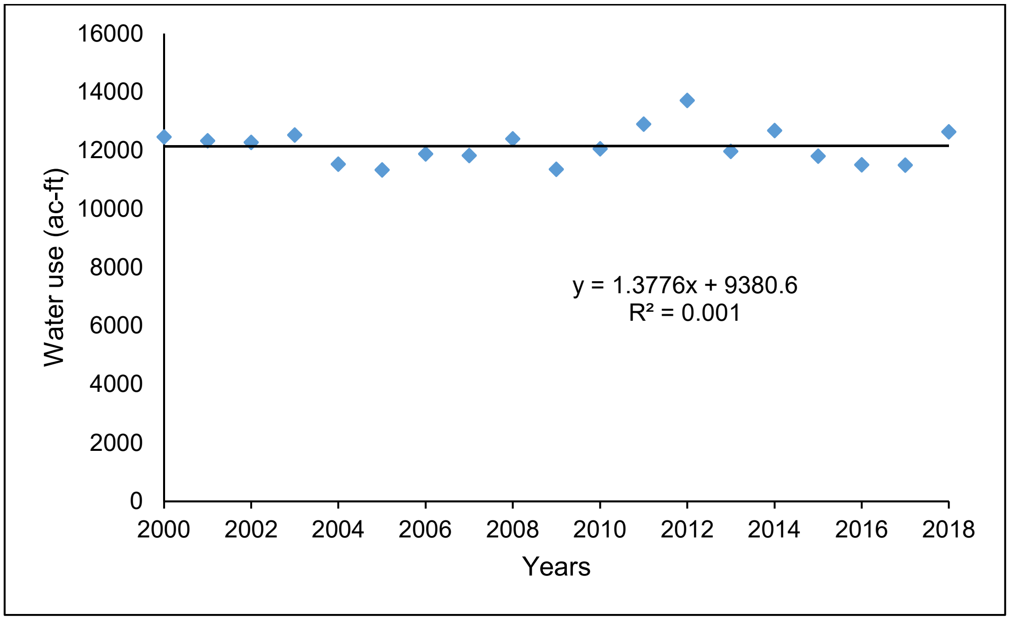

Figure 3.3. Linear regression of the sum of Bakken oil and gas water use over the years from North Dakota State Water Commission permits. Shown is the trend line, linear equation and R^2 value.

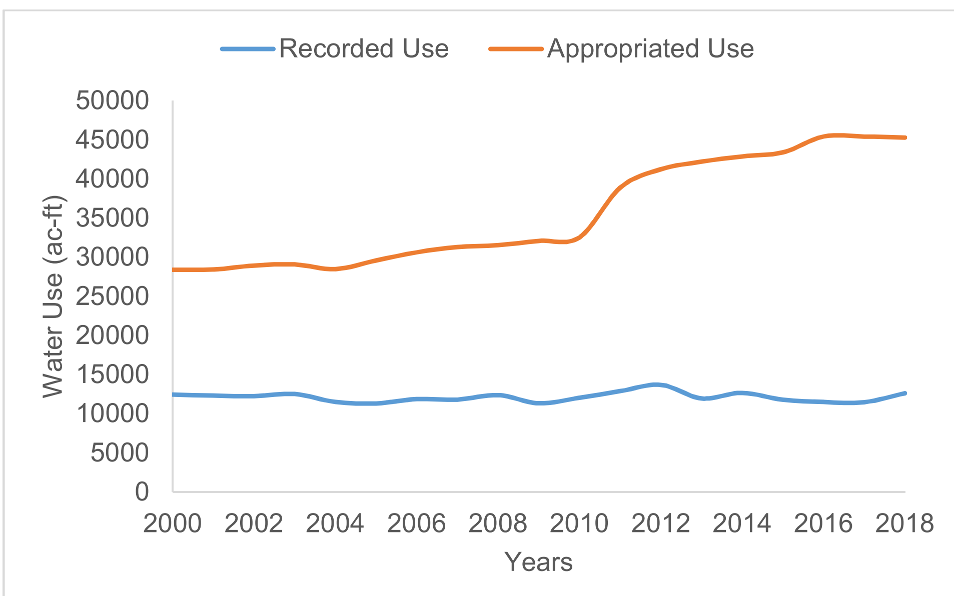

Figure 3.4. Bakken water use for oil and gas appropriated use vs. recorded total water use for all permits.

The coal category of water use had a positive trend over time with a weak correlation between time and coal water use in the Bakken region (Figure 3.5). These results are supported by the results of Maupin et al. (2014), who reported a 39% increase in water use for mining, which did not affect the overall decrease in total overall water use, between 2005 and 2010 in the US. Power generation water use in the Bakken showed a downward trend in water use over time with a weak correlation (Figure 3.6). Similar results were found by Lin et al. (2018) that show water use for power generation purposes decreased, coming close to their original levels in 2000. At this time there is no clear reason as to why this decline is occurring and may be due to the variety of possible causes such as changing power generation practices and water conservation practices.

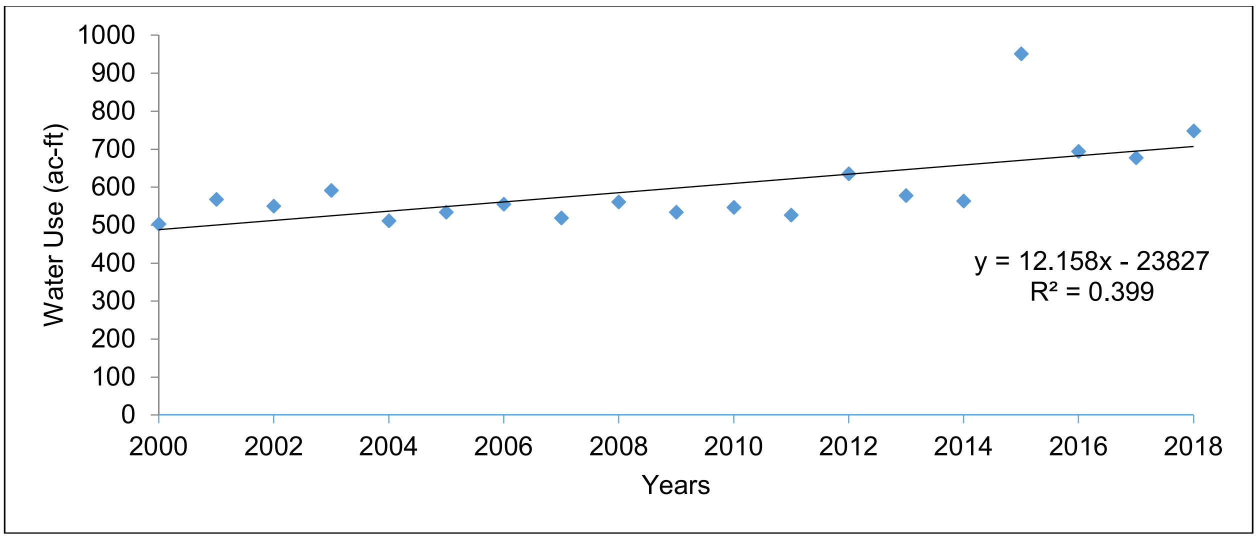

Figure 3.5. Linear regression of the sum of Bakken coal water use over time from North Dakota State Water Commission permits. Shown is the trend line. Linear equation and R^2 value.

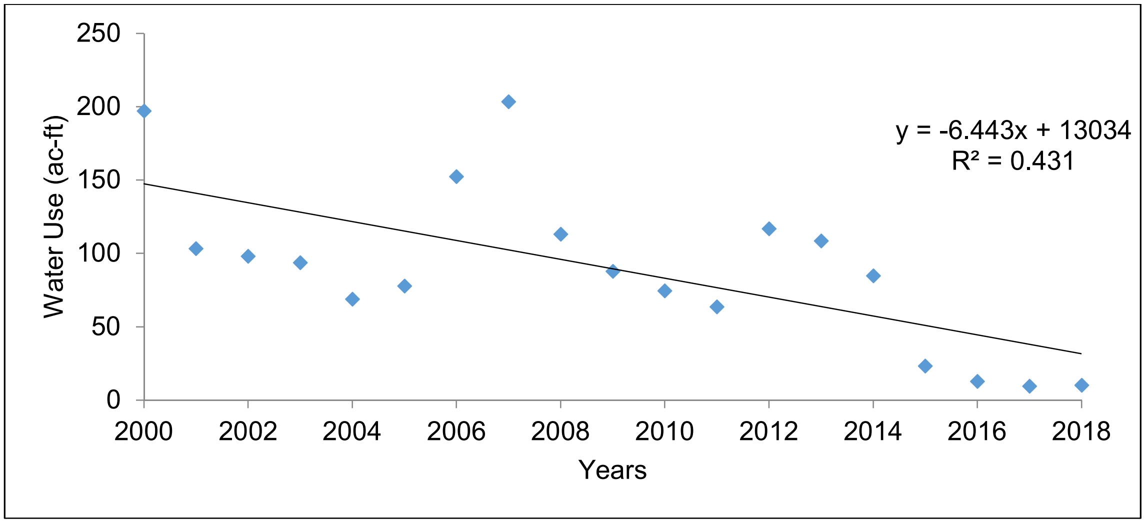

Figure 3.6. Linear regression of the sum of Bakken power generation water use over time. Shown is the trend line, linear equation and R^2 value.

Manufacturing data in the Bakken was analyzed under only one subsection, heavy manufacturing. Heavy manufacturing in this case is defined by those manufactures who engage in large scale production of goods. Other forms of manufacturing used extremely variable amounts of water with many years of "no use" reported, and did not lend themselves well to analysis. Heavy manufacturing showed a slight increasing trend (Figure 3.7). The amount of water used for heavy manufacturing is magnitudes less compared to the other water use categories and is subject to high variability. There is currently only one heavy manufacturer permit holder in the Bakken region, and authors assume that the 2011 spike in use is most likely a reporting error.

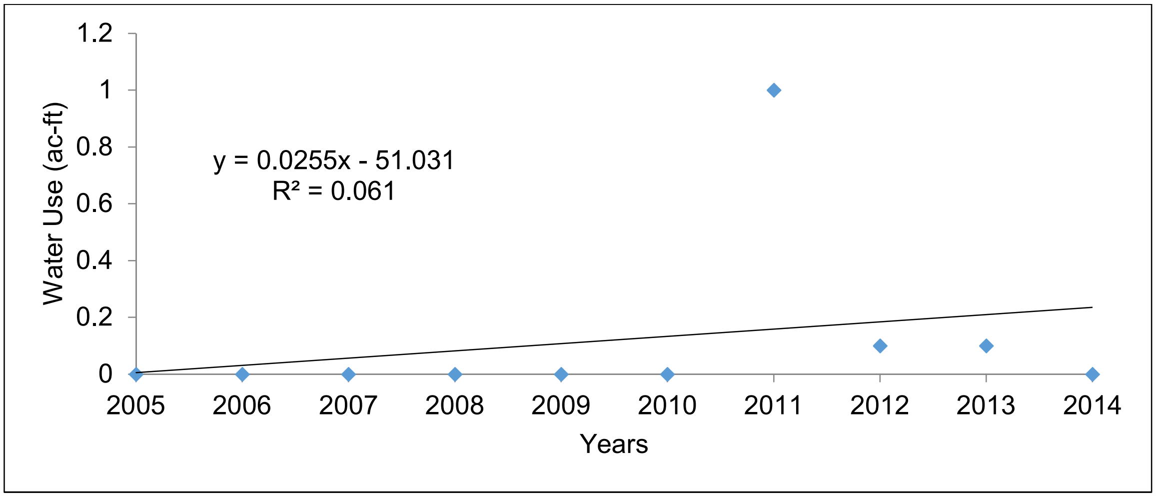

Figure 3.7. Linear regression of the sum of Bakken heavy manufacturing water use over time. Shown is the trend line, linear equation and R^2 value.

Commercial use in the Bakken had a strong upward trend in water use over time (Figure 3.8). This is likely attributed to the growth of not only the population in the Bakken region, but bolstering businesses reacting to the oil activity and increased population. In the Ellingson et al. (2019) study they showed that commercial water use can vary depending on use type. It is assumed, based on the growth in the Bakken region, that at least some commercial businesses that increased production were large water users. A possible explanation as to why commercial water use has not followed the boom-bust trend is that the population demands in the area have increased, as well as the need for commercial users. This unusual rise in use after the bust of the oil industry could be due to a change in reporting, as more permit holders in the Bakken region are obtaining or switch their permits to a commercial use type, or due to changes from traditional hydraulic fracturing methods to those that utilize more water and fewer chemicals. Researchers speculate that the above mentioned increase is due to the switch in water use to commercial water permits (as opposed to oil and gas permits) to supply water demands in the oil fields. Researchers further analyzed the increase in use and found 21.6% (16.5% of the appropriated water) of total water use was categorized inappropriately. Based on the number of permits, instead of overall water used, there were 92 commercial permits in the category, however 15 (12.6%) of them should have been accounted for in the oil and gas category and were not. To obtain these numbers researchers cross checked the organized NDSWC database with survey responses from permit holders (see Chapter 2). Those that are speculated to be improperly categorized had no survey information to reference, but based on their location and use amounts it appears that their water use would have correctly belonged in the oil and gas category. Another 55 commercial permits (59.7% of the total 92 permits) could also be improperly categorized, but with the inability to contact these permit holders to accurately confirm categorization, this discrepancy remains unconfirmed. These 55 permits make up 70.4 % of all water use (41.7% of appropriated water use) in the commercial category for the Bakken region. This is a large amount of the water used in the region, and inaccuracies in categorization do not allow for a representation of the commercial category's use. This means that future plans that use this data could lead to inaccurate projections and planning.

