GAUGING CATEGORIES OF MUNICIPAL WATER USE SPATIALLY ACROSS NORTH DAKOTA IN DIFFERENT SIZE MUNICIPALITIES

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ABSTRACT

Little is known about municipal water use in the state of North Dakota. Typically, the only water use information reported to the North Dakota State Water Commission is the amount of water withdrawn as part of a municipal water permit. The goal of this study was to expand current knowledge on municipal water use in the state. Two questionnaires were developed and administered to all cities with populations greater than 1,000 residents that were willing to participate. Questions focused on who is in charge of water-use data, how the data are recorded and stored, and if municipalities try to conserve water through various measures. Additionally, the project attempted to classify water-use data into categories and sub-categories of similar water using entities to develop per capita coefficients and normal commerce for different size cities. Results of the study will aid researchers and water managers in future water planning.

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CHAPTER 1: LITERATURE REVIEW

Water End Uses

Municipal water is used in a variety of ways from commercial to industrial to residential settings. Within the residential sector, water is used for many purposes including drinking, bathing, cooking, cleaning, and outdoor landscaping. Since there is a myriad of ways municipal water is used, many studies have focused on determining the end use of water in urban environments (Mayer et al., 1999; Blokker et al., 2009; Stewart et al., 2009; Willis et al., 2013; Rathnayaka et al., 2015).

The vast majority of municipal water studies have focused on water use in the residential sector, as this sector consumes the most water in urban environments (Kim & McCuen, 1979; Grimmond & Oke, 1986; Kostas & Chrysostomos, 2006; Balling & Gober, 2007; Polebitski & Palmer, 2009; Mini et al., 2014). Outside of the residential sector, industrial and commercial users of water, especially manufacturers, have also been studied, but to a lesser degree (Mercer & Morgan, 1974; Kim & McCuen, 1979). Recently, more attention has been paid to commercial and industrial users of water to determine how they use water as part of the urban environment (Morales et al., 2009; Morales et al., 2011). Even though attention has been paid to non-residential water users recently, a majority of studies that break water use down past broad categories (residential, commercial, industrial), are still concentrated in the residential sector (Zhang & Brown, 2005; Wentz & Gober, 2007; Blokker et al., 2009).

Typically, over half of all municipal water is used for residential purposes, leading many studies to determine how and where the water is being used (Grimmond & Oke, 1986; Mayer et al., 1999; Cole & Stewart, 2013; Mini et al., 2014). Many times, end use studies are carried out in an attempt to determine where water can be conserved, either as a proactive action or in response to water stress, such as a drought (Stewart et al., 2009). Along with conservation, one all-encompassing reason to study water end uses is because “what you don’t measure, you can’t manage” (Hauber-Davidson & Idris, 2006). Thus, without this information, water conservation measures have no basis.

Residential water use is often broken down into two components, indoor and outdoor use. Although total water use can be influenced by seasonal changes (Willis et al., 2013; Gnoinsky, 2017), indoor water usage which includes, toilets, showers, washing machines, and taps, remains fairly constant throughout the year (Attari, 2014; Mini et al., 2014). On the other hand, residential outdoor water use, which is mostly comprised of irrigation for gardens and lawns, varies throughout the year (Power et al., 1981; Grimmond & Oke, 1986; Rathnayaka et al., 2015).

Since the mid-2000s, smart water metering technology has allowed real time data collection on water consumption (Hauber-Davidson & Idris, 2006). Using this technology, determining how much water is consumed, and when it is consumed, for end uses is possible (Hauber-Davidson & Idris, 2006; Cole & Stewart, 2013). This technology has become more widely used in research over the past ten years, especially in Australia, and has substantially aided indoor end use water research (Beal et al., 2013; Britton et al., 2013; Cole & Stewart, 2013; Willis et al., 2013). For example, toilets have been found to be the largest users of residential water in North America (Vickers, 2001c) and Asia (Bradley, 2004), while Willis et al. (2013) found that showers use the largest share of residential water in Australia. A study by Power et al. (1981) also found that approximately 80% of all indoor water was used by toilets, bathing, and washing clothes.

Research shows total indoor water use is approximately stable throughout the year; a study from Australia discovered that the quantity of water used by various end uses changed over the course of a year (Rathnayaka et al., 2015). Conducted in Melbourne Australia, the study assessed the impacts of seasonality on water end uses. They found the amount of water used by toilets and showers varied seasonally. Interestingly, the proportion of water used for showering was higher in the winter for one district and higher in the summer for the second district. The reason for these differences is not known, although the authors hypothesized that the higher winter water use was attributed to longer showers, while higher water use in the summer was due to more showers being taken. Additionally, by utilizing smart metering technology, the authors were able to analyze different aspects of bathing, such as shower frequency and duration, to help explain these unexpected results (Rathnayaka et al., 2015).

Based on this information, if indoor residential water conservation measures are desired, focusing on showers, toilets, and washing machines will provide the greatest impact. One method to reduce water consumption, that has already shown to be effective, is the use of high efficiency water fixtures and appliances (Bradley, 2004; Willis et al., 2013). Retrofitting showerheads and toilets can provide substantial water savings and represents cost effective conservation methods (Willis et al., 2013; Attari, 2014).

Outdoor water use, specifically irrigation, represents the most sporadic end use in the residential sector (Vickers, 2001b). Tremendous variation exists regarding the amount of residential water used for outdoor purposes. Across climates, an enormous range exists regarding the fraction of water used for outdoor purposes. Vickers (2001b) discovered that water use ranged from 10% of total residential water usage in Ontario, Canada to 75% of total water usage in Texas. Another study in Florida found that on average, approximately 65% of water used by residential properties went towards outdoor irrigation (Haley et al., 2007). Even in the same geographical location, the amount of water used outdoors throughout the course of the year varies. As would be predicted, multiple studies have shown that more water is used for irrigation in the summertime, than the cooler winter months, although this also depends on climate (Grimmond & Oke, 1986; Mini et al., 2014; Rathnayaka et al., 2015). Furthermore, water use is greater during droughts and periods of high temperatures, compared to average or cool, wet conditions (Zhou et al., 2000; Balling & Gober, 2007; House-Peters et al., 2010).

Considering outdoor irrigation can significantly affect the amount of water used in the residential sector, multiple studies have examined this topic more in depth (Haley et al., 2007; Endter-Wada et al., 2008; Mini et al., 2014; Rathnayaka et al., 2015). A few studies have determined that many people water their lawns to keep them looking nice, neat, and green (Power et al., 1981; Endter-Wada et al., 2008). Additionally, a large percentage of the time, excessive amounts of irrigation water are applied, compared to what is actually needed (Haley et al., 2007; Endter-Wada et al., 2008). Although irrigation water is often applied in excess, a study by Haley et al. (2007) found that the method of irrigation greatly impacts the amount of water used. They found that water applied using programmed sprinkler systems was more likely applied excessively, than irrigational water applied by hand with a hose (Haley et al., 2007). Since outdoor irrigation is often applied in excess and accounts for a large fraction of the residential water use budget, water conservation measures aimed at outdoor water use have great potential (Mini et al., 2014).

Commercial Water Use

Little information regarding commercial water use exists, with the vast majority of information and studies focused in the residential sector. A majority of the information on commercial water use exists in books and reports (Dziegielewski et al., 2000; CoSF, 2001; Vickers, 2001a; Brown, 2002; Seneviratne, 2007). For example, the city of Santa Fe, New Mexico created a report about water usage in the city (CoSF, 2001). They analyzed approximately 1,500 water use records, breaking them down into 22 different commercial sub-categories to examine water use within each sub-category (CoSF, 2001). Many reports, though, focus on one specific sub-category such as hotels, carwashes, or other major water user groups (Brown, 2002; O'Neill et al., 2002). Various books also provide information on commercial water use. A book by Vickers (2001a) provides average daily water demand for 37 sub-categories of commercial, industrial, and institutional water uses. *A Practical Approach to Water Conservation for Commercial and Industrial Facilities* broke down commercial water usage in California into nine categories, presenting the percentage of total commercial water each of the nine categories used (Seneviratne, 2007).

As mentioned previously, less information is known about commercial water usage compared to residential usage, with this trend holding true for scientific studies as well (Malla & Gopalakrishnan, 1999). A study by Kim & McCuen (1979) investigated factors that could help predict commercial water use, specifically water use in the retail sector, while a study by Malla & Gopalakrishnan (1999) looked at the economic side of commercial water use in Hawaii. Both studies are almost, if not, twenty plus years old. As population size, economic expansion, and water efficiency has changed over the past two decades, the information may be outdated and not applicable in practice anymore.

More recently, commercial sectors in Florida have been analyzed to look for trends in water use in different commercial categories (Morales et al., 2009; Morales & Heaney, 2010; Morales et al., 2011). Morales et al. (2009 and 2011) used heated building area to predict commercial, industrial, and institutional water use. Morales & Heaney (2010) developed water use coefficients for 24 different sub-categories of commercial users. They found that hotels and shopping centers were the two largest commercial water users, using approximately thirty percent of all commercial water, and the public school system was the largest institutional user (Morales & Heaney, 2010; Morales et al., 2011).

Some scientific studies focus on a specific sub-category within the commercial sector. Endter-Wada et al. (2008) looked at a specific aspect of commercial water, investigating commercial irrigational water use in Utah. Another study focused on water use in public schools in Italy (Farina et al., 2011). Farina et al. (2011) found that the type of school, pre-school versus elementary school, affected the amount of water used on a per student basis. Pre-schools used thirty to seventy liters per day per student, whereas elementary schools had lower usage between ten and thirty liters of water used per day per student (Farina et al., 2011).

Modeling and Forecasting Water Use

Models are developed to forecast water demand in the future. Models can be developed to forecast water demand, hours, days, weeks, or months in advance (Smith, 1988; Shvartser et al., 1993; Altunkaynak et al., 2005; Ghiassi et al., 2008). Models that forecast water demand for time periods of less than a year, create short term forecasts (Zhang et al., 2014). On the other hand, some models forecast water demand for time periods of one year or more (Polebitski & Palmer, 2009); these models generate long term forecasts (Zhang et al., 2014).

There are many reasons to forecast short term water demand. A major reason for short term forecasting is planning and management (Yurdusev et al., 2009). Municipalities do not want to run out of water, especially during peak use. Thus, short term forecasts help estimate water demand hours to weeks in advance. This helps ensure enough water is available, especially if water has to be released or pumped in from reservoirs (Smith, 1988; Bougadis et al., 2005). Short term forecasting can also help provide guidance on specific water regulations or effective measures to reduce water use (Yuan et al., 2014).

While short term forecasting is used for immediate planning and management, long term forecasting is a tool that can be used to look at potential changes in water demand due to a number of variables. A study by Khatri and Vairavamoorthy (2009) looked at potential impacts of climate change, population growth, and public attitudes and how these could affect future water demand in the UK. The study incorporated different scenarios dealing with climate change, weather variables and population growth to forecast future water use. The authors found that future water demand would be determined by changes in populations and socio-economic variables, rather than climate change. They also noted that due to the uncertainties of the future, they would not assess the impacts of climate change. While it is unknown how these factors will actually change, using a scenario approach when analyzing these variables helps provide an idea of how water demand might change in the future (Khatri & Vairavamoorthy, 2009).

Not only can models be categorized based on their forecasting time frame, they are also commonly split into groups based on the type of statistical analysis they carry out (Qi & Chang, 2011). There are many different statistical analysis techniques incorporated into models and some of the more common statistical techniques are discussed below. In general, models are capable of carrying out both long and short term forecasting, irrespective of the statistical analysis techniques used.

Both regression analysis and time series analysis are great options for relatively simple water forecasting models. Regression analysis is based on statistics. Generally, these models assume that past relationships between water demand and some other variable will continue into the future (Qi & Chang, 2011). For example, one model based on regression analysis used air temperature and rainfall to forecast water use in nine different cities (Maidment & Miaou, 1986). Foster and Beattie (1979) used regression analysis to determine the impact of city size on water demand. Time series analysis is based on the idea that trends in water use contribute to changes in water demand over time (Qi & Chang, 2011). Zhou et al. (2000) used time series analysis to create a forecast of water demand by consumers in Melbourne, Australia 24 hours ahead of time by utilizing past demand data and climatic variables, to ensure enough water was released from storage reservoirs to meet consumers demands. Another model that utilized time series analysis relied upon socioeconomic variables to help forecast daily municipal water use (Smith, 1988). While both regression and time series analysis can be used for short and long term forecasting, time series analysis is used almost exclusively for short term forecasting (Qi & Chang, 2011).

Another set of modeling approaches, based on computational intelligence techniques, allows analysis of more complex situations. Artificial neural networks (ANN) are one of the most common types of computational intelligence techniques used for water demand forecasting (Qi & Chang, 2011). Generally, ANN usually contain at least three layers (input layer, output layer, hidden layer) and are purely driven by data (Qi & Chang, 2011). Ghiassi et al. (2008) developed a dynamic artificial neural network model (DAN2) to forecast water demand anywhere from 48 hours to 24 months into the future. The DAN2 model produced very promising results as it produced very accurate forecast (greater than 99% accuracy) and outperformed the most common ANN model (Ghiassi et al., 2008). Regression models have also been compared to ANN when modeling short term water demand; a study in Canada found that ANN models reliably produced better results than regression models (Bougadis et al., 2005).

There are also hybrid approaches that integrate numerous models together to create a model that is advantageous over a single method model (Qi & Chang, 2011). For example, a demand behavioral model was developed that uses both time series analysis and pattern recognition to forecast hourly water demands (Shvartser et al., 1993). The authors determined this model performed well for its intended purpose, forecasting hourly demand to insure optimal operating efficiency (Shvartser et al., 1993). In Florida, a system dynamics model was developed to estimate water demand by utilizing unemployment rate and income (Qi & Chang, 2011). This model was useful for estimating future water demand under changing economic conditions in Manatee County, Florida. The authors noted however, that this model is limited in scale, as it does not perform the same when global economic changes were incorporated (Qi & Chang, 2011). A study by Wong et al. (2010) used general statistics to develop a statistical model for daily water consumption. Their model did a fair job of modeling daily water use, when compared to the actual amount of water consumed, and displayed pronounced differences in water use between weekday and weekend days (Wong et al., 2010). There are a plethora of statistical techniques available to model water demand; the goals of the model will influence the statistical technique chosen.

Recently, new models have been developed that go beyond simply forecasting water demand, and now encompass the entire urban water cycle. Mitchell et al. (2001) developed a model known as Aquacycle, which combines indoor water use, climatic data, and the physical characteristics of the urban environment to determine stormwater, wastewater, and water use. Aquacycle provides guidance on how to reduce the amount of high quality water (potable water) pumped into the urban environment by providing guidance on ways to use stormwater and wastewater for uses that don’t require high quality water (Mitchell et al., 2001). Aquacycle thus provides a better understanding of the urban water balance. Another model, the Dynamic Urban Water Simulation Model (DUWSiM) was developed by Willuweit and O'Sullivan (2013). DUWSiM takes into consideration the major components of the urban water cycle, mainly runoff, water demand, water supply, and wastewater, in an attempt to look at the long term demand of water in the urban environment (Willuweit & O'Sullivan, 2013).

Although there are many benefits to forecasting water demand for the future, models are not always correct or reliable. As Gleick (2003) stated, data used in models is often incomplete, inadequate, and indirectly measured, which can lead to inappropriate and inaccurate models. The fact that models can be wrong, has caused many to shy away from using them and has resulted in partial acceptance by professionals overall (Sampson et al., 2011). Furthermore, use of models has not taken off for various reasons including: their complex nature; the fact they are time consuming to run; and the fact that policy makers generally have a limited understanding of models and what they can bring to the table (Maidment & Parzen, 1984; Sampson et al., 2011). Overall, even though there are drawbacks to models and forecasting, the information they produce can be useful if used correctly. Since domestic water is the most important component of municipal water consumption, ensuring that water resources are managed to meet this need is of utmost importance (Yurdusev et al., 2009). Thus, incorporating models into water planning is a good idea.

Variables Influencing Water Use

Variables that influence water use are often incorporated into models that forecast water demand. Not only are these variables helpful when creating forecasts, but they can provide insight into what drives water demand. Climatic conditions and socioeconomic conditions are the two general categories of variables that are associated with water use (Gleick, 2003; Kenny &

Juracek, 2012). These variables are generally associated with the residential aspect of municipal water use, although there are conflicting views regarding the impacts climate and weather may have on commercial water consumption (Kim & McCuen, 1979; Endter-Wada et al., 2008). Kim and McCuen (1979) stated that commercial water use does not vary seasonally or daily, yet a study in Utah found that commercial water use can vary throughout the year (Endter-Wada et al., 2008). Variation in commercial water use can be attributed to irrigation of business landscaping (Endter-Wada et al., 2008). Therefore, climate and weather can both affect and not affect commercial water consumption, depending on the presence of landscaping (Kim & McCuen, 1979; Endter-Wada et al., 2008).

Socioeconomic Variables

Many different socioeconomic factors have been considered important when forecasting future water demand. Price of water and/or income are two factors that are generally incorporated into models (Dziegielewski & Boland, 1989; Arbués et al., 2003; Polebitski & Palmer, 2009). In general, as price increases, demand for water decreases (Foster & Beattie, 1979; Dziegielewski & Boland, 1989). Similarly, as would be expected, as income increases, demand for water generally increases as well (Foster & Beattie, 1979; Dziegielewski & Boland, 1989; Willis et al., 2013). Population size is a third common socioeconomic variable that is often considered in models (Gleick, 2003; Yurdusev et al., 2009). A model based on ANN found that the addition of a population variable to the model, which already incorporated other factors, provided better results than models without this population variable (Yurdusev et al., 2009).

While price, income, and population size are the most common socioeconomic factors used to determine water demand, many other variables have been investigated. Structural factors such as type of building/house, built square feet, and building densities have all been linked to water demand (Dziegielewski & Boland, 1989; Polebitski & Palmer, 2009). Additionally, property factors such as lot size, lot value, presence of a pool, and landscaping investment, have been shown to be related to water demand (Morgan & Smolen, 1976; Wentz & Gober, 2007; Polebitski & Palmer, 2009).

Many variables have been shown to be useful in forecasting water demand; however, some variables have not useful. Building age was not found to be a significant factor concerning water consumption in Portland, Oregon (Chang et al., 2010). Another study found that city size was not a good method to determine water use per house (Foster & Beattie, 1979). Variables that have been shown to be effective indicators of water demand, may not work in all places. A report by the U.S. Geological Survey (USGS) found that the socioeconomic variables they considered, including water price, were not useful at the national level, although they were useful at smaller scales (Kenny & Juracek, 2012).

Climatic Variables

Many models take climatic and weather factors into consideration (Maidment & Miaou, 1986; Zhou et al., 2000). Yet, a model developed for forecasting daily water demand excluded weather variables due to the difficulty of accurately predicting the weather (Smith, 1988). This model was developed to forecast summer demand of water in the Washington D.C. area, in order to schedule the release of water from reservoirs. It used a ratio of average daily water demand on a certain day of the year and the average daily water use over the entire year to forecast seasonality and day of the week effects. This base model does not incorporate any climatic or weather variables, but Smith noted inclusion of observed precipitation data could be useful (Smith, 1988). However, the USGS states that climatic variables are important factors to consider when looking at a specific city's water demand (Kenny & Juracek, 2012).

Weather conditions have been, and still are, considered important factors to include when modeling water demand. The two most common weather variables considered are precipitation and temperature (Morgan & Smolen, 1976; Aly & Wanakule, 2004). Generally, water demand decreases with precipitation, which is generally attributed to a short-term decrease in outdoor use (Zhou et al., 2000; Balling & Gober, 2007). Incorporating more than just the presence or absence of rainfall can positively influence forecasts. Actual rainfall amounts, as opposed to occurrence or non-occurrence, and number of days since the last precipitation event can improve forecasting (Aly & Wanakule, 2004; Bougadis et al., 2005). On the other hand, as temperature increases, water demand and use generally increases as well (Grimmond & Oke, 1986; Zhou et al., 2000; Balling & Gober, 2007). When using temperature to forecast water demand, the best variable to use is daily maximum temperature (Maidment & Miaou, 1986; Zhang et al., 2014). The Maidment and Miaou (1986) study looked at the impacts of water use and temperature in cities in three different states and found that there is a threshold (70°F) above which water use rises steadily with maximum daily temperature. Overall, inclusion of both precipitation and temperature generally provides better results than not including climatic data. Out of these 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 using the variable "water use per employee" (Mercer & Morgan, 1974). This method produced mediocre results. In one study, the water use category "arboretum, botanical, and zoological gardens" used the most water per employee. Yet, it is important to note that this employment sector had a very small employee base, which resulted in minimal impacts on total water used (Mercer & Morgan, 1974). Thus, to better understand commercial water usage, variables beyond water use per employee need to be investigated.

Retail stores were the focus of a study by Kim and McCuen (1979). The goal of the study was to determine what factors were helpful in predicting commercial water use, specifically for retail stores. It was discovered that there are three general categories of factors that influence water demand at retail stores: the employee factor, the customer layout factor, and the customer water facility factor. For example, the employee factor consisted of the following variables: number of employees in a retail store; area, layout, and design characteristics of the store; employee water use facilities. All three groups of factors had multiple aspects within them; the final factors deemed most appropriate to predict water use in retail stores included gross store area, length of display windows, and number of drinking fountains (Kim & McCuen, 1979). More recently, heated building area has been proposed as a new approach in estimating commercial water demand (Morales et al., 2009; Morales et al., 2011). This method appears to offer an improvement over the water use per employee factor. Yet, it can still be limited by the ability to obtain reliable data (Morales et al., 2009).

Trends in Water Use

Trends in water use are important to understand how water is used and can provide a glimpse into the future of water resources (Kenny & Juracek, 2012). This information is of the utmost importance due to the fact that water is a finite resource (Kostas & Chrysostomos, 2006). Trends in water use can be identified by looking at past data on water use and can vary by country, and even regionally within a nation (Kenny & Juracek, 2012). For example, trends in water use in the Bakken region of North Dakota varied from the rest of the country and even eastern North Dakota, during the oil boom from 2005 until 2015 (Carter et al., 2016; Horner et al., 2016; Lin et al., 2018). Over time, 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). As population grows and urbanization increases, more water is demanded by municipalities (Molden & Sakthivadivel, 1999). These two factors help explain the fact that regions with the fastest growth in domestic water use are usually those areas that have had low water consumption levels in the past (Portnov & Meir, 2008). Yet, this trend of increased water demand does not continue indefinitely.

Although a trend of increased water demand has been associated with increased affluence and population growth, more recent trends have displayed a different tendency, stable or decreased water use (Bradley, 2004; Franczyk & Chang, 2009; Maupin et al., 2014). In many countries throughout the world, reductions in per capita water use have been reported (Bradley, 2004). For example, in Oregon, increasing income per capita eventually led to lower water use (Franczyk & Chang, 2009). While there are many factors at play, one explanation is that households with higher incomes are more likely and able to purchase more water efficient appliances (Stewart et al., 2009). In a more general sense, more accurate reporting practices and the increasing trend of water conservation could also be impacting the long term trends in water demand (Konieczki & 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 that details water use throughout the U.S.; these reports were first published in 1950 and now encompass over 60 years' worth of data (Dieter & Maupin, 2017). To breakdown total water use, the USGS looks at eight different categories: "public supply, domestic, irrigation, livestock, aquaculture, industrial, mining, and thermoelectric power" (Maupin et al., 2014).

These USGS reports provide great 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, at 355 billion gallons per day (Maupin et al., 2014); this was down 13% from five years prior in 2005 (Maupin et al., 2014). Looking more specifically at the public water supply category, 2010 was the first year that this category saw a decline in water consumption since the USGS started creating reports in 1950 (Maupin et al., 2014). In 2010, public supply withdrawals were down 5%, even while the total U.S. population increased 4% (Maupin et al., 2014). Moreover, the population again increased by 4% between 2010 and 2015 and water withdrawn for public supply still decreased 7% (Dieter & Maupin, 2017).

Since the population continues to grow in the U.S. and water consumption is decreasing, various factors are influencing this trend. As mentioned previously, the expansion of more efficient water appliances could be a factor impacting the decrease in water use (Bradley, 2004; Stewart et al., 2009), although this likely isn't the only factor. Another factor may be the current style of living; urbanization may be affecting housing styles and dwelling types. For example, in Malaysia there is a trend towards living in condo's and apartments, which is partially attributed to the decrease in per capita water use (Bradley, 2004). In Phoenix, Arizona, approximately 50% of municipal water use occurred at single-family homes (Wentz & Gober, 2007). Although this occurred in an arid climate, other studies have shown that the single family home sector uses more total water than the multi-family dwellings and apartments sectors (Loaiciga & Renehan, 1997; Chang et al., 2010; Mini et al., 2014). Additionally, water conservation measures may be having an impact. In California, an informational campaign reduced water demand by 8% (Renwick & Green, 2000). Yet, this does not mean that all informative campaigns will work. Another study found that these types of informative public campaigns may only work where local citizens are already aware or impacted by water shortages (Nieswiadomy, 1992).

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CHAPTER 2: NORTH DAKOTA WATER USE QUESTIONNAIRE

Abstract

Municipal water use is of the utmost importance, but little is known regarding how this information is collected, stored, and utilized. Tremendous variation exists between how different cities, states, and countries classify water use and the units used to record water consumption (gallons, acre-feet, cubic-feet, etc.). Additionally, water conservation measures have become more common in the past few decades, but little is known about how these conservation measures are implemented at the city level. The goal of this study was to increase the breadth of knowledge available regarding how municipal water-use data are stored. Two questionnaires were developed and administered to all municipalities in the state of North Dakota with populations greater than 1,000 residents who were willing to participate. Questionnaires focused on: 1) who is in charge of water-use data at the city level, 2) how the information is recorded and stored, 3) if the information is public, and 4) if municipalities try to conserve water through various measures. Results indicate that municipality size influences aspects of water-use data including the department responsible for water-use data, method of data collection, and specific storage location of data. Additionally, only a small percentage of cities utilize water conservation methods. Results from the study will aid state and national water use professionals by providing valuable information on water-use data and storage. This information will also help researchers and future studies of water use in making comparisons across different areas and assessing trends in water use to aid in future water planning.

Introduction

Water is essential for life. Municipal water has garnered increased attention recently as professionals try to ensure adequate supplies of water are available as urbanization increases

(Wong et al., 2010). Currently, most municipal water studies focus on trends in water use (Wong et al., 2010) and forecasting water demand (Zhou et al., 2000; Qi & Chang, 2011). Additionally, water conservation measures and the effectiveness of those measures have been the focus of a few studies in arid regions over the past few decades (Loaiciga & Renehan, 1997; Fielding et al., 2013; Mini et al., 2015). Regardless of the specific focus of these studies, all required the use of and access to water-use data, with the availability of these data greatly influencing the scope of projects and applicability of results. However, few if any studies to date have explored the types of water use data that can be obtained from municipalities.

Since water is one of the most important natural resources on earth (Arbués et al., 2003), water conservation and conservation measures have increased in prevalence as professionals try to manage this vital resource. Water conservation can encompass many different actions that all contribute to reducing the amount of water used (Gleick, 2003; Hauber-Davidson & Idris, 2006). Outdoor watering restrictions are a common method applied to reduce outdoor water use for irrigation purposes, with many studies demonstrating that while voluntary restrictions can reduce water consumption, mandatory restrictions are more effective (Polebitski & Palmer, 2009; Fielding et al., 2013; Mini et al., 2015). In general, studies looking at water conservation have been conducted in arid environments or in locations experiencing drought (Kenney et al., 2004; Mini et al., 2015). Although these studies are important because of the implications for water shortages, more knowledge is needed regarding water conservation measures, such as how and when they are applied and how city size or climate affects the presence or absence of conservation measures.

Tremendous variation exists in how water use information is measured, stored, and accessible to outside entities. Additionally, different entities and studies use different time frames and units of measure in relation to water use (House-Peters et al., 2010; Kenny & Juracek, 2012; Mini et al., 2014). The majority of publications by the United States Geological Survey (USGS), the main federal agency dealing with water use in the United States (U.S.), provide average water use on a daily basis, such as gallons per day or gallons per capita per day (Hutson et al., 2004; Kenny & Juracek, 2012; Maupin et al., 2014; Dieter & Maupin, 2017). Moving down to the state or local level, more variation exists. For example, a report regarding water use in the City of Santa Fe, New Mexico, USA, provided categorical averages in acre-feet per year (CoSF, 2001). Another study looking at water use in six different states obtained data from both the state and local level, with numerous units of measure including acre-feet, cubic-feet, and gallons (Kenny & Juracek, 2012). Furthermore, water-use data in the U.S. is generally recorded using the imperial system, whereas the metric system is more commonly utilized by the rest of the world (Zhou et al., 2000; Khatri & Vairavamoorthy, 2009), which can make cross country comparisons extremely difficult. Since there is tremendous variation in how water use data are recorded and stored, a better understanding of how this information is recorded is needed.

Beyond the units used to measure the amount of water consumed, classification of water use is also extremely variable. The state of North Dakota, where this study took place, has six water use categories that encompass domestic, municipal, livestock, irrigation, industrial, and fish, wildlife, and other outdoor recreational uses (N.D.C.C. § 61-04). Similar to North Dakota, the neighboring state of Minnesota has six water use categories for water permits, yet the Minnesota categories are different. Minnesota's water permit categories include irrigation, industrial processing, water supply, power generation, consumption use, and "other", which includes activities such as air conditioning, construction, water level maintenance, and pollution confinement (MNDNR, 2018). Similar to North Dakota and Minnesota, most states have slight differences in their water use categories, with few common consistencies. Nationally, the USGS examines eight separate categories when studying water use and withdrawal throughout the U.S. including public supply, domestic, irrigation, livestock, aquaculture, industrial, mining, and thermoelectric power (Maupin et al., 2014). Globally, there is even more inconsistencies between water use categories. A report on Canada's water broke down the countries usage into seven different categories including: electric power generation, transmission and distribution; manufacturing; household; crop and animal production; all other industries; mining, quarrying and oil and gas extraction; and natural gas destruction, water, sewage, and other systems (Statistics Canada, 2017). Thus, comparing state and national water use data can be challenging due to different classifications and categories, and comparing across countries would be even more problematic as different countries have different systems developed over hundreds of years.

Few, if any, studies have looked specifically at how water-use data are recorded and stored. Generally, studies analyzing data for trends or modeling purposes provide the source of their data in the methods section (Chang et al., 2010; House-Peters et al., 2010), but do not provide any specific information about obtaining the data, the form in which it was received (PDF, Excel file, CSV, etc.) or how the source (i.e. municipality) stores the data. Additionally, some studies explicitly state how the data was reported to them (i.e. gallons, acre-feet, etc.) (Polebitski & Palmer, 2009; House-Peters et al., 2010), while others do not (Wentz & Gober, 2007; Mini et al., 2014). Although this information is not always critical to the outcome of the study, obtaining and utilizing water use data for comparison or replication purposes can become difficult. Furthermore, depending on how long recorded data are stored, developing comparable per capita coefficients for a state, region, the U.S., or across countries is difficult if not impossible. If water-use data are only kept for a short period of time, only a small window of time exists to collect the data to be analyzed for trends and to make projections. Thus, because there is such a disparity in the breadth of available water use data due to differences in recording, collection, and reliability of data (Gleick, 2003), expanding on this knowledge will help future water use research and projects.

The goal of this study is to determine how water-use data are recorded within municipalities across North Dakota. Specifically, the study looks at who is in charge of water-use data at the municipal level, how the information is recorded and stored, if the information is public, and if municipalities try to conserve water through various measures. Knowledge on water use-data collection, storage, and length of time data are stored is important to water managers and researchers, as this knowledge may help identify usable data and ensure studies are feasible with the data available. Additionally, knowledge on conservation measures and how they are implemented at the city level can provide insight to water managers during times of drought, growth, or water stress, and help determine if more restrictions need to be implemented.

Methods

The state of North Dakota was the study area for the project. All municipalities with population sizes greater than 1,000 residents (n=53) were contacted to see if they would be willing to participate (Appendix A). Additionally, all municipalities with populations between 500 and 1,000 residents in the Bakken region and its margins (n=6) were contacted (Appendix A). The Bakken region and its margin were delineated using the GIS layer of active well pads (Wells.zip) obtained from the North Dakota Oil and Gas Division website (downloaded 03/10/2017), summaries of the top oil producing counties in North Dakota (NDIC, 2010; NDIC, 2011; NDIC, 2012; NDIC, 2013), and researchers' knowledge of the area. Areas west of U.S.

Highway 83 and north of Interstate 94 are considered part the Bakken and its margin (here after referred to as the ‘Bakken’) for the purposes of this project (Figure 2.1). This area has been most affected by population growth during the most recent North Dakota “oil boom.”

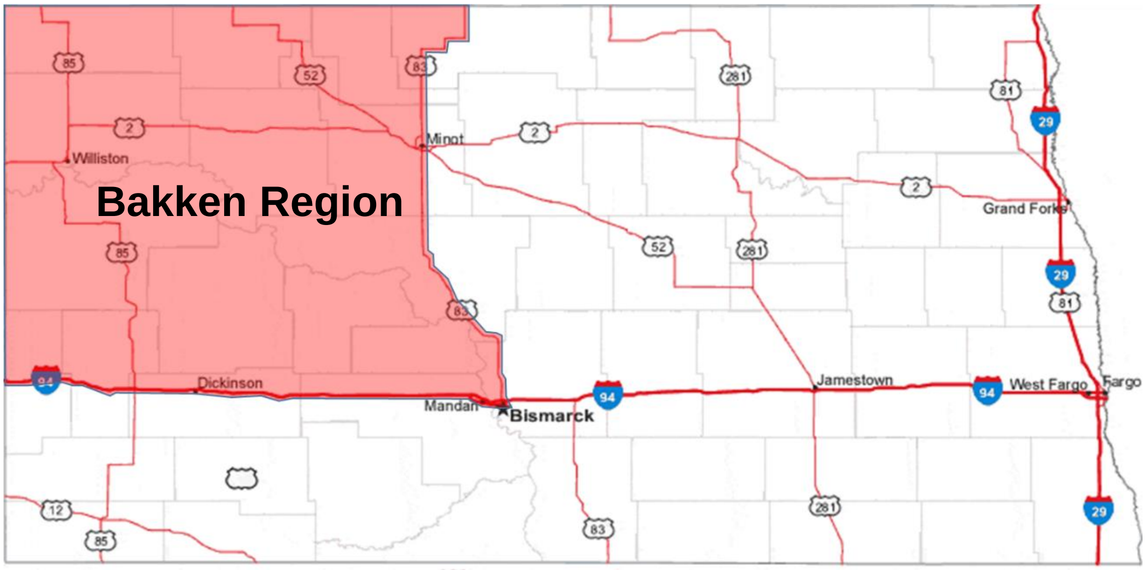

Figure 2.1. Location of the Bakken region in North Dakota.

Municipalities were broken down into three categories based on population size. Small cities are those with populations between 1,000 and 5,000 residents. Additionally, municipalities with populations between 500 and 1,000 residents in the Bakken region are also considered small cities. Medium sized cities have populations between 5,000 and 10,000 residents, with large cities having populations over 10,000. These distinctions were chosen based on the population sizes and number of cities of these sizes within the state.

A questionnaire was developed to assist researchers in determining how municipalities record and store water-use data across the state of North Dakota. Two focus groups were utilized to gauge whether questions would provide insight into water-use data at the city level and to ensure questions were easily understandable. Initially, professionals from academia and the water use industry were consulted to determine the type of information desired and to ensure clarity of questions. After questions were refined, water use professionals at the national level were consulted to review questions and ensure the information collected would help expand knowledge nationally. The questionnaire consisted of two separate parts, with municipalities afforded the option to participate in the first part, second part, or both parts.

Part one of the questionnaire consisted of nine main questions, with some questions containing sub-questions based on responses (Appendix B). The focus of the first set of questions was to determine who is in charge of water-use data in individual municipalities, how this information is recorded and stored, and if this information is public and could be shared with researchers. All municipalities contacted were initially contacted via phone (n=59), with the majority of part one questionnaires administered over the phone by researchers. Three municipalities did not wish to answer questions over the phone, but indicated they would be willing to fill out the questionnaire; therefore, questionnaires were emailed to these cities. All 59 cities participated in the first part of the questionnaire. Part two of the questionnaire consisted of seven main questions, with all questions containing sub-questions depending on responses (Appendix C). This second set of questions focused on the water source for each municipality and if municipalities try to conserve or reduce water through seasonal water rates, conservation measures, or water restrictions. Part two of the questionnaire was administered both over email and via phone interviews. Over half of part two questionnaires were administered via email (n=39). Email was the chosen method for cities whom researchers had previously been in contact with via email, plus it allowed for a large volume of questionnaires to be administered in a short time-frame. Thirty-two of the 39 cities contacted via email answered the questionnaire. The remaining 20 questionnaires were administered over the phone, with 19 of 20 cities participating by answering the questions. Overall, 51 of the 59 municipalities participated in the second part of the survey.

The majority of questions were open-ended, as limited information is available regarding how water-use data are stored. Although questions were open-ended, researchers occasionally provided three to four possible common answers to clarify the type of response they were looking for and to help respondents understand the questions. In addition, questions on conservation measures and water restrictions were accompanied by definitions and examples to ensure that respondents knew what each word meant and what these actions might look like at the city level.

Once answers from all questionnaires were completed by cities willing to participate, information was digitized into Microsoft Excel and data were coded. Due to the nature of the study and the fact that the entire study population answered the first questionnaire and 86% of the population answered the second questionnaire, basic statistics were used to compare answers. Percentages were determined by dividing the number of similar responses by the total number of responses. When large and medium cities were analyzed separately from small cities, the number of responses by the large and medium cities was divided by the total number of responses of that answer, unless otherwise noted.

Results and Discussion

One-hundred percent of municipalities contacted (n=59) answered the first questionnaire. Additionally, 86% (n=51) of cities answered the second questionnaire, with large, medium, and small cities responding 89%, 100%, and 85% of the time respectively. Responses from each question are discussed below. For the purposes of this study, small cities are those with populations between 500 and 5,000 residents (n=46), medium cities 5,000 - 10,000 residents (n=4), and large cities 10,000 or more residents (n=9).

The auditor's office is responsible for collecting and storing water-use data in 68% of municipalities (Figure 2.2a and 2.2b). Public works, finance, and water departments are the next most common divisions in charge of water-use data in 10%, 7%, and 5% of cities respectively. In cities where the auditor's office oversees the water-use data, 95% of these cities are considered small cities. Conversely, 83% of cities that utilized the public works department were medium or large cities. Similarly, 100% of municipalities where the water department was in charge of water data and 50% of municipalities where the finance department was in charge of this data were medium or large cities in the state. Based on these results, it appears that as cities grow in population size, the city government grows concurrently adding additional departments, which can take responsibility for municipal water billings.

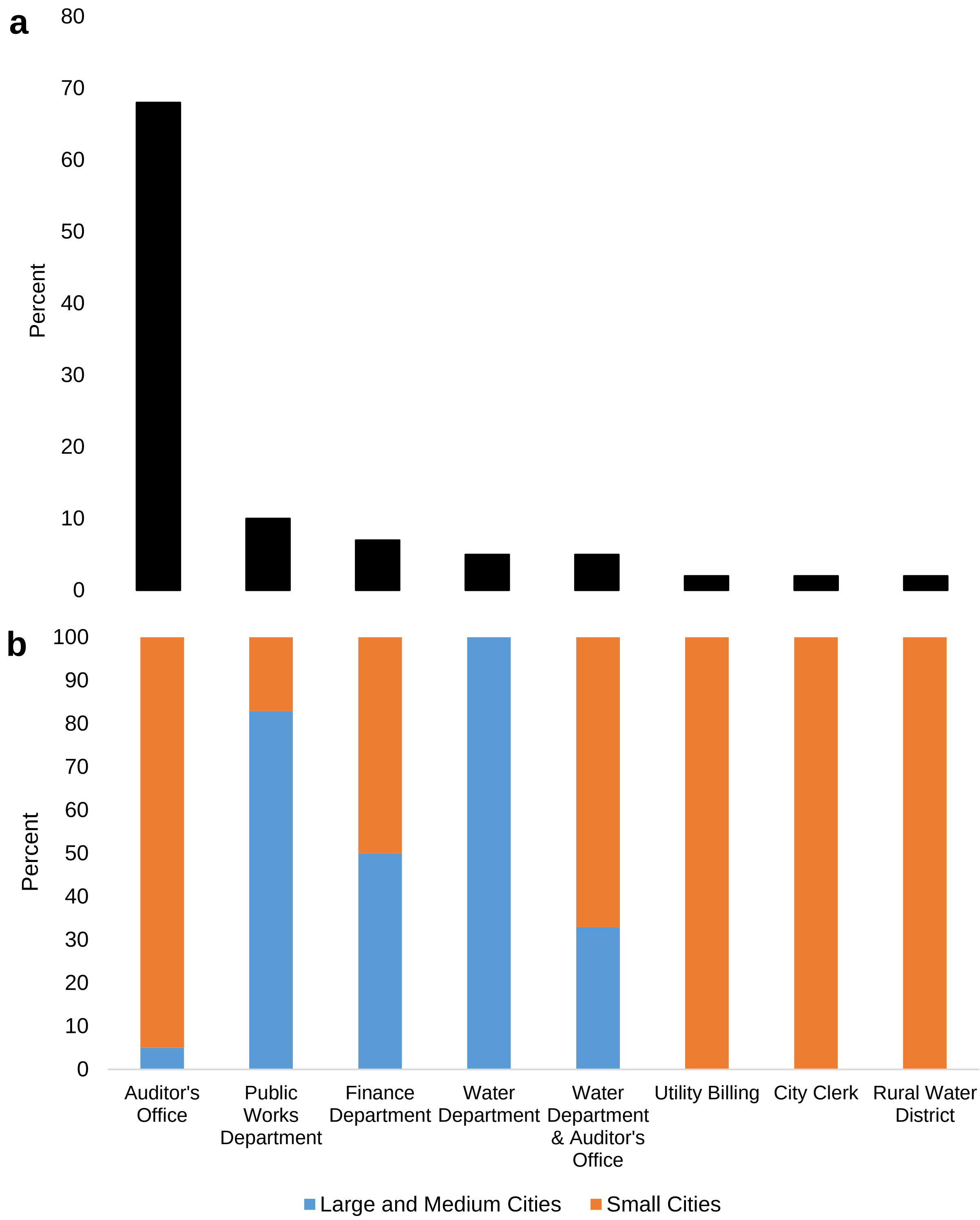

Figure 2.2. Water-use data responsibility within municipalities: a) all municipalities (n=59); b) large and medium (n=13), and small municipalities (n=46), represented as the percent of municipalities within each size category who utilize a specific department.

Data Collection

Water-use data are collected by a variety of methods with few or no standards (Gleick, 2003). This was evident to researchers in this project as well, as the collection of municipal water-use data existed on a continuum from self-reported usage to completely automated readings (Figure 2.3a and 2.3b). The vast majority of municipalities collect water meter readings from their customers (Figure 2.4a and 2.4b). When cities collect this information, it is most commonly collected via radio reads occurring 72% of the time. This method of collection uses radio waves to "ping" meter readings to a computer or receiver that passes by the meter, usually inside the cab of a vehicle driving by on the street. Eleven percent of municipalities still read all meters manually, with another 13% of municipalities using a combination of radio reads and manual reads to collect data from water meters. Notably, 7% of all municipalities still utilize self-reported data as of 2017. Additionally 12% of municipalities use automatic meters, with 71% of these automatic meters found in cities with more than 5,000 residents. Again, city size plays a role in how water use data are collected, with smaller cities more likely to have self-reported data and larger cities more likely to have automatic collection of data via automated meters.

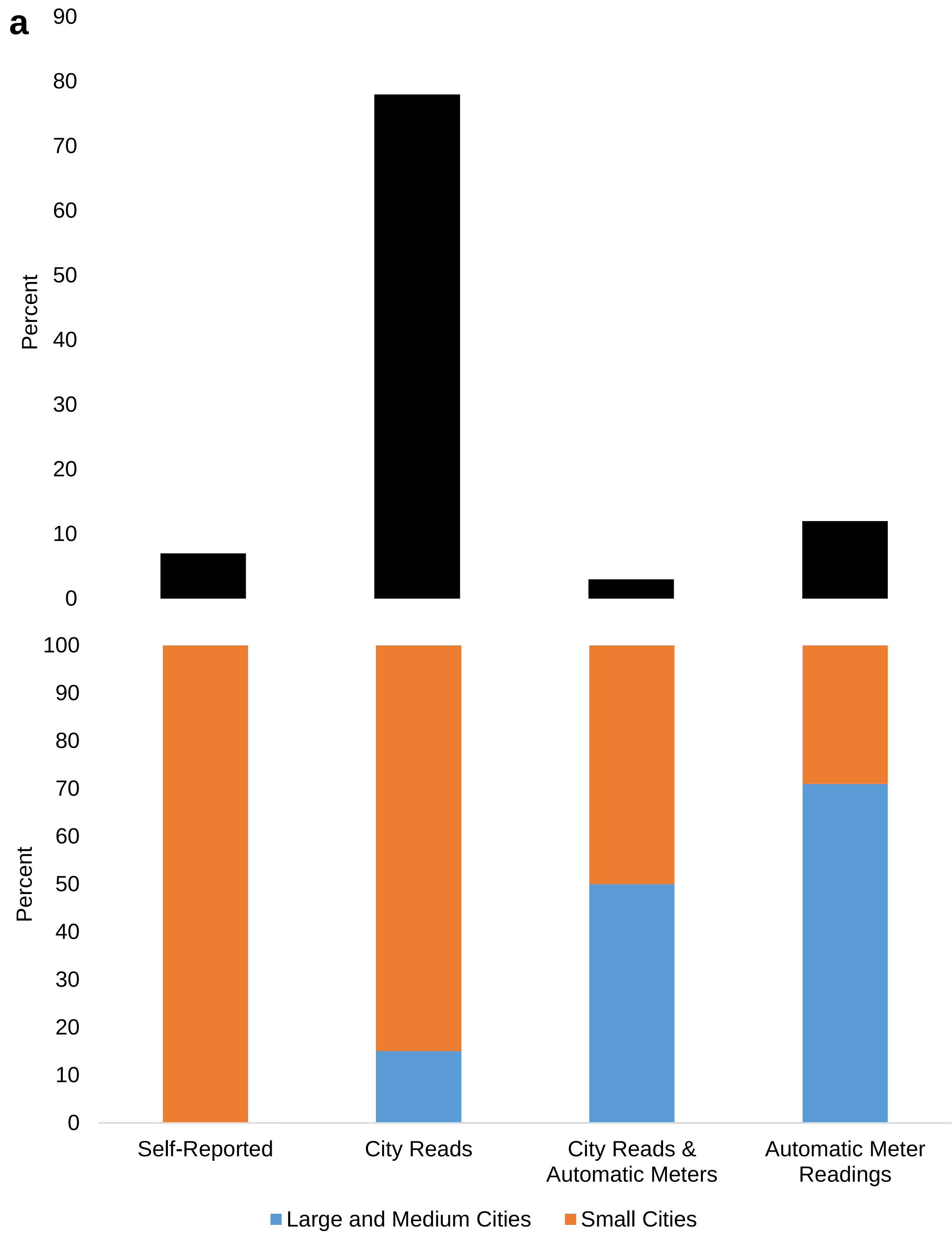

Figure 2.3. Method used by municipalities to collect water-use data: a) all municipalities (n=59); b) large and medium (n=13), and small (n=46) municipalities, represented as the percentage of municipalities within each size category who utilize a specific method.

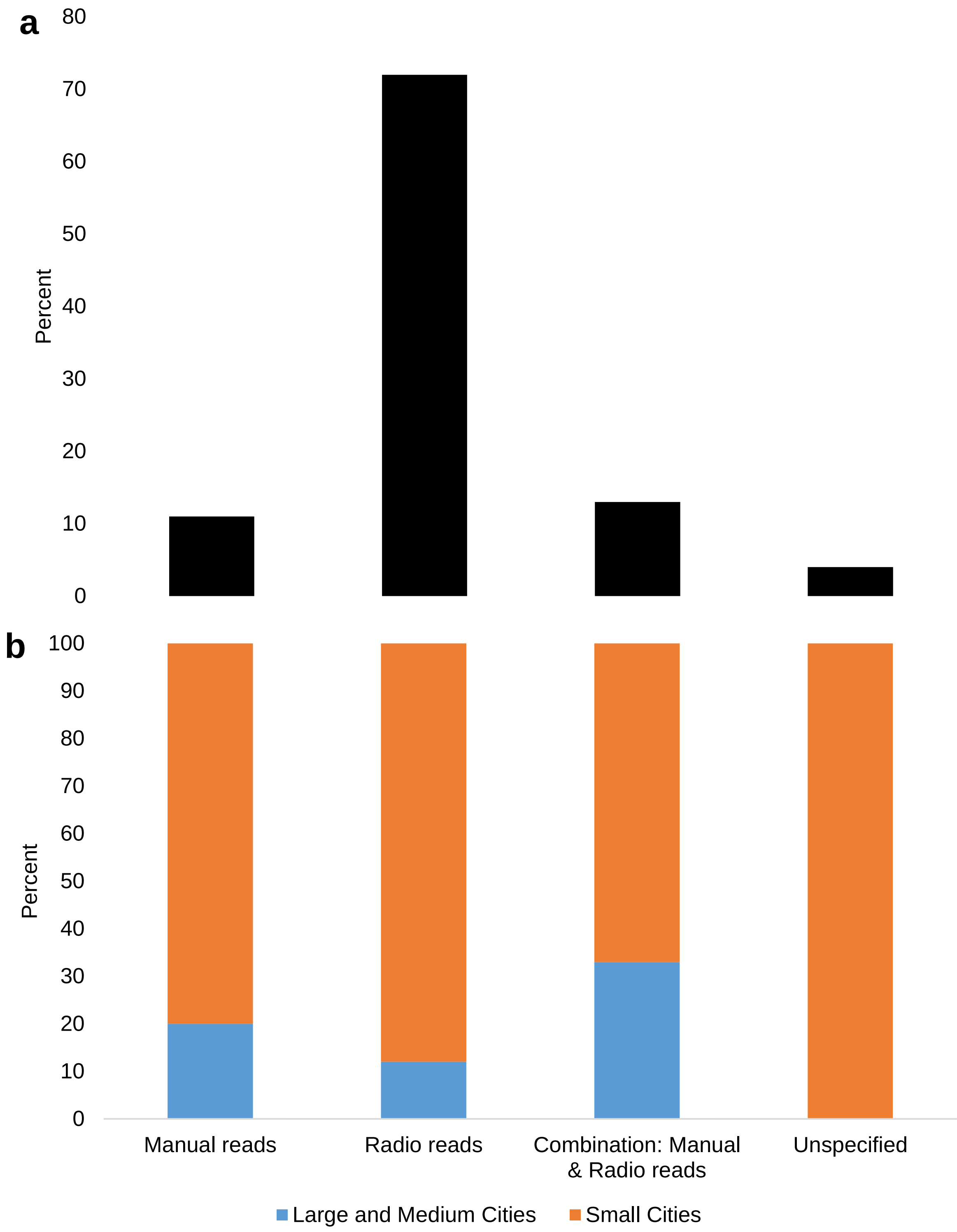

Figure 2.4. Method of water-use data collection by municipalities when city employees collect water meter readings: a) all municipalities (n=46); b) large and medium (n=8), and small (n=38) municipalities, represented as the percentage of municipalities within each size category who utilize a specific method.

Use of automatic meters typically requires a high initial investment, with larger municipalities often having a greater ability to secure funds for these types of meters. A cost-analysis comparing different water meter reading methods in Tampa Bay, Florida, found that automatic meters based on fixed networks were more expensive than meters read via radio-reads, but they offered long-term savings on operational costs (McKenzie & Houston, 2011). Additionally, automatic meters eliminate the need for city staff to read meters, either manually or via radio reads, allowing staff to focus their attention on other tasks. Conversely, smaller municipalities may not have the funds to invest in automatic meters and collection of meter readings may not monopolize city employee's time when the city only has a few hundred meters to read compared to thousands of meters larger cities have.

All municipalities with self-reported water-use data had under 5,000 residents. Although only a small fraction of municipalities rely on self-reported data, the validity of this information is unknown. Fifty percent of cities with self-reported data only verify readings if there are discrepancies or non-normal usages, and another 25% have absolutely no verification at all. While the authors are unaware of research specifically focused on the validity and reliability of self-reported water-use data, a study focused on water use in the energy sector demonstrated that self-reported information does not always include all desired information (Averyt et al., 2013). Additionally, a study from the health field indicates that the reliability of self-reported data varies depending on the situation (Shipton et al., 2009). Specifically, the environment and context of questions posed when collecting self-reported data influences how people may answer (Shipton et al., 2009). Thus, it is plausible that people may report inaccurate water meter readings to save money on their water bills. Although no water-use data are perfect (Wong, 1972), self-reported data garners increased speculation regarding its accuracy and reliability.

Water Use Recording Units

Variation in units used to measure water use is common, as data are collected and presented in different forms including acre-feet, liters, hundred-cubic feet, gallons, and cubic-meters (CoSF, 2001; Aly & Wanakule, 2004; Wentz & Gober, 2007; Polebitski & Palmer, 2009; Cole & Stewart, 2013). Gallons was the most common unit used by municipalities, with 83% of municipalities using gallons (Figure 2.5a and 2.5b). Although gallons was the most common unit, there was variation within this unit; cities may record to the exact gallon, record every ten gallons, every hundred gallons, or every thousand gallons. This is similar to what Kenny & Juracek (2012) noted when analyzing data from twenty-one cities in six states. For their study, Kenny & Juracek (2012) received data that was recorded in "various multipliers of gallons", as well as acre-feet and cubic feet. Cubic-feet and hundred cubic-feet were two other units used to record water usage by 14% and 4% of municipalities respectively. The less common units of cubic-feet and hundred cubic-feet were more likely to be used by medium and large cities than by small cities. One hundred percent of those municipalities recording water usage in hundred cubic-feet were large, with populations over 10,000 residents and 50% of municipalities that recorded water usage in cubic-feet were medium or large with populations over 5,000 residents. This is similar to how other municipalities with greater than 10,000 residents in different parts of the nation record water-use data. Studies utilizing water billings from large cities such as Seattle, Washington and Hillsboro, Oregon indicated that those cities recorded their water billing data in hundred-cubic feet (Polebitski & Palmer, 2009; House-Peters et al., 2010).

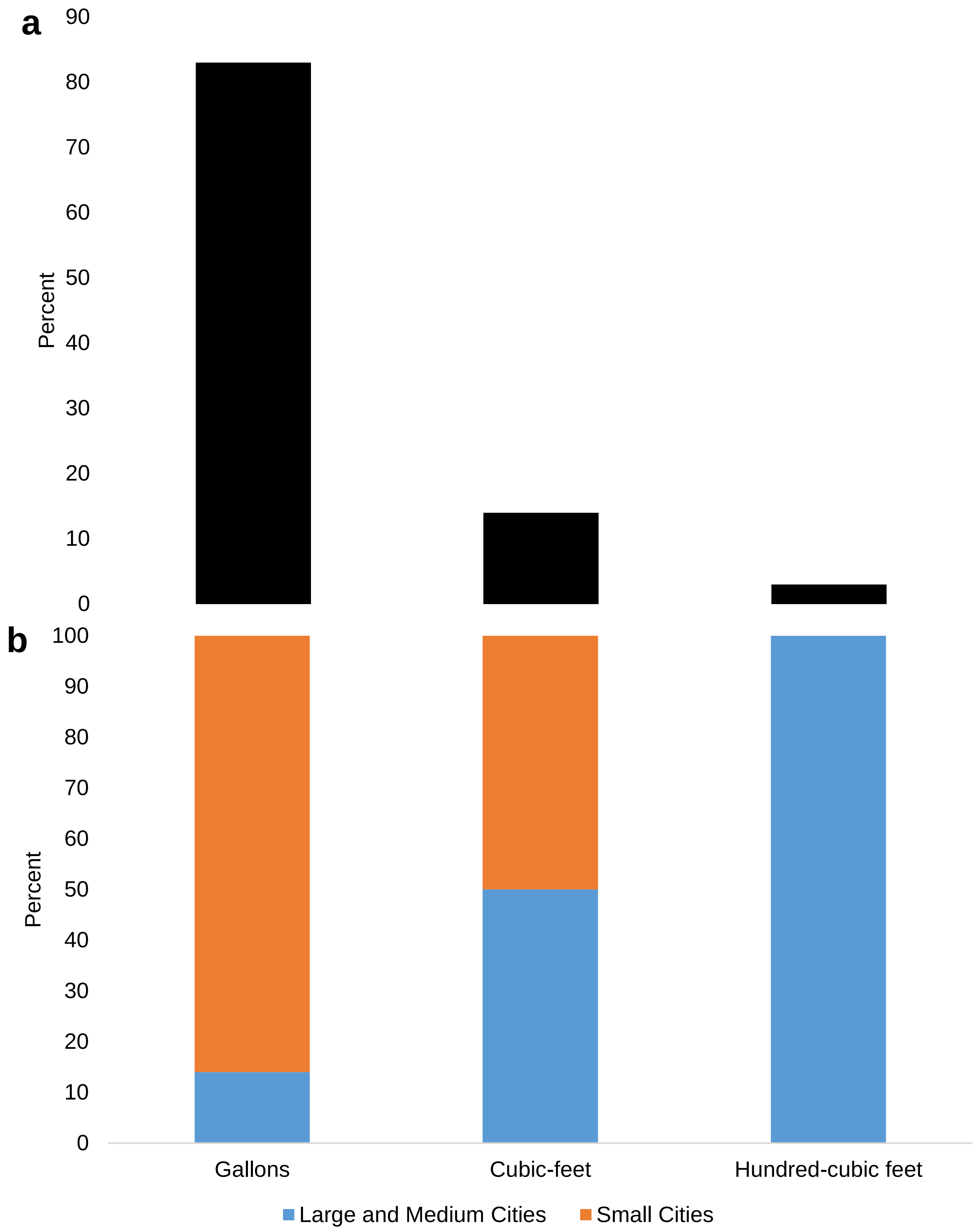

Figure 2.5. Units used to record water usage within municipalities: a) all municipalities (n=59); b) large and medium (n=13), and small (n=46) municipalities, represented as the percentage of municipalities within each size category who measure usage with a specific unit of measure.

Data Categorization

The vast majority of municipal water studies have focused on water use in the residential sector, as this sector often consumes the most water in urban environments (Kim & McCuen, 1979; Grimmond & Oke, 1986; Kostas & Chrysostomos, 2006; Balling & Gober, 2007; Polebitski & Palmer, 2009). Given this fact, determining if municipalities categorize their water accounts (bills) is an important question. Over eighty percent (83%) of municipalities in this study split their water accounts into categories, with 100% of large and medium sized cities separating accounts into categories (Figure 2.6). The most common method for all cities was to categorize accounts into residential and commercial categories, with 73% of municipalities only using these two categories (Figures 2.7 and 2.8). Very few municipalities (6%) have more than three water use categories, and 67% of these cities had populations over 10,000. It is important to note that the number and type of categories received via the questionnaire may not be one-hundred percent accurate. The questionnaire administered to municipalities was part of a larger project examining the influence of city size on water use, with the goal of developing average water use coefficients for different categories and sub-categories of water users. Authors received water-use data, by accounts, from municipalities whom answered the questionnaire and discovered that occasionally there were more category classifications associated with the data then what respondents had indicated via the questionnaire.

Figure 2.6. Percentage of all municipalities (n=59), large and medium (n=13), and small (n=46) municipalities that classify water billings and accounts into categories.

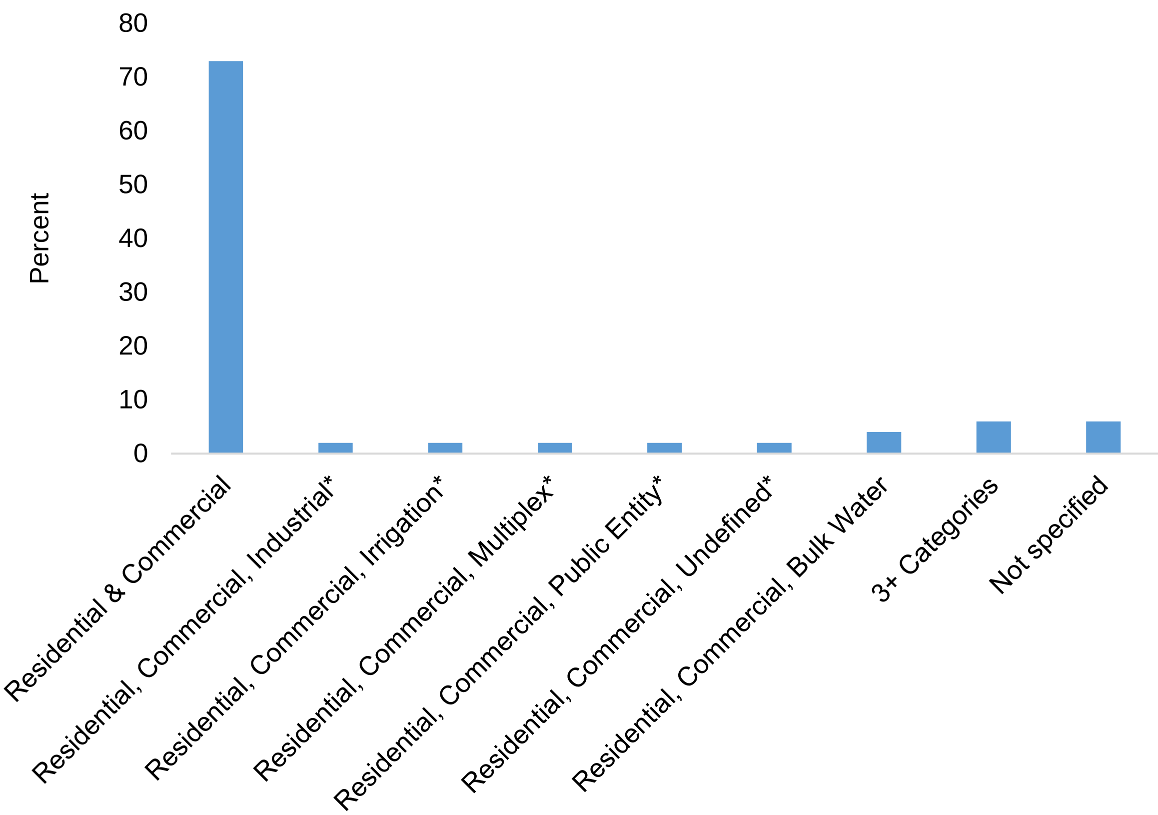

Figure 2.7. Categories used to classify water accounts as percent of all municipalities (n=49) who use specific categories.
Note: * indicates that only one municipality uses the specific classification.

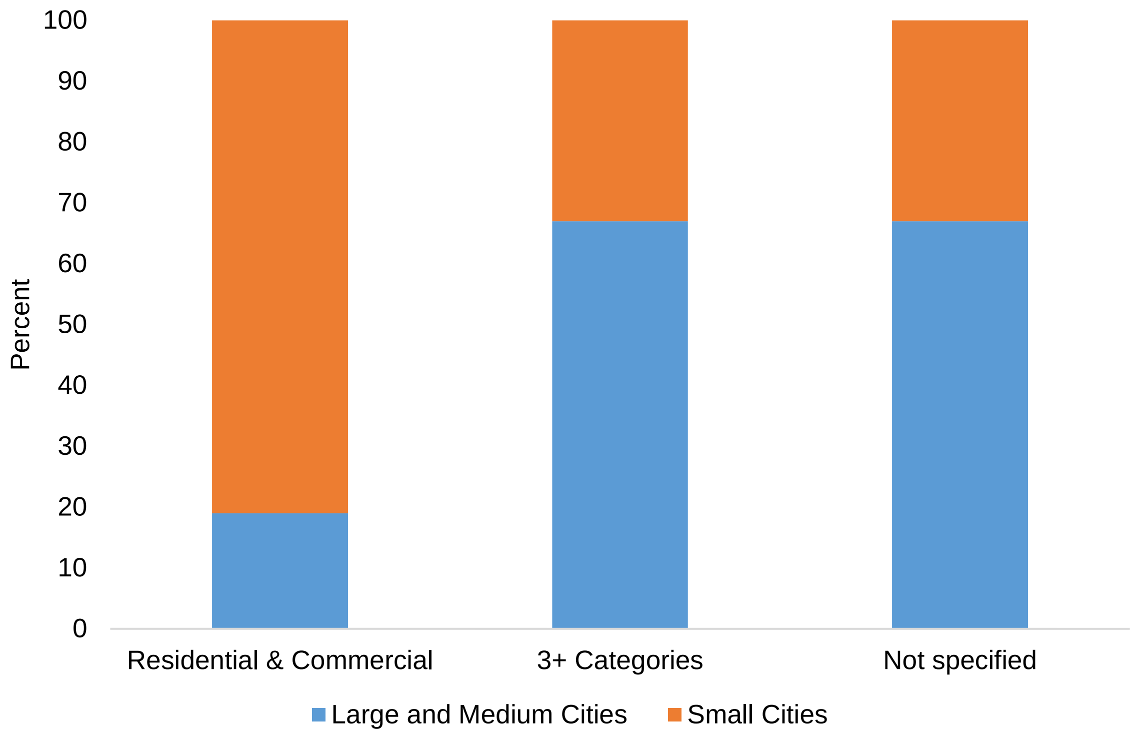

Figure 2.8. Categories used to classify water accounts within large and medium (n=11), and small municipalities (n=31), represented as the percentage of municipalities within each size category who utilize a specific categories.