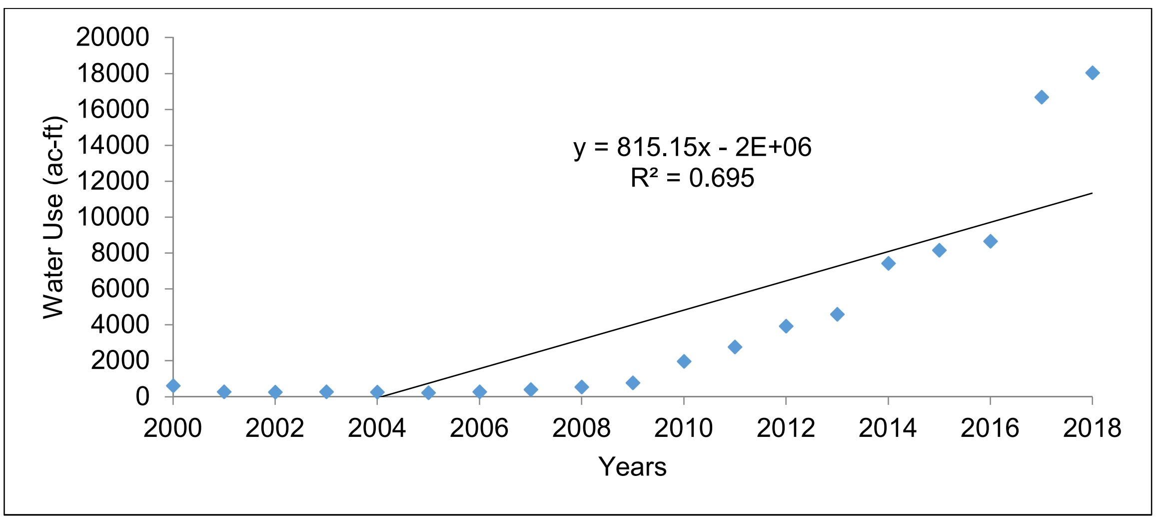

Figure 3.8. Linear regression of the sum of Bakken commercial water use over time. Shown is the trend line, linear equation and R^2 value.

Total dominant end use comprises almost all of the Bakken NDSWC permitted water use from 2000 to 2012 (Figure 3.9). After 2012, the increase in Bakken NDSWC permitted water use almost exclusively is due to increases in commercial use. This increased commercial water use is in response to increasing population, but as speculated previously, some of this commercial water use is likely supplying water to the oil and gas industry.

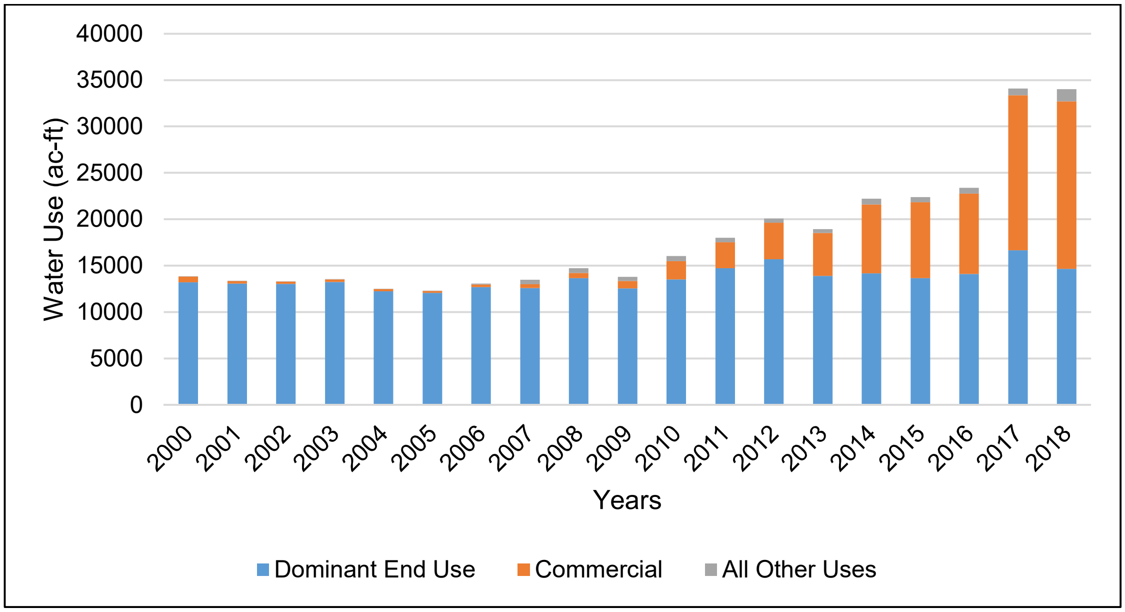

Figure 3.9. Comparison of Bakken dominant end use (includes landscape irrigation, coal, power generation, and oil and gas) to commercial and all other uses (eating places, lodging, manufacturing, and office building) over the years for North Dakota State Water Commission permits.

Non-Bakken

Dominant end water use in the non-Bakken area of North Dakota was analyzed over three sub-categories: landscape irrigation, oil and gas, and coal. Power generation was not included due to lack of permits in this category. Landscape irrigation showed a decreasing relationship over time (Figure 3.10). Many places outside of the Bakken saw a decrease in their population over the same time frame (2000-2018), though a few larger cities saw increases (USCB 2020). While the lack of small population increases can explain a portion of the decrease in water use in the region, it cannot explain it all. Likely a portion of the decrease in water use can be attributed to weather patterns, age of population, city size, and services available (Ellingson et al. 2019), but the data to determine the actual contribution of these specific variables is unavailable for this study. These factors all lead to the system becoming more efficient and less water being used. Other factors, such as wetter years where landscaping does not require additional water, may have also contribute to the decline in water use.

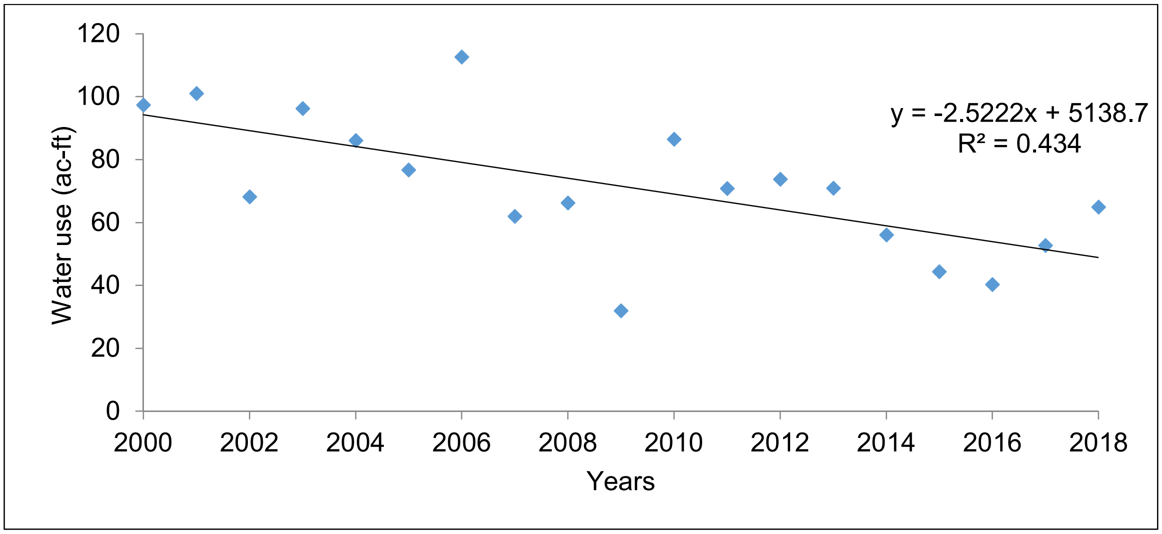

Figure 3.10. Linear regression of the sum of non-Bakken landscape irrigation water use over-time for North Dakota State Water Commission permits. Shown is the trend line, linear equation and R^2 value.

Oil and gas water use in NDSWC non-Bakken permits started at fairly low levels in. 2000 and increased 18 fold by 2018 (Figure 3.11). The non-Bakken region does contain both oil wells and facilities like pipelines and refineries. However, the wells and facilities outside of the defined Bakken region are not directly associated with the Bakken oil formation. Authors speculate the large increase is due to permits not using their maximum permitted water, and therefore they were easily able to increase water use without a new permit or further allotment. There may also have been new permits in the non-Bakken region allowing for increased water use. It appears that some of the water use needed in the Bakken region was transferred to the non-Bakken where more permitted water was available. At this point, no one explanation fully explains the situation, and more investigation is required to come up with well supported reasons for the increase in oil and gas outside the Bakken.

Figure 3.12 shows recorded total water use in the non-Bakken region for the oil and gas category in the NDSWC database, as well as appropriated water use. Recorded water use started increasing in 2002, while appropriated water use increased drastically in 2005. The NDSWC during this time had a policy that raised the limit of appropriated water use and allowed for selling of water beyond permitted categories, such as if commercial water had excess water it could be sold to the oil and gas industry. When oil use spiked again in 2013, the appropriated limit was raised again. Researchers believe that many of the commercial use permits were actually selling water to oil and gas, however due to the policy allowing permits to sell their excess allotted water for other purposes it is recorded as commercial water use and not oil and gas. More data would be needed before this claim could be verified, and since additional information wasn't recorded the data isn't available to verify.

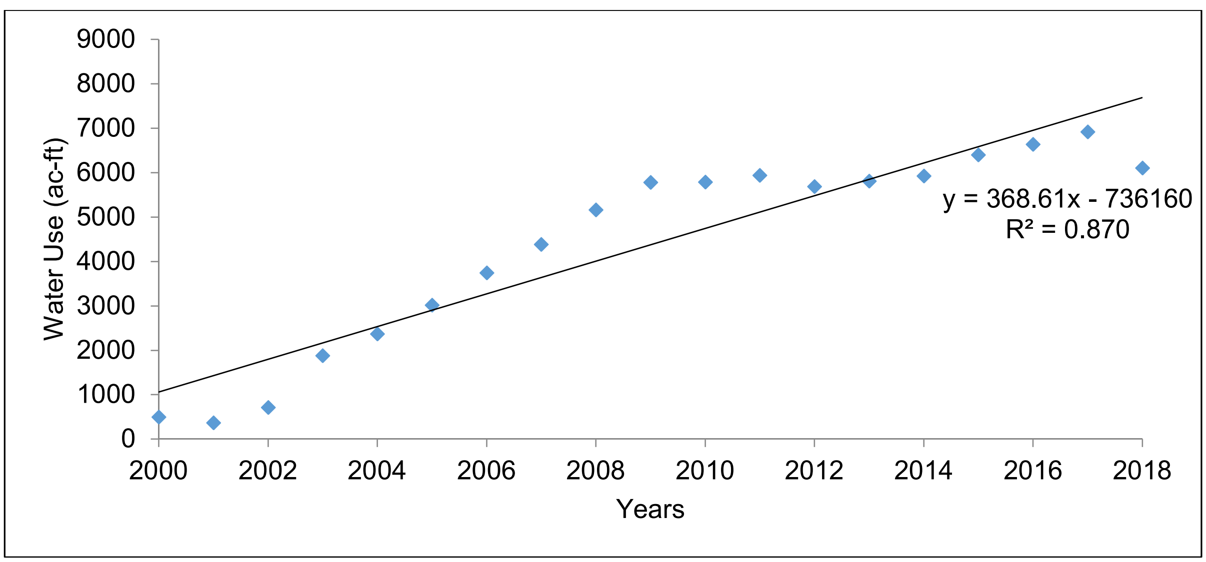

Figure 3.11. Linear regression of the sum of Non-Bakken oil and gas water use over time. Shown is the trend line, linear equation and R^2 value.

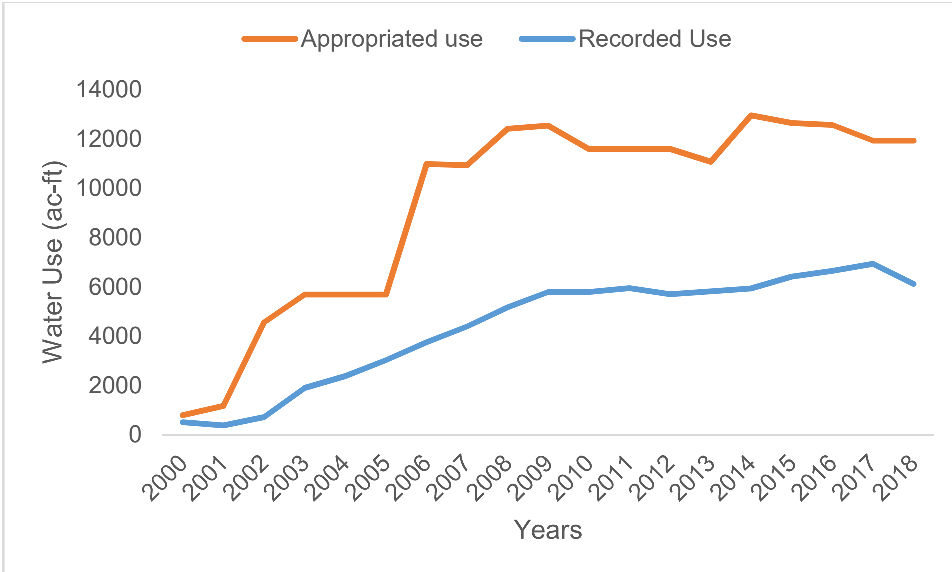

Figure 3.12. Comparison of the sum of non-Bakken oil and gas appropriated use vs. recorded total water use for all permits.