Data Records Storage

As expected, the majority of water use data are stored electronically. Notably, 3% (n=2) of municipalities still store their data on paper. All cities with only paper records were small cities. Additionally, 16% of municipalities that store their data electronically also have some paper records. Despite the fact that the majority of municipalities store data electronically, the length of time the electronic format has been utilized is an important factor when trying to study long term trends in water use. Generally, most municipalities have been utilizing the electronic format for over five years (Table 2.1). Furthermore, while some cities have stored water use data electronically for over twenty-five years, if the data are only kept for a certain number of years, analysis of twenty-five years' worth of data is not possible.

Table 2.1

Length of time municipalities have stored water-use data electronically, displayed as a percentage of municipalities.

Length of time	All cities
< 5 years	8%
5+ years (5-9)	31%
10+ years (10-14)	24%
15+ years (15-19)	19%
20+ years (20-24)	1%
25+ years (25-29)	5%

Over two thirds (73%) of municipalities have water billing records on file for over five years, while 8% of municipalities have twenty plus years of data (Table 2.2). An uncommon, but interesting, response was that the municipality has water records for the lifespan of the meter. Although this data could provide years' worth of data, a complete set of records for all meters in the city would not be available for the same time frame. In addition, 14% of municipalities indicated they keep records as long as North Dakota Century Code (NDCC) requires. Although this appears to be a logical answer and time frame to abide by, NDCC does not indicate how long water use records have to be kept on file. Therefore, it is unknown how many years' worth of records these municipalities have on record. A few cities whom answered NDCC expanded slightly, but the length of time data was kept on file ranged from four to seven years. Additionally, while a municipality may have water use records for over fifteen years, some of that data may be paper records, making it slightly less useful for trends and analysis purposes. Likewise, multiple cities noted that while they have multiple years' worth of records, some of the data is inaccessible for different reasons. A common reason was the city updated or changed software and the old data are on an old computer or the software is no longer accessible. Additionally, one of the common software packages (Banyon) used to store municipal water-use data only allows the last twelve months of data to be accessed. Thus, the city may have five, ten, or twenty years of data, but only the previous twelve months are accessible.

Table 2.2

Years' worth of water billing records municipalities keep on file, expressed as a percentage of municipalities with data stored for a specific time period.

Length of time data stored	All cities
< 5 years	10%
5+ years (5-9)	24%
10+ years (10-14)	27%
15+ years (15-19)	14%
20+ years (20-24)	8%
Follow ND Century Code	14%
Lifespan of meter	2%
Unknown	2%

In general, city size did not influence how far back a city has water-use records or how long the city has stored data electronically. However, the storage location of the data was influenced by city size. Seventy-five percent of municipalities use one of two utility billing software (Black Mountain and Banyon) to store their water use data. Twelve other software packages were used to store water-use data (Appendix D). Eighty-eight percent of cities using one of the two common software programs were small, while over half (62%) of the uncommon software packages were used by medium and large cities. The differences in software choice may be due to the ease of use and functions the software can accomplish. Larger municipalities not only have more accounts and information, but may also store additional information in the software. Furthermore, the method of data collection (self-reported, city collected, automatic meters) may influence software choice, as 78% of all cities that have automatic meters used one of the uncommon software programs.

Although certain aspects of municipal water-use data are influenced by city size, other facets are not. How often water meter readings are taken is not influenced by municipality size. Ninety-eight percent of municipalities collect and record water use data monthly. The other 2% (n=1) collect water readings quarterly. Many studies in the past have utilized monthly or bi-monthly water consumption data (Morales et al., 2009; Polebitski & Palmer, 2009; House-Peters et al., 2010; Mini et al., 2014), indicating that water meter readings are collected similarly throughout the country. Since the majority of data are collected monthly, it is no surprise that over 95% of municipalities store this information monthly. Only 3% (n=2) of cities store water use data yearly, although 19% of municipalities that store water-use data monthly also store it yearly. How data are stored temporally influences the type of analysis that can be carried out. For example, analysis of seasonal water trends is possible with monthly data, but not with yearly data.

As previously mentioned, this questionnaire was administered as part of a larger project examining the influence of city size on water use. As such, municipalities were asked if they would be willing to share one or two years' worth of monthly water-use (billing) data with researchers. To the author's knowledge, the information requested was all public information, although 3% of cities said it was not public information. Ninety-seven percent of cities stated the data was public, with 44% of cities sharing their municipal water-use data with researchers. The 53% of cities that did not share water use data, but indicated it was public, provided a variety of reasons for not sharing data (Table 2.3). Kenny & Juracek (2012) noted that obtaining requested data from cities without assistance from a state reporting program was more difficult than when the state collected such information. This makes our success rate (42%) impressive, as North Dakota does not have a state reporting program for the type of water-use data researchers were seeking. The top two reasons for not sharing water consumption data included the city was too busy and did not have time to help (26%) and the city could not create a report with the data researchers requested (26%). Interestingly enough, 78% of cities that indicated they could not create a report with the data researchers were looking for, technically likely could have, as other cities with the same software created reports that suited the needs of the study. Additionally, 6% of municipalities said they were not able to share names associated with the data. Although names were not required (or even preferred by researchers), researchers did require some way to classify the data into water use categories (both commercial and residential). Without names, an address or another means of determining which category each water bill was associated with was necessary, otherwise data was not useful to researchers.

Table 2.3

Reasons municipalities did not share data with researchers expressed as the percentage of municipalities answering a certain way.

Reason for not sharing data	All Cities
Can't create report with data requested	26%
Don't have time/too busy	26%
Can't share names	6%
Not Public Information	6%
Data messed up	3%
No reason given	32%

Buying and Selling Water

Due to the location, quantity available, and quality of water throughout the state, many municipalities buy the water they sell to their municipal customers. Over half (53%) of cities with populations over 500 residents buy some or all of the water they sell to their municipal customers, with the majority (93%) of municipalities buying water from rural water districts or rural water projects. In North Dakota, rural water projects are larger in size, providing municipal water to multiple counties and tens of thousands of residents (NDSWC, 2017). Rural water districts, on the other hand, are smaller in nature, usually encompassing only a few counties.

Small cities are more likely to purchase water than medium or large cities, with 59% of small cities purchasing some or all of their water, while only 31% of large and medium cities purchase water. When large cities buy water, they most commonly purchase water from a rural water project, while small cities are more likely to purchase water from a rural water district. These findings may be due to the locations of cities. The majority (75%) of large and medium cities that purchase water are located towards the western side of North Dakota, which is also where the rural water projects are located in the state (Figure 2.9). Additionally, rural water districts cover the majority of the state (Figure 2.10). Thus, since there are more small cities than medium or large cities in the state, and smaller cities are more likely to purchase water, it makes sense they would buy more water from rural water districts than larger cities.

City size is not the only factor that influences if a city buys water. Location of municipalities also appears to play a role in purchasing water. Municipalities located in the Bakken region are more likely to purchase water than municipalities located outside this region, with 71% of cities located in the Bakken purchasing water, while only 37% of cities outside this region buy water. A major reason for this, is due to the accessibility of quality potable water. In many areas of the state, aquifer accessibility and water quality are a problem. Many water sources have relatively high levels of certain elements, such as arsenic and uranium (Roberts, 1992; NDDoH, 2006; NDDoH, 2015; EWG, 2018). Thus, water supply projects (rural water projects) were developed, and are continually expanding, to provide adequate supplies of quality water to residents in North Dakota.

The entity that municipalities purchase water from depends on their location in the state (Figures 2.11 through 2.13). Cities in the Bakken region are more likely to purchase water from a rural water project, whereas municipalities not located in the Bakken region are more likely to purchase water from a rural water district. This can again be explained by spatial location of municipalities in the state, as most rural water projects are located in and around the Bakken region.

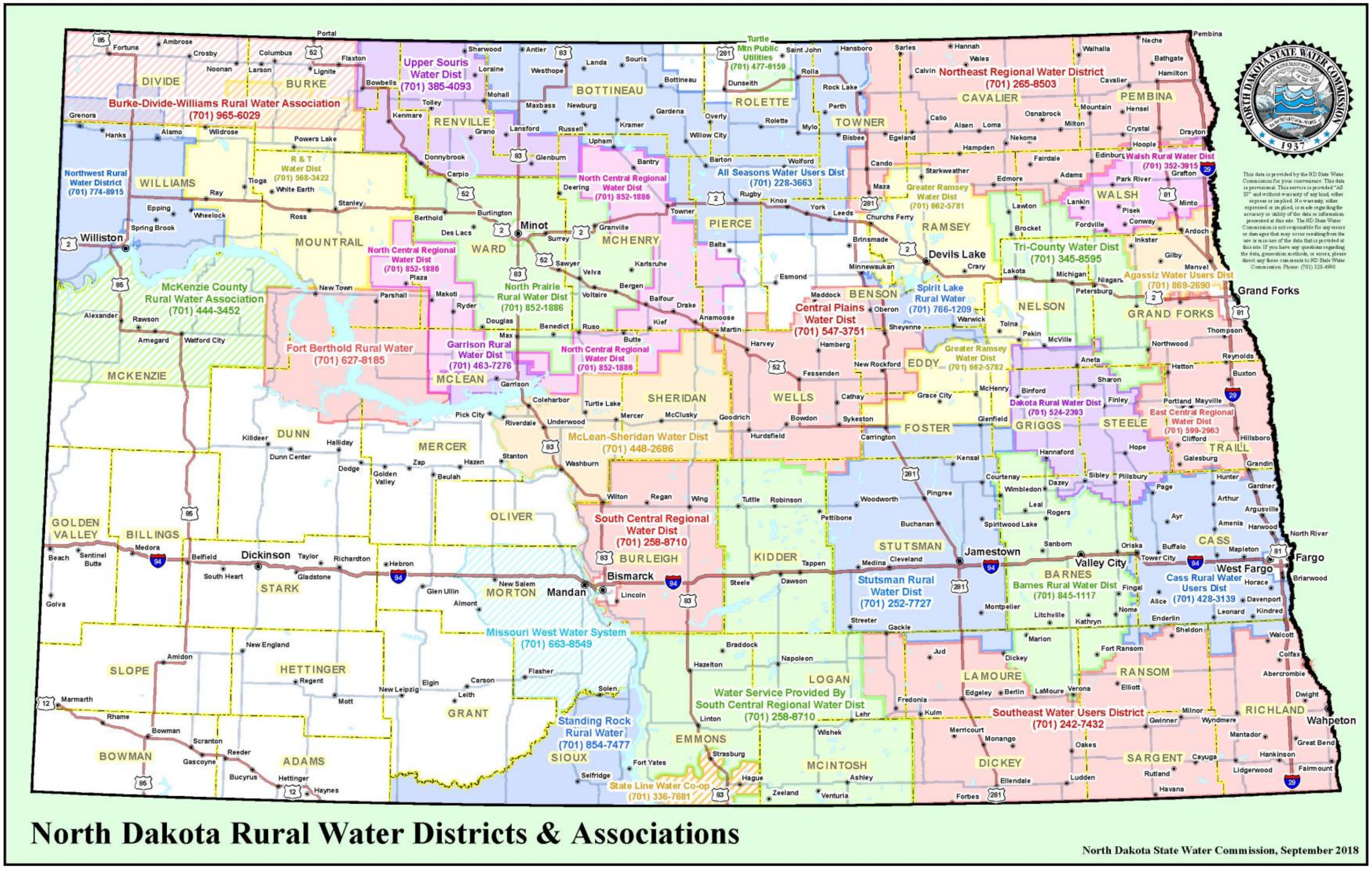

Figure 2.9. Map of rural water districts in North Dakota (NDSWC, 2018a).

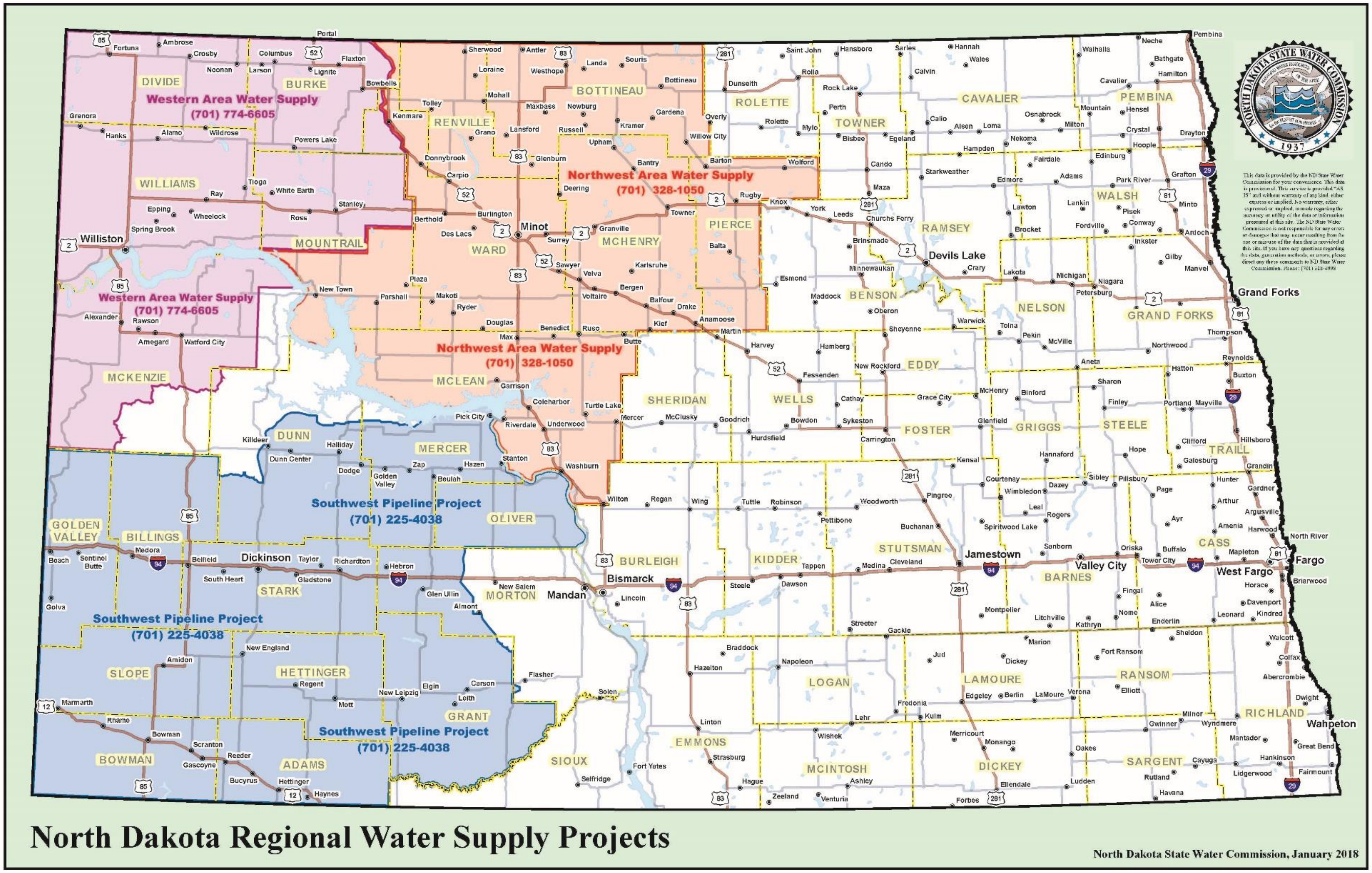

Figure 2.10. Map of rural water projects in North Dakota (NDSWC, 2018b).

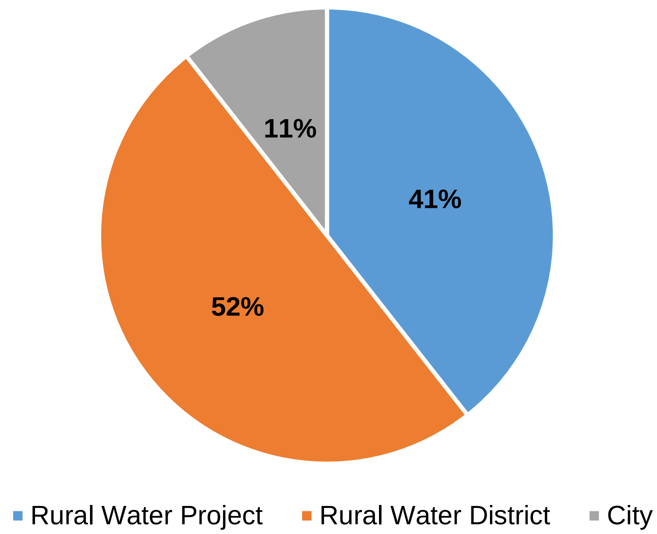

Figure 2.11. Entity whom municipalities purchase water from, expressed as a percentage (n=27). Note: percentages do not necessarily add up to 100% as some municipalities buy from more than one entity.

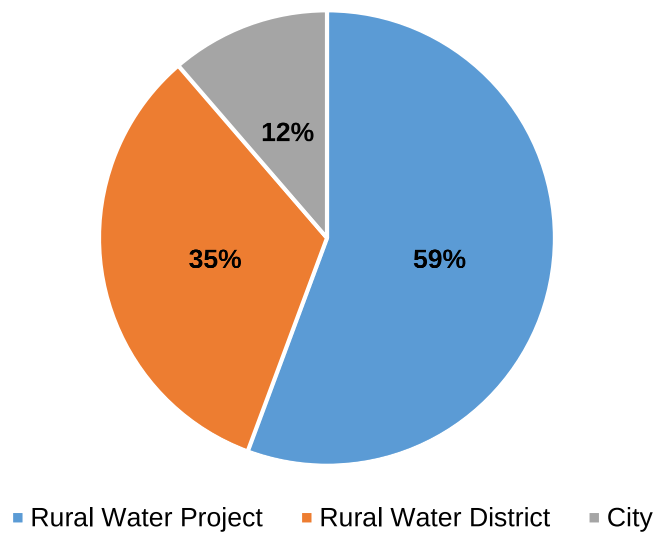

Figure 2.12. Entity whom municipalities in the Bakken region purchase water from, expressed as a percentage (n=17).
Note: percentages do not necessarily add up to 100% as some municipalities buy from more than one entity.

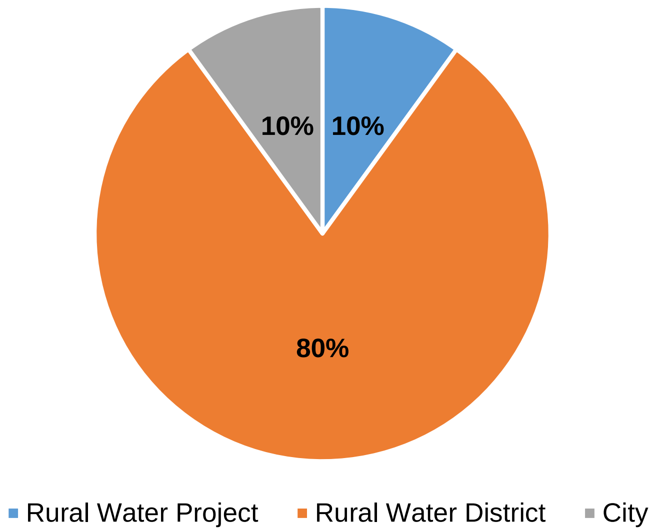

Figure 2.13. Entity whom municipalities located outside the Bakken region purchase water from, expressed as a percentage (n=10).

Conversely to buying, over half (55%) of cities sell water to more than just their municipal customers. Approximately half of cities that buy or sell water do both, while only 22% of cities neither buy nor sell water. Fifty-four percent of municipalities that sell water, sell bulk water (Table 2.4). Bulk water includes water sold to industry (including the oil industry), for agricultural purposes, construction, or other miscellaneous uses. Most commonly, bulk water is sold to farmers for agricultural purposes or to industry. Small cities were far more likely to have a water depot and sell bulk water than medium or large cities. Although city size influenced whom water is sold to, there is not a difference in the likelihood of cities selling water, based on population size, with 50% of large and medium, and 56% of small cities selling water. Moreover, over half (60%) of municipalities selling bulk water were located in the Bakken region. Bulk water sales in the Bakken region can be explained by two factors. One, this region of the state is where bulk water sales to industry take place, as water is sold for mining, oil, and gas. Additionally, a precipitation gradient covers the state with the eastern side receiving more precipitation and the western part of the state receiving less precipitation (NOAA, 2018). Thus, water for many purposes may be in higher demand in the western part of the state, which coincides with the Bakken region.

Table 2.4

Number of all (n=28), large and medium (n=6), and small (n=22) municipalities that sell water to certain entities.

Entity Sell Water To	All Cities	Large & Medium Cities	Small Cities
Bulk Water	15	2	13
City	2	2	0
Rural Water District	12	4	8
Rural Water Project	1	1	0
Indian Reservation	1	0	1
College	1	1	0
Jail/Prison	1	1	0

Note: some municipalities sell water to more than one entity.

In order to manage water resources, knowledge of the water source is needed. Water permits in North Dakota are issued by the North Dakota State Water Commission (NDSWC) when over 12.5 acre-feet of water is withdrawn per year (N.D.C.C. § 61-04-02). Thus, all municipalities that withdraw their own surface or ground water should have a permit issued by the state. Groundwater is the most common source of municipal water, with 59% of municipalities obtaining at least part of their water from underground aquifers (Table 2.5). Specific sources of water for each municipality can be found in Appendix E. Nationally, 61% of water is from surface water, while 38% is from groundwater (Dieter & Maupin, 2017). This highlights the variability in water sources geographically, as North Dakota’s water sources appear to be opposite of the national average. Furthermore, because many municipalities purchase their water from another entity (city, rural water district, rural water project) at least 25% do not withdraw water at all. Furthermore, the majority of municipalities generally knew where their water came from (i.e. groundwater or surface water), but 29% did not know the exact source, such as the specific body of water or aquifer. Although the NDSWC keeps records on water sources and withdrawals, misinformation about water sources can cause problems (Averyt et al., 2013), especially for future water planning.

Table 2.5

Percentage of municipalities who withdraw municipal water from different water sources.

Water Source	All Cities
Surface Water	16
Groundwater	55
Surface & Groundwater	4
*Not Applicable	25

*Not Applicable are municipalities who purchase their water and the city does not withdraw any water.

Water Conservation Measures

Since water is one of the most important natural resources on earth and exhibits characteristics of both renewable and non-renewable resources, the topic of water conservation has become an important topic recently (Arbués et al., 2003; Bradley, 2004; Gleick & Palaniappan, 2010). Water conservation can mean many things, but in its most basic form, it simply refers to reducing water use (Gleick, 2003; Hauber-Davidson & Idris, 2006). For the purposes of this study, water conservation measures were defined as long-term measures that prevent the excessive or wasteful use of water, and only 14% of cities had water conservation measures. All cities whom indicated they had water conservation measures indicated they replaced old meters with new meters that were assumed to be more efficient. Although meter replacement may not directly conserve water, meters that are more efficient can provide more accurate readings and should help identify possible leaks, which should reduce the amount of water lost. Additionally, one city installed additional flow meters and leak monitoring, while a second city provides a water analytics program to their customers to monitor their usage.

Furthermore, implementation of water conservation measures was not based on city size or location. As previously mentioned, the western side of the state, which encompasses the Bakken region, generally has a drier climate than the central and eastern part of North Dakota. Although only 14% (n=7) of total cities in North Dakota have water conservation measures, 57% (n=4) of those municipalities are located in the Bakken region (Figure 2.14). Past studies examining water conservation measures, including watering rates and restrictions, have generally been conducted in arid climates or areas experiencing drought (Loaiciga & Renehan, 1997; Kenney et al., 2004; Mini et al., 2014). Additionally, many practices and technologies that improve water use efficiency have been developed in areas lacking abundant water (Gleick, 2003), indicating that locations where water resources are scarce are more likely to use and adapt water conserving practices and technologies than water rich locations. Although the results of municipalities with conservation measures in the Bakken region and outside the Bakken region were fairly similar, there is a general trend to the drier side of the state having more conservation measures.

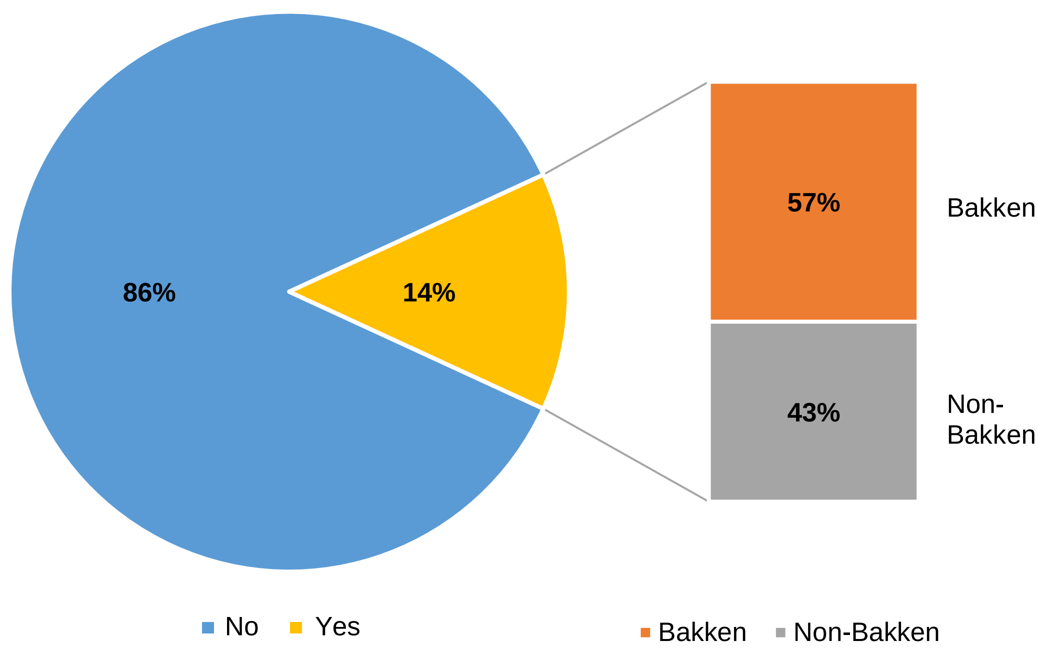

Figure 2.14. Percentage of all municipalities (n=51) who have water conservation measures, excluding outdoor watering restrictions and seasonal watering rates. Of municipalities with water conservation measures (n=7) divided in to Bakken vs. Non-Bakken areas.

Many studies examining water conservation measures or potential ways to reduce water consumption have occurred in large municipalities (Loaiciga & Renehan, 1997; Polebitski & Palmer, 2009; Mini et al., 2014; Mini et al., 2015). Larger municipalities generally feel greater pressure, regarding urbanization, on water resources than smaller municipalities (Fielding et al., 2013). Yet, city size did not play a large role in municipalities adopting water conservation measures, with slightly more small municipalities having water conservation measures in North Dakota than larger municipalities (Figure 2.15). One important item regarding cities in North Dakota though, is there are not many cities with over 5,000 residents (n=13) and even fewer with over 10,000 residents (n=9). Thus, it is not too surprising that city size does not play a role in municipalities adopting water conservation measures in North Dakota.

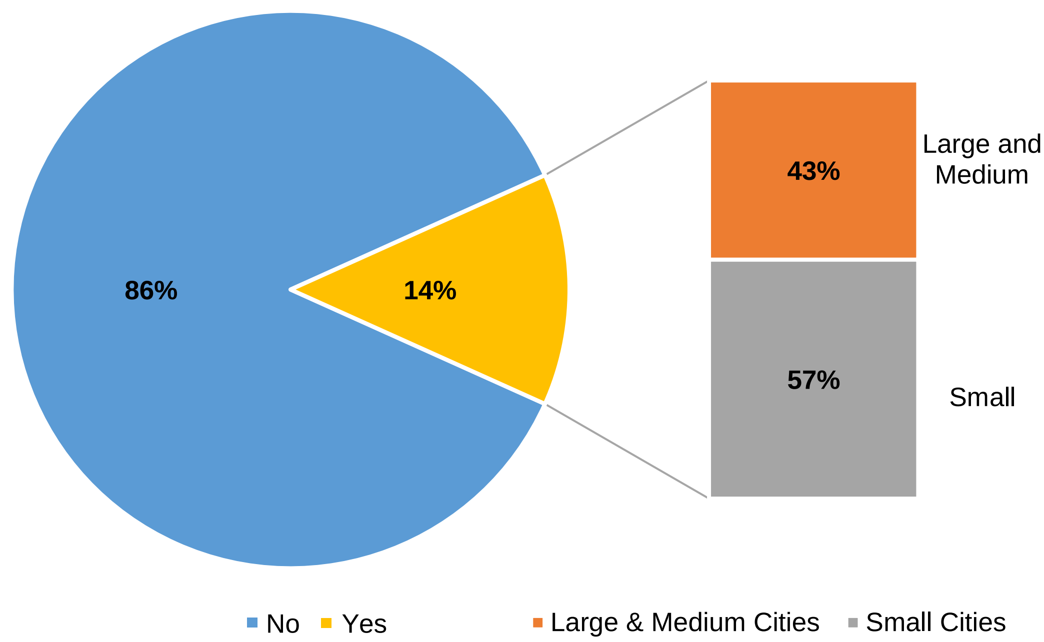

Figure 2.15. Percentage of all municipalities (n=51) who have water conservation measures, excluding outdoor watering restrictions and seasonal watering rates. Of municipalities with water conservation measures (n=7) broken down into city size categories.

One method identified as an option to reduce water use is the price of water or water rates (Loaiciga & Renehan, 1997). Only 2% (n=1) of cities in North Dakota applied seasonal water rates to customers. Although water rates are usually used as a method to reduce excessive irrigation by increasing the cost of water in the summer time (Lyman, 1992; Polebitski & Palmer, 2009), the city that applied seasonal rates in North Dakota provided cheaper rates in the summer time than winter time. Winter rates, in this city, are the average water usage January through March. The amount of water used over this base winter rate in June through September is then applied the summer seasonal rate, which is cheaper than the winter rate. Therefore, while seasonal rates in this study are very uncommon, when seasonal rates are applied, they do not discourage water use.

Watering restrictions are another common method that attempts to reduce water used for outdoor purposes (Halich & Stephenson, 2009). In North Dakota, over half (59%) of municipalities never have watering restrictions, while only 6% of municipalities have restrictions every year. Additionally, 35% of municipalities only have watering restrictions in certain situations, such as droughts. In general, city size and location did not affect municipalities having watering restrictions. When municipalities have watering restrictions every year, regardless of weather, they are generally focused on outdoor irrigation. Restrictions are applied throughout the city with addresses determining what days people are allowed to irrigate their yards. The length of time restrictions are in place depends on the city, with some restrictions only in place during the summertime (Memorial Day through Labor Day), while others run from spring through fall (April through October). Not surprisingly, when cities have yearly watering restrictions, they are based on the honor system, with no enforcement.

Most commonly, when watering restrictions are only used during certain circumstances, they are usually used in times of drought. Seventy-eight percent of the time, restrictions are put into places due to a drought, although the severity of drought and conditions of implementation varied greatly between municipalities (Figure 2.16), with some municipalities implementing watering restrictions in dry summers and others waiting until a county drought emergency has been declared. During periodic watering restrictions, limiting outdoor water used for washing cars and watering lawns is the most common restriction, occurring 56% of the time. Even when watering restrictions are in place, it is not uncommon for them to be voluntary with no enforcement.

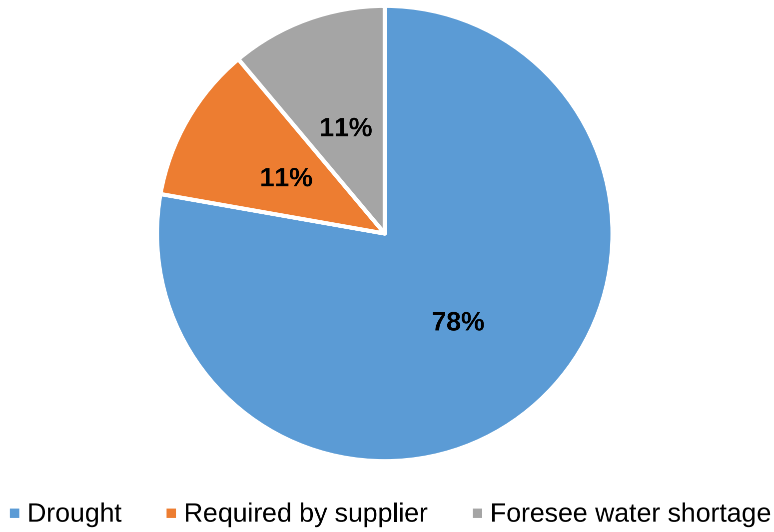

Figure 2.16. Reasons periodic watering restrictions are put into place by municipalities (n=18). Note: "Foresee water shortage" is not necessarily related to drought, and could be related to weather or other reasons.

The use of reclaimed or reused water is another means of reducing the amount of water consumed. Approximately 5% of municipalities in the state use reclaimed or reused water. Of the cities indicating they use this type of water, 67% (n=2) refer to it as reuse water and use it for construction or heating (via a boiler) purposes. The remaining 33% (n=1) of municipalities refer to this water as reclaim water and it is used for irrigation purposes. Two thirds of municipalities using reused water have populations over 5,000 residents and all are located in the Bakken region of the state. As previously mentioned, a precipitation gradient lays across the state, with the amount of annual precipitation received decreasing from east to west (NOAA, 2018). The use of reuse or reclaimed water has the potential to reduce the amount of water withdrawn and increase the supply of water available (Yi et al., 2011). Thus, it is not surprising that all cities who utilize reclaimed or reused water are located on the drier, more drought prone, side of the state, where water resources are less abundant.

Finally, a method that can help monitor the amount of water used by a city is monitoring system losses. Although this is not a direct way to reduce or conserve water, paying attention to water losses can help detect leaks and potentially conserve water by having less water lost to leaks. Over 80% of municipalities monitor or meter system losses, with 83.33% of medium and large sized cities monitoring losses (Appendix F).

Cities that monitor losses generally use one of two methods to determine losses: 1) compare water purchased to water sold; or 2) compare readings from the water plant to water sold (Figure 2.17). Cities also generally look at their losses in terms of gallons lost or the percentage of water lost. Although most municipalities indicated they record losses in terms of gallons, the majority of municipalities provided researchers with their water losses as a percentage. Monitoring water losses is important both at the city and state level, as it can help reduce water lost, which can in turn conserve water and potentially save money.

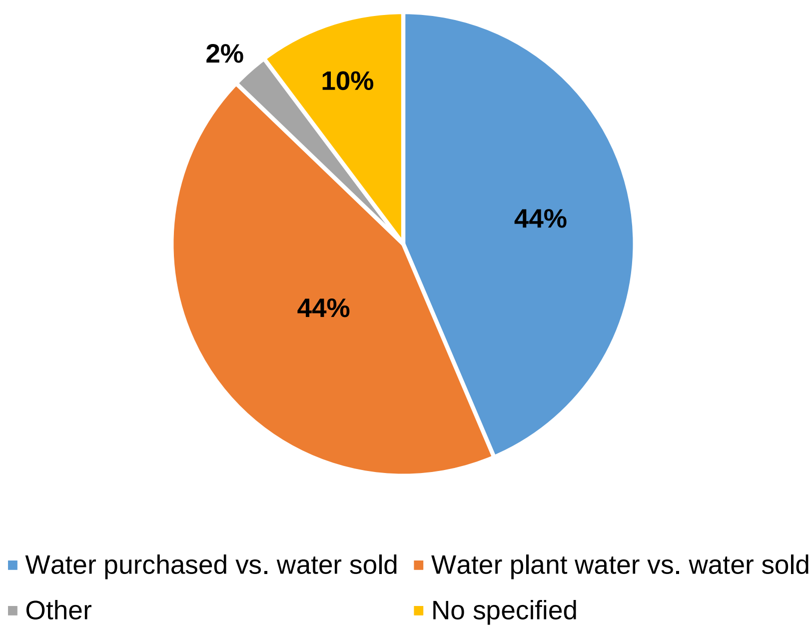

Figure 2.17. Method by which municipalities determine water system losses, as a percentage (n=41).

Management Implications

The purpose of this research was to expand knowledge on how municipal water-use data are stored and gain insight into how water conservation measures are applied at the city level. Water is essential for life and therefore is one of the most important components of municipal utilities. Consequently, knowledge on municipal water-use data is needed to continually increase the accuracy of water use forecasts and better assess the impacts of water conservation measures. This information can not only assist local, state, and national professionals, but can help researchers in making international comparisons, analyzing trends in water use, and creating models and forecasts of future water use.

Certain aspects of municipal water-use data were influenced by city size and location. Self-reported data was used by some small cities, while the use of automatic meters was more common in medium and large cities. Overall, collection of water meter readings via radio reads was most common. Most cities stored their water-use data on the computer, although the specific computer program was influenced by city size. Small cities were more likely to use one of two common utility billing software programs, Black Mountain or Banyon; medium and large cities were more apt to use different types of software, sometimes created specifically for their municipality. The majority of cities had five of more years of water-use records on hand, although the full time frame of data was not always accessible. Knowledge of the length of time data is available for and the reliability of that data (self-reported versus automatic meters) greatly impacts the types of analysis that can be conducted on water-use data.

Water conservation measures were not commonly used in municipalities. Although use of watering rates and reused or reclaimed water was uncommon, city size and location did affect which municipalities used these methods to reduce water consumption. Yearly watering restrictions were uncommon throughout all municipalities, and when watering restrictions were utilized due to drought or water shortages, many times these restrictions were not enforced. Knowledge of water conservation measures across municipalities is important to determine what measures can be taken in the future in case of water shortages.

Information pertaining to water-use data collection, storage location, and length of time data are stored is important to water managers and researchers. This information is especially pertinent to researchers who wish to analyze water-use data, as this knowledge may help them identify usable data and ensure the research they wish to carry out is feasible with the data available. Additionally, information regarding water conservation measures is especially important to water managers. Knowledge on if and how conservation measures are implemented can provide insight into what additional actions could be implemented in times of drought or water stress.

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CHAPTER 3: ANALYSIS OF WATER-USE DATA IN NORTH DAKOTA

Abstract

Quality municipal water-use data is lacking in most areas of the world. Studies focused on municipal water use generally assess either yearly water use for an area, water consumption for short periods of time, or if categories of water use are assessed it is generally either for one city or one category. This is the first study of its kind to analyze water-use data across an entire state to develop per capita coefficients across commercial and residential categories, as well as look at normal commerce water use across different size municipalities. All municipalities in the state of North Dakota with populations over 1,000 residents were asked to participate, with a total of 25 municipalities providing water-use data. Data was verified and then disaggregated to the lowest level possible with over 80 different sub-categories of water users. Cities were classified into three groups based on population size and averages from all sub-categories were compared between different size municipalities to determine if population size influenced the amount of water used per category. Type of residential dwelling (apartment, duplex, townhome, single family home) affected the average amount of water consumed per month. Additionally, food-processing was the largest water user in large cities, while manufacturing and nursing homes/assisted living facilities were the largest users in medium and small cities respectively. Overall, there was a strong relationship between city size and total amount of water used. Results from this study provide valuable information regarding per capita coefficients of water used by different residential and commercial entities in different size cities, as well as provide insight into what new commercial businesses are expected to develop as city size changes. Additionally, information is useful to water managers in different areas to plan for future growth and times of water stress.

Introduction

Municipal water has garnered increased attention recently as professionals try to ensure adequate supplies of water are available as urbanization increases (Wong et al., 2010). Many municipal water studies focus on water use in the residential sector, as this sector typically consumes the most water in urban environments (Kim & McCuen, 1979; Grimmond & Oke, 1986; Kostas & Chrysostomos, 2006; Balling & Gober, 2007; Polebitski & Palmer, 2009; Mini et al., 2014). Additionally, most residential water use studies focus on single family homes (Wentz & Gober, 2007; Polebitski & Palmer, 2009; Mini et al., 2014), with very few studies focused on water consumption in multi-family dwellings (Bradley, 2004). Information on how water is used in the residential sector is extremely valuable when planning for future city growth and preparing for times of water stress. Without a comprehensive assessment of all types of residential dwellings, it is difficult to accurately plan for water needs. Therefore, additional information is needed on water use in multi-family dwellings.

Water consumption by commercial entities is also an important variable in urban water use, but it is not commonly researched (Gleick, 2003). Commercial water use can be difficult to assess due to the variability and intensity of water use, and the diversity of entities and ways in which they use water (Morales et al., 2011). When commercial water use is the focus of research, generally only one or a few commercial users are examined (Kim & McCuen, 1979; Brown, 2002; Farina et al., 2011). Thus, there is a need to comprehensively study all commercial water users in municipalities to determine how water use changes between different types of commercial entities.

The majority of water use research examines water use in large cities, with populations of at least 10,000, but generally with populations over 100,000 (Wentz & Gober, 2007; Polebitski

& Palmer, 2009; House-Peters et al., 2010; Mini et al., 2014). Few, if any studies, have looked at water use in small municipalities, especially municipalities with less than 5,000 residents. It is important to look at different sized cities to determine how population size influences residential and commercial water use patterns.

Many studies regarding municipal water use come from urbanized regions in Australia and China (Zhou et al., 2000; Zhang & Brown, 2005; Stewart et al., 2009; Wong et al., 2010; Cole & Stewart, 2013; Yuan et al., 2014; Zhang et al., 2014). Most studies conducted in the United States (U.S.) are conducted in the arid west, especially California and Arizona (Konieczki & Heilman, 2004; Balling & Gober, 2007; Wentz & Gober, 2007; Mini et al., 2014). Many of these areas experience frequent or prolonged water stress; therefore, these studies generally focus on ways to conserve water and plan for the future. While this information is helpful to locations with similar climate, water availability, and water needs, the results of these studies do not always transfer well to regions of the world that generally have sufficient water to meet the needs of local communities or normal water use. Furthermore, it is important to assess water use during times of normal water use to determine what constitutes normal commerce of water use for residential and commercial categories to help with future planning.

In general, most studies focused on municipal water use focus on a single city (Balling & Gober, 2007; Wentz & Gober, 2007; Polebitski & Palmer, 2009; House-Peters et al., 2010). Occasionally studies examine a small group of cities, but many times the cities are located over a vast geographical area encompassing many different states and sometimes multiple countries (Maidment & Miaou, 1986; Mayer et al., 1999; Dziegielewski et al., 2000). Although studies that utilize multiple different municipalities in different locations can provide enhanced results compared to single city studies, these studies usually utilize cities with very different climates.

This can influence results, as many studies have found relationships between water use and various weather and climatic variables, such as precipitation and temperature (Grimmond & Oke, 1986; Maidment & Miaou, 1986; Zhou et al., 2000; Balling & Gober, 2007; Zhang et al., 2014). Therefore, there is a need to study multiple cities with similar climatic conditions, to develop per capita coefficients.

The goal of this study was to determine what constitutes normal water consumption for different categories of residential and commercial water use in the municipal landscape across the state of North Dakota. Specifically, the study looked at seasonal water trends, per capita coefficients across residential and commercial categories, and how these change across different size municipalities. The information from this project will assist in future water planning for temperate climates that previously had little to no scientific data to plan water use. Additionally, coefficients were developed for different size municipalities to provide tools for water planning as cities grow. The results of this study can help water managers to provide better water use estimates for growth as well as planning for times of water stress.

Methods

The state of North Dakota was the study area for this project. All municipalities with population sizes greater than 1,000 residents (n=53) were contacted to see if they would be willing to share municipal water-use data with researchers. Furthermore, all municipalities with populations between 500 and 1,000 residents in the Bakken region and its margins were contacted (n=6). For the purposes of this project, the Bakken region and its margins (here after referred to as the ‘Bakken’) is approximately defined as the area along and north of Interstate 94 and west of Highway 83 in North Dakota (Figure 3.1). Smaller municipalities were contacted in the Bakken region because this is the region of North Dakota whose population was most affected during the most recent "oil boom".

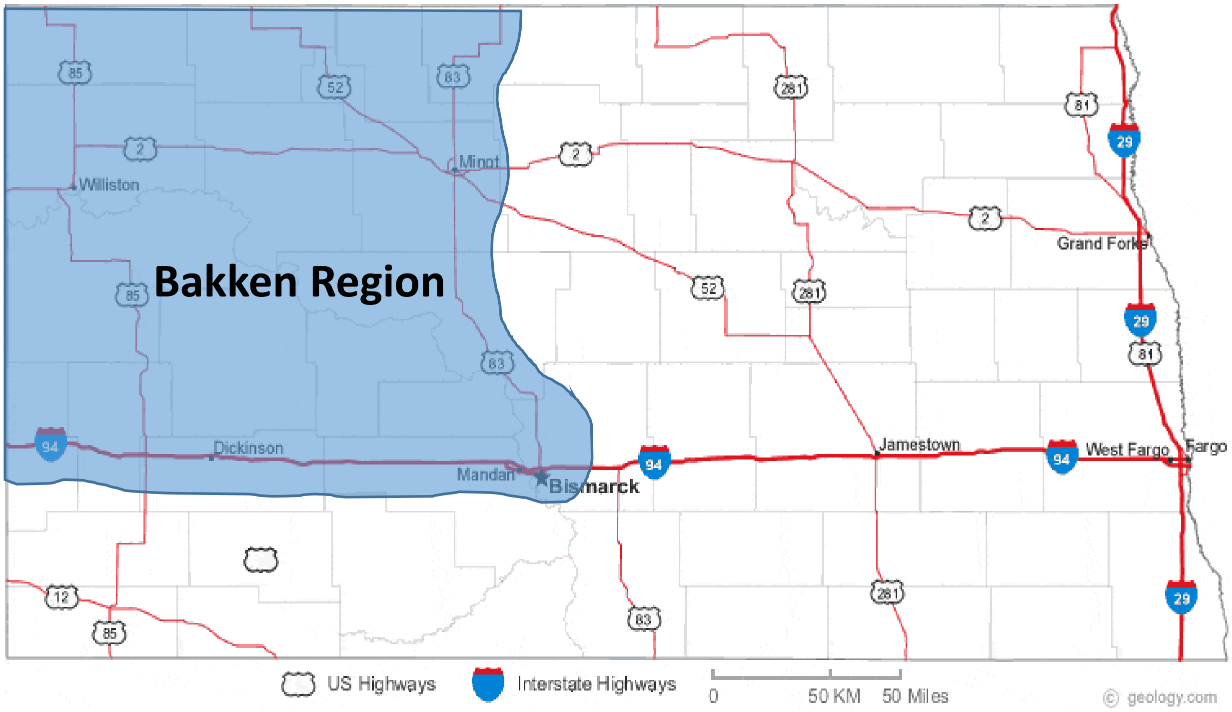


Figure 3.1. Map of North Dakota indicating what is considered the Bakken region for the study.

Since approximately 2010, increasing oil prices caused North Dakota's Bakken oil shale formation to become increasingly cost-effective to extract oil. Consequently, as oil production started to increase, so did population. From 2010 to 2015, North Dakota's population increased 12.5% or by approximately 84,000 people (USCB, 2015). Although not all growth occurred in the Bakken region, Munasib and Rickman (2015) estimated that 70,000 jobs were created. Even though all workers did not permanently move to North Dakota, municipalities saw extraordinary increases in local populations, as workers needed housing. Williston, North Dakota almost doubled in size from 2010 to 2015, while Watford City, North Dakota saw its population skyrocket from 1,744 to 6,708 (USCB, 2016). Since population was increasing in this area of the state and the fact that larger cities consume more water overall, researchers wanted to examine additional cities in this region.

All 59 municipalities were originally contacted via phone. Researchers described the project over the phone and initially asked if cities would be willing to share individual water meter data. If municipalities said they would be willing to share data or might be able to share depending on specific details, an email was sent to explain the project in more detail and provide the exact description of the type of data researchers were seeking. Researchers continued follow-up with cities via email if no response was received within two or three weeks. After three follow-up emails were sent with no response, researchers called the city and inquired about the possibility of receiving data. If cities still stated they would share data during the second phone call and yet did not share data or reply to emails, researchers physically drove to these select cities (n=7) to inquire about their water-use data. After a physical visit to the city, those cities whom indicated they would share data, received up to three additional follow-up emails about three weeks apart (first email was sent the day after the city visit, second was sent three weeks later, third was sent another three weeks later). If no response was received two months after the city visit, the city was no longer considered willing to share their data.

Twenty-five municipalities throughout the state of North Dakota were willing and able to share water-use data in the form of water billing information (individual accounts associated with all water meters and the amount of water used). Forty-two percent of municipalities contacted shared data; 33% of large cities, 75% of medium sized cities, and 41% of small cities contacted shared data. Water billing information was received in multiple ways and a variety of formats. The majority of data was received via email, either in the form of Microsoft Excel (Excel) files or as Portable Document Formats (PDFs). Paper copies of data were physically picked up by researchers from three cities, with one additional city mailing paper copies via the U.S. Postal Service. To make data cohesive and easy to work with, all data was moved or entered into Excel files. Data received as physical paper copies was manually typed into Excel, and information was reviewed to ensure data was accurately entered. Information received as PDF documents was exported to Excel or Microsoft Word using Adobe Acrobat Reader Pro.

Twenty-four municipalities shared water billing data associated with individual accounts, while one municipality shared water-use data grouped into categories used by the city to classify water accounts in their software. All individual accounts were classified to the lowest level possible. Categories were originally developed utilizing North Dakota Century Code (NDCC) categories and the United States Geological Survey (USGS) water use and withdrawal categories. North Dakota Century Code includes six water use categories that encompass domestic, municipal, livestock, irrigation, industrial, and fish, wildlife, and other outdoor recreational uses (N.D.C.C. § 61-04), while the USGS water use categories include public supply, domestic, irrigation, livestock, aquaculture, industrial, mining, and thermoelectric power (Maupin et al., 2014). Researchers separated these main categories into sub-categories with similar purposes and water use such as hotel or hotel with pool. In total this created 82 different sub-categories including six residential categories (Table 3.1) and 76 commercial categories (Table 3.4).

Municipal data was classified and sorted based on the associated account information received. Except for one city that provided individual accounts, all other cities provided reports which provided water usage per meter for the city and associated account information to distinguish and classify accounts. Most water consumption reports utilized one of two methods to distinguish residential and commercial water meters. One type of report had a “user type” column indicating if the account and associated water use was associated with a commercial account or residential property. The other method of distinguishing commercial and residential accounts was based on account numbers, with certain account numbers corresponding to commercial and residential accounts. When account numbers were utilized to distinguish account types, the city would indicate in the report, via email, or over the phone which numbers were associated with which account type. Generally, the first number determined the account type (“01-” or “02-“), although for a few cities the account type switched once a certain number was reached (i.e. less than 70000 residential, over 70000 commercial). Additionally, multiple cities did not want to share names associated with residential accounts, but were happy to share commercial account names. Thus, the city would delete names in the “account name” column for residential accounts and leave the commercial account names, making it easy to distinguish the two types of accounts. This was used as a starting point for distinguishing these two broad categories, commercial and residential.

The majority of municipalities provided names associated with commercial accounts. Some municipalities did not wish to share actual business names, and thus went through the data and labeled all commercial accounts as to the type of business each account was associated with, while other municipalities provided addresses for commercial accounts. Google, Google Maps, Bing Maps, Facebook, and municipality websites were used to determine the type of business each account was associated with based on business name or address, before placing it into its respective category.

When account classifications did not match the associated name, for example a user type of commercial with an account name of Jane Doe, clarification was sought. As previous studies have stated, data quality can vary greatly and it is not always valid and reliable (Kenny &

Juracek, 2012; Averyt et al., 2013). Thus, to ensure the most accurate per capita coefficients and normal commerce calculations possible, all accounts with questions and contradicting account information were discussed with the respective municipality to ensure the account was classified as accurately as possible.

Of the 82 categories, six were associated with the residential water use sector. Generally, duplexes, townhomes, apartments, and single family homes were not separated into individual categories by municipalities. For the purposes of this study, single family homes are homes that stand alone, duplexes contain two units and have a shared wall, townhomes contain three or more "homes" with shared walls, and apartments are buildings with more than 3 units connected both vertically and horizontally. Duplexes, as well as condominiums (condos), were occasionally classified differently than single family homes by certain municipalities, while apartments were located in both residential and commercial categories depending on the municipality. Even when multi-unit dwellings were classified separately from single family homes, they were not always correct. To ensure the data was as accurate as possible, researchers utilized Google Maps, Bing Maps, and county GIS (Geographic Information Systems) parcel/tax information to locate multi-family dwellings.

While virtually "driving" the streets of cities, researchers recorded all duplexes, townhomes, and apartments observed to try and match these dwellings to accounts with help from the city's water billing department. During this process, addresses of duplexes, townhomes, and apartments were recorded on a piece of paper. If the address was not visible on Google Maps, researchers either looked at Bing Maps or the county GIS parcel viewer. Generally, county GIS tax parcel viewers provided the property address, so this method of address identification was preferred. Not all counties in North Dakota have a countywide GIS system with city parcel information; therefore, when no GIS was available, Bing Maps was used to attempt to determine the property address. In rare instances where addresses could not be determined, a description of the property and where it was located in the city was recorded. After all addresses in question were recorded, an email with questions was sent to the municipality asking if it would be possible to associate addresses with account numbers in order to allow researchers to separate different dwelling types. This method was used to classify multi-family dwellings for the vast majority of cities in the study.

Due to the fact that it is difficult, if not impossible, to distinguish condos from townhomes, duplexes, and apartments based on photographs alone, all multi-family dwellings were based upon appearance and condos was not a sub-category researchers used. In rare instances where the city had accounts classified as condos, or the account name had condo in it (e.g. Eagle Run Condo Association), researchers attempted to determine the type of dwelling (i.e. townhome or apartment). If researchers were not able to determine which category the condo belonged in, the account was excluded from sub-category analysis, but was included in total residential water use analysis.

All accounts were classified into a single sub-category. Occasionally, accounts were not able to be classified into a specific category, either because there was no way to distinguish certain accounts (e.g. could not determine which accounts were duplexes and which were single family homes) or because the account was a single meter, but two different categories used water (e.g. business on main floor with apartment above business both using a single meter). When this occurred, these accounts were not included in sub-category analysis, but were included in large picture analysis of residential and commercial water usage.

To examine the influence of city size on average water use in different sub-categories, cities were broken down based on population size. For the purposes of this project, small cities have populations between 500 and 5,000 residents. Medium sized cities have between 5,000 and 10,000 residents, while large cities have more than 10,000 residents. These city size classes were chosen based on population sizes and number of cities in North Dakota with these populations.

Monthly data for individual accounts for 2016, and if possible 2015, were requested from municipalities. Additionally, when working with cities, it was discovered that one type of utility billing software (Banyon) only allows the past 12 months of data to be accessed. Thus, some data received contained readings from both 2016 and 2017 (a 12-month rolling year). To account for temporal differences in data, averages for each city were developed before averages for each sub-category were calculated at the city size group level. When a city provided monthly data for 2015 and 2016, all 24 months were used to create the cities monthly average usage per account for each respective sub-category. Additionally, regardless if one calendar year or a "rolling" year of data was provided, 12 months of data were used to create cities monthly averages for sub-categories in which only 12 months of data was provided by the city. Although there were temporal differences in the data and weather conditions are different each year, this factor is offset by spatial differences in the data. North Dakota is over 500 kilometers long. Data from a municipality on the Minnesota/North Dakota border was analyzed, as was data from a municipality near the North Dakota/Montana border. A precipitation gradient covers the state from east to west, with average amount of precipitation decreasing from 22 inches (56 cm) in the east to 14 inches (36 cm) in the west (NOAA, 2018). Additionally, North Dakota is a state with extreme temperature fluctuations. The average summertime temperature ranges from 65°F (18°C) in the northeast to 72°F (22°C) in the south, and the western side of the state averages more days above 90°F (32°C) than the east, highlighting the variability of temperatures in North Dakota (NOAA, 2018). Thus, weather conditions in the same year could be different on opposite sides of the state. Therefore, since weather conditions could be different for different cities, differences in the time frame of data received were not considered a major obstacle.

Per capita coefficients were developed by creating average water used per account in each city for a specific sub-category and then taking the average of all averages for each city size to develop per capita coefficients for each population group. Additionally, water use per account for all accounts in a specific sub-category were analyzed to determine if there was a linear relationship between water used per account and city size for all commercial sub-categories. Simple linear regression was used and the coefficient of determination (r^2 value) was used to judge the strength of the relationship. When information regarding number of hotel rooms, number of beds/units in assisted living and nursing home facilities, number of beds in hospitals, and number of bays associated with carwashes was available, average monthly per unit water use was determined.

Results and Discussion

Initially, 59 cities were contacted and asked if they would be willing to share data, with 42% (n=25) of cities sharing data with researchers and 96% of cities whom shared data (n=24) providing data for all individual accounts in the city. After accounts were classified, per capita coefficients and average monthly water use per category was determined for different sized city groups. Additionally, citywide analysis of water use seasonality and residential versus commercial consumption was conducted.

There was a slight trend (r^2=0.17) between city size and percent of water used by the residential sector in cities (Figure 3.2). Overall, the trend of residential water consumption in

North Dakota followed the same pattern that other studies have found in the past, with over half of municipal water used in the residential sector (Zhang & Brown, 2005; Balling & Gober, 2007; Mini et al., 2014). Additionally, in the majority of cities in North Dakota, residential water accounted for between 50 and 80% of all municipal water. This is not all that surprising as Vickers (2001a) reported this is a common amount of water consumed by the residential sector in the U.S. When residential water use is examined more closely, it shows that cities whose residential sector utilized more than 70% of the city's municipal water were small. Furthermore, two small municipalities used more than 90% of their total water in the residential sector, with one city using 98% of their water residentially. Thus, these small cities use very little commercial water, indicating that only a few businesses use water from the municipal water permit or there are very few commercial water users in small cities. Although these high usages may be related to the small city being close to larger cities, small cities have been shown to be more variable in their water consumption (Maidment & Miaou, 1986).

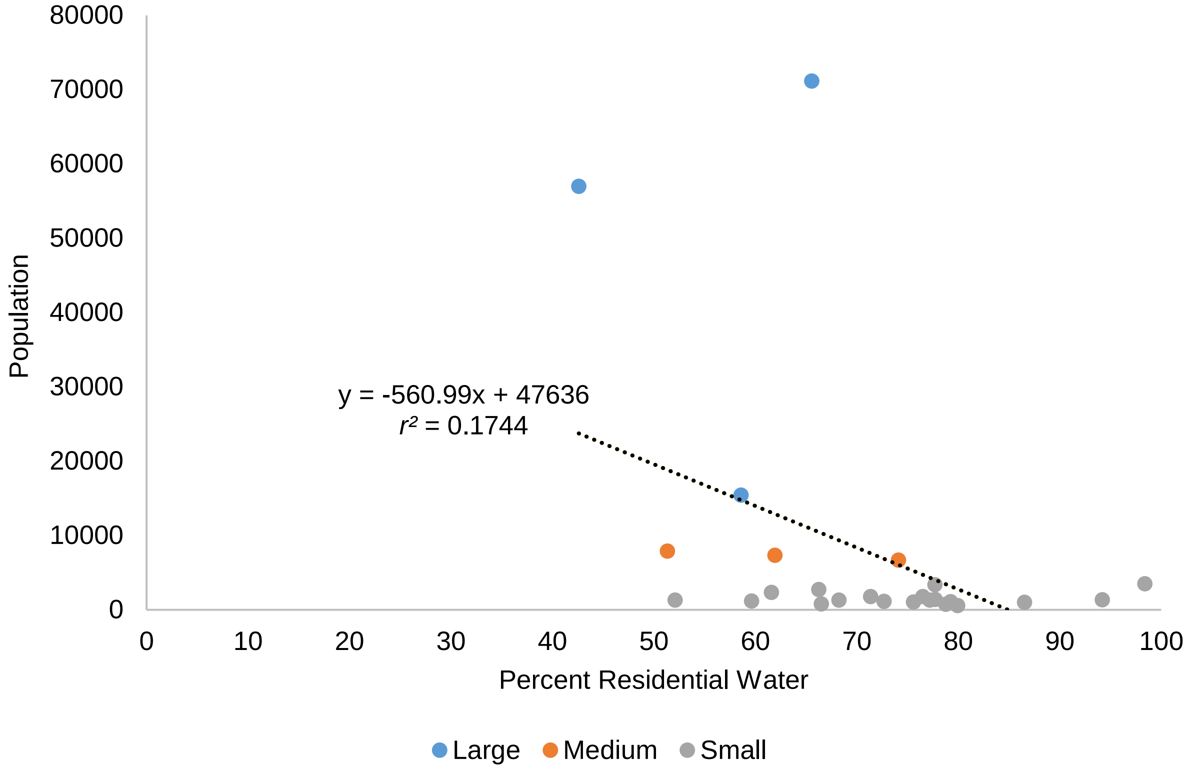


Figure 3.2. Percent of total municipal water used by the residential sector in large (n=3), medium (n=3), and small (n=19) cities.

Total Water Use

There is a strong relationship between city size and total amount of water used in cities (r^2=0.99) (Figure 3.3). In North Dakota, this means one can predict the average amount of water used in a city based on the population. Because this relationship is so strong, water managers can use any deviation from this relationship as a reason to investigate water use. When total water usage is broken down into residential and commercial water users, the trend between city size and residential (r^2=0.94) or commercial (r^2=0.94) water still exists, although there is slightly more variation. Appendix G includes each individual city, population, total, commercial, and residential water use.

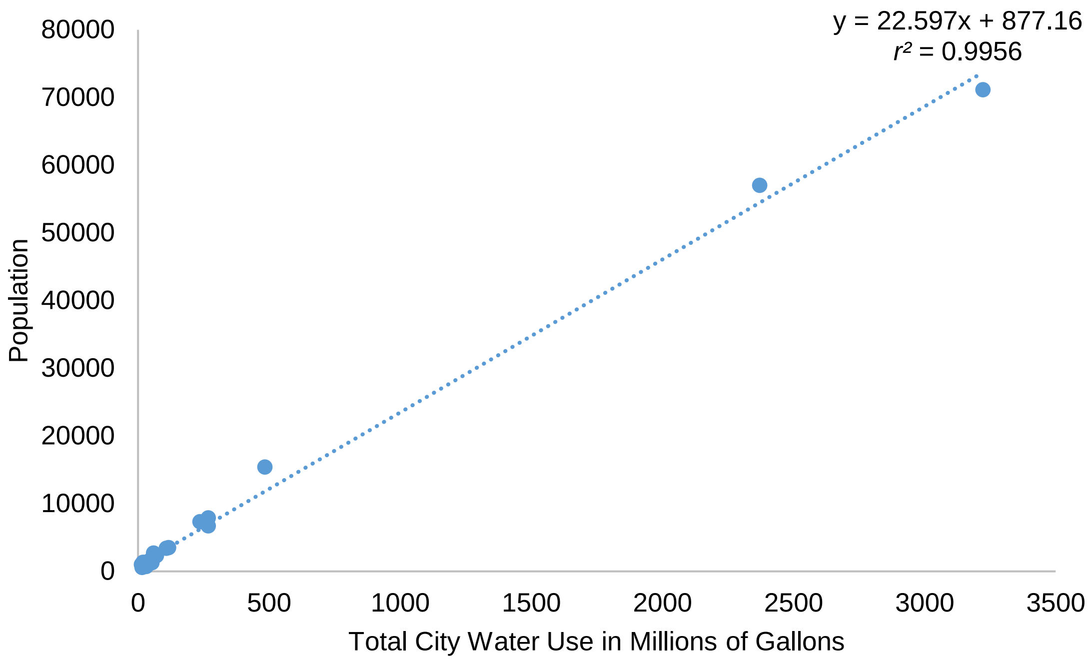


Figure 3.3. Total water used by cities in millions of gallons.
Note: when two years of data were received, the average was used for total water use.

Total water use was also compared to city tax revenue. Tax revenues for the North Dakota fiscal year of 2015 were used (NDTC, 2016), with three cities, Burlington, Lincoln, and Thompson excluded from analysis because researchers were unable to obtain tax information for those cities. Overall, there was a relationship between tax revenue collected in cities and the total amount of water used (r^2=0.92). This relationship was strongest for commercial water use (r^2=0.96) (Figure 3.4) and weaker for residential water use (r^2=0.80). Although the relationship for commercial water use and tax revenue is strong, there is variation, especially in small cities. Tax revenue as an economic indicator for small cities may be less predictive of water use because of the variability in small cities. Some small cities have a large commercial sector, while other small cities contain very little commercial industry. Thus, with such great variability in the make-up of small cities, utilization of an economic indicator may be less predictive of water use, although it can still be useful for predicting total water use.