Water use for coal has been nonexistent in the non-Bakken region of the state for quite some time. This is due to the fact that most of the coal reserves, mines, and plants remain in the Bakken region. Therefore, there are no permits for coal related water use in non-Bakken areas.

Heavy manufacturing showed a negative trend line for water use (Figure 3.13). Water use of this type peaked at 3992.6 acre feet in 2005 and decreased to 328.8 in 2018. This decrease could be due to the innovation of new and more efficient manufacturing water use systems (Vickers 2001). However, many users may have either closed or failed to report their water use for some time. There may be instances where permit holders fail to report water use because it was noticed in the NDSWC permit database that some users go years between reporting their water use amounts.

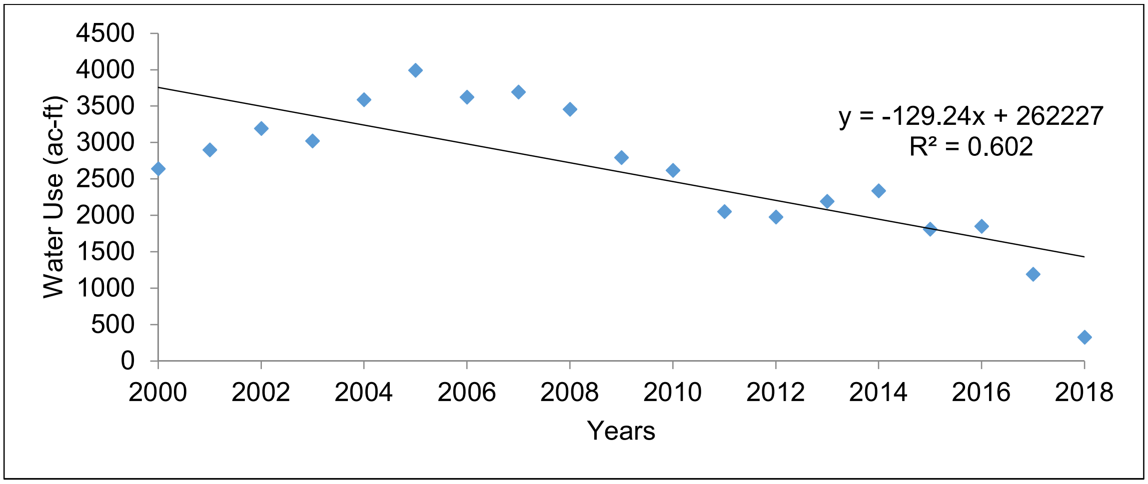

Figure 3.13. Linear regression of the sum of Non-Bakken heavy manufacturing water use over time. Shown is the trend line, linear equation and R^2 value.

Other manufacturing in the non-Bakken showed a slight upward trend in water use, but overall has changed very little over the last 18 years (Figure 3.14). The steady water use could be due to the number of food processors who have permits, with much of their product being exported out of state where there is a steady demand (NDDoC 2020).

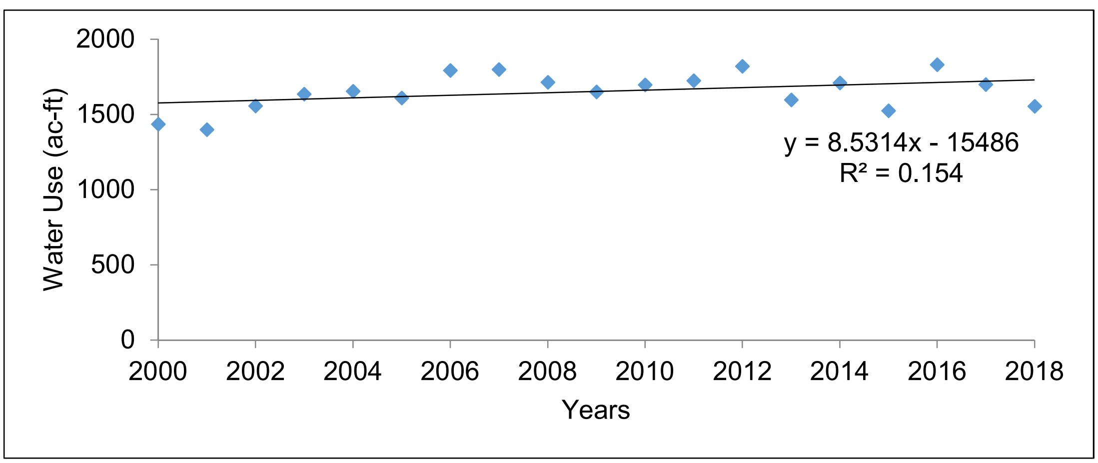

Figure 3.14. Linear regression of the sum of non-Bakken other manufacturing water use over time. Shown is the trend line, linear equation, and R^2 value.

Commercial water use in the non-Bakken area experienced a rise in the early 2000s, but has since decreased (Figure 3.15). There were many reporting errors in this category, with some permit holders going years without reporting any use. Such errors could account for some of the declines in water use, but it is also possible that some of the decline was due to commercial users implementing new policies and procedures to decrease water use (Vickers 2001). Comparing data from the survey (Chapter 2) to NDSWC permitted data, the percentage due to error could be as high as 51% (n=15 permits) of use. This would mean that up to 31.9% of the appropriated water for this for Bakken commercial use belongs in the category of oil and gas use. There were a total of 27 permits categorized as commercial use, and 10 of the permits (37%) may be wrongfully categorized as non-Bakken commercial use. Further understanding these systems requires additional data beyond what is available in the NDSWC permit database. Information from rural water systems and individual industries would be needed, and that information is not easily available. Without knowing more about the permit holders and if their water use was being provided to oil and gas for extraction procedures, researchers can only speculate.

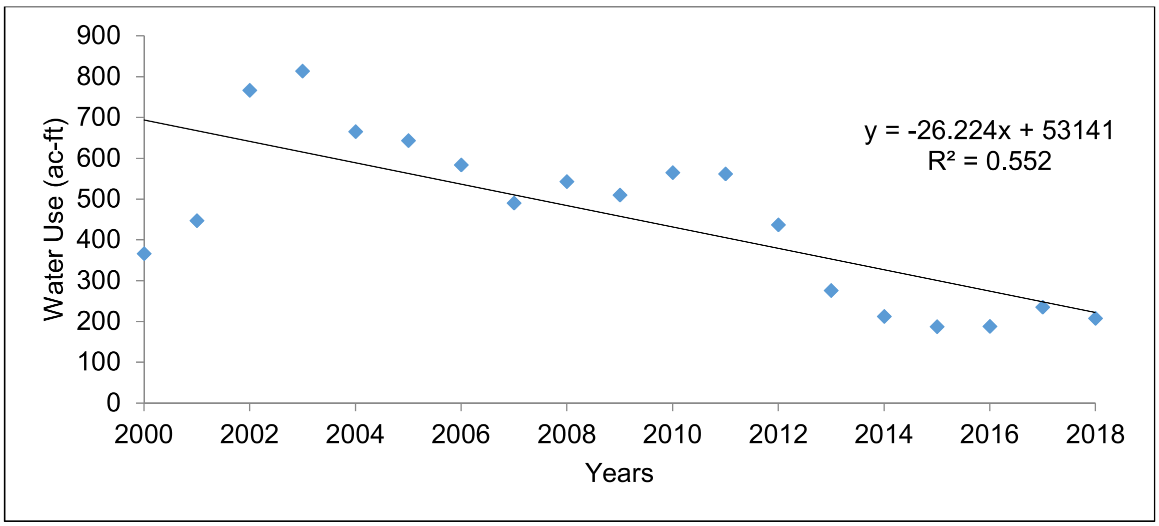

Figure 3.15. Linear regression of the sum of non-Bakken commercial water use over time. Shown is the trend line, linear equation, and R^2 value.

Total dominant end water use shows a continuous rise in water use as a share of all non-Bakken permitted water use 2000 to 2018 (Figure 3.16). This rise is due to the increasing water use in the oil and gas category over the years. Conversely, all other categories show a slow decline in water use. Much of this decline is due to the decreasing water use in manufacturing, which makes up the major portion of all other uses. Commercial water use appears to decline over the years, but if the categorization of the permits had been more accurate, water use in this category would have increased due to water being sold to the oil and gas industry.

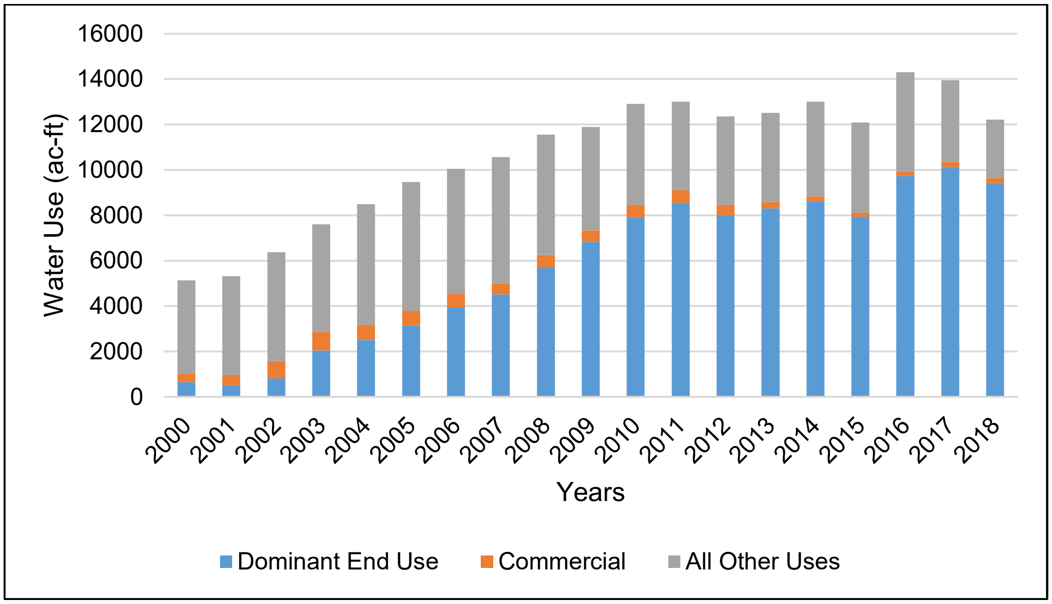

Figure 3.16. Comparison of non-Bakken dominant end use (includes landscape irrigation, coal, power generation, and oil and gas) to commercial and all other uses (lodging, manufacturing, and office building) over the years for North Dakota State Water Commission permits.

Comparing Bakken and Non-Bakken

Comparing Bakken and non-Bakken landscape irrigation water use, the non-Bakken has shown a reduction in use, while the Bakken has had an increase (Figure 3.17). The increasing Bakken water use is most likely a response to population increasing and more demand for landscape irrigation. The non-Bakken data shows that without the rapid growth in population and development, there would likely be a slow decline in water use.

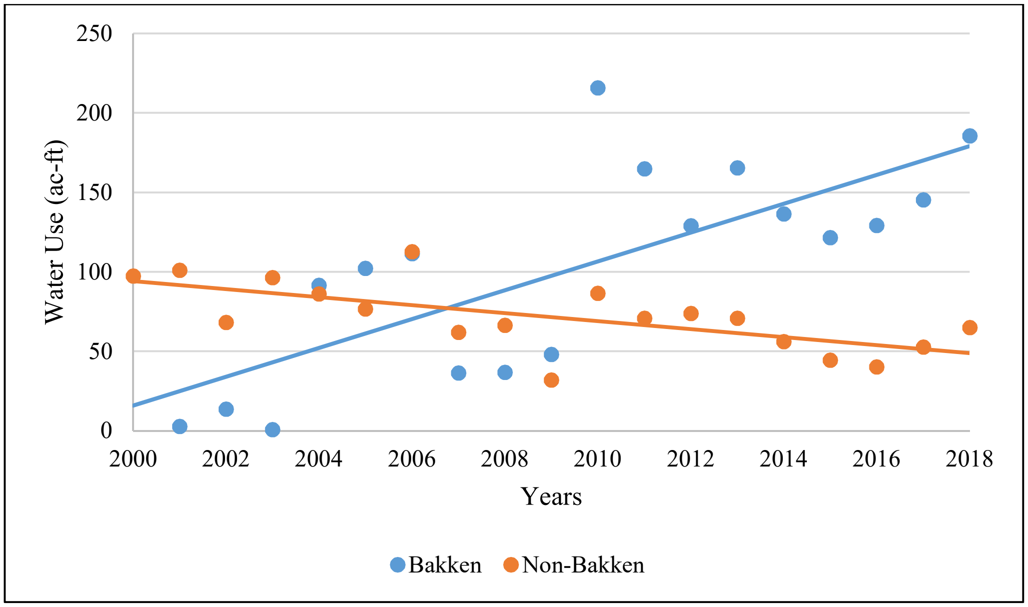

Figure 3.17. Amount of North Dakota State Water Commission permit water used landscape irrigation category in the Bakken and non-Bakken regions. Linear trend lines are shown.

Water use in the oil and gas category surprisingly shows that the Bakken stayed steady in water use, while the non-Bakken steadily increased (Figure 3.18). This increase went from very little, to almost half of what is used in the Bakken. A likely explanation for the increase is a combination of spill-over effects of the oil and gas activity from the Bakken into the non-Bakken region, as well as potential increases in oil activity that is not associated with the Bakken formation. The lack of increase in the Bakken region is not entirely understood as outlined earlier in the paper.

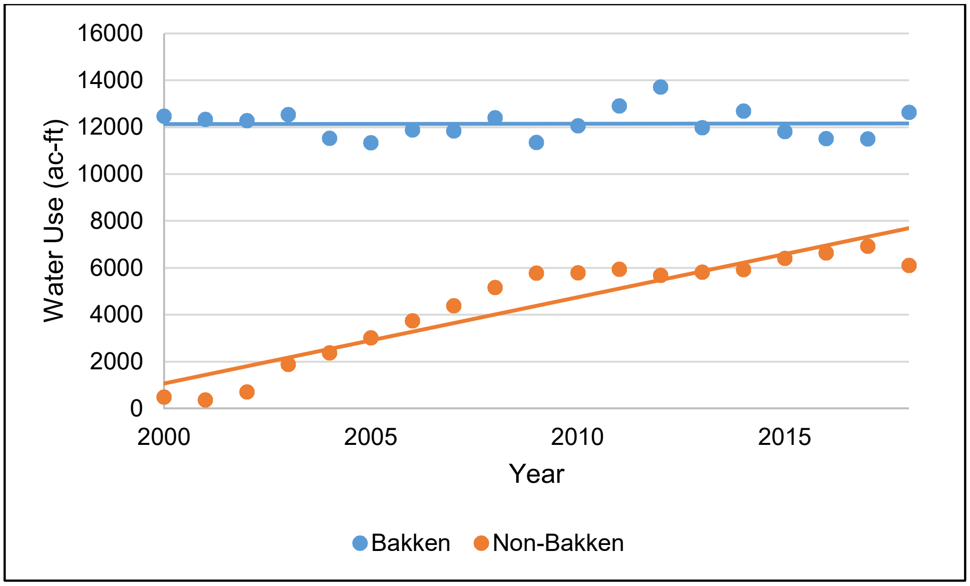

Figure 3.18. Amount of North Dakota State Water Commission permit water used in the oil and gas category in the Bakken and non-Bakken regions. Linear trend lines are shown.

Water use in the Bakken commercial category grew considerably in comparison to the non-Bakken (Figure 3.19). This increase is likely due to a combination of response to the increasing population and the possibility of water being sold to the oil and gas industry. The Bakken increase grew from similar water use levels as the non-Bakken, which did not change during the years shown, demonstrating that the increase in commercial use is unique to the Bakken.

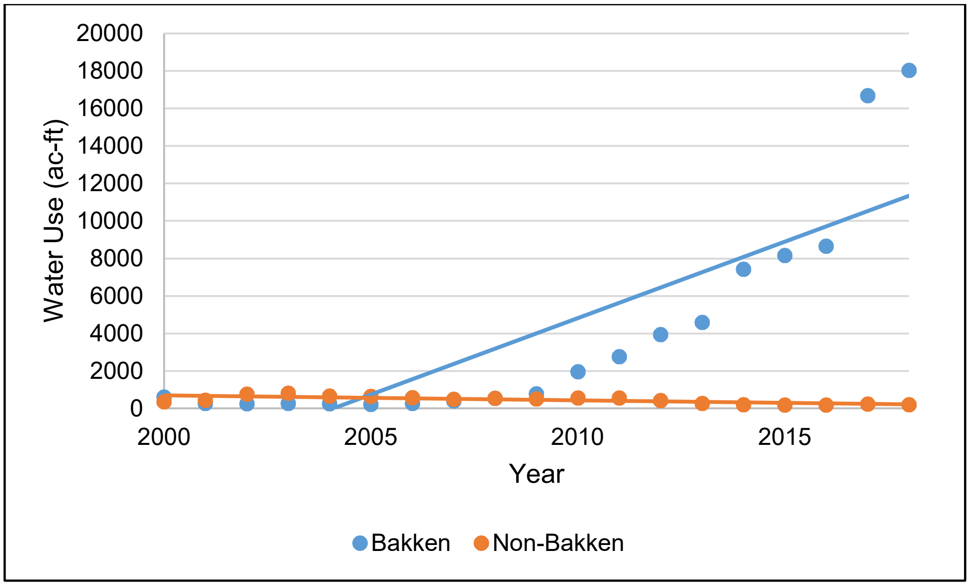

Figure 3.19. Amount of North Dakota State Water Commission permit water used in the commercial category in the Bakken and non-Bakken regions. Linear trend lines are shown.

There is no comparison for the categories of power generation, coal, and manufacturing. Comparisons were not done for the following reasons: 1) lack of use in one of the regions; 2) high use variability making comparisons difficult to interpret; and 3) inconsistent reporting of permitted water use making interpretations suspect.

The following points can be concluded from the analysis of NDSWC water use permits in the Bakken and non-Bakken regions.

- There was a large increase in commercial water use in the Bakken beyond what is seen in the non-Bakken region. It is speculated this increased use is due to population growth and commercial water use likely being used for oil and gas activity.
- There are some oil wells outside of the Bakken region, which likely led to the increase in water use in the non-Bakken oil and gas category, though there could be spill over effects from the Bakken region. This increase also accounts for much of the increase in water use in the dominant end use within the non-Bakken region, as other uses are steady or decreasing.

Southwest Water Authority Data

Bakken

Dominant end use for SWA data was not aggregated into subcategories for analysis because there was insufficient information on the end point user to make a determination for subcategories. Dominant end use in the Bakken increased from almost zero water use to an 800 times increase by 2019 (Figure 3.20). This increase is likely due to SWA putting in more infrastructure over time, becoming more effective at supplying water to different areas and entities since its start in 1991, as well as increased population and oil and gas activity in the Bakken. Data from the USCB (2020) reported large changes in population over this 19 year time period, and the increases in dominant end use appear to coincide with this growth.

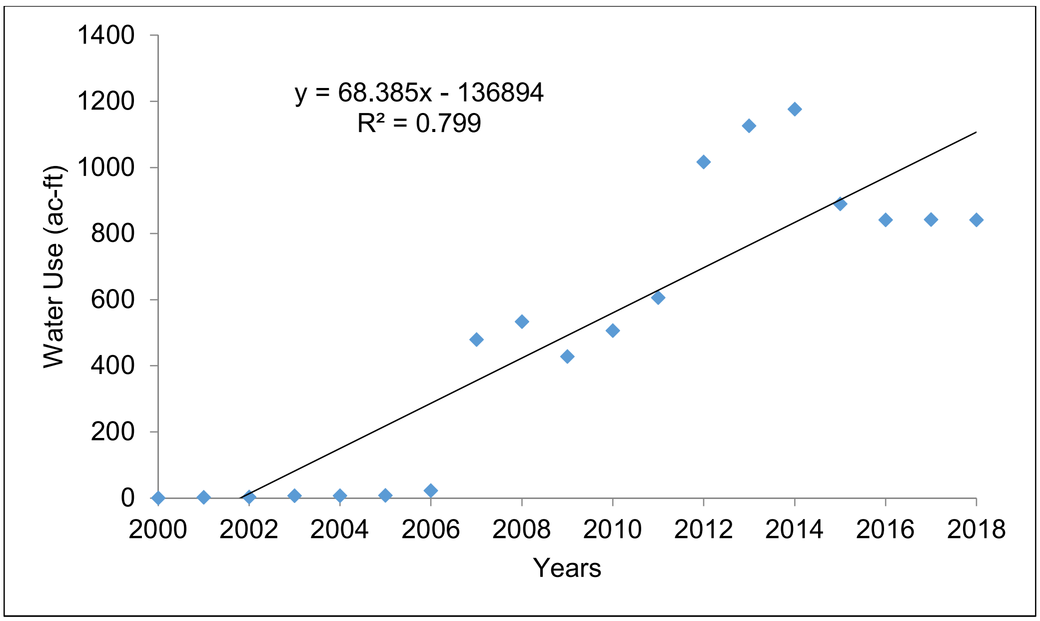

Figure 3.20. Linear regression of the sum of Bakken dominant end use over time. Shown is trend line, linear equation, and R^2 value.

Commercial water use from SWA data shows a steady increase over the years, though water use levels greatly fluctuated over the 18 year period (Figure 3.21). The tenfold drop in recent years (2017 and 2018) is not fully explained, as the region saw an increase in population

(USCB 2020). It is speculated that if commercial water is being used for oil and gas, one reason for the large changes could be that oil production was still high, however there were not new wells being drilled. It is the drilling portion of the oil process that uses fracking and therefore the large amounts of water. The change can also be a result of commercial users changing their permit type and source, switching between using water from SWA and NDSWC. There may also be other reasons for the large viability, but this needs to be furthered investigated.

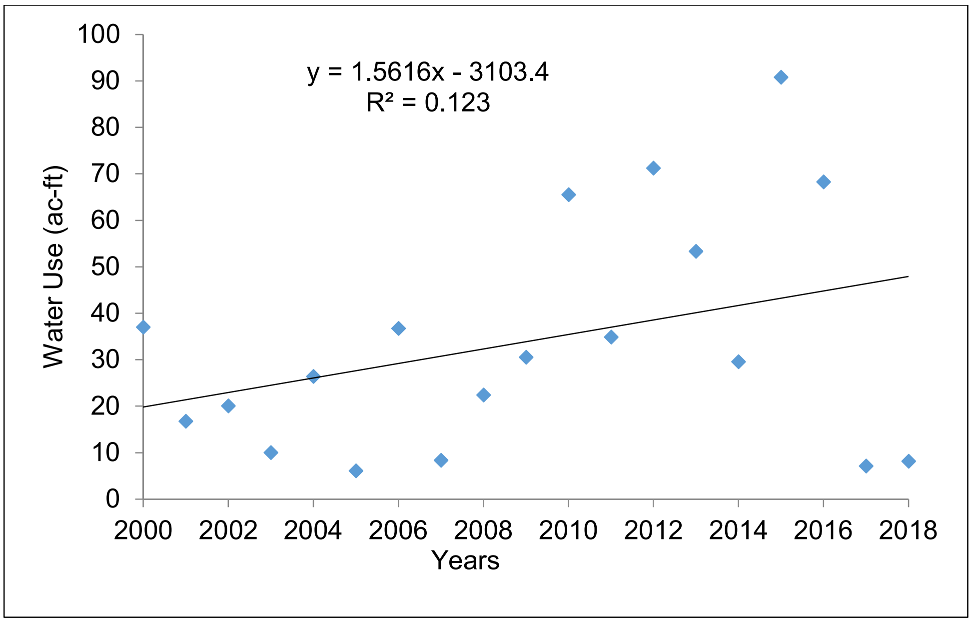

Figure 3.21. Linear regression of the sum of Bakken commercial use over time. Shown is the trend line, linear equation, and R^2 value.

Manufacturing for SWA water use in the Bakken had a strong correlation to time (Figure 3.22). Water use dropped during the boom and resumed its high use once the bust occurred. This is unique, but not surprising since other manufacturing categories in this study saw a rise and fall depending on their region. It would only take one or two end users changing their use to result in these fluctuations, since the amount of water use is small compared to other categories.

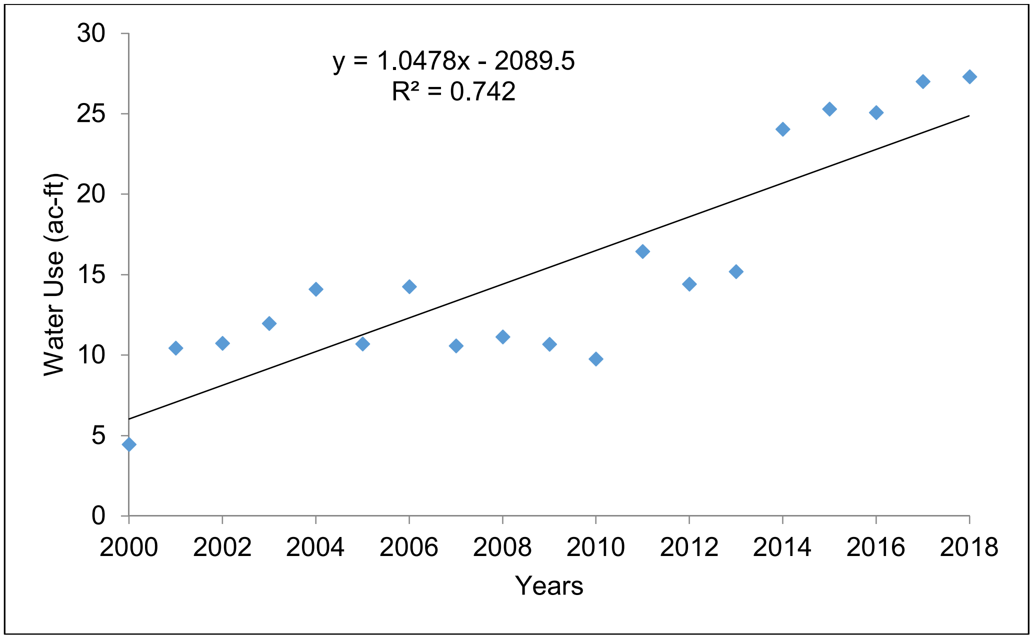

Figure 3.22. Linear regression of the sum of Bakken manufacturing use over time. Shown is the trend line, linear equation, and R^2 value.

Examining total industrial water use for the Bakken SWA data shows there was a large increase in water use over time, and this is mostly due to the increases in the dominant end water use (Figure 3.23). It is unknown if this large increase will continue into the future or be susceptible to changes in the area. The water provided by SWA is dependable and may avoid some of the water quality issues found in local groundwater (wells) and surface water sources (SWA pipes water from the Missouri River). These issues were the original reason for the creation of SWA and why SWA water is in high demand in the area.