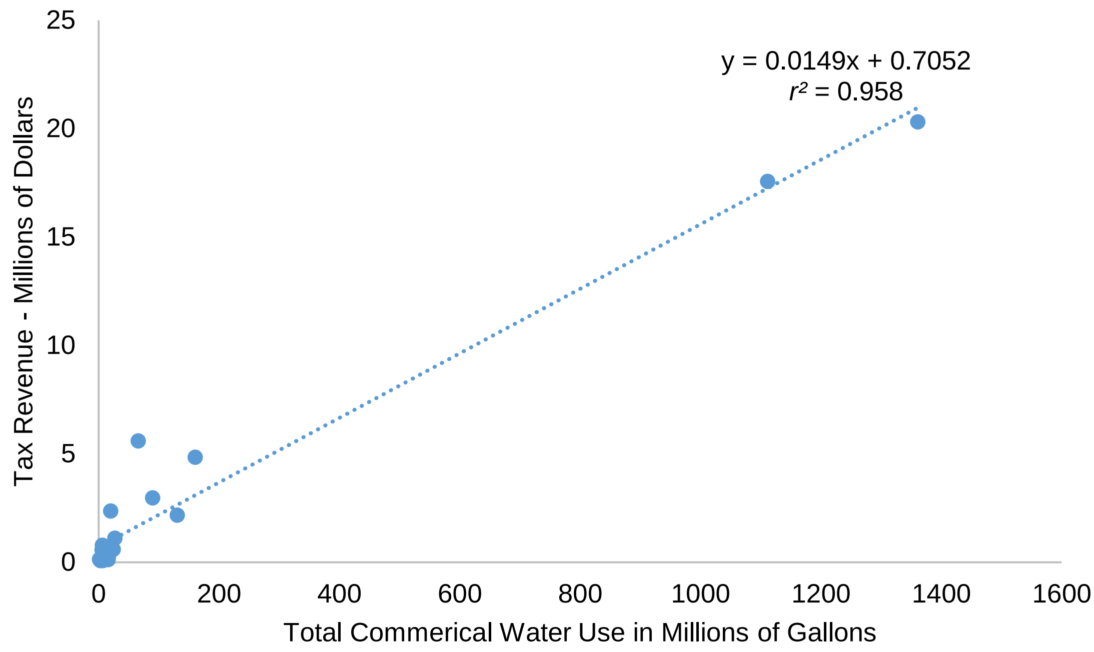


Figure 3.4. Total commercial water used by cities in millions of gallons.
Note: when two years of data were received, the average was used for total water use.

Water Use Seasonality

Many studies have shown that water use throughout the year is not uniform (Wentz & Gober, 2007; House-Peters et al., 2010; Cole & Stewart, 2013; Mini et al., 2014). The seasonality of water use was determined for 24 out of the 25 cities by creating a ratio of maximum and minimum use. Minimum use, or base water use, generally occurs in the wintertime, while maximum use occurs during the summer time, generally due to outdoor water use as shown in other studies (Polebitski & Palmer, 2009; Cole & Stewart, 2013). Minimum use in the current study was consider the month that used the least amount of water in the city falling between December and March. This period of time generally has little to no outdoor water usage in North Dakota and so it was considered citywide base use. Maximum use was considered the month that used the greatest amount of water in the city, falling between June and September. The seasonal water use ratio was calculated by dividing the amount of water used in the maximum month (June – September) by the amount of water used in the minimum month (December – March), which displays the variation in the amount of water consumed between minimum and maximum monthly use. Additionally, one city was excluded from seasonal analysis because the data was billed at a base use for 10 months of the year, with actual readings only taken two months out of the year, resulting in inaccurate seasonal usage.

The majority of cities (n=15) had seasonal water ratios of less than two, indicating that during the month in the summer when water usage for the city was at its highest, it was less than double the amount of water used during the lowest water usage month in the winter (Figure 3.5). On the flip side, four cities used over triple the amount of water in their highest usage month compared to their lowest usage month. The city with the highest seasonal water use ratio, Watford City, North Dakota, is a medium sized city located in the Bakken region. Watford City had a seasonal water use ratio of 7.48, indicating they used over seven times the amount of water during their highest usage month. Once their seasonal water usage was broken down into commercial and residential usage, it was obvious that the residential usage was influencing water use seasonality, as the residential and commercial seasonal ratios were 11.89 and 2.4 respectively. Thus, the residential sector in this city used extraordinarily more water in the summer than in the winter.

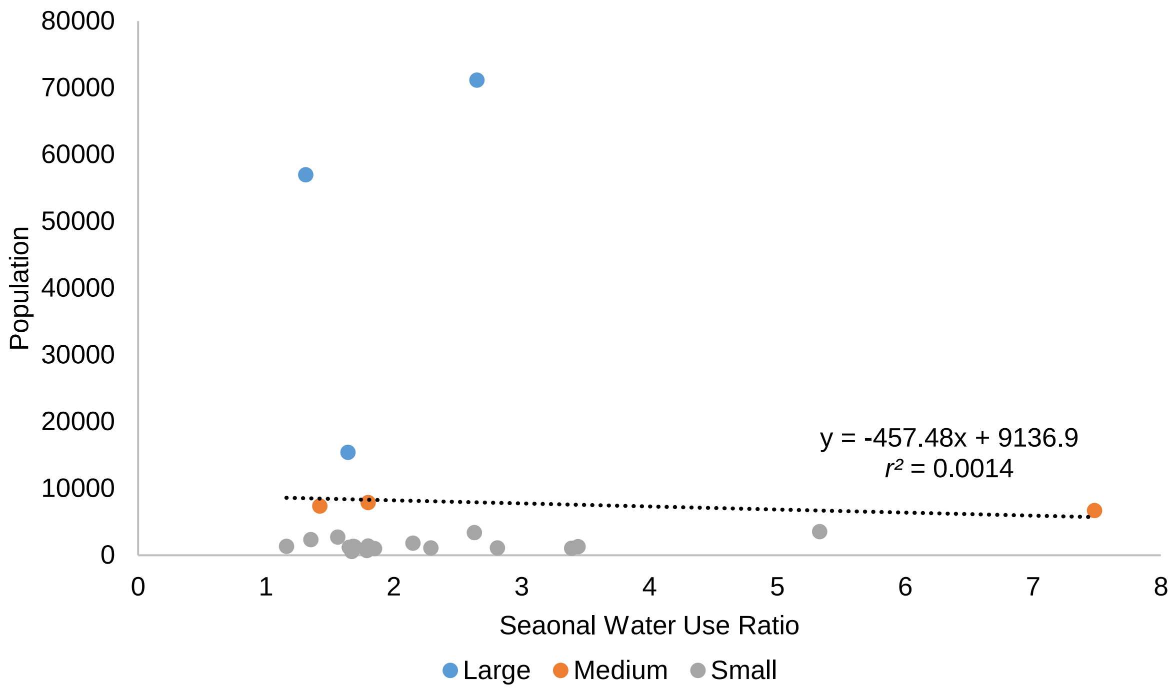


Figure 3.5. Seasonal water use ratio for large (n=3), medium (n=3), and small (n=18) cities.

Two cities had their respective commercial seasonal water use stick out from the rest. One small city, Thompson, North Dakota, had an overall seasonality ratio of 1.85, but the commercial seasonality ratio was 10.05. This is most likely due to the fact that Thompson is small, with a population around 1,000 residents, and doesn't have many commercial entities (less than 20 commercial water use accounts). In looking at the data, one reason for the increased water use was the carwash in Thompson, which uses a more water in the summer and has a low base consumption in the winter. The other increase in use was due to the local school. It seems odd to researchers that the school had increased use in the summer, as students are out of school from the end of May until the end of August. Researchers can only hypothesize on why the water use is so high in the summer at the school, but assume it has to do with outdoor recreational activity such as watering lawns and playing fields or supplying water for an outdoor pool. Surrey, North Dakota, was the second municipality whose commercial seasonality ratio stuck out. Surrey is also a small town, yet their seasonal water use was extremely different from all other cities. Surrey's highest commercial water usage occurred in January and its lowest water usage occurred in July (seasonality ratio of -2.60). The city had a total of 11 commercial accounts and the largest commercial user was the local public school. Due to the fact that students are on summer break during the summer months, it makes sense that the school would use less water during this time period than the rest of the year. Additionally, according to the U.S. Drought Monitor, during July of 2016, Surrey was not abnormally dry nor in a drought (USDM, 2016). Thus, it seems likely that due to the low amount of water consumed by commercial entities in Surrey and the fact that the public school is the largest water consumer, it appears that the school's water use dominates the commercial water use profile in Surrey.

Residential Water Use

Residential water use was disaggregated to the lowest water user level possible for each municipality. Multiple studies have found that residential dwelling type affects water use (Martinez-Espineria, 2002; Troy & Holloway, 2004; Schleich & Hillenbrand, 2009; Chang et al., 2010). Thus, when possible, accounts were classified into six different subcategories including apartment, duplex, group home, single-family home, townhome, and trailer park. Each individual municipality's average water use per account for each sub-category was then combined (averaged) into its respective city size group. Due to the ability, or inability, to classify accounts into different categories based on available data for each municipality, not all municipalities were sub-categorized. Additionally, a municipality may only be sub-categorized into one or two categories, but not all six based on data available to researchers.

Trailer parks consumed the most water, per account, of all residential accounts regardless of city size (Table 3.1). This makes sense as many individual trailers, often entire trailer parks, are connected to a single meter. Apartments were the next largest residential user per account. Apartments used the most water in large cities, with medium sized cities using less water than large cities, but more water than small cities per month. Larger cities generally have larger apartment complexes, which in turn have more individual living units and thus use more water on a single meter. On the other hand, smaller cities generally have fewer apartments and smaller apartment buildings in general resulting in less water used per account.

Table 3.1

Averages of all, large, medium, and small cities monthly average water usages per account per city in gallons. Number of cities used in the averages specified in parentheses.

Category	All Cities	Large Cities	Medium Cities	Small Cities
Apartment	19,027 (20)	35,973 (3)	24,919 (2)	14,852 (15)
Duplex	4,022 (16)	5,299 (2)	3,546 (2)	3,889 (12)
Group Home	15,289 (5)	14,201 (2)	16,922 (3)	-
Single Family Home	4,330 (18)	5,624 (2)	4,112 (2)	4,176 (14)
Townhome	3,627 (13)	6,327 (2)	3,690 (2)	3,012 (9)
Trailer Park	135,228 (16)	504,884 (3)	91,741 (3)	37,377 (10)

When possible, group homes were placed into their own category. For the purposes of this project, group homes included shared homes for people with disabilities, transitional care housing, and outpatient living facilities. It is important to note that not all group homes may be included in the group home category, as sometimes these types of facilities are located in residential neighborhoods and can be difficult to distinguish from large single family homes. Identification of group homes most commonly occurred when addresses identified the non-profit group who runs the facility or via property classification from county GIS parcel viewers. Clearly, group homes are large users of water, as they consume approximately 15,000 gallons a month. Thus, even though group homes and single family homes can be located in the same neighborhoods, group homes use a lot more water than the single family homes found around them.

Although water use per account is easy to calculate and can potentially provide useful averages for certain sub-categories, such as single family homes, water usage per account does not tell the whole story. Accounts associated with apartment buildings, duplexes, townhomes, and trailer parks can all have multiple living units connected to one meter. Thus, a more useful number when examining accounts that serve multiple units is average water use per living unit. Thus, water use per unit (i.e. water use per individual apartment units, individual living units for duplexes or townhomes, and individual mobile home) was calculated and can be found in Table 3.2. In general, for most categories, there is an increasing trend for monthly water use per individual living unit as population size increases.

Table 3.2

Averages of all, large, medium, and small cities monthly average water use per unit per city in gallons. Number of cities used in the averages specified in parentheses.

Category	All Cities	Large Cities	Medium Cities	Small Cities
Apartment	2,109 (19)	3,026 (2)	2,557 (2)	1,927 (15)
Duplex	3,094 (16)	3,439 (2)	2,883 (2)	3,071 (12)
Single Family Home	4,330 (18)	5,624 (2)	4,112 (2)	4,176 (14)
Townhome	2,631 (13)	3,346 (2)	2,855 (2)	2,422 (9)
Trailer Park	2,711 (13)	4,410 (2)	4,544 (3)	1,925 (8)

Apartments

Water used per apartment unit was able to be calculated for 19 out of the 25 different cities including two large cities, two medium sized cities, and 15 small cities. The apartment category included multi-family dwellings that contain three or more individual units, which includes all apartment buildings regardless of size and single family homes that have been converted to have three or more separate living units. In general, there is a weak trend between city size and the amount of water used per individual apartment (Figure 3.6). Water usage per unit had the greatest variation in small municipalities. The lowest average usage per apartment unit for a small city was 825 gallons per month, with the highest small city averaging 4,713 gallons per month. Cities whose apartment units consumed the least amount of water per individual unit, may be due to occupancy. To create water use coefficients for individual apartment units, the total amount of water used by apartment buildings in each city was divided by the total number of individual units in the city. Because it is unlikely that all apartment units in a city were occupied, or that all cities had the same occupancy rate, city to city differences are expected.

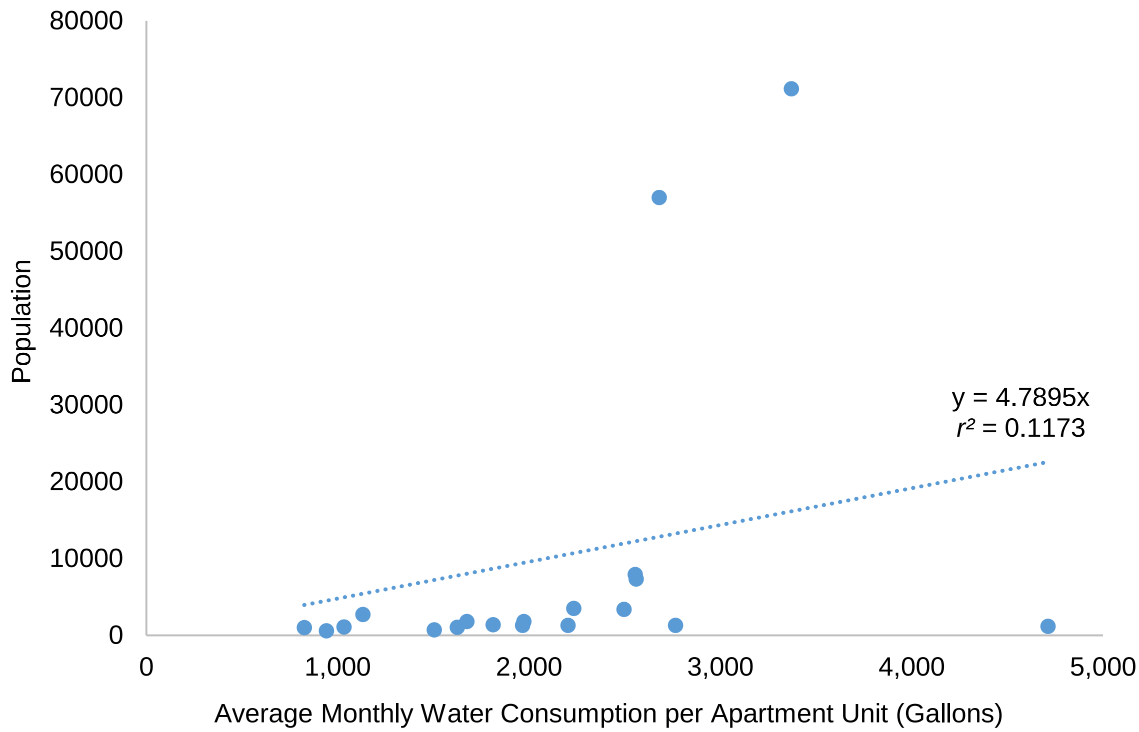


Figure 3.6. Average monthly water consumption per individual apartment unit for 19 different cities (gallons).
Note: one city's average monthly use per apartment unit includes only 86% of the apartments in the municipality because the number of apartment units was not available for all accounts.

The overall average monthly usage for an individual apartment unit in North Dakota was 2,109 gallons per month. In Santa Fe, New Mexico, the average monthly water used by an individual apartment unit was 5,700 gallons per month (CoSF, 2001). Even the large city average monthly water use per apartment unit in North Dakota of 3,026 gallons per month is considerably lower than the city of Santa Fe's usage. It is important to note that North Dakota and New Mexico have very different climates, and climatic factors could play a large role in the amount of water used by apartment complexes, which would in turn affect the amount of water associated with each individual apartment unit.

Geographical location in North Dakota did not appear to play a role in the average amount of water used per apartment unit, even though there are temperature and precipitation gradients that run through the state. The top two municipalities who consumed the most water per individual apartment unit, on average, were located in the Bakken region. Yet, three of the four lowest apartment unit consuming cities were also in the Bakken region. These results highlight the variability of water use per apartment unit in different cities, regardless of city size or location.

Duplexes

Average water use for individual units of duplexes was calculated for 16 out of the 25 cities including two large, two medium, and 12 small cities. Duplexes were considered all residential dwellings that contained two units and share a wall and single family homes that have been converted to include two separate living units. Average water use per individual unit of a duplex was 3,094 gallons per month. There appears to be slight differences in consumption based on city size, but there is no trend (r^2=0.02). Although geographical location of municipalities in the state did not influence overall usage, location did affect extreme usages (Figure 3.7). Municipalities located in the Bakken had the highest average usage per duplex unit as well as the lowest average usage per duplex unit. Occupancy of duplex units, or lack thereof, could be a factor influencing cities with low average water use in duplexes. The three cities that used the most water per duplex unit were all small and in the Bakken Region. Two of these municipalities used more water per duplex unit, 5,867 and 4,553 gallons per month, than the average single family home did in all small cities, 4,176 gallons per month. The municipality that used 4,553 gallons per month per unit of a duplex was the same city that used 4,713 gallons per month per apartment unit. It is unknown why this city had such a high per unit usage per month. Additionally, it is unknown why Stanley, North Dakota, the city with the highest average monthly water use per duplex unit (5,867 gallons) used so much water per unit. Although authors speculate it may be due to the fact that the vast majority of duplexes in Stanley are located in new developments where each unit has a small yard, which owners would be expected to establish and irrigation is typically necessary for lawn establishment in North Dakota.

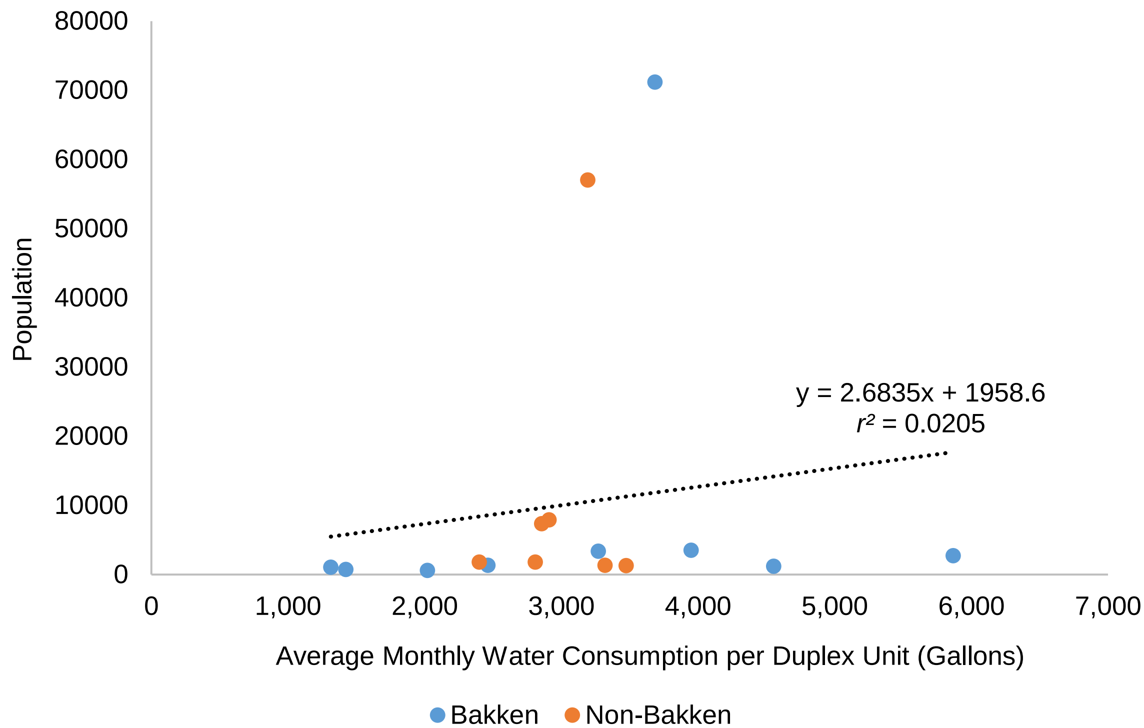


Figure 3.7. Average monthly water consumption per individual duplex units for 16 different cities (gallons).

Townhomes

Similar to apartments, there was a weak trend between increasing amount of water used per unit of a townhome and city size (Figure 3.8). For this project, dwellings were considered townhomes when three or more “homes” had adjoining walls. Additionally, presence of a garage, which was usually but not always attached to the living unit, was used to distinguish townhomes from certain types of apartments. Average monthly water use per townhome unit was calculated for 13 out of the 25 cities including two large, two medium, and nine small cities. On average, townhomes used 2,631 gallons per unit per month. Overall, the average amount of water used by individual units of townhomes and duplexes was fairly similar within each city size category (Table 3.2).

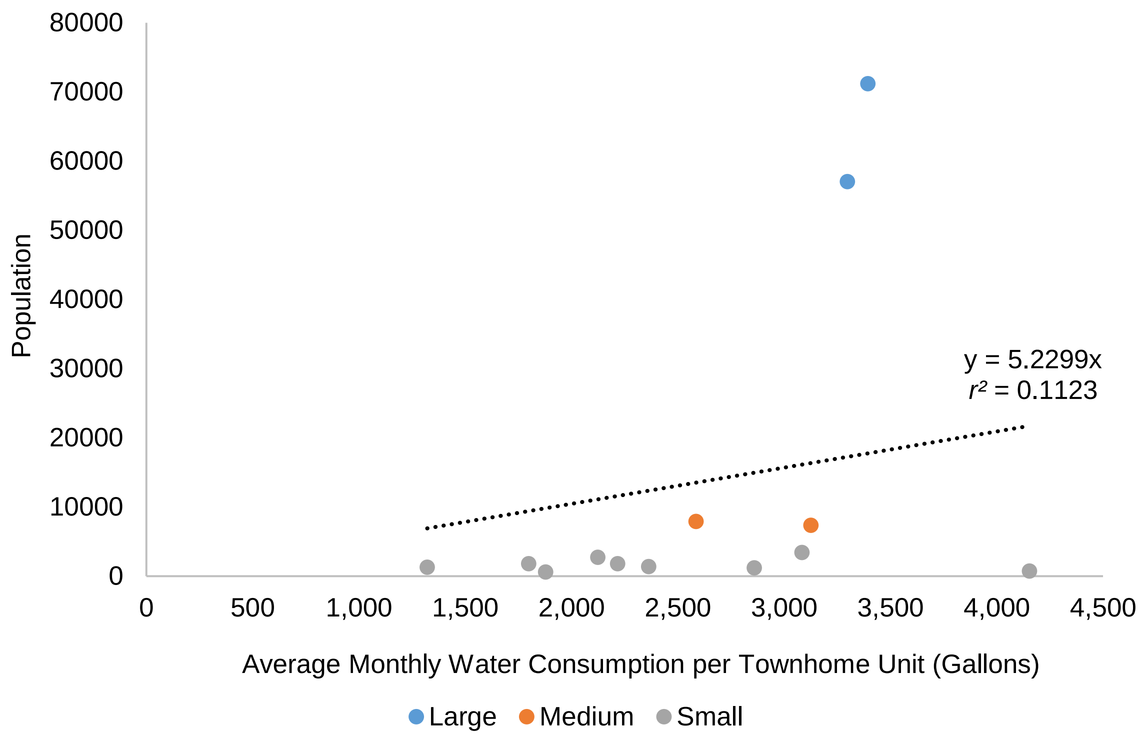


Figure 3.8. Average monthly water consumption per individual townhome unit for 13 different cities (gallons).

Trailer Parks

Trailer parks generally have multiple or all mobile home units attached to a single water meter. To calculate the average monthly water use per trailer, total water purchased by trailer parks was divided by the number of mobile homes or spots in the city. Average water use per trailer was calculated for 13 out of the 25 cities including two large, three medium, and eight small cities. It is important to note that some cities provided the number of mobile homes/trailer homes connected to meters, while other cities provided the total number of spots in trailer courts. Additionally, only a fraction of the trailer homes in one city were broken down by average water use per unit, because information was not available for all accounts. Although authors expected total water used at trailer parks to be influenced by city size, there was also a slight trend between city size and amount of water consumed per individual trailer (Figure 3.9). Average water usage for individual mobile homes in small cities was 1,925 gallons per month, while both medium and large cities used more than double the amount of water using 4,544 and 4,410 gallons of water per month respectively. Compared to the average water usage of 5,400 gallons per month by mobile homes in Santa Fe, New Mexico (CoSF, 2001), North Dakota's overall mobile home average of 2,631 gallons per month and even the consumption by medium and large cities is low. Again, climatic conditions of New Mexico and North Dakota are very different, so this may be a main factor in the differences between average water usage by individual mobile homes.

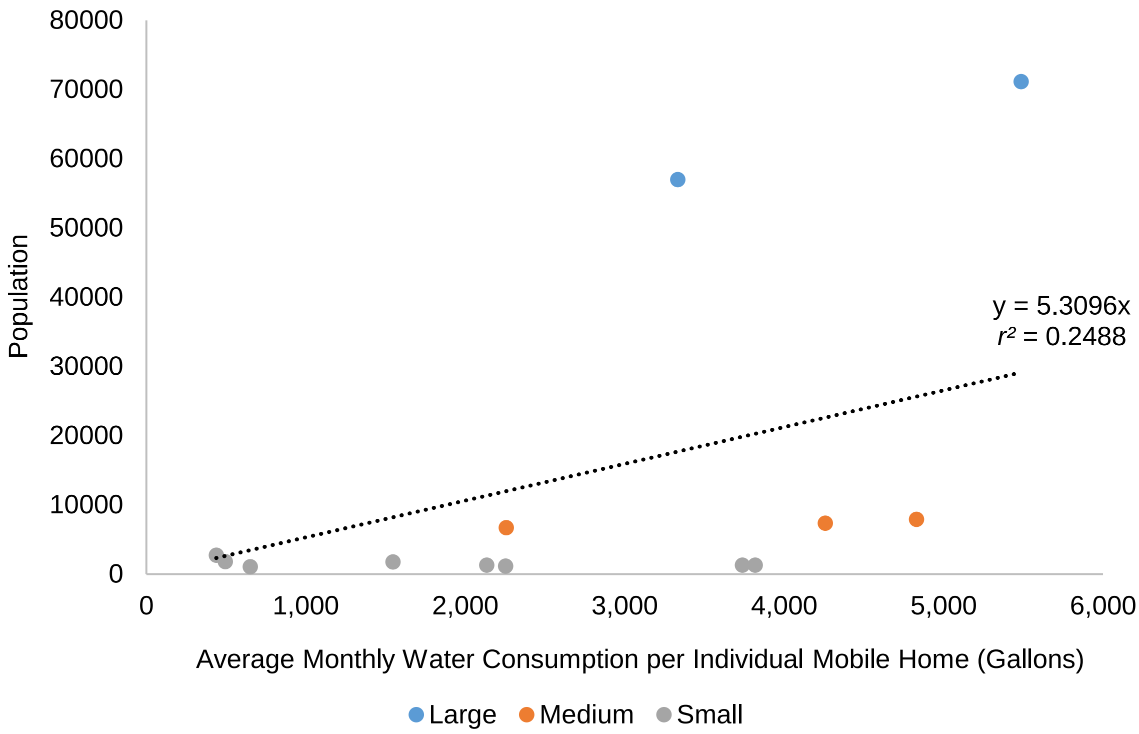


Figure 3.9. Average monthly water consumption per individual mobile home in trailer parks for 13 different cities (gallons).

Additionally, although city location did not influence the overall water used per mobile home, two of the three cities with the lowest average water use per mobile home were located in the Bakken region. One possible reason for these cities low usage per mobile home is the time frame of data received. The 'Bakken oil boom', 2005-2015, brought with it an economic and population surge. From 2010 to 2015, the state's population increased by approximately 12.5% (USCB, 2015). North Dakota is currently in a post-boom period, resulting in less new oil development, which causes a decrease in the oilfield workforce. Water-use data from these two cities was from 2016, with a few months from 2017, which was a period of time on the downward cycle of the oil boom. One of the two cities called their trailer park a crew camp (i.e. man camp). Thus, if the entire camp/park is not full, usage per trailer would decline. There appears to be a similar situation in the second town. At least half of the trailer units in the second town were temporary housing/worker camp style units. Again, with the decrease in new oil development, these units probably had a lower occupancy rate than other cities.

Single Family Homes

Single-family homes were able to be separated into their own category for 17 out of the 25 cities including two large, two medium, and 13 small cities. The average monthly use, regardless of population size, for single-family homes in North Dakota was 4,330 gallons per month. The average amount of water used by single family homes per month was highest in large cities, while there was minimal differences in the amount of water used in medium and small sized cities (Table 3.1). Inspecting the histograms of the water use for each city finds that most cities had a skewed right distribution. Some of the distributions had long right tails with many outliers. This resulted in many cities having a small percentage of homes consuming a large percentage of the water (Figure 3.10).

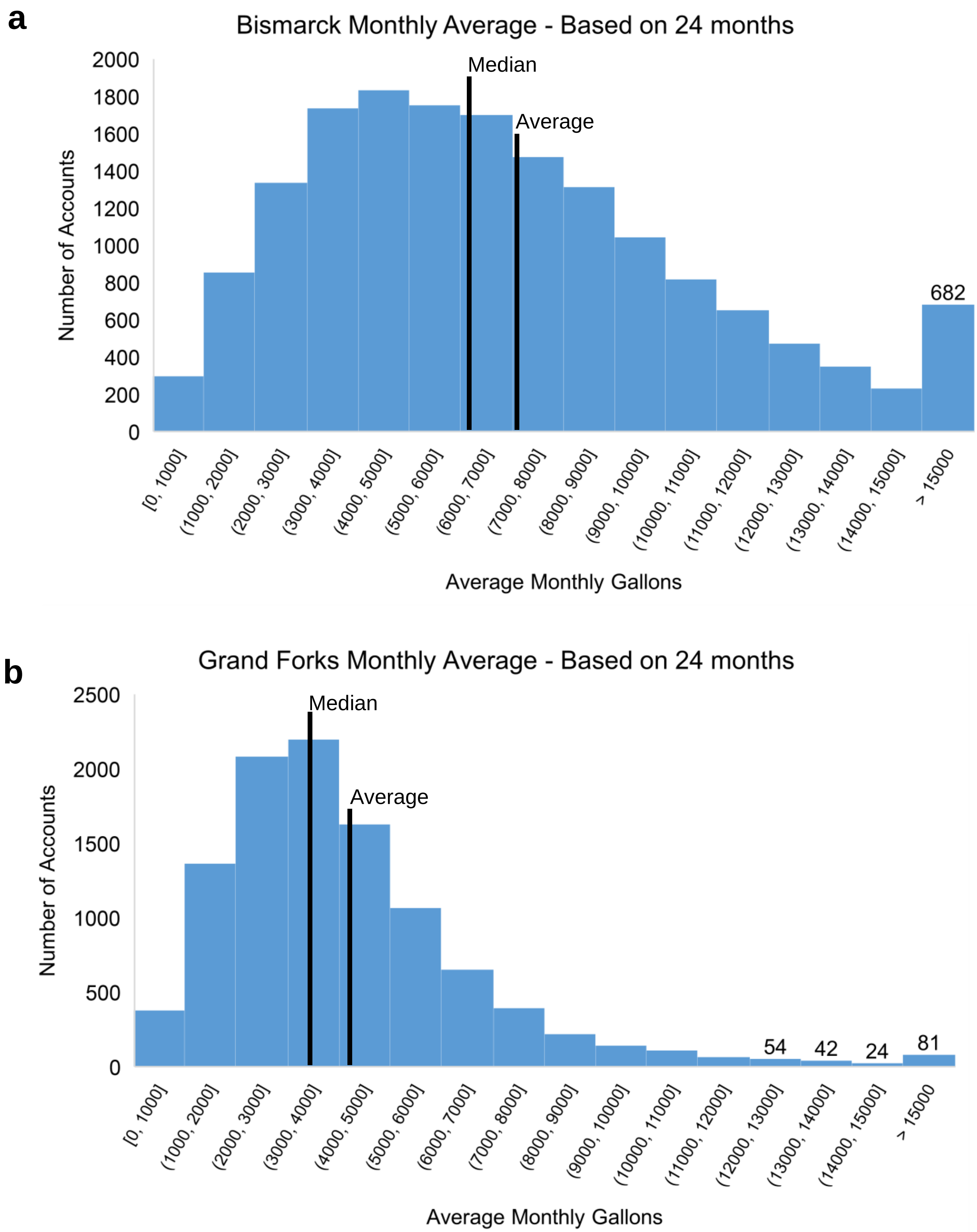
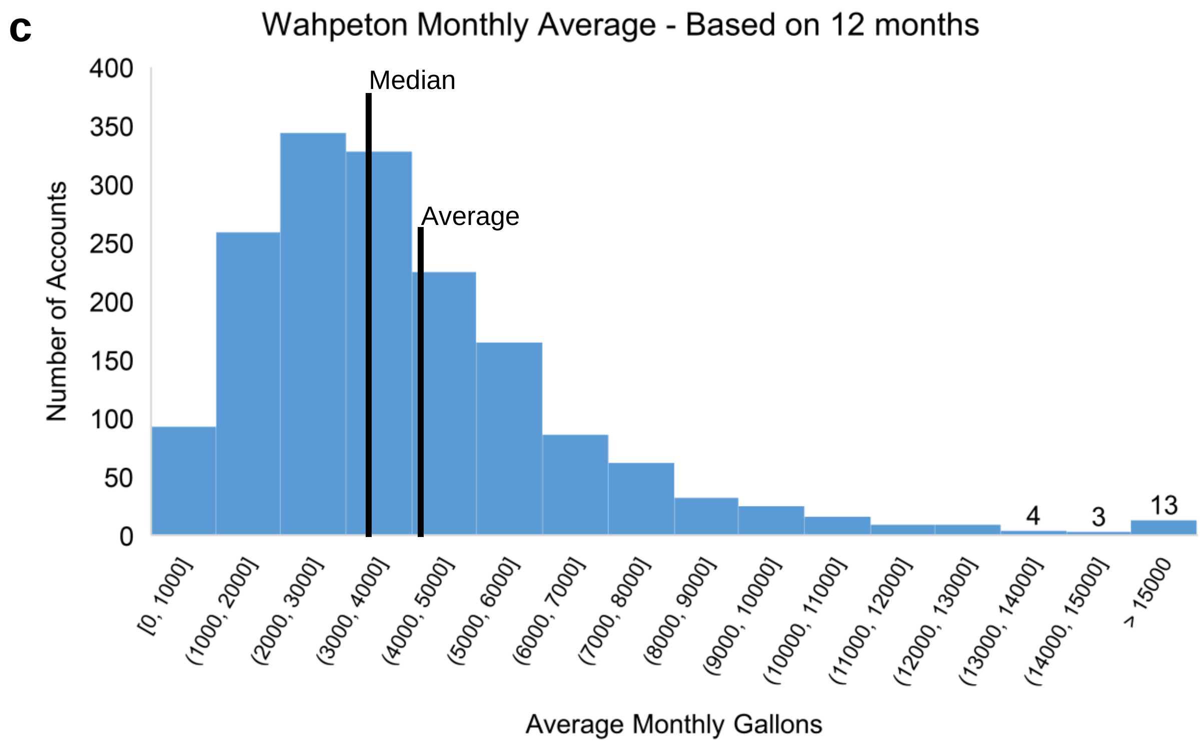


Figure 3.10. Average monthly water use consumed by individual single family homes. Average monthly usage was calculated based off the total water consumed by each single family home for the entire time frame of data received (12 or 24 months).