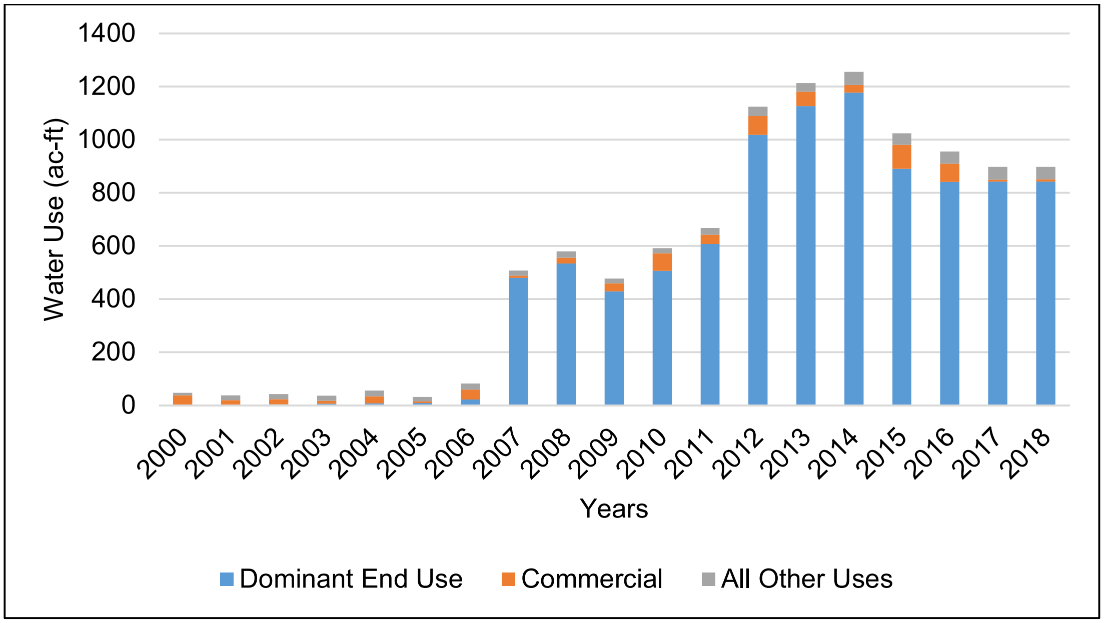

Figure 3.23. Comparison of Bakken dominant end use water use to commercial and all other uses (health care, lodging, manufacturing, religious building, schools, and office building) over the years for Southwest Water Authority data.

Non-Bakken

Dominant end use in the non-Bakken shows an increasing trend over time (Figure 3.24). This increase could be due to SWA providing more infrastructure and becoming more effective at supplying water. There may also be some effect from the non-Bakken being close to the Bakken, and its increased population and oil and gas activity spilling into the non-Bakken region. The categories of commercial and manufacturing water use for non-Bakken are not reported because of the low and highly variable in use and at times the water use is non-existent. All industrial non-Bakken water use shows variable levels (Figure 3.25). This variability again may be due to low levels of use and the chance of one end point user changing their use is greatly affecting the overall total water use. Comparisons between Bakken and non-Bakken in SWA data were not done because the non-Bakken water use are magnitudes less than the Bakken and are highly variable. For this reason comparisons were judged to not be useful at this time.

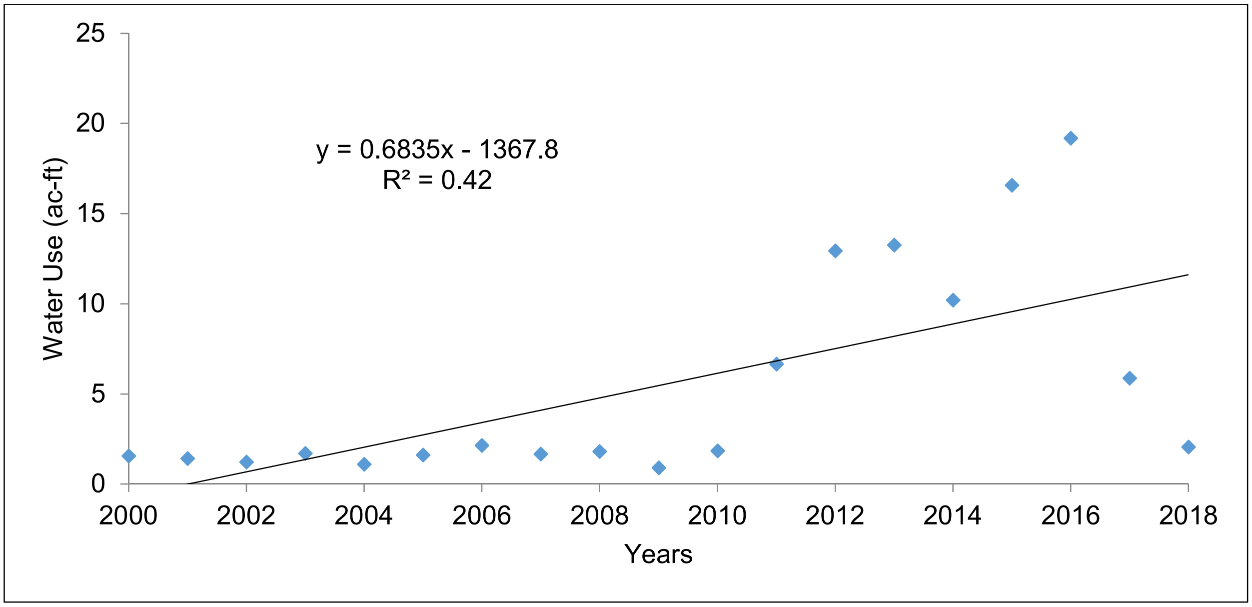

Figure 3.24. Linear regression of the sum of non-Bakken dominant end use over time. Shown is trend line, linear equation, and R^2 value.

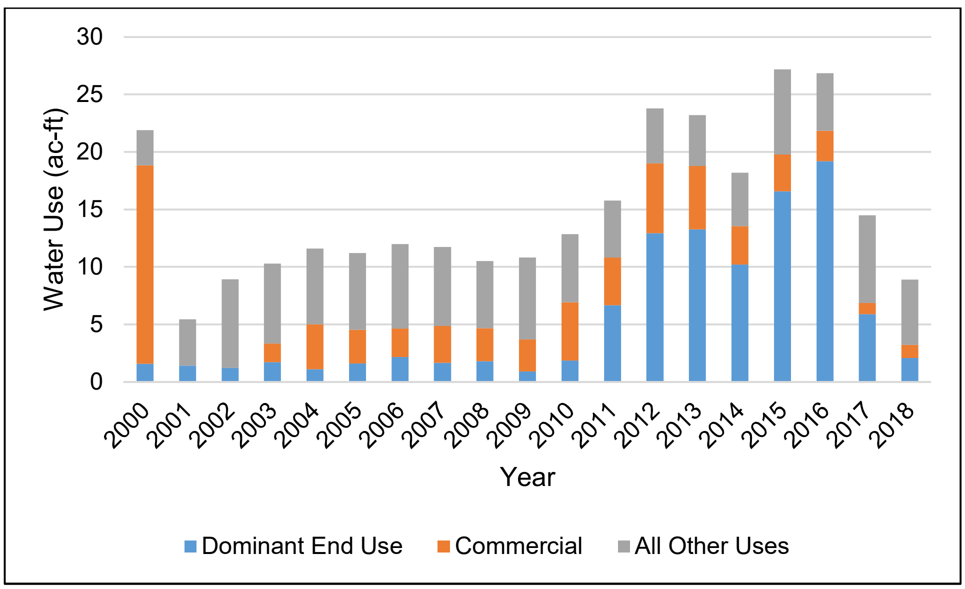

Figure 3.25. Comparison of non-Bakken dominant end use water use to commercial and all other uses (manufacturing and schools) over the years for Southwest Water Authority data.

Comparison of Bakken North Dakota State Water Commission and Southwest Water Authority Data

Due to the differences in how categories are designated within NDSWC and SWA datasets, only total dominant end use and commercial water use were compared. The SWA water use in the Bakken region is magnitudes less than the NDSWC permitted water use for dominant end use and commercial categories (Figure 3.26 and 3.27). There is a steady increase in NDSWC commercial water use. While SWA is increasing in the amount of commercial and dominant end use water use, it is less than NDSWC. Authors speculate that SWA will continue to increase the amount of water provided to the Bakken region for dominant end uses. The magnitude of difference will continue between the NDSWC and SWA, however as SWA will continue its focus on water for residential and municipal users and commercial users do not always require the same quality of water.

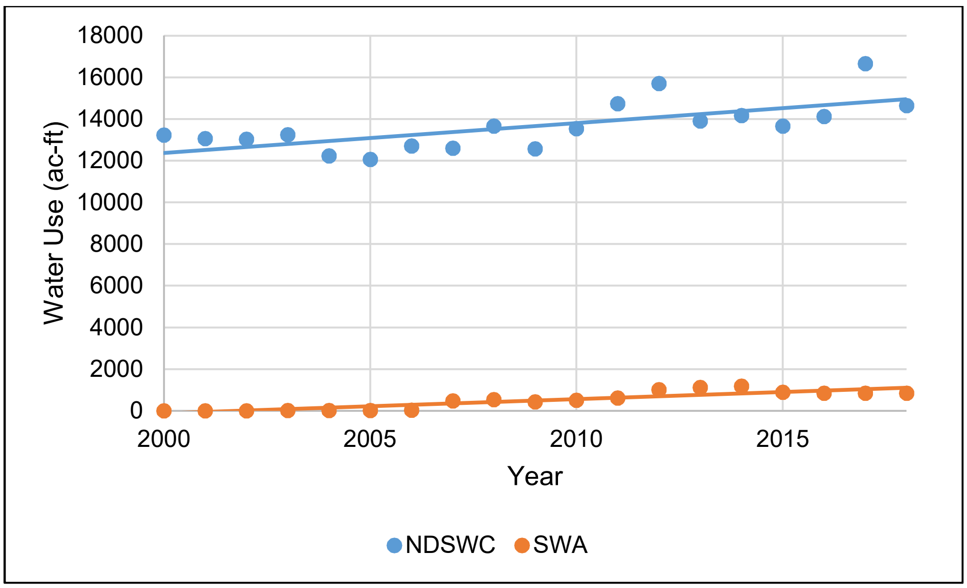

Figure 3.26. Comparison of the amount of North Dakota State Water Commission and Southwest Water Authority, Bakken water use for the dominant end use category over the years. Linear trend lines are shown.

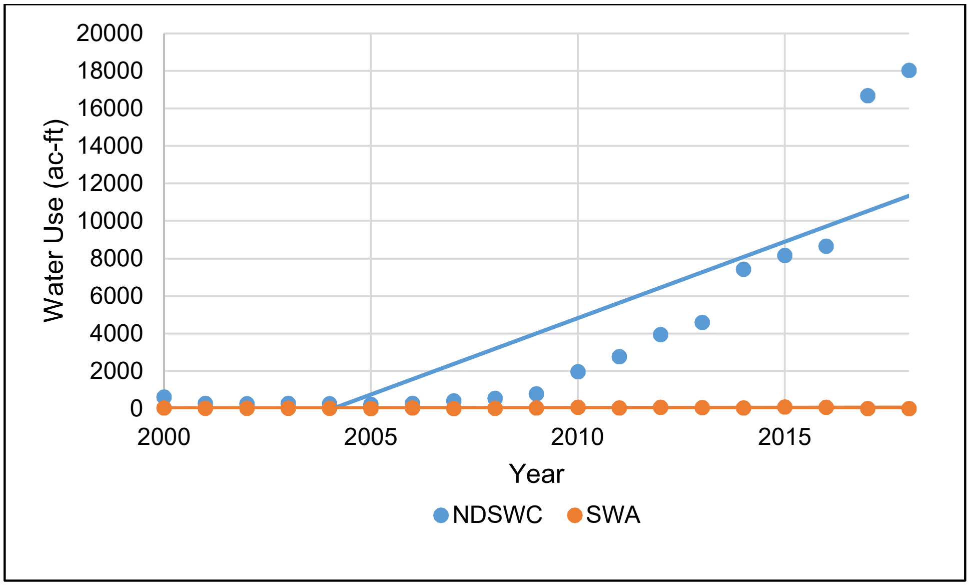

Figure 3.27. Comparison of the amount of North Dakota State Water Commission and Southwest Water Authority, Bakken water use for the commercial use category over the years. Linear trend lines are shown.

Municipal

North Dakota State Water Commission

Bakken

Total water use for the 22 municipal permits in the Bakken region does fluctuates with a slight increase over time, though the correlation is weak and gives little support to the increasing trend (Figure 3.28). Population estimates from the USCB (2020) show a rising population in the Bakken region starting in 2005. During that same time, oil activity in the region was increasing (NDICb 2020). Surprisingly, the increasing population and oil activity is not reflected in municipal water use, which showed little response to these trends. This lack of response is not easily explainable. It is speculated that municipal areas were getting water from other sources beyond NDSWC permits to fill their increasing municipal water use needs. This is supported by information shared with authors from the R&T Water Supply Association, which supplies water to municipal districts, as some of their water supply comes from groundwater permits classified as industrial water use. In addition, some of the R&T water supply now comes from the Williston Region Water Treatment plant. Such commingling of water sources makes tracking water use via municipal NDSWC permits problematic. Another possible explanation is how water use is reported, in that permit holders may be reporting maximum use of a permit, when in reality they were early on only using part of the permitted water. Later, on the permit holders could have started to increase their actual use to fill needs from increasing population and oil development activity, but this would not change the overall use reported to the state. This explanation would require more investigation to judge the extent that this may or may not be happening. Another explanation could be that the infrastructure of cities was unable to keep up with demand so water was trucked in or taken from water depots that don't utilize water from a municipal permit.