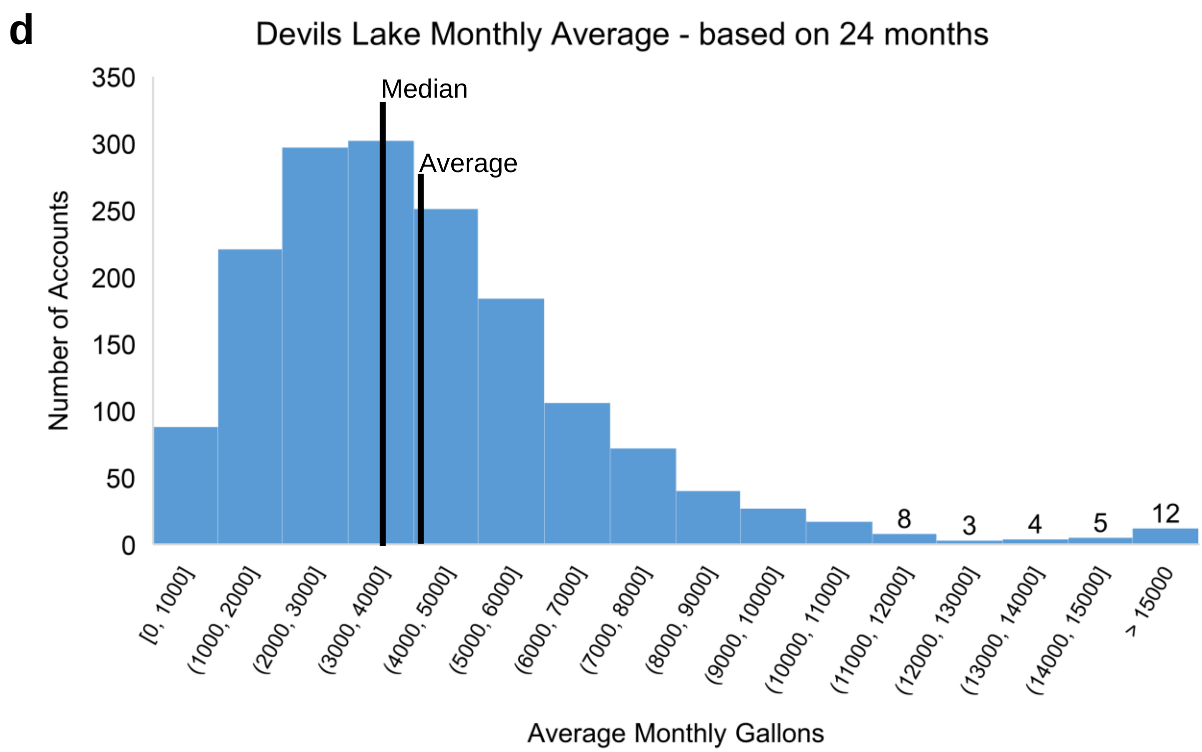


Figure 3.10. Average monthly water use consumed by individual single family homes (continued). Average monthly usage was calculated based off the total water consumed by each single family home for the entire time frame of data received (12 or 24 months).

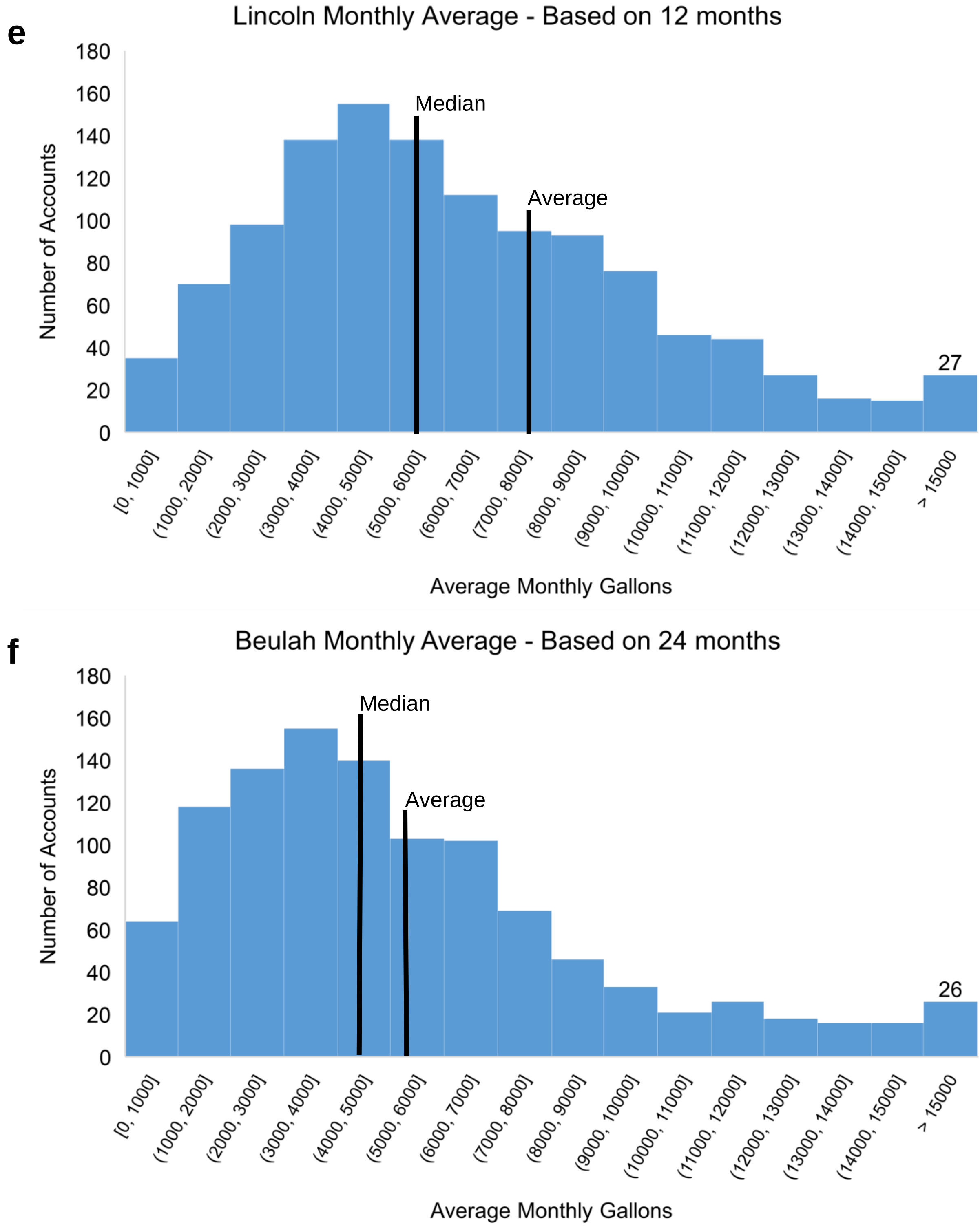
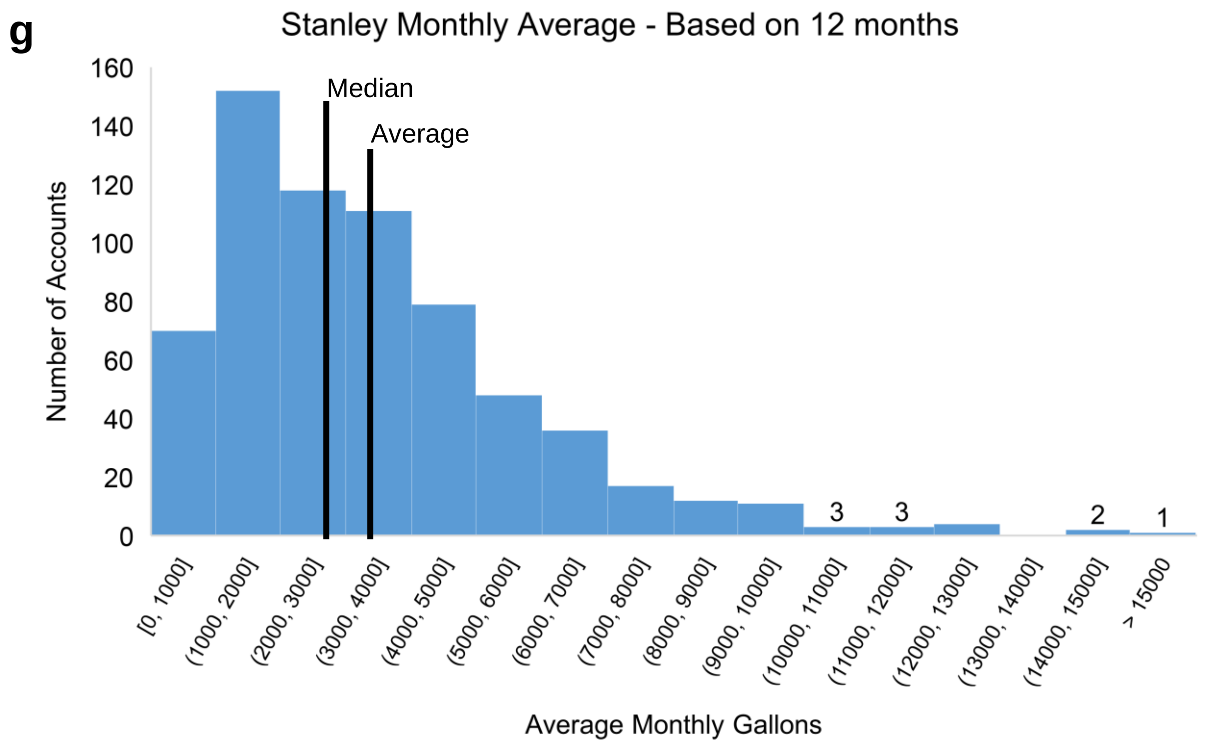


Figure 3.10. Average monthly water use consumed by individual single family homes (continued). Average monthly usage was calculated based off the total water consumed by each single family home for the entire time frame of data received (12 or 24 months).



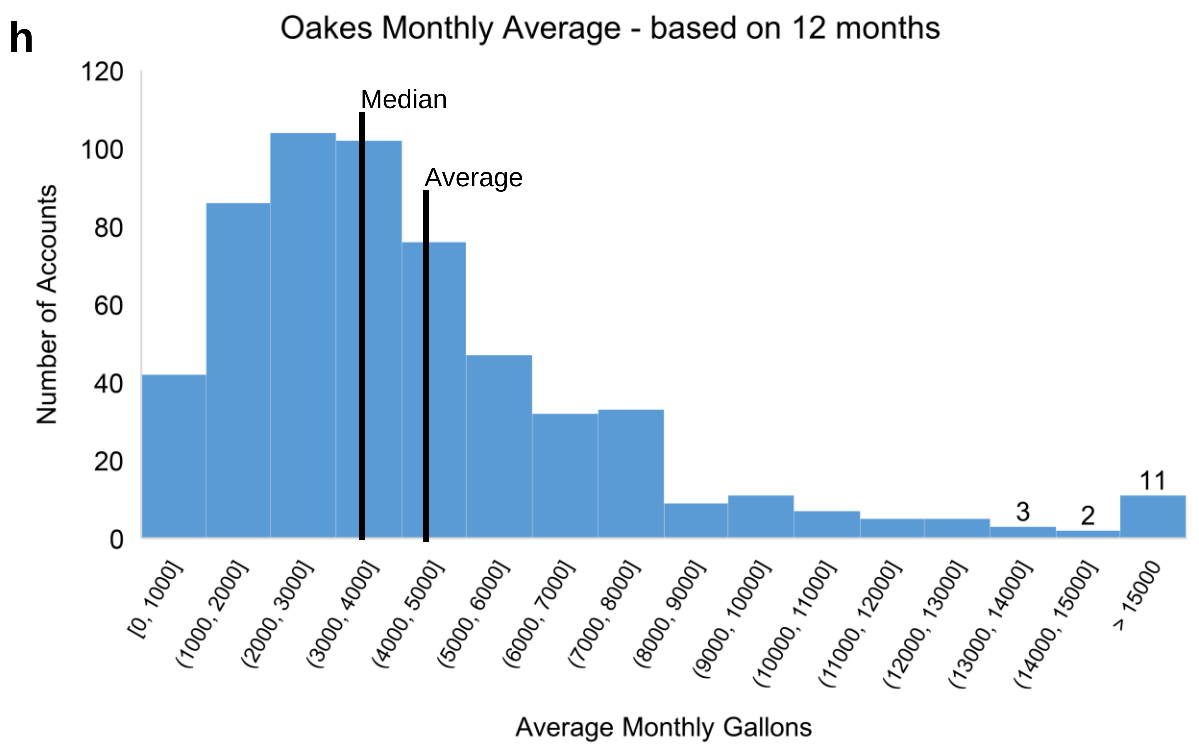
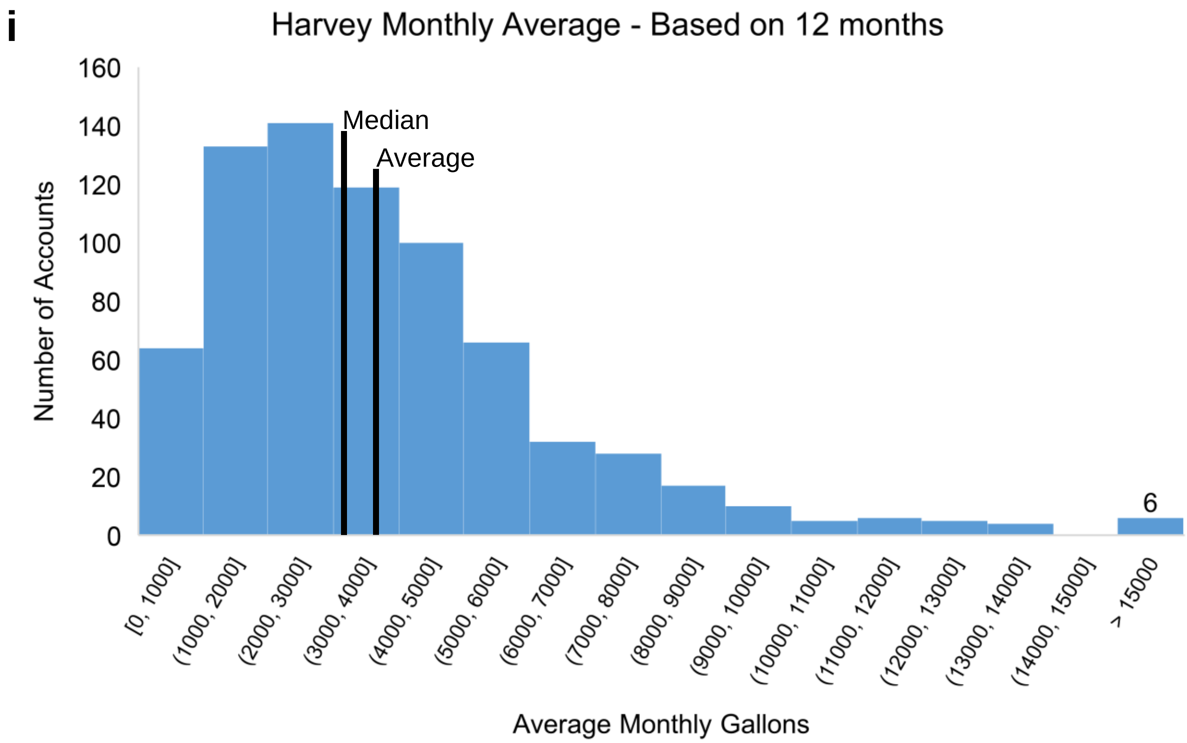


Figure 3.10. Average monthly water use consumed by individual single family homes (continued). Average monthly usage was calculated based off the total water consumed by each single family home for the entire time frame of data received (12 or 24 months).



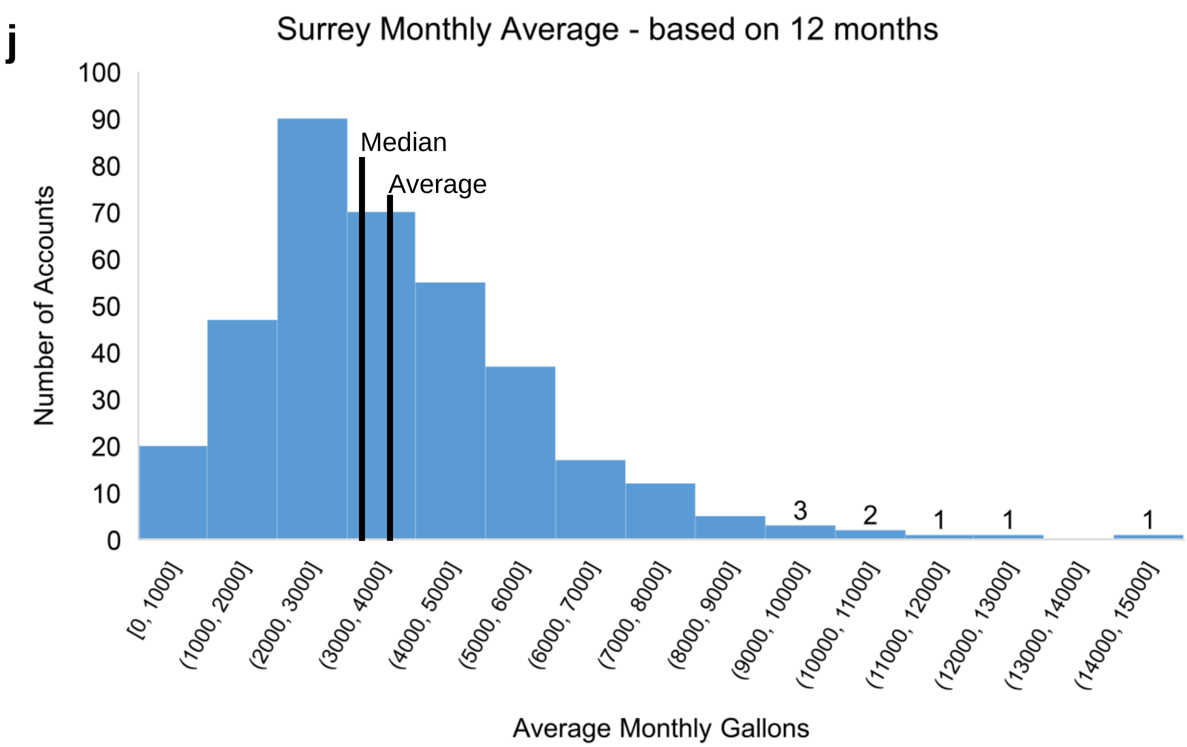
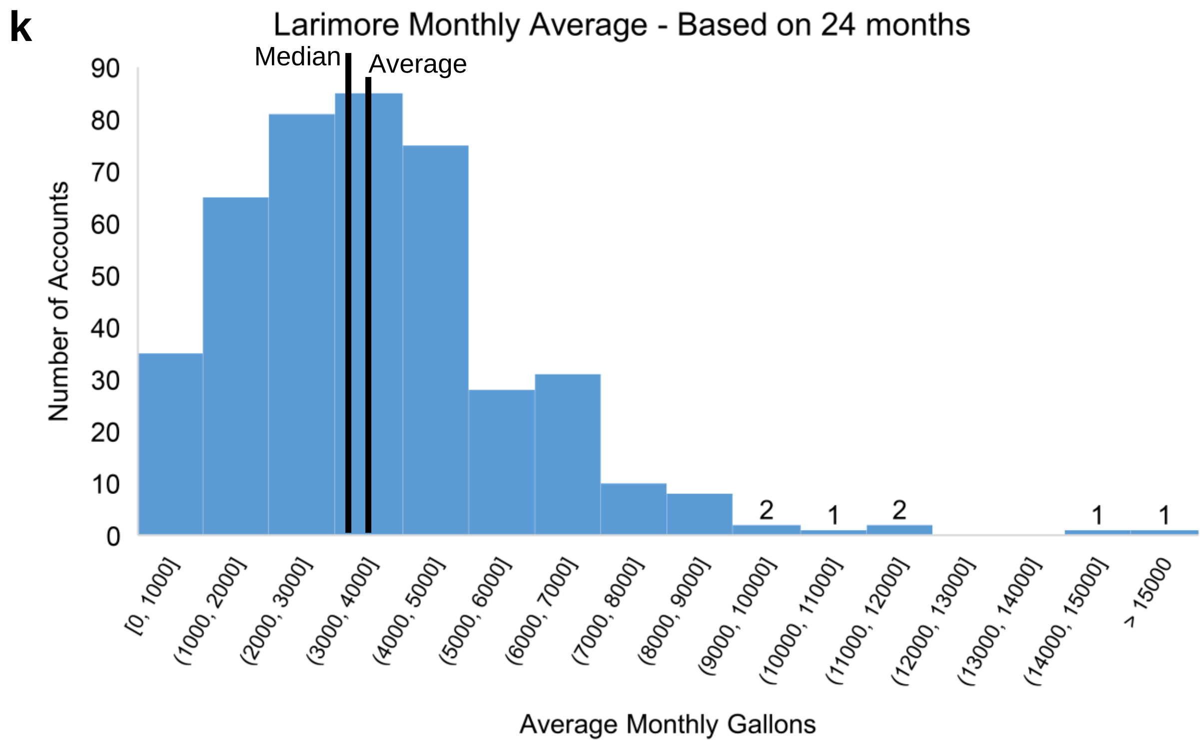


Figure 3.10. Average monthly water use consumed by individual single family homes (continued). Average monthly usage was calculated based off the total water consumed by each single family home for the entire time frame of data received (12 or 24 months).



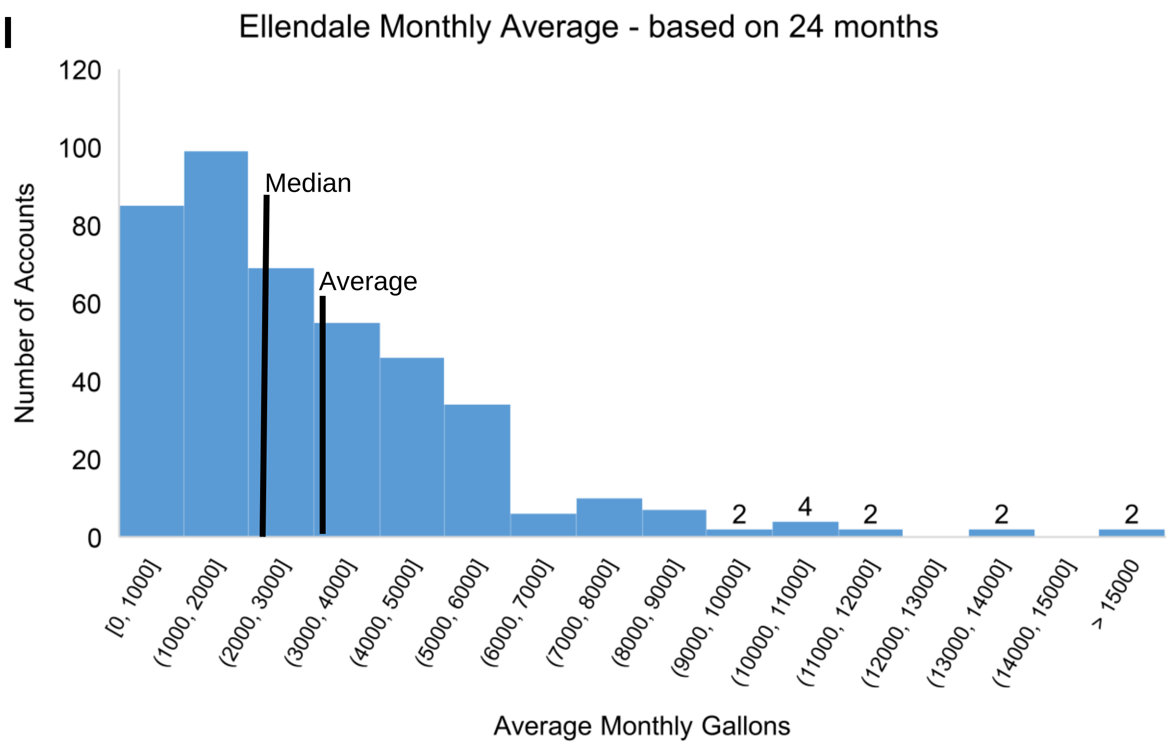


Figure 3.10. Average monthly water use consumed by individual single family homes (continued). Average monthly usage was calculated based off the total water consumed by each single family home for the entire time frame of data received (12 or 24 months).

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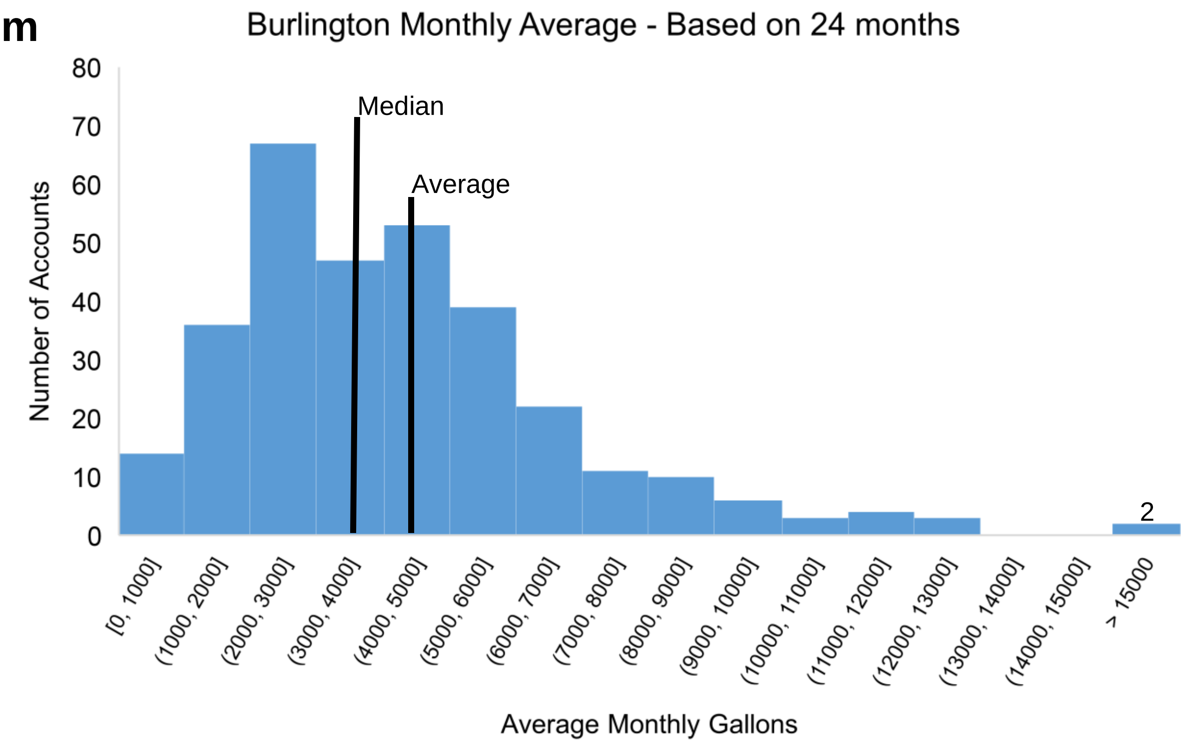

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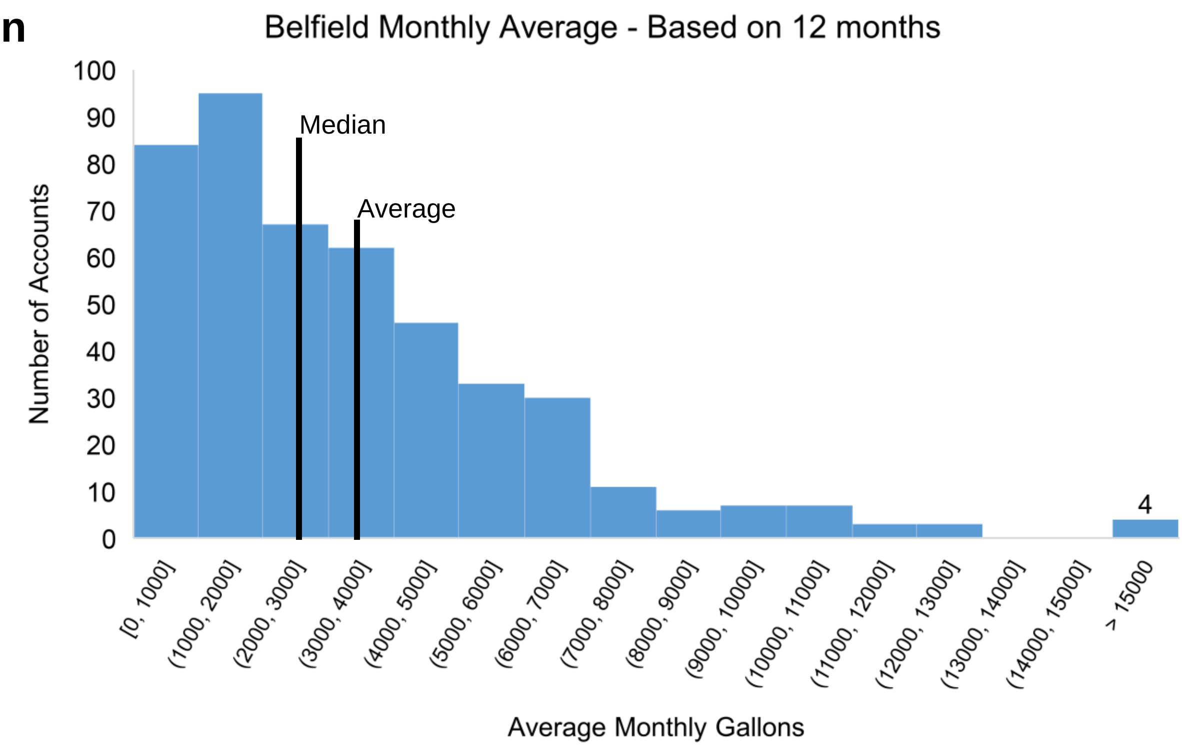

Figure 3.10. Average monthly water use consumed by individual single family homes (continued). Average monthly usage was calculated based off the total water consumed by each single family home for the entire time frame of data received (12 or 24 months).