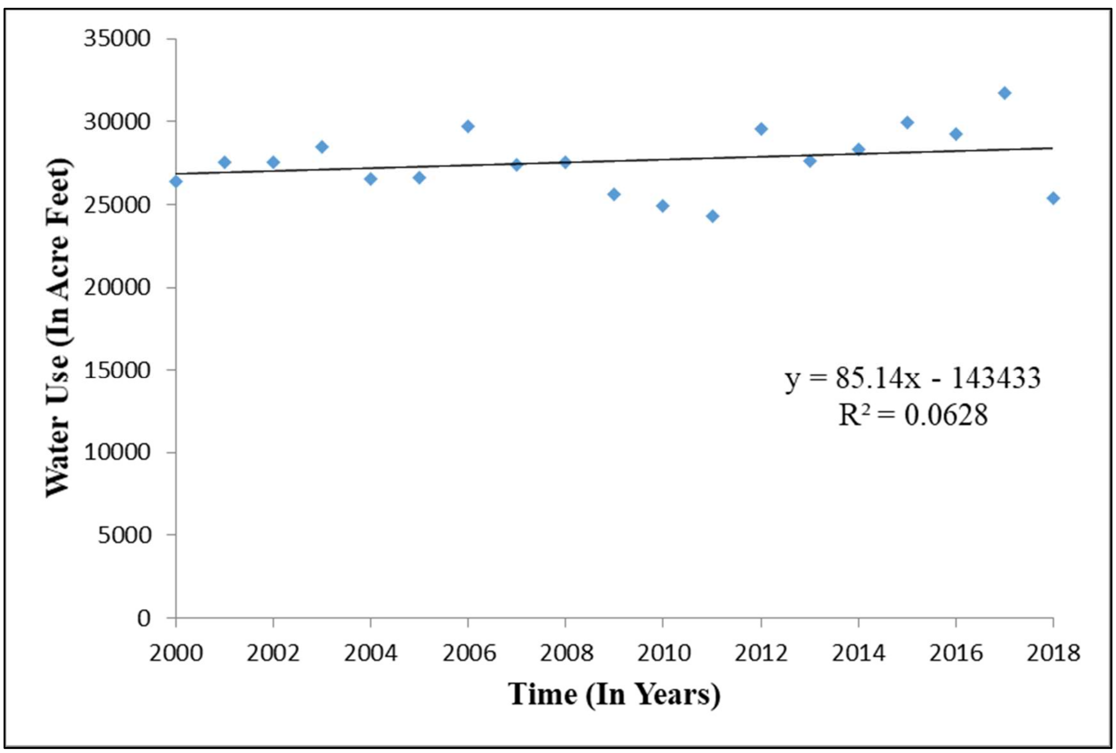

Figure 3.28. Municipal water use provided by North Dakota State Water Commission permits in the Bakken region over time. Shown is trend line, linear equation and R^2 value.

Strange results and problems interpreting these results led to researchers investigating certain cities to reveal more about water use. As Ellingson (2018) states, cities in the Bakken region should have had an increase in water use as their population increased. The following figures show the individual use of three of the largest cities in the Bakken region utilizing NDSWC data: Watford City (Figure 3.29), Williston (Figure 3.30) and Minot (Figure 3.31). Water use in Minot shows a slight increasing trend, but with fluctuating water use. Watford City's water use contrasts with Minot. Watford City had quickly increased water use, but then in 2013 abruptly stopped using their water use permit with the NDSWC. The city switched to a new water provider, the Western Area Water Supply Project. This provider gets water from the Williston Regional Water Treatment Plant, along with water from the R&T Water Supply Association. As stated earlier, the R&T Water Supply Association has permits that are classified as industrial, while the Williston Regional Water Treatment Project has industrial water permits from the NDSWC. This means that water use later on in Watford City may be accounted for in the Williston NDSWC permits, but because of comingling, it is not a perfect accounting of water use. Williston shows a big increase in municipal water use, though the increased water use lags at the start of the boom in 2004 (Figure 3.30). Williston then drops to zero in water use in 2018, which is puzzling and deserves more investigation as to why there is no water use. Williston most closely, even with one year of zero use, follows the pattern described by Ellingson (2018) with increasing water use with population increases.

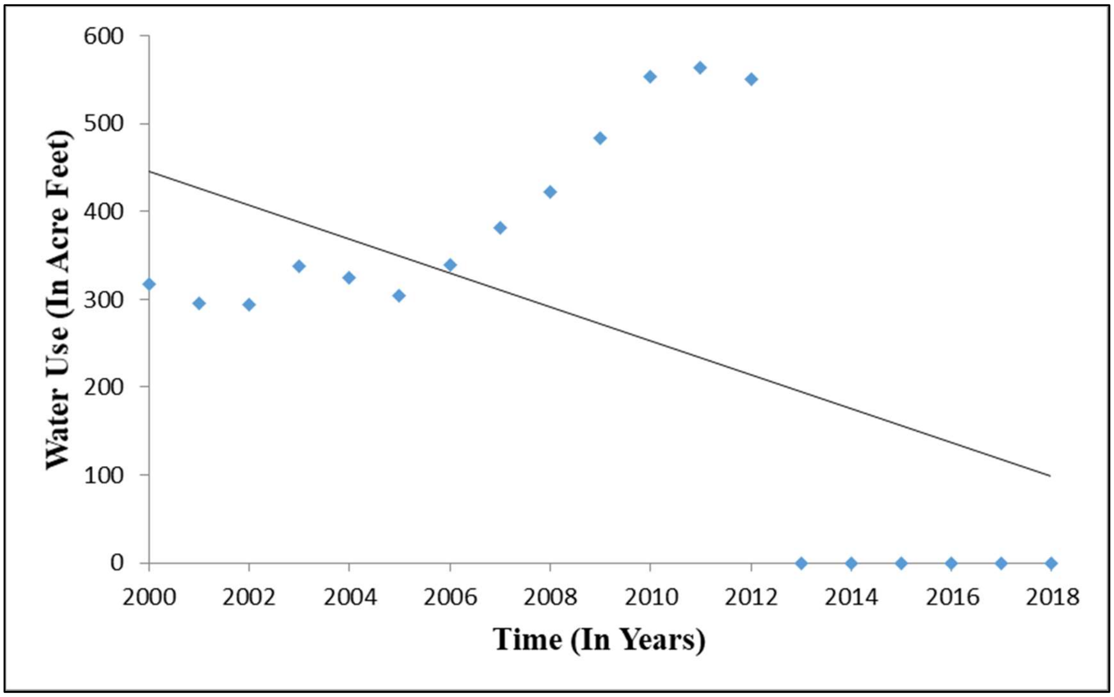

Figure 3.29. Watford City's municipal water use over time from North Dakota State Water Commission permit information. Shown is trend line.

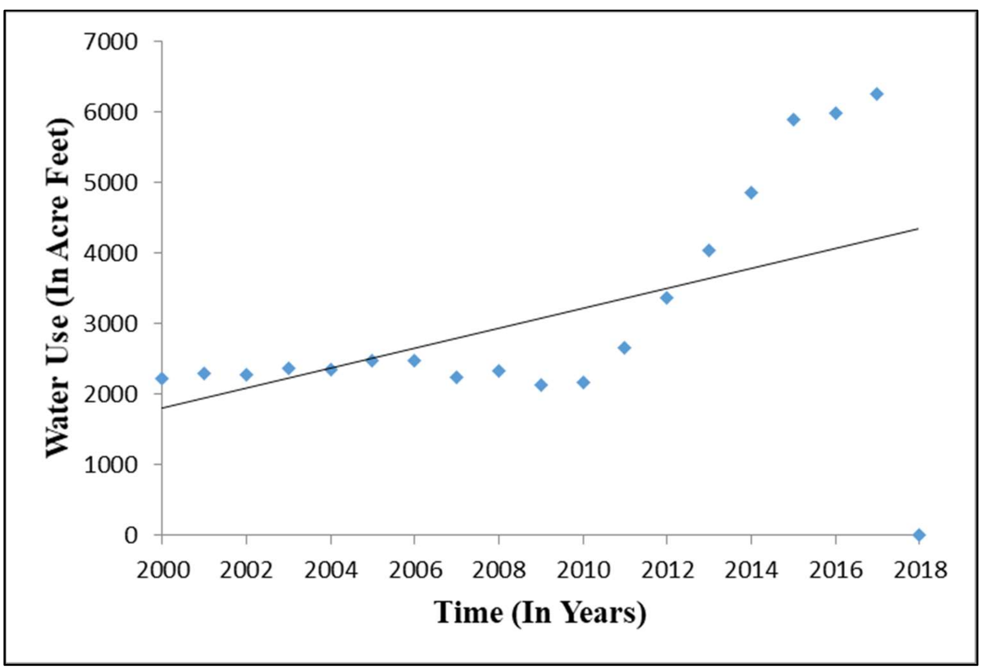

Figure 3.30. Williston's municipal water use over time from North Dakota State Water Commission permit information. Shown is trend line.

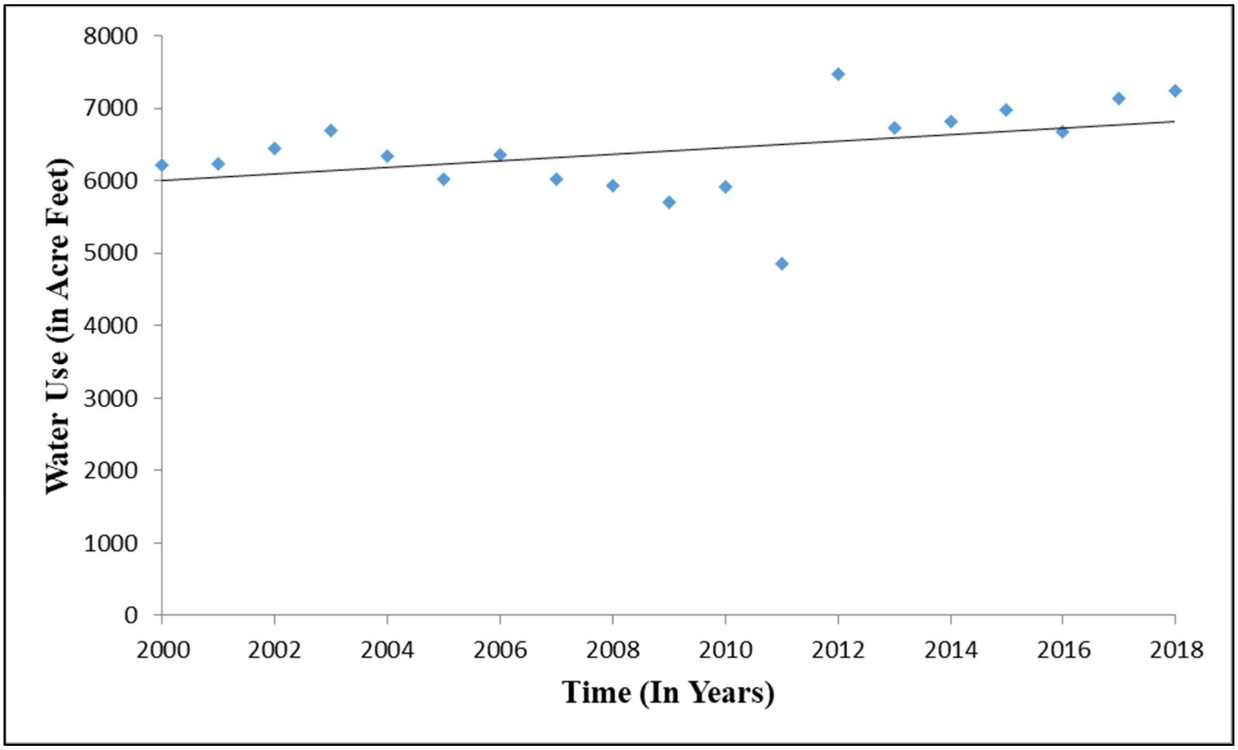

Figure 3.31. Minot's municipal water use over time from North Dakota State Water Commission permit information. Shown is trend line.

Comparing total municipal water use from NDSWC permits, where the large cities are separated out, finds that only Williston shows increases in water use with time, while the other large cites show steady use (Figure 3.32). In the all other cities category (Bakken), there are in water use early on, but decreasing water use later. Many of the cities, in the all other cities category, had municipal permits early on, but they, like Watford City, switched to regional water providers like the Western Area Water Supply Project later. This likely accounts for some of the decreases in water use for the all other cities category. Switching to regional water suppliers further supports the observation that tracking Bakken municipal water use using just NDSWC permits may not accurately reflect the amount of municipal water being used, and may skew projections of water use.

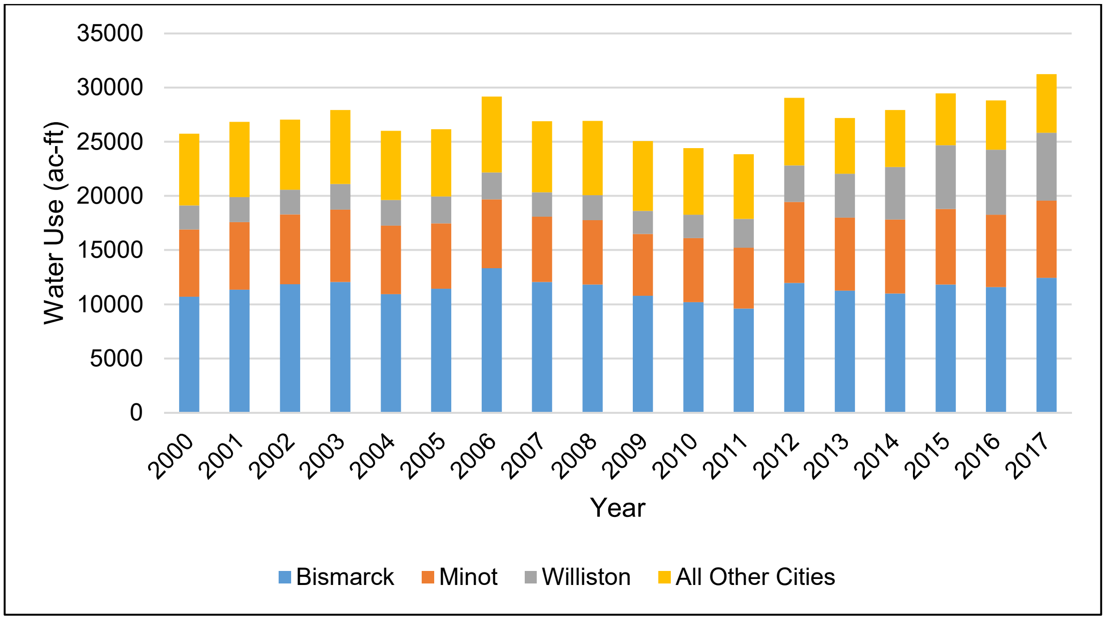

Figure 3.32. Total municipal water use 2000-2017, with Bismarck, Minot, and Williston, and all other cities in the Bakken separated. The year 2018 excluded as Williston did not report any North Dakota State Water Commission permit use.

Non-Bakken

Water use for the 34 non-Bakken municipal permits saw steady use, with a large drop in 2018 (Figure 3.33). This large drop in use around 2018 is surprising. The water use drop could be a reporting error, where information is not updated in a timely fashion. The drop could also be explained by switching to regional providers similar to the Bakken. The prevalence of cities switching from municipal permits to regional providers in the non-Bakken region should be further investigated.

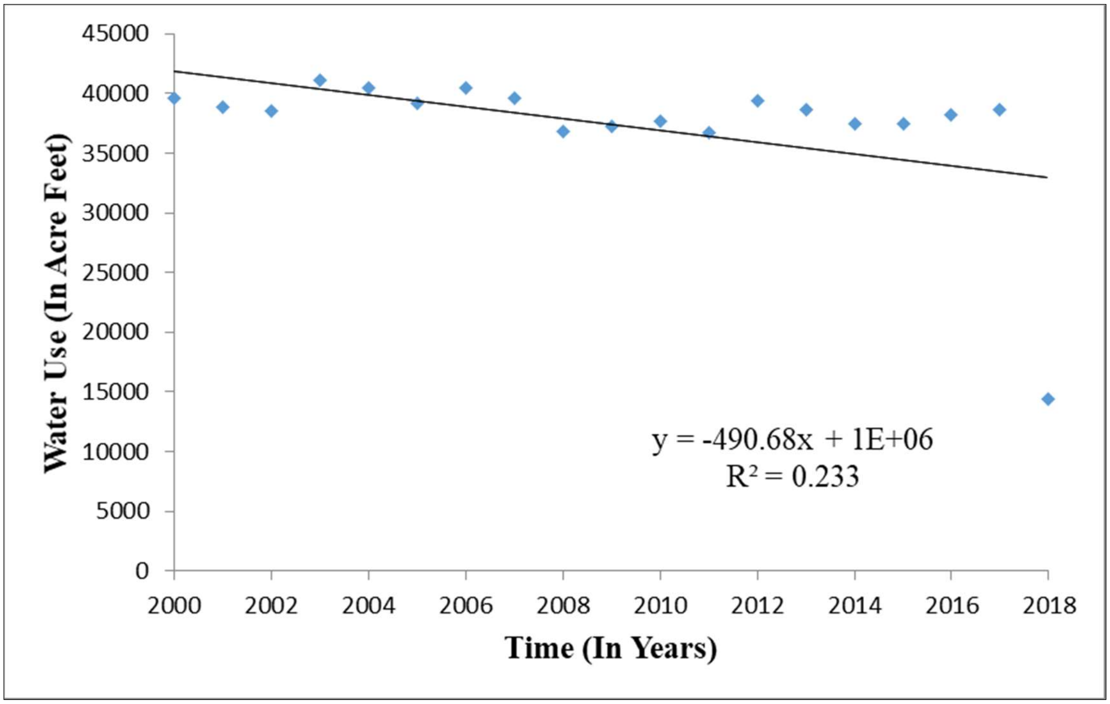

Figure 3.33. Municipal water use provided by North Dakota State Water Commission permits in the non-Bakken region over time. Shown is trend line, linear equation and R^2 value.

Comparison of North Dakota State Water Commission Bakken and non-Bakken Municipal Water Use

Comparing NDSWC permitted municipal water use between the Bakken and non-Bakken finds that the Bakken has less total use, but a small increase over time; while the non-Bakken has a slight decrease (Figure 3.34) (2018 data were excluded from analysis since there is a question of reliability). The Bakken increase fits the hypothesis that with increasing population and oil activity water use would increase. However, larger increases in municipal water use were expected by researchers. This slight increase does fit the analysis of Lin et al. (2018), who found municipal water increased, but only slightly in the Bakken region. By including cities like Bismarck in the Bakken region, increasing water use from cities like Williston was further diluted because of the large water use in Bismarck. Additionally, focusing solely on NDSWC permit data fails to encompass cities that have switched to regional water suppliers and diminishes increasing trends in water use.

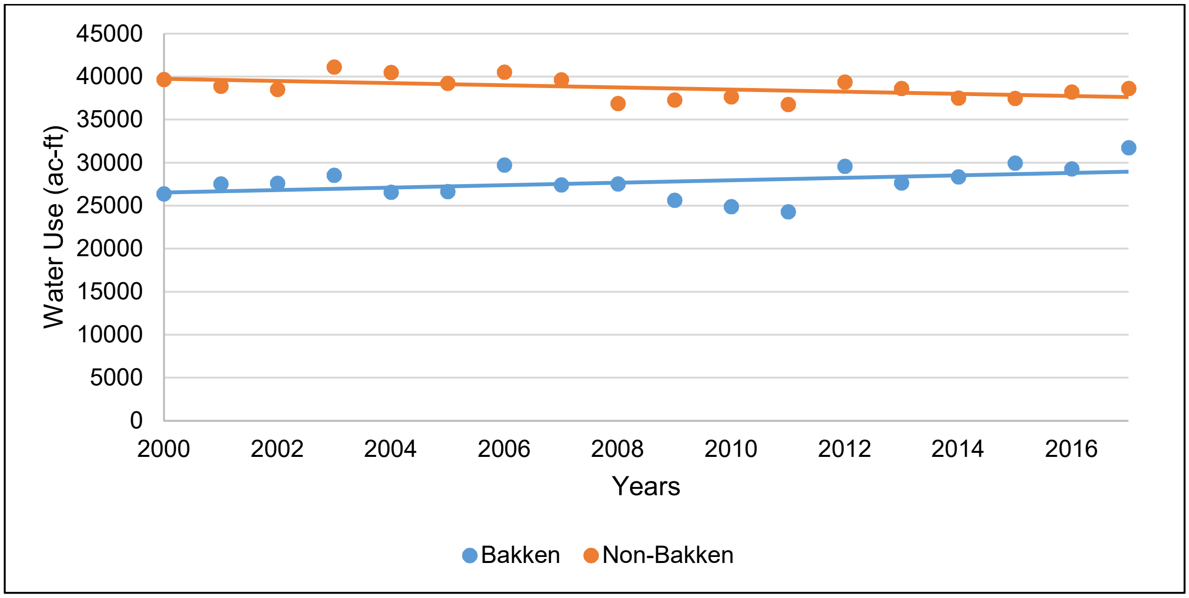

Figure 3.34. Total municipal water use from North Dakota State Water Commission permit data for the Bakken and non-Bakken region. The 2018 data were excluded because of their potential unreliability. Linear trend lines are shown.

Southwest Water Authority

Bakken

Data from SWA showed that cities in the Bakken saw a rise in municipal water use (Figure 3.35). The increase in water use follows the trend of increasing population (USCB 2020) and oil activity in the Bakken (NDIC 2020a). In addition, to the urban area SWA supplies, many small towns and rural users are included in their data which may contribute to the increased water use. In some instances, rural use can account for large increases and may drive the SWA increase in water use. The idea that rural water users can drive use increases has also been shown by Fry (2006) and Portnov and Meir (2008). The increase in water use could also be due to municipalities switching from NDSWC permitted water to SWA supplied water, which both the cities of Dickinson and Richardton have done.

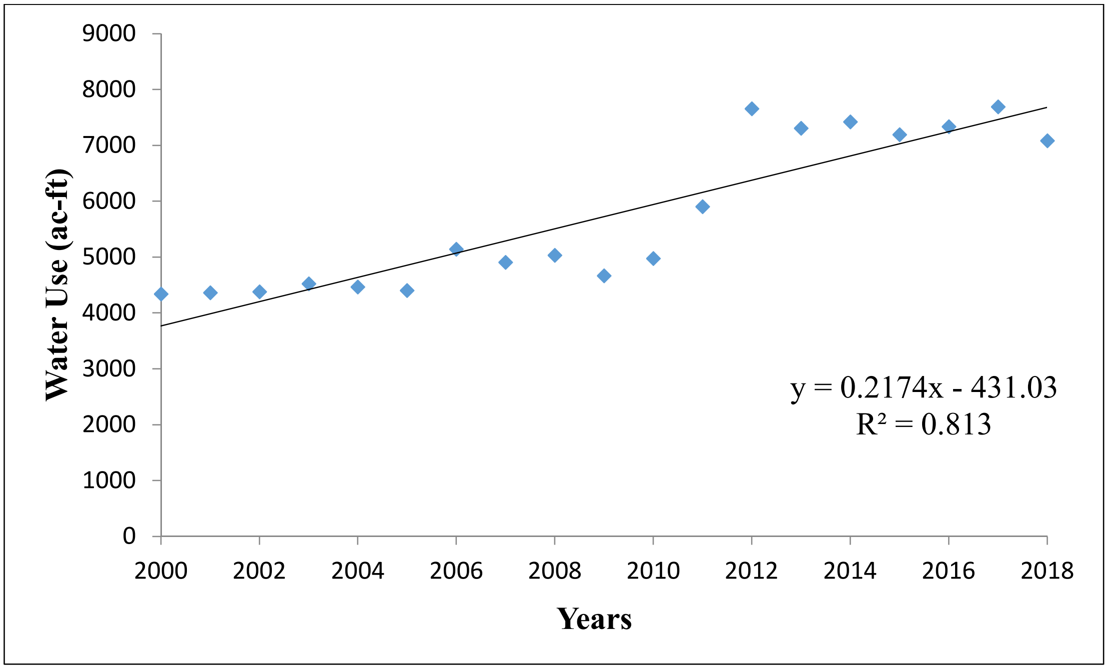

Figure 3.35. Municipal water use provided by Southwest Water Authority in the Bakken region over time. Shown is trend line, linear equation and R^2 value.

Non-Bakken

The SWA provides water to cities in the non-Bakken area for municipal purposes. These cities showed an overall positive trend in use, with water use well above where it started in 2000 (Figure 3.36). Like the Bakken region, non-Bakken municipal users had an increase in use as the boom took root in North Dakota (2005 and 2006). This could be attributed to SWA supplying water to the southwest part of North Dakota, and this area is the most likely to experience spillover effects from the Bakken population and oil activity. Therefore, the increase in SWA water use during this time could be due to oil development, even though it is in the non-Bakken region. In addition, there is oil and gas activity in the non-Bakken area supplied by SWA. This oil production is part of a different geological formation and is not associated with the Bakken, thus it is not included in the Bakken region calculations. Nonetheless, the high oil prices following 2004 affected these areas, and so increased municipal water use could be attributed to the oil boom in the whole of North Dakota.

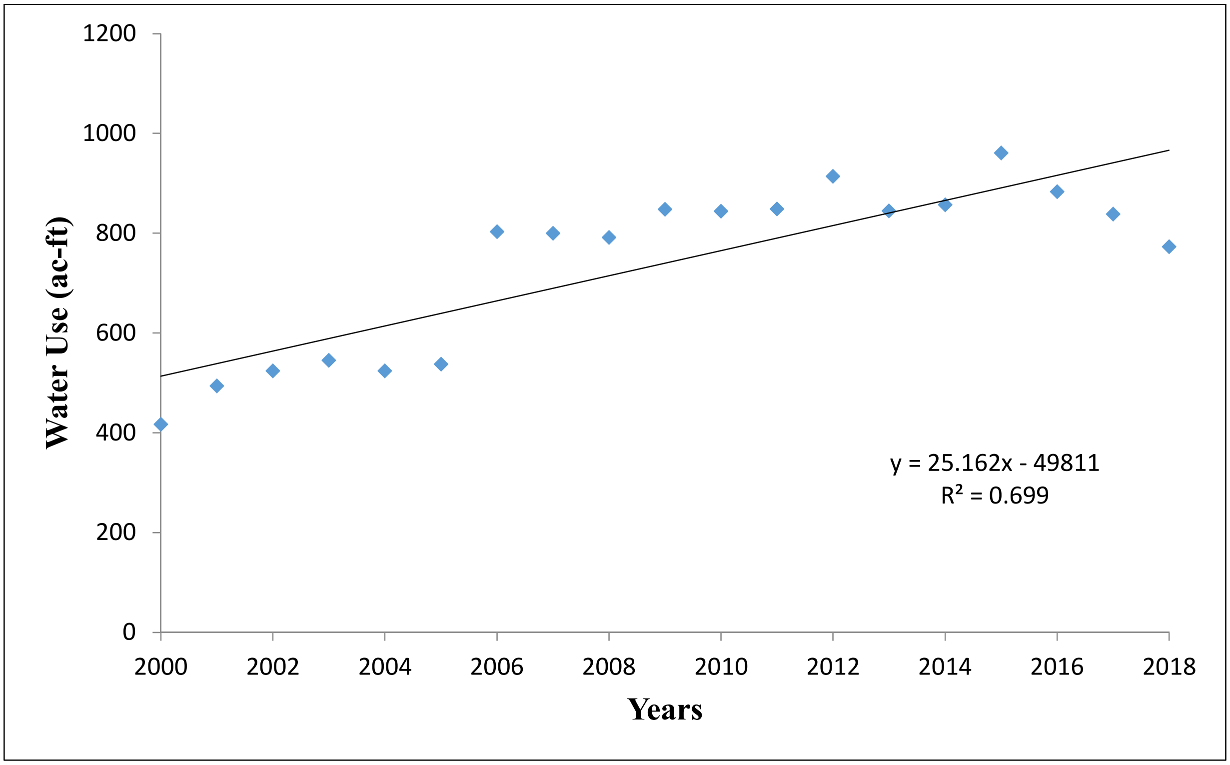

Figure 3.36. Municipal water use provided by Southwest Water Authority in the non-Bakken region over time. Shown is trend line, linear equation and R^2 value.