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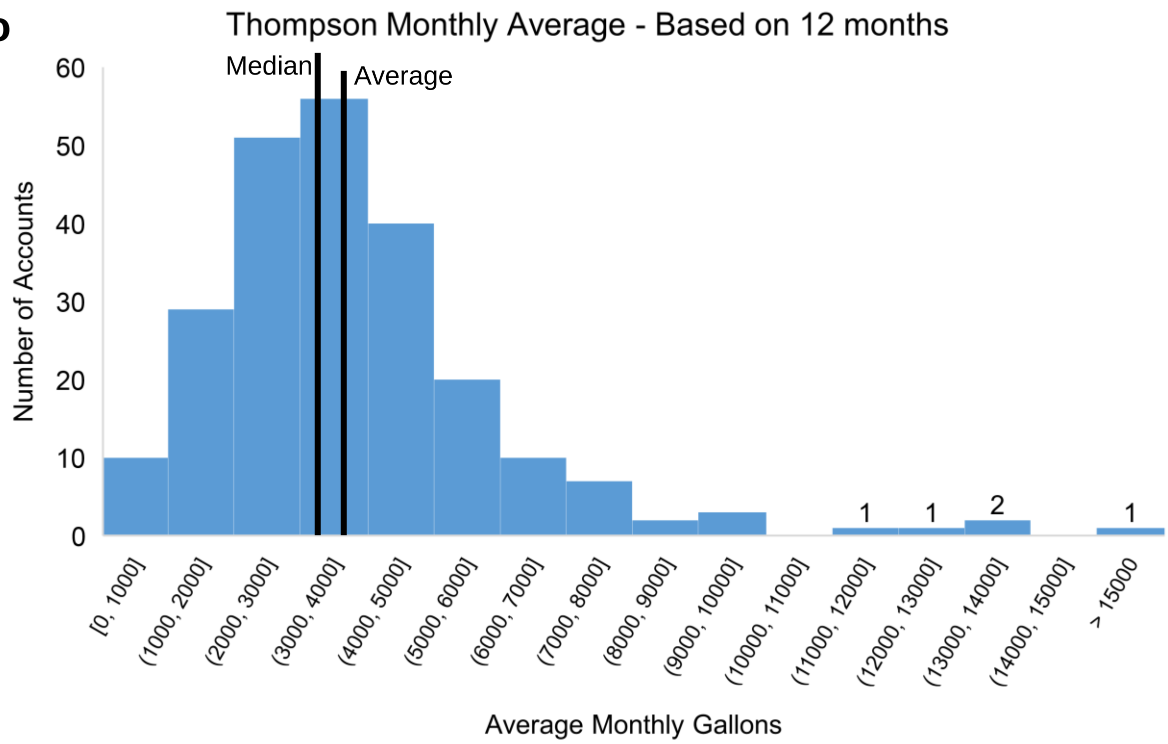

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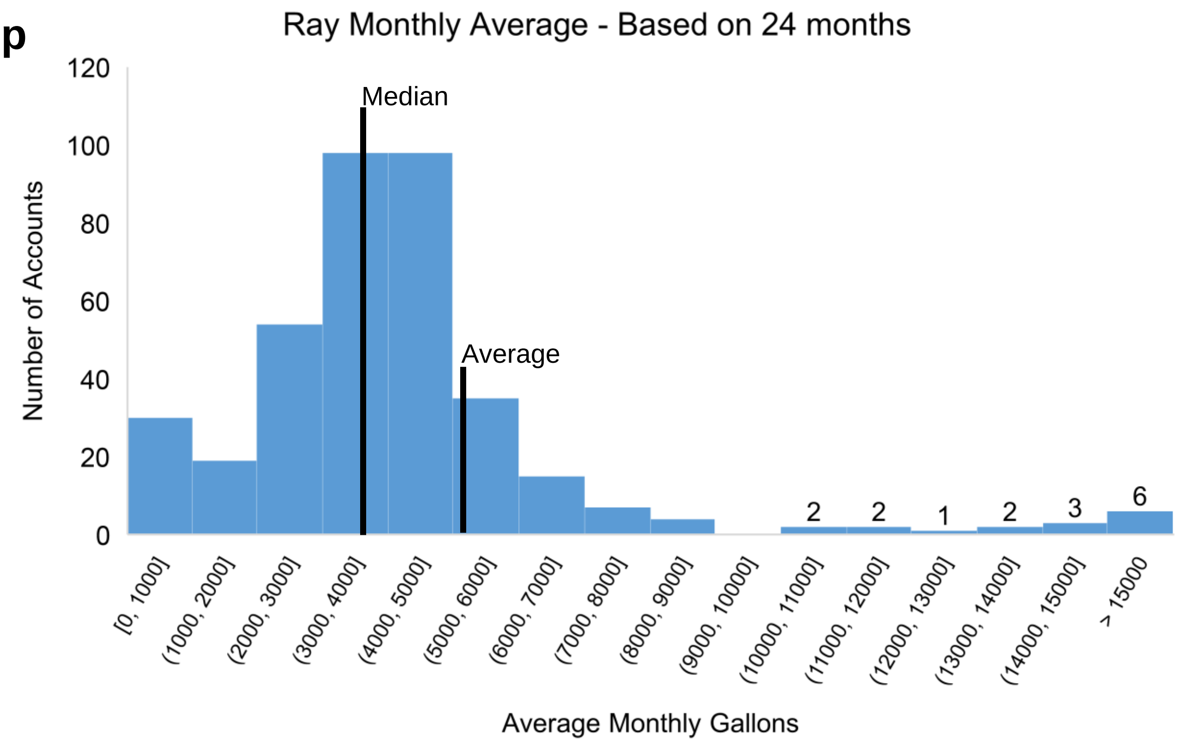

Figure 3.10. Average monthly water use consumed by individual single family homes (continued). Average monthly usage was calculated based off the total water consumed by each single family home for the entire time frame of data received (12 or 24 months).

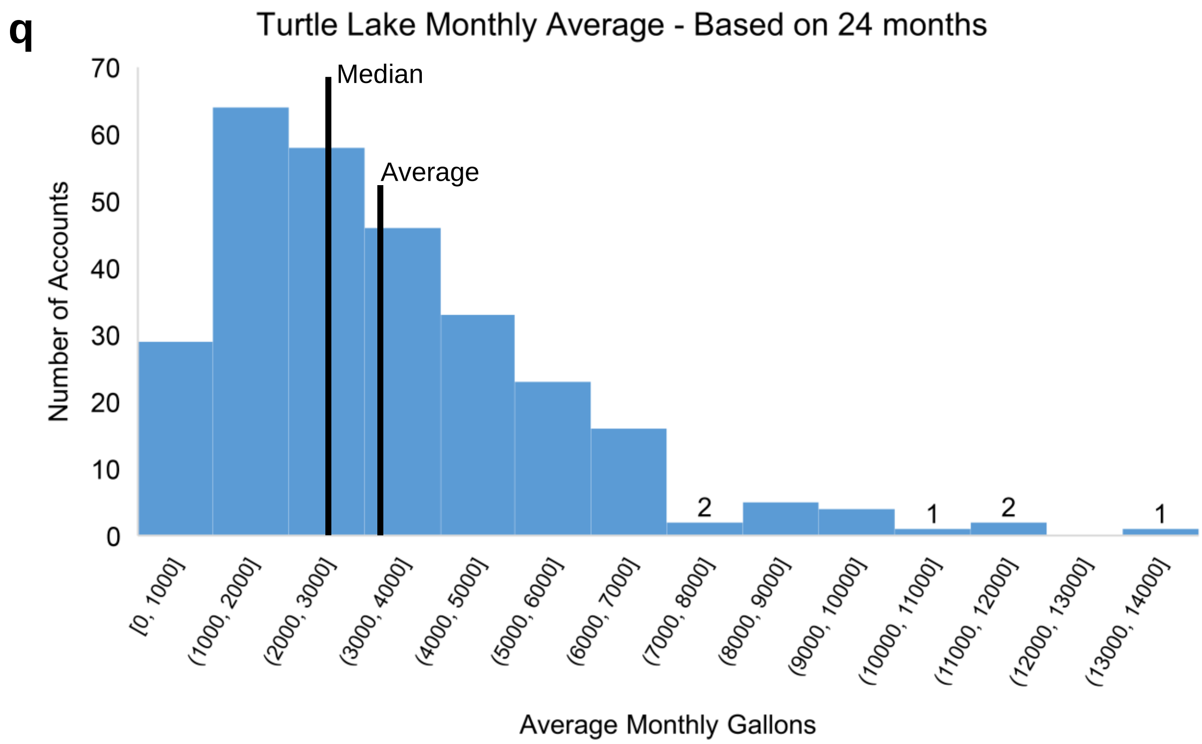

Figure 3.10. Average monthly water use consumed by individual single family homes (continued). Average monthly usage was calculated based off the total water consumed by each single family home for the entire time frame of data received (12 or 24 months).

Most cities had similar median single family home average monthly water usages, using between 2,000 and 4,000 gallons. The median is a good indictor of how much water single family homes use in different towns, because the average amount of water consumed will be affected by outliers (homes that use substantially more or less water than the normal home). Three cities had high median values, all three cities, Bismarck, Lincoln, and Beulah, are located in the Bakken region. Although it is unknown why these three cities have more single family homes using more water per month than other cities, one possible reason is that the Bakken region coincides with the drier side of the state. Additionally, Bismarck is the capital of North Dakota, while Lincoln is a suburb of Bismarck. Thus, these two cities specifically, may have more homes that irrigate lawns in the summer to keep yards looking nice, neat, and green.

The top 10% of water using single family homes generally consumed approximately 25% of the total water used by single family homes, while the bottom 10% of water consuming single family homes only consumed 1-2% of the total water used by single family homes (Table 3.3). In Ray and Lincoln, North Dakota, the top 10% of single family homes accounted for over 35% of all water used by single family homes. Additionally, in Ray, Ellendale, and Belfield, North Dakota, the bottom 10% of single family homes accounted for less than 1% of all water used by single family homes.

Table 3.3

Percent of the total water used by single family homes by the top 10% of single family home accounts and by the bottom 10% of single family homes accounts. Average water used in gallons by single family homes in each city.

City	Top 10%	Bottom 10%	Average Monthly Use (Gallons)
Wahpeton	26.35	2.43	4,057
Turtle Lake	24.34	1.54	3,282
Thompson	22.79	2.79	3,825
Surrey	22.49	2.86	3,718
Stanley	25.42	1.37	3,437
Ray	38.72	0.94	5,147
Oakes	28.51	1.98	4,423
Lincoln	35.99	1.66	7,716
Larimore	22.23	1.84	3,615
Harvey	26.89	1.66	3,876
Grand Forks	24.45	2.68	4,204
Ellendale	28.43	0.65	3,001
Devils Lake	24.11	2.05	4,164
Burlington	24.37	2.32	4,411
Bismarck	23.99	2.09	7,022
Beulah	26.46	1.42	5,386
Belfield	28.53	0.55	3,412

North Dakota’s average monthly water use (4,330 gallons) is comparable to single family home usage in two Canadian cities. Both Waterloo and Cambridge, Ontario, Canada, used approximately 5,825 gallons of water per month at single family homes (Mayer et al., 1999), which is very comparable to the amount of water used per month by single family homes in large cities in North Dakota (5,624 gallons). Additionally, Mayer et al. (1999) examined average water use by single family homes in twelve different cities in North America ranging from Ontario, Canada to Florida and Arizona, USA. They found that the average monthly water use for all cities was 12,175 gallons per month, which demonstrates the variability in the amount of water used at single family homes, depending on location and climate.

Commercial Water Use

Commercial accounts were disaggregated to the lowest water user possible, utilizing 76 sub-categories. Cities were only included in each category if the data could be completely disaggregated. For example, not all municipalities with assisted living or nursing home facilities are included in the averages, because these accounts were not able to be singled out. Additionally, some cities had accounts for the hospital and apartments or a nursing home facility, but either all accounts used a single meter or if multiple meters were used, they were not specifically for one purpose. Thus, these accounts are not included in the disaggregated sub-categories but were included in total commercial water used.

Sub-category average water use was analyzed two different ways. First, the average use for each category was calculated (per account) for each city. Average use for each category was then used to create per capita coefficients for each water sub-category for the different city size groups. An overall average for the state of North Dakota was created, utilizing all cities with water use in a specific category regardless of city size, plus averages were created for large, medium, and small sized cities (Table 3.4). Additionally, water used per account for all sub-categories was plotted against city size, when there were at least 15 individual accounts in the sub-category, to determine if water use per account (water meter) was influenced by city size (Appendix H).

Table 3.4

Per capita coefficients for each commercial sub-category for all cities combined, large, medium, and small cities, based on average use per account for cities in each respective category. Plus, the coefficient of determination for all accounts compared to city size.

Category	All Cities	Large Cities	Medium Cities	Small Cities	r^2
Agriculture	8,771	23,349	5,068	7,218	0.048
Airport	9,011	12,074	8,928	70	0.023
Assisted Living Facilities & Nursing Homes	137,088	127,318	92,408	150,273	0.031
Auto Repair	2,350	4,966	3,085	1,632	0.035
Auto Supply	2,748	3,374	2,478	2,614	<0.001
Bank	5,675	18,390	9,204	2,630	0.068
Bar	13,157	24,320	22,690	8,722	0.071
Beverage Maker	136,557	250,642	37,896	7,047	0.091
Big Box Store	68,188	104,508	61,818	36,113	0.001
Butcher	15,552	17,217	52,971	7,403	0.001
Campground	29,740	82,654	43,820	5,952	0.114
Car Dealer	6,454	13,209	6,970	2,091	0.048
Car Wash	81,419	149,898	129,552	46,436	0.059
Cemetery	22,709	31,731	4,667	-	0.086
Chiropractor	3,404	5,009	3,065	2,643	0.171
Church	4,427	10,319	4,522	3,236	0.115
Clinic	13,777	42,001	14,060	4,274	0.023
College	70,107	72,987	108,816	27,077	0.019
Combo	17,293	39,125	25,791	12,439	0.064
Commercial Irrigation	74,980	74,980	-	-	*
Concrete Batch	51,583	67,028	72,163	33,571	0.002
Construction & Contractor	4,617	5,613	7,661	3,859	0.013
Daycare	9,888	18,310	20,323	3,602	0.203
Dentist	7,436	11,227	9,647	5,436	0.042
Entertainment	7,214	16,802	9,072	4,572	0.060
Fast Food	22,089	35,512	23,225	11,453	0.077
Fire Station	5,164	12,006	1,930	2,353	0.463
Food Processing	607,031	1,270,870	380,917	18,564	0.006
Funeral Home	7,930	13,350	13,384	3,853	0.095
Gas Station	22,654	35,750	23,909	19,963	0.055
Gas Station with a carwash	163,404	202,194	182,637	105,382	0.060
Golf Course	123,925	242,868	10,583	2,182	0.131

Table 3.4. *Per capita coefficients for each commercial sub-category for all cities combined, large, medium, and small cities, based on average use per account for cities in each respective category. Plus, the coefficient of variation for all accounts compared to city size* (continued).

Category	**All Cities**	**Large Cities**	**Medium Cities**	**Small Cities**	r^2
Government	10,935	42,011	21,853	3,525	0.059
Grocery Store	27,981	50,757	61,309	12,681	0.065
Gym	13,033	17,777	25,963	963	0.076
Hair Salon	3,093	6,150	2,724	2,473	0.207
Hospital	193,235	415,904	163,898	40,902	0.015
Hotel	43,584	85,678	51,204	32,111	0.097
Hotel w/pool	123,016	198,438	102,923	40,025	0.120
Jail	257,700	352,823	-	67,454	0.068
Kennels	9,623	9,623	-	-	*
Landscaping	8,890	13,504	8,754	2,103	0.045
Laundromat/Laundry Services	88,281	188,227	71,327	38,486	0.050
Machine Shop	7,729	3,579	25,000	4,739	0.083
Mall	19,152	11,623	7,204	53,687	0.009
Manufacturer	67,205	69,637	95,867	2,581	0.015
Military	452,693	646,637	64,806	-	0.005
Miscellaneous	23,231	13,289	10,659	32,762	-
Multi-Business	31,694	61,820	48,262	9,703	0.006
Office	3,713	9,963	7,449	1,573	0.042
Oilfield	8,807	-	13,757	7,570	0.005
Optical	3,338	8,733	417	1,128	0.590
Parking Lot	7,924	7,924	-	-	*
Parks	13,786	40,316	14,329	3,701	0.037
Private School	20,907	26,992	11,778	-	0.208
Public Pool	37,450	87,867	3,666	20,688	0.134
Public School	28,965	54,439	40,930	22,725	0.037
Residential Irrigation	14,352	14,352	-	-	*
Restaurant	22,453	51,263	33,414	13,402	0.175
Restaurant-Bar	33,728	78,881	52,380	16,326	0.175
Retail	2,850	6,928	2,082	2,023	0.038
Service	4,205	7,598	6,170	2,969	0.021
Shop	2,561	1,013	659	3,361	0.009
Shop Condo	2,292	2,647	1,936	-	<0.001
Spa	6,980	6,580	11,922	2,637	0.001
Sports Complex	47,356	74,884	38,211	15,208	0.055
Storage Units	1,398	1,570	-	1,225	0.049
Strip Mall	15,078	12,967	23,550	10,838	0.006
Truck Parts Service	13,506	11,473	7,953	18,059	0.005

Table 3.4. *Per capita coefficients for each commercial sub-category for all cities combined, large, medium, and small cities, based on average use per account for cities in each respective category. Plus, the coefficient of variation for all accounts compared to city size* (continued).

Category	All Cities	Large Cities	Medium Cities	Small Cities	r^2
Trucking Company	12,584	5,776	18,743	12,908	0.019
Utility	4,923	15,317	4,930	1,457	0.095
Veterinarian	10,431	8,088	21,196	8,562	0.023
Warehouse	5,762	9,461	6,207	3,276	0.0176
Waste Water Treatment Plant	268,047	268,047	-	-	*
Zoo	218,447	218,447	-	-	*
Bulk Water†					

* denotes that coefficients of determination were not calculated for certain categories either because there were less than 15 total accounts in the category, or because categories were only present in large cities. Additionally, the coefficient of determination was not calculated for the miscellaneous category because this category did not necessarily contain similar businesses.
† Bulk water sold by the city was its own category, but average bulk water sold was not included in the averages because bulk water sales data received did not always include all bulk water sales depending on the city, software, and payment method.

Many small cities did not provide water use data for accounts associated with city government owned property. Either the city does not meter city owned properties (city government offices, shops, etc.) or the monthly water use is not included in the water billing reports, since cities do not charge themselves for water. Average water use per account for government entities is highest in large cities and lowest in small cities (Table 3.4). Additionally, commercial and residential irrigation sub-categories were only used when a city had these accounts specifically separated/labeled as irrigation.

Shops were considered to be buildings that were either labeled as someone's personal workshop or garage, or were a garage/metal building type structure with no business association. Accounts associated with shops used the most water on average in small cities, using 3,361 gallons per month, while large and medium sized cities used 1,013 and 659 gallons per month respectively. This was unexpected, but this could be due to more large garage/workshop type buildings being owned by individual people in small cities.

Prior to analyzing the data, researchers predicted certain sub-categories of water users, such as fast food, would have differences in average water use based on population size. On average, in large cities fast food accounts had significantly higher water use per month, using an average of 35,511 gallons of water per month, compare to small cities fast food accounts which used 11,453 gallons of water per month (t-test 173,7; p <0.001) (Table 3.4). Yet, water use per fast food account was not related to city population (Figure 3.11). The reason for the conflicting results are that averaging water use takes out the variability. When the data is examined per individual account, the variability is included. Thus, in general, there is higher water use by fast food entities in larger cities, but you cannot predict that for individual accounts because the variability is high.

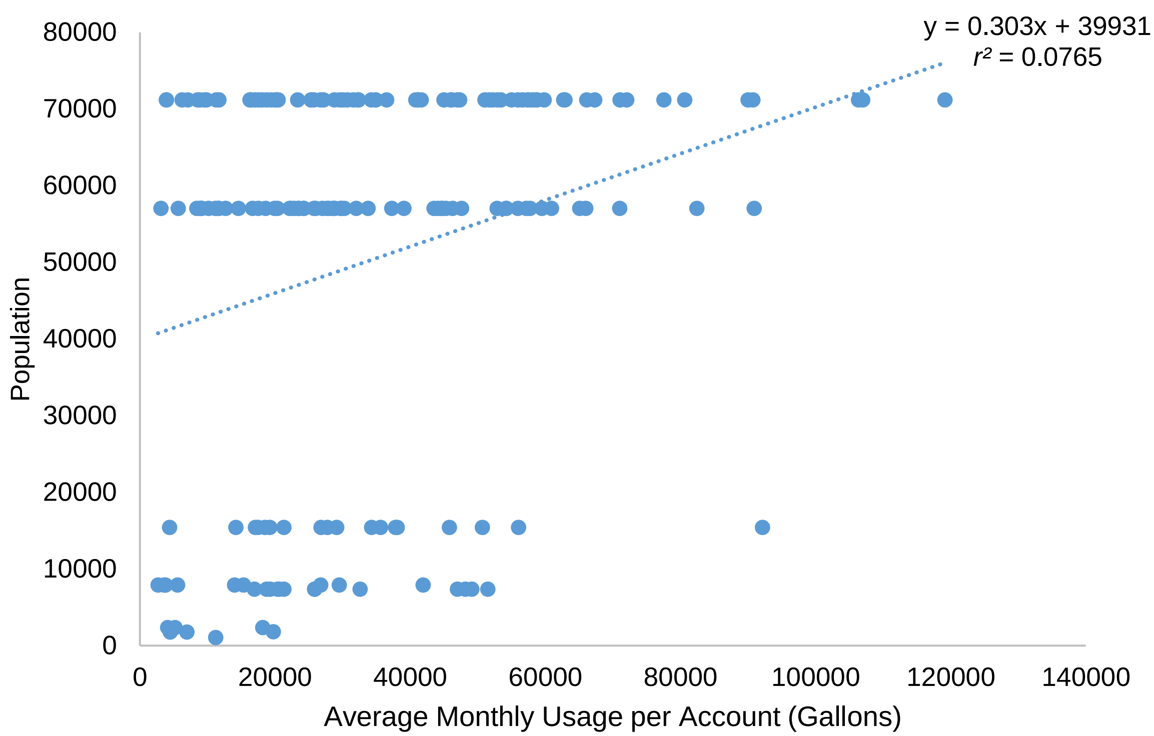

Figure 3.11. Average monthly water use per fast food account (gallons).

Similar to fast food establishments, researchers predicted hospitals would use more water in larger cities than smaller cities. On average, hospitals in large cities used significantly more water per account per month, using an average of 415,904 gallons per month, compared to small cities hospital accounts, which used an average of 40,921 gallons per month (t-test 80,8; $p<0.001$). Yet, water use per account was not influenced by city size (Figure 3.12). Thus, there is higher water use by hospitals in large cities, but you cannot predict that for individual accounts because of the high variability. Overall, average water use by hospital accounts in North Dakota was 193,235 gallons per month, which is less than the average amount of water used per connection for hospitals in the Vancouver, British Columbia, Canada area, which used an average of 249,743 gallons per month (Vickers, 2001b). Although the average of all cities hospital water use is lower in North Dakota, the average water use of hospitals in larger cities is actually a bit higher (415,904 gallons) than that from Vancouver, highlighting the variability in water use per account for hospitals.

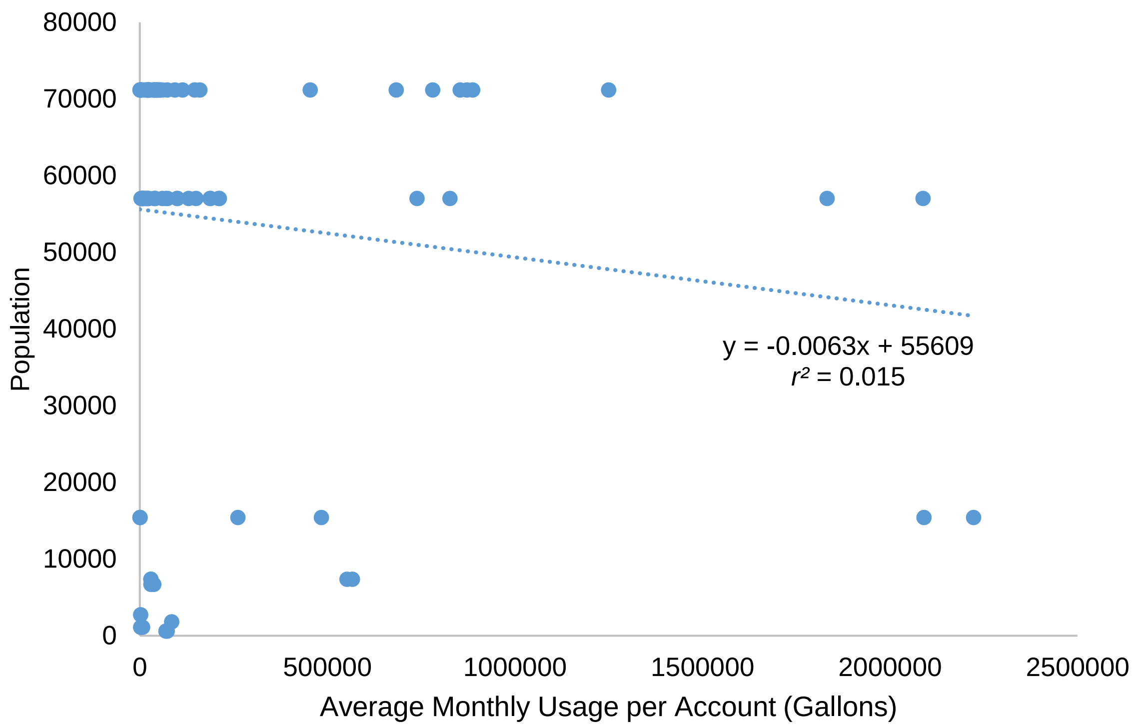

Figure 3.12. Average monthly water use per hospital account (gallons).

Even though some categories had no relationship between average monthly water use per account and city size, other categories did (Table 3.4). Fire stations had the strongest relationship between average monthly use per account and city size (Figure 3.13). This finding was unexpected but makes sense. Larger cities have a need for more fire stations, which may be used more frequently and intensely than smaller stations. Although it is unknown if firefighter type (volunteer versus career) greatly influences monthly water use per account, it is interesting to note that cities with less than 25,000 people are more likely to have volunteer firefighters (Haynes & Stein, 2017) and also have the lowest monthly water use per account.

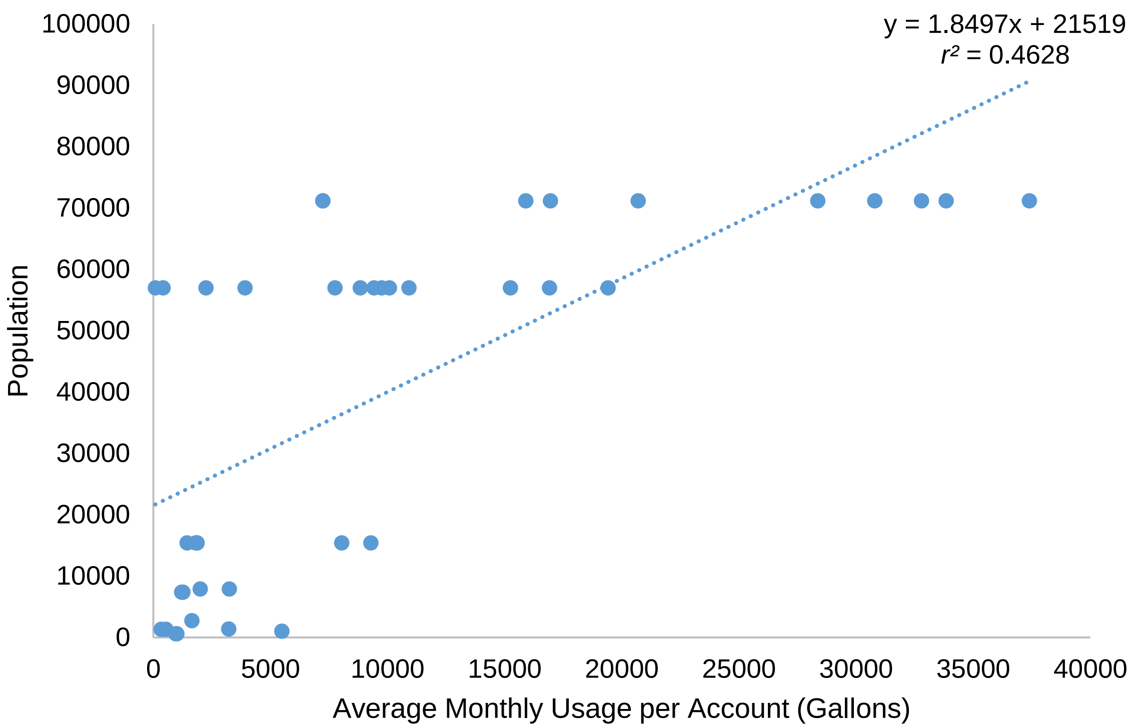

Figure 3.13. Average monthly water use per fire station accounts (gallons).

Hotels and hotels with pools also showed slight trends towards greater water use per account as city size increased (Figures 3.14 and 3.15). Additionally, average water used per hotel account (no pool) differed by city size, with large, medium, and small cites using 85,678 gallons, 51,204 gallons, and 32,111 gallons per month respectively. Furthermore, hotels with pools followed the same pattern and used more water than hotels without pools for each city group. Hotels with pools located in large and medium sized cities used double the amount of water compared to hotels without pools in their respective categories. Vickers (2001b) reported that hotels, motels, and tourist courts used an average of 436,175 gallons per month, per meter connection in Vancouver, British Columbia. This is much higher than the amount of water used by hotels in North Dakota (Table 3.4).

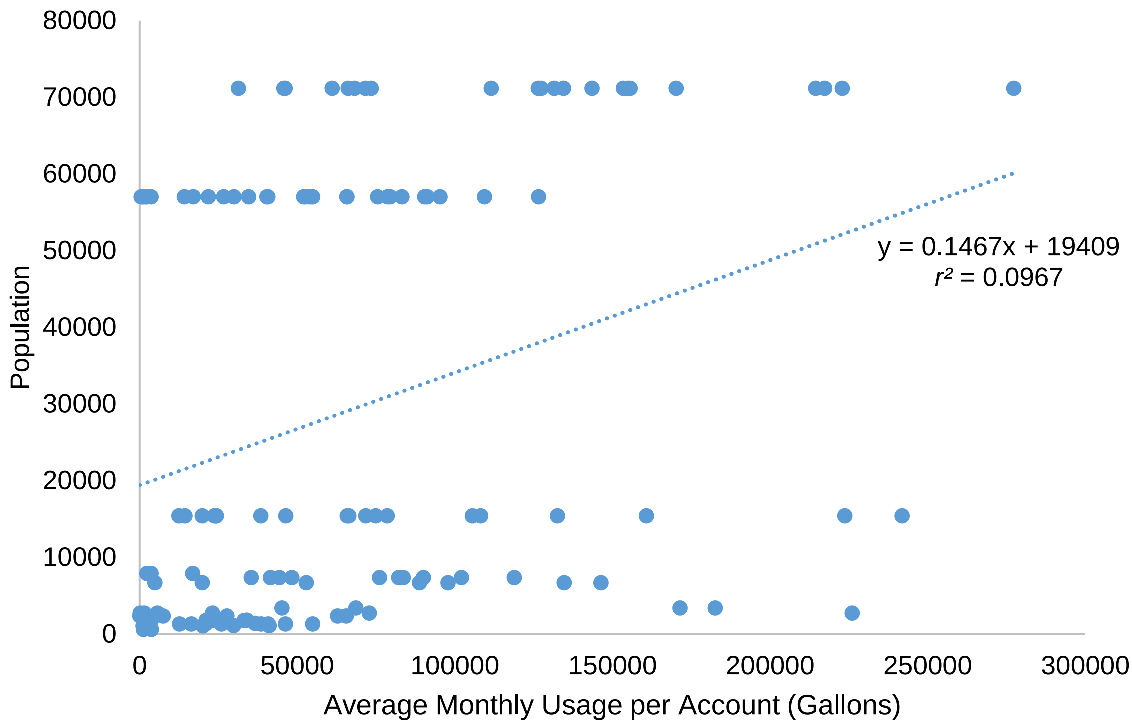

Figure 3.14. Average monthly water use per hotel account (gallons).