Comparison of Bakken Southwest Water Authority and North Dakota State Water Commission

Municipal water use for both SWA and NDSWC data showed that NDSWC water use was on average five times higher than SWA water use (Figure 3.37). The higher water use of NDSWC is a function of the number and size of cities provided by NDSWC permits. The fact that both increased at a similar rate shows that planning in the Bakken can expect increased use, but not at high rates. Constraints to increased municipal water use, such as use limits, inability to build new infrastructure, and conservation efforts may be responsible for the slower growth in municipal use. However, Ellingson et al. (2019) showed that water conservation measures were low in the state, and especially in the Bakken region. The increasing municipal water use corresponds with a higher population in the Bakken, but given that population and oil and gas activity fluctuate (boom and bust), the ability to quickly respond to these changes may be limited. However, at minimum, a slow increase in municipal water use in the Bakken over time is evident as a response to growing water needs in the area.

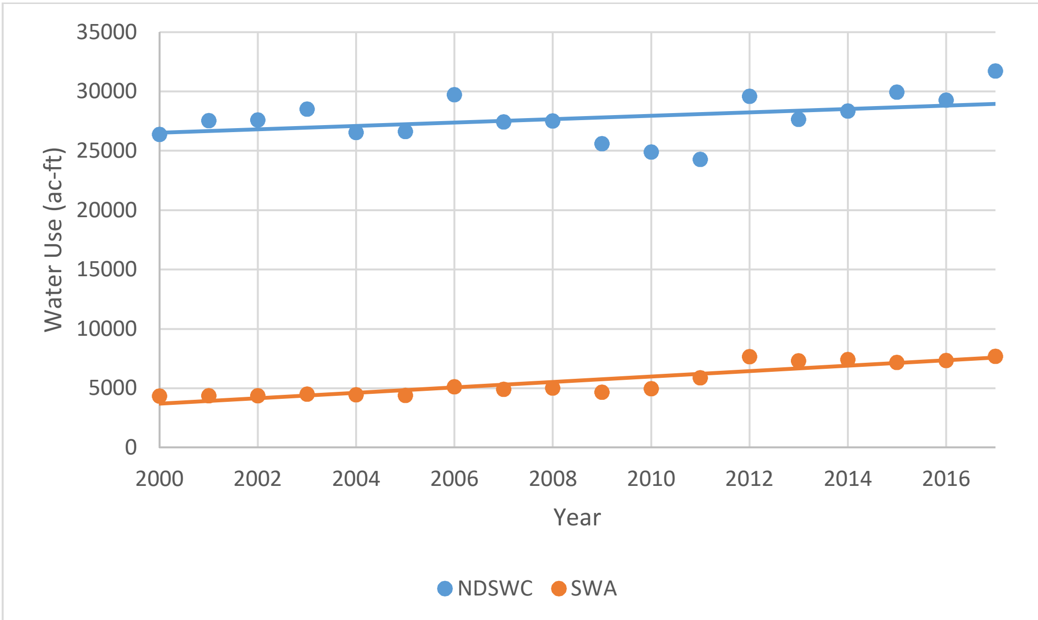

Figure 3.37. Municipal water use from information provided by the North Dakota State Water Commission and Southwest Water Authority over the years. Linear trend line is shown.

Conclusion

Analysis of industrial water use in the Bakken from the NDSWC permit database showed commercial water use increasing to the point in 2018 where it is the largest category of all industrial water use. The oil and gas category in the Bakken showed steady use, even though there was increased oil activity in the Bakken. The increase in commercial water use in the Bakken could be a response to increased population and oil activity, but it is unknown exactly what uses this water is going to. It is suspected some of the commercial water is going to oil activity, as well as other uses, because commercial permit holders are selling excess permitted water. The analysis of SWA water use found that there is an increasingly dominant end use of water in both the Bakken and non-Bakken. This is attributed to the expansion of SWA water sales and increased oil activity in the whole of southwest North Dakota.

The only increasing water use from NDSWC permits in the non-Bakken was due to oil and gas classified dominant end use. All other categories saw steady to slightly declining use. The increase in non-Bakken oil and gas water use is attributed to spillover effects from the increased Bakken oil activity. In addition, there is oil activity in the non-Bakken region that is not associated with the Bakken formation, and also contributes to non-Bakken oil and gas water use.

Bakken municipal water use, irrespective of using NDWC permit or SWA water use data, shows a slow increase over time. This is in contrast to non-Bakken municipal water use, which showed a slow decrease. The lack of a dramatic increase in municipal water use in the Bakken due to increased population and oil activity could be related to constraints on infrastructure to deliver more water, conservation efforts associated with growth, and permits not reflecting actual use. The realization that permits are not reflecting actual water use came when it was found that many Bakken municipalities are switching to regional water suppliers. Some of these regional water suppliers are comingling water from municipal and industrial permits. As more municipalities switch from NDSWC permits to regional water suppliers, information will be needed from the regional water suppliers to accurately track water use. At this time, the SWA provides useful information, but others will need to provide similar information to accurately track and understand water use. Without tracking this data it will be hard to have a full picture of where water is going and how it is being used; and it will make it nearly impossible to make accurate water use projections for the future.

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APPENDIX A. MUNICIPAL INTERVIEW CALL FORM

Municipal Permit Interview Call Form

Name of City:

Name of Contact Person:

Phone Number:

Time and Date:

Questions:

1. How many permits does the city have from the ND State Water Commission?
    a. Are these permit(s) industrial (use more than 12.5 acre feet of water for commercial enterprises such as mining, manufacturing, and processing) or municipal (use more than 12.5 acre feet for noncommercial uses such as institutions, facilities, and general residential use for domestic purposes)?
2. If multiple permits, what was the reason for obtaining additional industrial or municipal permits?

If city does not hold an industrial permit skip to 5

3. If you have an industrial permit, what purpose do you use it for (pick one of the following categories)? If multiple permits please specify number and/or names of industrial permits in different categories.

Agriculture	Funeral Home	Public Pool
Airport	Gas Station	Public School
Assisted Living Facilities & Nursing Homes	Gas Station with a carwash	Residential Irrigation
Auto Repair	Golf Course	Restaurant
Auto Supply	Government	Restaurant-Bar
Bank	Grocery Store	Retail

Bar	Gym	Service
Beverage Maker	Hair Salon	Shop
Big Box Store	Hospital	Shop Condo
Butcher	Hotel	Spa
Campground	Hotel w/pool	Sports Complex
Car Dealer	Jail	Storage Units
Car Wash	Kennels	Strip Mall
Cemetery	Landscaping	Truck Parts Service
Chiropractor	Laundromat/Laundry Services	Trucking Company
Church	Machine Shop	Utility
Clinic	Mall	Veterinarian
College	Manufacturer	Warehouse
Combo	Military	Waste Water Treatment Plant
Commercial Irrigation	Miscellaneous	Zoo
Concrete Batch	Multi-Business	Bulk Water†
Construction & Contractor	Office	
Daycare	Oilfield	
Dentist	Optical	
Entertainment	Parking Lot	
Fast Food	Parks	
Fire Station	Private School	
Food Processing		

4. For the industrial permit(s) held by the city what percent of water is used in making a product? What percent of water is used by employees in restrooms, at water fountains, cleaning offices/work areas, etc.? If these two don't add up to 100% what is the additional water used for?

5. Do you know of any industries in town that pull water from their own industrial permit (separate from the city)? If so how many (estimate is fine)? ______________ Do you know of any industries that pull water from a combination of their own industrial permit and the city's water permit(s)? If so how many (estimate is fine)? _______________

a. If there are industries that pull water from their own industrial permit and not the city permit
    i. Do you know why they got their own permit from ND State Water Commission (prior appropriation – earliest water right possible, pull more water than city can provide, etc)?
    ii. Do other similar industries have their own permit or fall under the municipal permit?
    iii. Do you know what criteria is used in your area/by industries to make the decision to pull an industrial permit or fall under the municipal permit?
b. If the industry(s) pull water from both their industrial permit and municipal permit:
    i. What criteria do they use for pulling water from the different permits. I.e. when does the industry pull from their own industrial permit vs. the municipal permit and why?
    ii. If more than one industry in city limits is doing this, do they use the same criteria?
        1. If different criteria is used, how is it different?

APPENDIX B. INDUSTRY INTERVIEW CALL FORM

Industrial Permit Interview Call Form

Name of Industry:

Name of Contact Person:

Phone Number:

Time and Date:

Questions:

6. How many industrial permits do you have currently?
    a. If multiple permits, are these permits for multiple sites?
    b. If multiple permits, what was the reason for obtaining multiple permits?
7. Are you located within city limits or outside of city limits?
    a. If within city limits, which city?
    b. Why did you choose to get an industrial permit vs. fall under municipal water permit from the ND State Water Commission?
    c. Did you have the option of using water from a municipal permit?
8. What category of water use does the water for the permit fall under (pick one of the following categories)? If multiple permits please choose multiple categories and specify number of permits in each.

Agriculture	Funeral Home	Public Pool
Airport	Gas Station	Public School
Assisted Living Facilities & Nursing Homes	Gas Station with a carwash	Residential Irrigation
Auto Repair	Golf Course	Restaurant
Auto Supply	Government	Restaurant-Bar
Bank	Grocery Store	Retail
Bar	Gym	Service

Beverage Maker	Hair Salon	Shop
Big Box Store	Hospital	Shop Condo
Butcher	Hotel	Spa
Campground	Hotel w/pool	Sports Complex
Car Dealer	Jail	Storage Units
Car Wash	Kennels	Strip Mall
Cemetery	Landscaping	Truck Parts Service
Chiropractor	Laundromat/Laundry Services	Trucking Company
Church	Machine Shop	Utility
Clinic	Mall	Veterinarian
College	Manufacturer	Warehouse
Combo	Military	Waste Water Treatment Plant
Commercial Irrigation	Miscellaneous	Zoo
Concrete Batch	Multi-Business	Bulk Water†
Construction & Contractor	Office	
Daycare	Oilfield	
Dentist	Optical	
Entertainment	Parking Lot	
Fast Food	Parks	
Fire Station	Private School	
Food Processing		

9. What percent of water do you use in making a product? What percent of water is used by employees in restrooms, at water fountains, cleaning offices/work areas, etc.? If these two don't add up to 100% what is the additional water used for?

10. Do you sell water to other entities? **If yes, keep going. If no skip to 6**.

    a. To whom do you sell it?

    b. How is the water that is sold transported (pipe, truck, other)?

    c. How do you determine to whom you sell water (distance, need, other)

        i. What criteria do you use to determine this (distance range, provide water over a certain amount)?

11. Would you be willing to provide us monthly water use data for your industrial permit for the last two years or if easily accessible, provide monthly water use data from 2000-2018?

APPENDIX C. MUNICIPALITIES (CITIES) INCLUDED IN SURVEY

Bakken or non-Bakken	City Name	Population
Bakken	Beach	1024
Bakken	Belfield	955
Bakken	Berthold	532
Bakken	Beulah	3235
Bakken	Bismarck	72777
non-Bakken	Bottineau	2094
non-Bakken	Bowman	1560
Bakken	Burlington	1420
non-Bakken	Cando	1083
non-Bakken	Carrington	2133
non-Bakken	Casselton	2677
non-Bakken	Cavalier	1130
Bakken	Crosby	1138
non-Bakken	Devils Lake	7344
Bakken	Dickinson	22882
non-Bakken	Ellendale	1211
non-Bakken	Fargo	121889
Bakken	Garrison	1623
non-Bakken	Grafton	4182
non-Bakken	Grand Forks	56500
non-Bakken	Harvey	1761
Bakken	Hazen	2543
non-Bakken	Hettinger	1065
non-Bakken	Hillsboro	1601
non-Bakken	Horace	2741
non-Bakken	Jamestown	15289
Bakken	Kenmare	939
Bakken	Killdeer	814
non-Bakken	Langdon	1924
non-Bakken	Larimore	1381
non-Bakken	Lincoln	3703
non-Bakken	Linton	972
non-Bakken	Lisbon	2009
Bakken	Mandan	22301
non-Bakken	Mayville	1808
Bakken	Minot	48261
Bakken	Mohall	704

Bakken or non-Bakken	City Name	Population
non-Bakken	New Rockford	1393
Bakken	New Town	2525
non-Bakken	Oakes	2129
non-Bakken	Park River	1499
Bakken	Parshall	1119
Bakken	Ray	495
Bakken	Richardton	851
non-Bakken	Rolla	1299
non-Bakken	Rugby	2724
Bakken	Stanley	2655
non-Bakken	Surrey	1053
non-Bakken	Thompson	1133
Bakken	Tioga	1062
non-Bakken	Turtle Lake	562
Bakken	Underwood	803
non-Bakken	Valley City	6460
non-Bakken	Velva	1379
non-Bakken	Wahpeton	7802
Bakken	Washburn	1391
Bakken	Watford City	6912
non-Bakken	West Fargo	35397
Bakken	Williston	27250