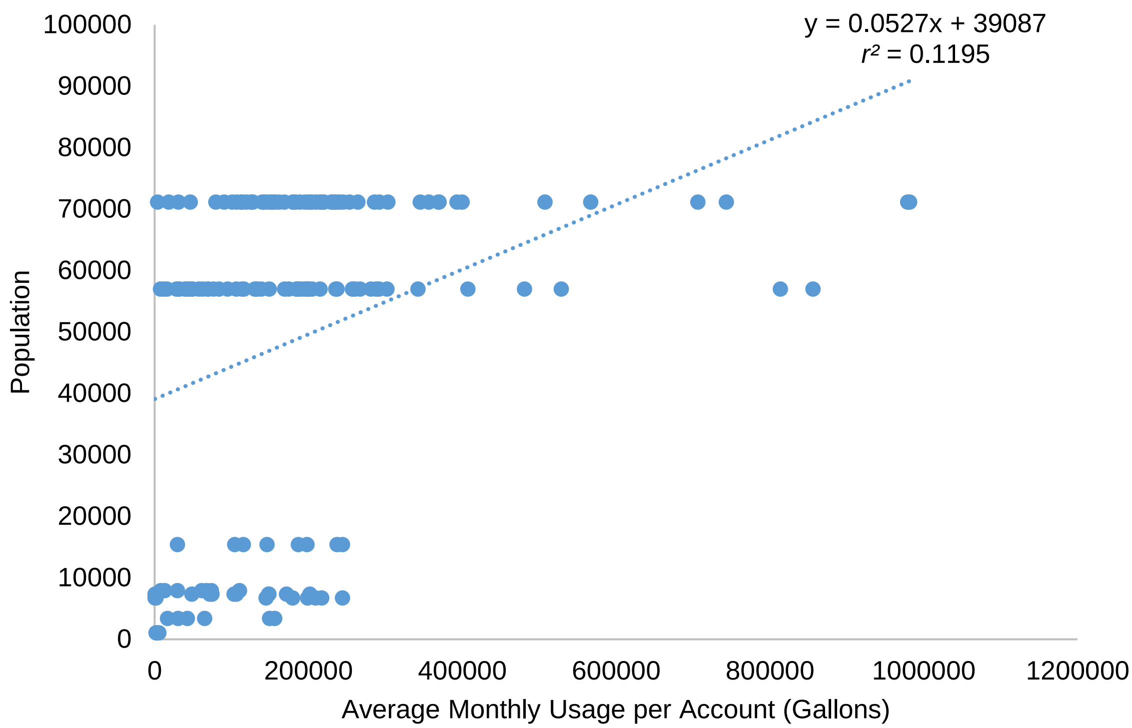

Figure 3.15. Average monthly water use per hotel with a pool account (gallons).

Another factor examined regarding hotel water use, was the average amount of water used per hotel room (Table 3.5). Average water use per hotel room was calculated for all eight cities that had hotels with pools, which included three large, three medium, and two small cities. One hotel from a large city was excluded from analysis because researchers were unable to calculate water use per room. Nineteen cities had hotels without pools including three large, three medium, and 13 small cities. All 19 cities had their hotel water usage broken down to water use per hotel room. A total of seven hotels from two large, two medium, and one small city were excluded from per room water use analysis, because number of rooms in these hotels could not be determined.

Table 3.5

Average monthly water used per hotel room (gallons).

Category	All Cities	Large Cities	Medium Cities	Small Cities
Hotel	1,727	1,695	1,441	1,831
Hotel with a pool	2,663	2,801	2,623	1,505

As expected, the overall average water use per hotel room was greater when a hotel had a pool in all, large, and medium cities. A study conducted in Seattle, Washington, USA, examined hotel water use in various hotels. They found an average water use per hotel room of 2,829 gallons per month and 6,053 gallons per month for two different hotels (O'Neill et al., 2002). The hotel that used 6,053 gallons per room per month in Seattle was a high-class hotel with a pool, restaurants, and banquet facilities. Thus, the water use of the second hotel, the one that used 2,829 gallons per room per month, in Seattle is a better comparison of water usage to hotels in our study. Hotels with pools used an average of 2,663 gallons per room per month, which is similar to what O'Neill et al. (2002) found in Seattle.

In small cities, hotels without pools actually had slightly higher water usage per room than hotels with pools. This can be partially explained by where hotels with pools were located. Only two small cities had hotels with pools, while 13 small cities had hotels without pools, making hotels without pools more common in smaller cities. Furthermore, one of the small city hotels that had a pool, had an outdoor pool. Due to the climatic conditions of North Dakota, this pool is probably used less than 6 months out of the year, which would decrease the amount of water used. Thus, the combination of an outdoor pool, the fact that hotels without pools are more common in small cities, and differences in occupancy rate, it makes sense that hotels with pools may use slightly less water per room than hotels (without pools).

Both carwashes and gas stations with carwashes were broken down further, when possible, to examine average monthly water use per carwash bay. Carwash accounts can include a single carwash bay or may include multiple bays, all which would influence the total amount of water used per account. Thus, to compare the amount of water used per carwash bay, average monthly water use per bay was determined for carwashes. Overall, large cities had a larger average water use per carwash bay per month than medium or small cities (Table 3.6). Although the average monthly use for large cities was over double the amount used by medium or small cities, there was no relationship between city size and carwash bay use (r^2=0.05). One possible reason for this large disparity was an outlier carwash. In one of the large cities, Grand Forks, North Dakota, a single carwash account, which has one carwash bay, used on average over one million gallons of water a month. When this outlier carwash was removed the average monthly water use per carwash bay for all cities became 45,975 gallons per month, while the monthly average for large cities became 54,905 gallons per month per bay, indicating that this outlier influenced the average water use per bay.

Table 3.6

Average monthly water used per carwash bay (gallons).

Category	All Cities	Large Cities	Medium Cities	Small Cities
Carwash	65,372	86,472	29,048	35,488
Gas Station with carwash	145,650	145,620	174,366	77,063

Another interesting finding regarding carwashes is that medium sized cities had the lowest average monthly usage per carwash bay for carwashes, while simultaneously having the highest average monthly usage per carwash bay when the carwash was located with a gas station.

Although it is unknown exactly why this occurred, the type of carwashes available may have influenced the amount of water used. A study by the International Carwash Association, found that the type of carwash (i.e. conveyor, in bay, self-serve) affected the amount of water used per wash (Brown, 2002). Since 44% of carwash accounts in medium sized cities were for "self-serve" carwash bays and carwashes associated with gas stations were automatic (in bay or conveyor), it appears that the type of carwash my be affecting where people wash their cars, which would in turn affect the water use of accounts associated with carwashes. Since almost half of carwash bays were not automatic, less water may be used per bay.

Large Commercial Water Users

City size influenced the top water consuming entities, as the top water consuming sub-categories for an entire year differed between city sizes (Table 3.7). Total yearly water consumption by all municipalities was calculated by taking the total water used for each sub-category in each city and creating an average. Food processing used the most water in large cities, while manufacturing used the most water in medium sized cities and colleges consumed the most water in small cities. Three sub-categories are one of the top water using categories in all cities regardless of size, and include colleges, hotels with pools, and assisted living and nursing home facilities. Additionally, both hospitals and food processing are top water users in large and medium sized cities. Gas stations with carwashes, multi-business (water meter with multiple business on one meter), and public schools were all top water users in medium and small cities.

Table 3.7

List of the top 10 large, medium, and small cities water consumers, with sub-categories consuming the most water per year on average in cities listed from top to bottom.

Large Cities	**Medium Cities**	**Small Cities**
Food Processing	Manufacturer	College
Commercial Irrigation	Food Processing	Assisted Living & Nursing Home
College	College	Gas Station with carwash
Hotel with pool	Hotel with pool	Hotel with pool
Military	Assisted Living & Nursing Home	Hotel
Hospital	Combo	Public School
Office	Public School	Jail
Jail	Gas Station with carwash	Oilfield
Assisted Living & Nursing Home	Hospital	Multi-business
Laundromat/Laundry Service	Multi-Business	Carwash

In large cities, food processing accounted for an average of 23% of the total water consumed in these cities. In California, different food processing sectors used between 2.3 and 10.5% of the industrial water (Seneviratne, 2007). Thus, there is a large difference in the percent water used for food processing in large cities and in California. One potential explanation is that one large city in North Dakota, used over 1.3 billion gallons of water in the food processing sector in a year. The other two large cities used 24 and 2 million gallons each. Therefore, the outlier city that used over 1 billion gallons of water in food processing a year, greatly inflated the amount of water used in this sector, which effected the overall percentage of water consumed by this sector.

Colleges were a major water user in all cities, regardless of city size. All facilities associated with colleges including dorms, educational buildings, and athletic complexes were included in college water use. In both large and medium cities, colleges used approximately 6% of total water used by commercial entities. Additionally, when colleges were located in small cities, they used an average of 11% of all water in these municipalities. A study by the American Water Works Association found that colleges and schools used about 8.84% of commercial and institutional water (Dziegielewski et al., 2000). Although the amount of water used in large and medium cities is less than the average reported in the study by Dziegielewski et al. (2000), the North Dakota averages do not include other school or institutional users. Thus, once water used by both public and private schools is added to college water consumption in large and medium cities, the percent water used by this group of categories increases to 7.8% for large cities and 11.2% for medium cities. Therefore, it appears cities in North Dakota use approximately the same percentage of water for educational facilities as the five water systems studied by Dziegielewski et al. (2000), with a greater proportion of water consumed by educational institutions as city size decreases.

Hotels with pools were major water users in all cities, using 5.4%, 4.5%, and 4.1% of total commercial water in large, medium, and small cities respectively. When hotels and hotels with pools were combined, large, medium, and small cities used 6.6%, 6.5%, and 7.0% of all commercial water. Compared to the entire commercial water use sector in California, where hotels used 1.6% of commercial water, North Dakotas use is high (Seneviratne, 2007). Yet, Dziegielewski et al. (2000) found that hotels and motels used approximately 5.82% of commercial water in five select cities in California and Arizona, which is comparable to our results.

Overall, the top ten water using sub-categories accounted for at least 50% of the total water used in each size city. The major water users in large cities consumed, on average, 60% of all commercial water in large cities. Major water users also used 63% and 50% of commercial water in medium and small cities respectively. Thus, a small group of water users consume a large percentage of all commercial water used in cities.

Management Implications

Information regarding the amount of water used by all commercial and residential users is crucial to future planning. This study was the first of its kind to look at water users across an entire state to develop per capita coefficients and understand normal commerce for different sized municipalities. Results show that city size influences the amount of water used by some residential and commercial categories, and that a city has to be a certain size before particular commercial water users are present.

Cities on average used more than 50% of all municipal water in the residential sector, although this varied greatly with some cities utilizing over 90% of all municipal water residentially. Additionally, different dwelling types (i.e. apartment, single family home, duplex, etc.) used different amounts of water, especially when water use was broken down per individual living unit. Results showed that a small percent of single family homes use a large percent of all water used by single family homes. The top 10% of water consuming single family homes consume approximately 25% of water used by single family homes, while the bottom 10% consume only 1-2% of all water used by single family homes. These results regarding water use in the residential sector are important for future city planning and could influence the types of residential dwellings municipalities pursue.

City size affected the amount of water used by certain sub-categories of water users such as fire stations, while it did not influence water consumption in other categories. Common large water users in cities of different sizes included colleges, assisted living/nursing home facilities, and hotels with pools. Overall, the top 10 water-using entities in cities used over 50% of all commercial water. Knowledge on top water consuming businesses is important when planning for future city growth, so planners know which businesses use a substantial amount of water. This knowledge is also important in times of drought, as some large users may be able to reduce water use if restrictions are put into place, such as less irrigation, while other businesses may not be able to reduce water consumption, such as manufacturers. Overall, the per capita coefficients developed for commercial entities provides information on various commercial water users that have been rarely studied in the past.

Overall, information from this study is important for water managers local to North Dakota, across the US, and even across the globe. This study is one of only a few studies that has focused on water use in a temperature climate and during normal water use years (i.e. not a drought situation). A strong relationship exists between total amount of water used by cities and city size. This is important because if cities deviate away from this relationship and see increased or decreased water use, managers have a reason to investigate what is occurring. The information found in this study is also useful for planning purposes, for example if a city increases in size they can predict the increased amounts of water that will be needed and in which categories of water use they might be needed. The information is also useful for planning in times of water stress to determine which types of water use are necessary and how much water those groups need.

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APPENDIX A. LIST OF CITIES CONTACTED

City	Population (2015)		City	Population (2015)
Fargo	118,523		Washburn	1,309
Bismarck	71,167		Ellendale	1,299
Grand Forks	57,011		Parshall	1,263
Minot	49,450		Velva	1,260
West Fargo	33,597		Hettinger	1,257
Williston	26,977		Killdeer	1,254
Dickinson	23,765		Cavalier	1,244
Mandan	21,382		Burlington	1,181
Jamestown	15,422		Cando	1,122
Wahpeton	7,899		Beach	1,115
Devils Lake	7,351		Kenmare	1,083
Watford City	6,708		Belfield	1,055
Valley City	6,669		Linton	1,039
Grafton	4,243		Thompson	1,005
Lincoln	3,519		Mohall	808
Beulah	3,393		Underwood	775
Rugby	2,846		Ray	729
Stanley	2,721		Turtle Lake	590
Horace	2,545		Richardton	563
Casselton	2,521		Berthold	501
New Town	2,521			
Hazen	2,488			
Bottineau	2,343			
Lisbon	2,145			
Carrington	2,072			
Mayville	1,829			
Oakes	1,797			
Langdon	1,787			
Harvey	1,779			
Bowman	1,744			
Tioga	1,643			
Hillsboro	1,580			
Garrison	1,538			
Crosby	1,408			
New Rockford	1,390			
Park River	1,375			
Surrey	1,358			
Rolla	1,325			
Larimore	1,313			

Note: table contains all cities in North Dakota with over 1,000 residents and all cities in the Bakken region with populations between 500 and 1,000 residents.

APPENDIX B. QUESTIONNAIRE PART ONE FORM

City Phone Interview Call Form

Name of City:
Location (please circle one): Bakken Margin Neither
Size Category: >10,000 5,000-10,000 1,000-5,000 500-1,000
Name of Contact Person:
Phone Number:
Time and Date:
Extra Contact information:

Questions:

1. Who is in charge of water use data – city, county, rural water district – assessor's office, tax department, water department, other?

2. How are water readings taken – self reporting, city reads meters, automatic meter readings, other?
    a. If self reporting, how often are the meters verified?

3. What units are used to record water-use data (gallons, hundred-cubic feet, acre-foot, other)?

4. How often are water readings taken (monthly, bi-monthly, quarterly, yearly)?

5. Do you separate water use bills/accounts into categories (residential, commercial, industrial)?

6. How do you keep your water use data/information – electronic format, paper?
    a. If electronic format, how long has this format been used (when did you switch over from paper)?
    b. How far back do the records go (don't need exact date (i.e. 1980s))?
    c. Is information stored monthly and/or yearly (year-in-review summary)?
    d. Where is this information stored – storage room, computer, other?

7. Who do you report this data to or does it stop at the city level?

8. Is this information public information?

9. Would you be willing to share this data with us (we don't need names associated with accounts, we just need to know the type of account (i.e. single family home, apartment, carwash, etc.) and water use (per month preferably but could be per year))?
    a. How can this information be accessed – website, by visiting the office, is it easily pulled up with a certain computer program, manually going through permits? (Skip if not willing to share data)

APPENDIX C. QUESTIONNAIRE PART TWO FORM

2nd Round - City Phone Interview Call Form

Name of City:
Name of Contact Person:
Phone Number:

Questions:

10. Does the city buy or sell water or both (besides municipal customers)?
    a. If "Yes" who do the city buy/sell water from/to?
    b. How does the city buy/sell water (pipe, truck, other)?

11. Do you withdraw surface water or groundwater or both?
    a. Where is the water from (name of aquifer, river, etc.)?
    b. How much water does the city withdraw?

12. Does the city use reclaimed or reused water?
    a. If use this type of water, please define the word you use (reclaim, reuse, grey water, other).

13. Does the city meter system losses?
    a. How does the city complete this?
    b. Are losses recorded as number of gallons/hundred cubic feet, other?
    c. Do you have the 2015 and/or 2016 water losses?

14. Does the city apply seasonal rates to water (example – irrigation rates in the summer)?
    a. If "Yes" what is the seasonal rate (and the normal rate)?
    b. How does the city determine who/where seasonal rates apply?

15. Does the city have water conservation measures?
    a. If "Yes" what are they?
    b. How are they applied?
    c. What percentage of customer base participates?

16. Does the city have water restrictions?
    a. If "Yes" what are they?
    b. How are they applied?

Conservation Measures: Prevention of excessive or wasteful use of water – long-term measure

- Replacing water meters with more efficient meters
- Rebates for high efficiency washers/low flow toilets/appliances that use water

Water Restrictions: Temporarily restricts/lowers water use

- Limiting when/how long water can be used (… to water lawns …)

APPENDIX D. LIST OF UTILITY BILLING SOFTWARES UTILIZED BY CITIES

Software	Number of Cities
Black Mountain	25
Banyon	18
AS400	2
Vanguard	1
JHawk	1
inhance	1
UBMax	1
Incode	1
SCADA	1
CIS New World (Fixed Network)	1
CUBIC	1
Great Plains Software	1
Excel	1
EBill	1
Unspecified	1

APPENDIX E. WATER SOURCES OF MUNICIPALITIES

City	Source	Amount withdrawn
Beach	Aquifer – unknown	800,000 gallons/year
Beulah	Knife River Aquifer	130,000,000 gallons/year
Bismarck	Missouri River Aquifer	3.65 billion gallons (2016)
Bottineau	Undefined Aquifer	-
Bowman	Fox Hills Aquifer	-
Carrington	Carrington Aquifer	-
Devils Lake	Spirtwood Aquifer	2 million gallons/day
Dickinson	Lake Sakakaewa	97,687,406 gallons (2017)
Ellendale	Lamoure Aquifer	40,255,000 gallons (2016) 45,074,000 gallons (2015)
Fargo	Red River & Sheyenne River	14-15 million gallons/day
Garrison	Lake Sakakawea	-
Grafton	Red River	180,546,989 gallons (2017) 201,597,800 gallons (2016)
Grand Forks	Red River & Red Lake River	-
Harvey	New Rockford Aquifer	325,000 gallons/day
Harvey	Lake Sakakaewa	7,000,000/month
Hillsboro	Galesburg & Hillsboro Aquifers	Purchased 143,042,000 gallons (2017)
Jamestown	James River Aquifer	1,254,613,200 gallons (2017)
Killdeer	Killdeer Aquifer	24,085,957 gallons (2017)
Larimore	Elk Valley Aquifer	48 million gallons/year
Lisbon	Undefined Aquifer	120 million gallons/year
Mayville	Galesburg Aquifer	106 million (2015), 110 million (2016)
Minot	Minot & Sundre Aquifers	-
Mohall	Cutbank Creek Aquifer	1 million gallons/year
New Rockford	New Rockford Aquifer	49,009,000 gallons (2017)
New Town	New Town Aquifer	-
Oakes	Oakes Aquifer	101,537,000 gallons

City	Source	Amount withdrawn
Park River	Fordville Aquifer	15 million gallons/year
Parshall	Missouri River	2 million = city; 4-5 million = sold to industry
Ray	Ray Aquifer	-
Rolla	Rolla Aquifer	130,000 gallons/day
Rugby	Pleasant Lake Aquifer	-
Stanley	Knife River	-
Thompson	Elk Valley Aquifer	-
Turtle Lake	Lake Nettie Aquifer	16.5 million gallons/year
Valley City	Sheyenne River & Valley City Aquifer	1900 gallons/minute
Wahpeton	Wahpeton Buried Valley Aquifer	300 million gallons/year
Watford City	Garden Creek Aquifer	250 acre-feet/year
West Fargo	Red River	75 million gallons/month
Williston	Missouri River	-

Note: information regarding water source reported above was verified with the NDSWC water permits (website).

APPENDIX F. CITY WATER LOSSES

City	2015 Loss	2016 Loss	Average Loss
Bismarck	8.19%	5.65%	-
Bowman	-	-	<5,000 gallons
Casselton	-	-	15%
Devils Lake	-	-	5-10%
Dickinson	2%	3.94%	-
Ellendale	15%	10%	-
Garrison	-	-	13-15%
*Grafton	40,000,000 gallons (24.33%)	44,000,000 gallons (24.87%)	-
Grand Forks	182,738,730 gallons (6.4%)	66,852,790 gallons (2.4%)	-
Lisbon	-	-	8-12%
Mayville	8,335,017 gallons (7.8%)	14,159,357 gallons (12.78%)	-
New Town	-	-	14-18%
Oakes	11%	15%	-
Park River	-	-	10-11%
Ray	2,143,674 gallons	3,485,731 gallons	-
Surrey	-	-	5-7%
Tioga	-	-	3%
Turtle Lake	-	-	8%
Underwood	-	-	12-15%
*Wahpeton	12.6 million gallons (4.26%)	19.6 million gallons (6.5%)	-

*Grafton water losses include water used by the water department, fire department (training and firefighting), and other city departments

*Wahpeton water loss includes zoo and parks (zoos and parks are not metered)

APPENDIX G. TOTAL WATER USE BY CITY

City	Population	Total Water (Gallons)	Commercial Water (Gallons)	Residential Water (Gallons)
Belfield	1055	25,540,472	6,230,250	19,310,222
Beulah*	3393	107,787,663	23,975,705	83,811,958
Bismarck*	71167	3,222,101,630	1,111,468,160	2,110,633,470
Bottineau	2343	69,852,605	26,832,530	43,020,075
Burlington*	1181	37,950,245	15,298,696	22,651,549
Devils Lake*	7351	235,430,466	89,604,413	145,826,053
Ellendale*	1299	34,677,595	15,569,895	19,107,700
Grand Forks*	57011	2,370,711,500	1,360,789,500	1,009,922,000
Harvey	1779	50,970,416	11,965,820	39,004,596
Jamestown*	15422	483,721,354	160,354,370	283,418,922
Kenmare	1083	25,337,987	5,255,073	20,082,914
Larimore*	1313	29,969,930	6,830,784	23,139,147
Lincoln	3519	116,819,897	1,846,540	114,973,357
Mohall	808	18,294,867	6,124,874	12,169,993
New Rockford	1390	33,585,452	7,468,380	26,117,072
Oakes	1797	50,554,000	14,474,000	36,080,000
Ray*	729	30,493,455	6,450,967	24,042,488
Stanley	2721	59,468,720	20,062,980	39,405,740
Surrey	1358	19,269,000	1,113,000	18,156,000
Thompson	1005	12,451,348	1,676,160	10,775,188
Turtle Lake*	590	14,645,228	2,940,400	11,704,828
Wahpeton	7899	267,966,000	130,339,000	137,627,000
Washburn	1309	52,869,713	16,785,292	36,084,422
Watford City*	6708	267,983,517	65,805,749	202,177,768

*City provided 2 years of data, so total is the average of the 2 years
Jamestown – Miscellaneous (39,948,062 gallon average)
Note: Jamestown miscellaneous water usage was from accounts that were not able to be classified. It was unknown if these accounts and associated water usage was associated with the residential or commercial water use sectors.

APPENDIX H. SUB-CATEGORY SCATTER PLOTS

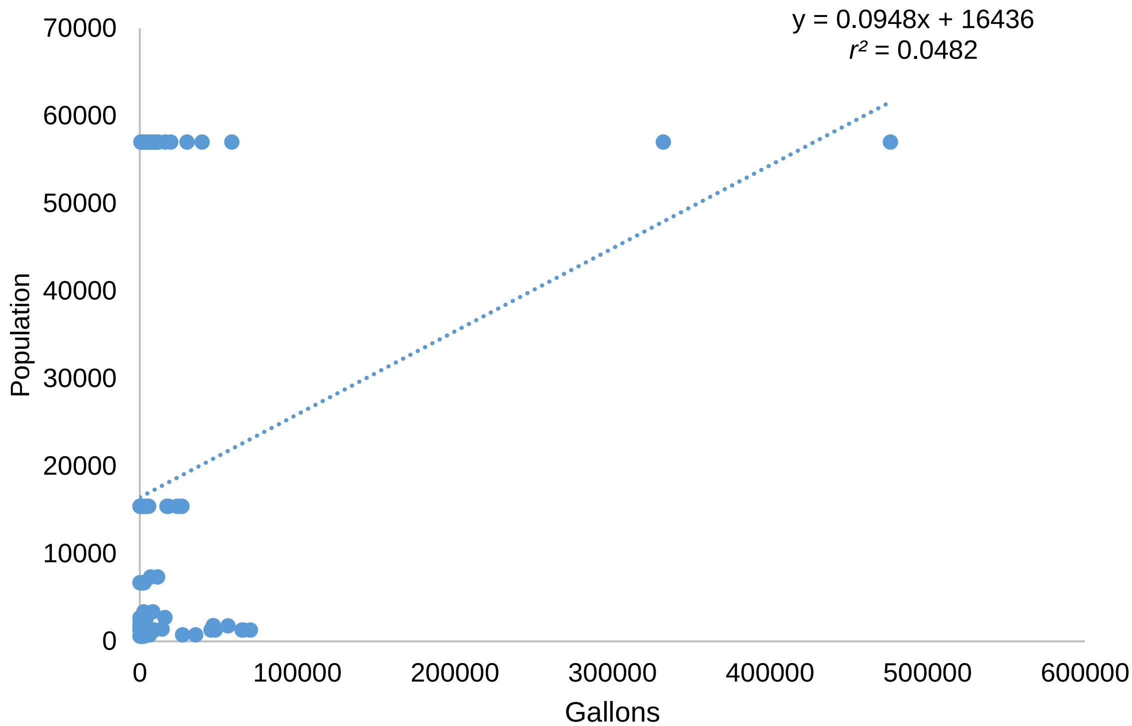

Figure F1. Average monthly water use per agriculture account (gallons).

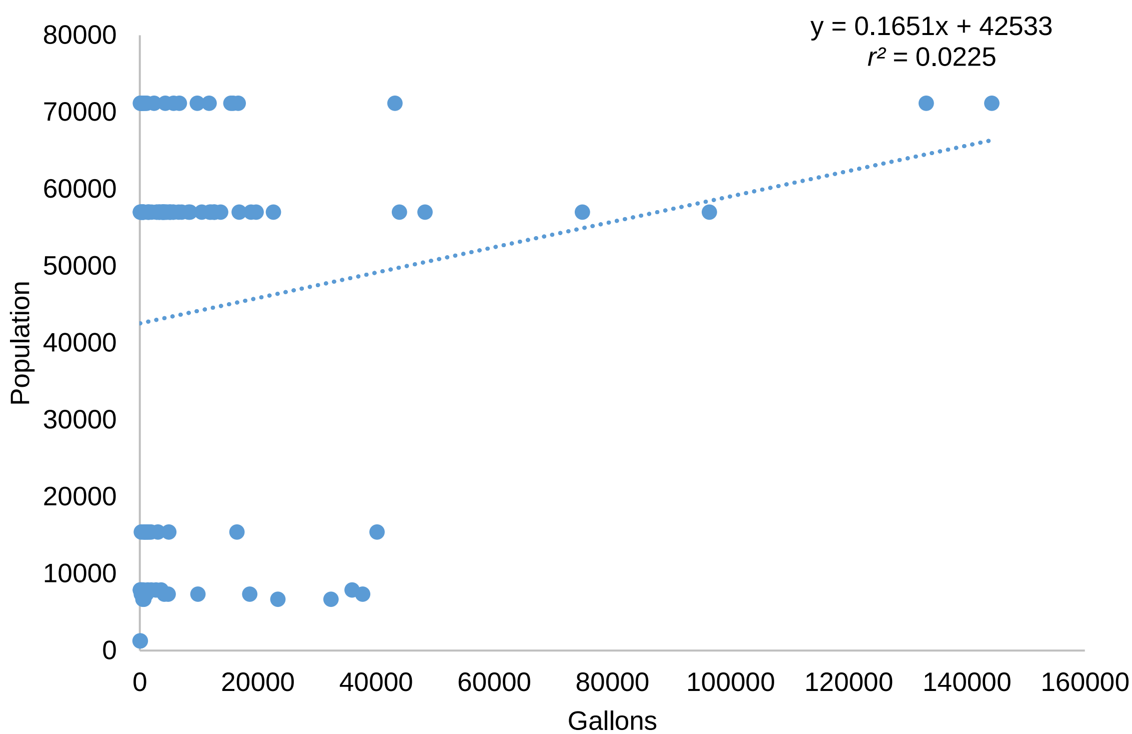

Figure F2. Average monthly water use per airport account (gallons).

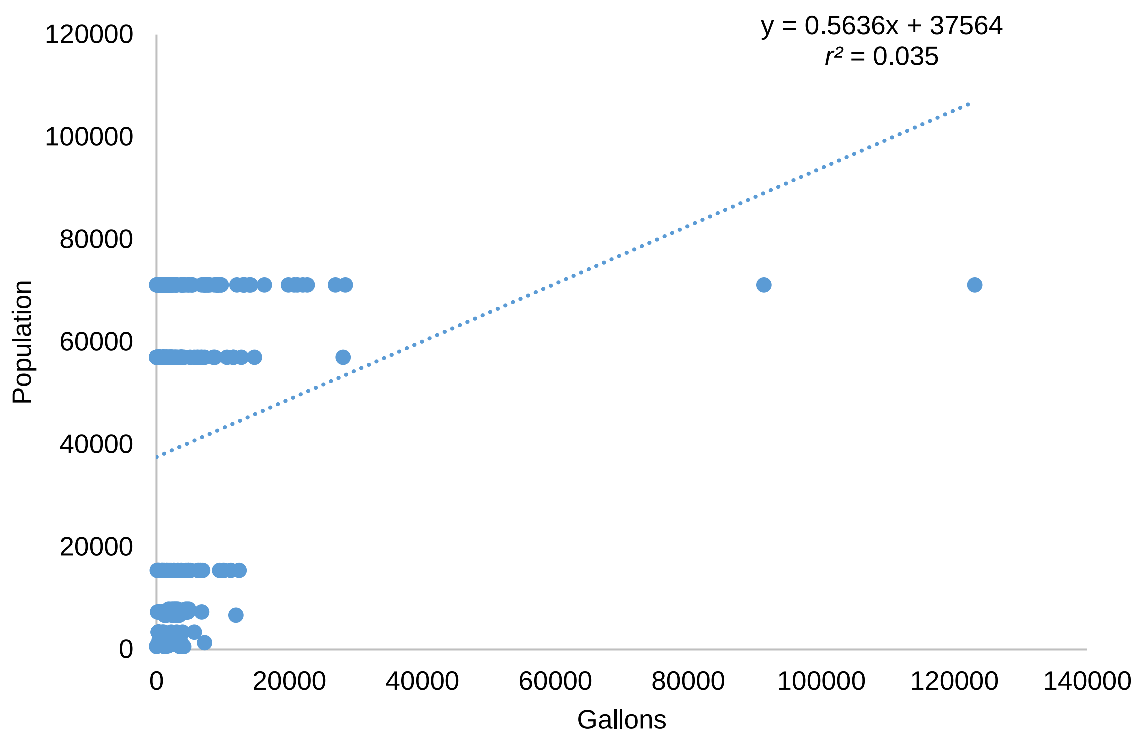

Figure F3. Average monthly water use per auto repair account (gallons).

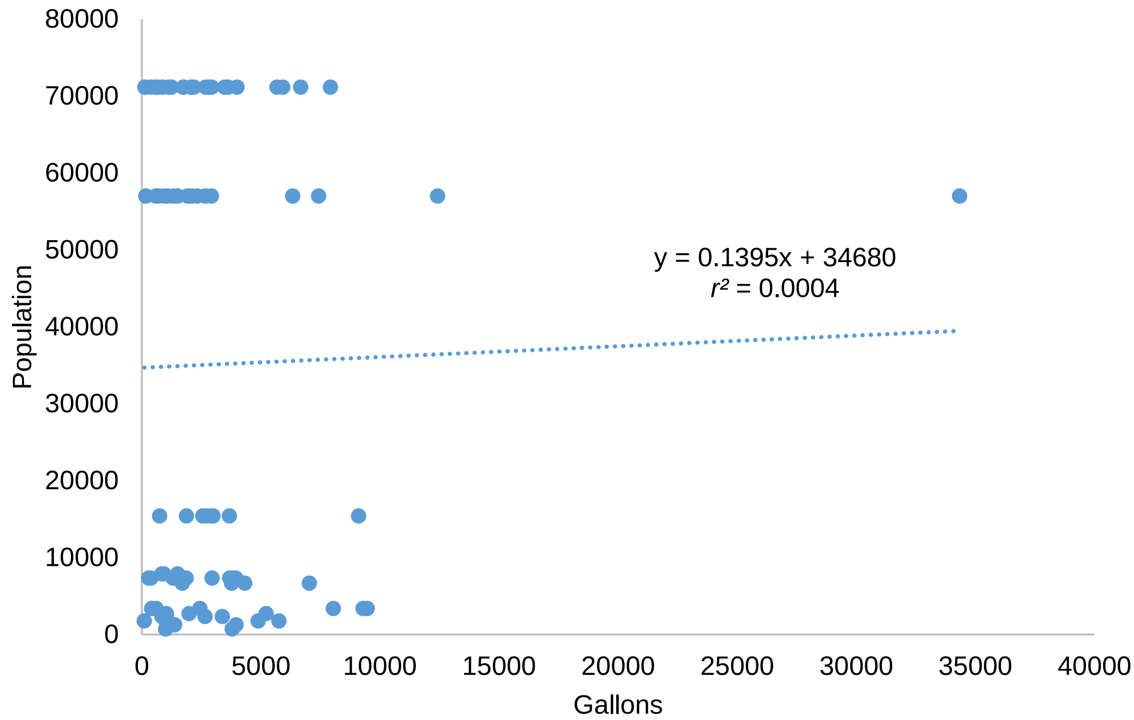

Figure F4. Average monthly water use per auto supply account (gallons).

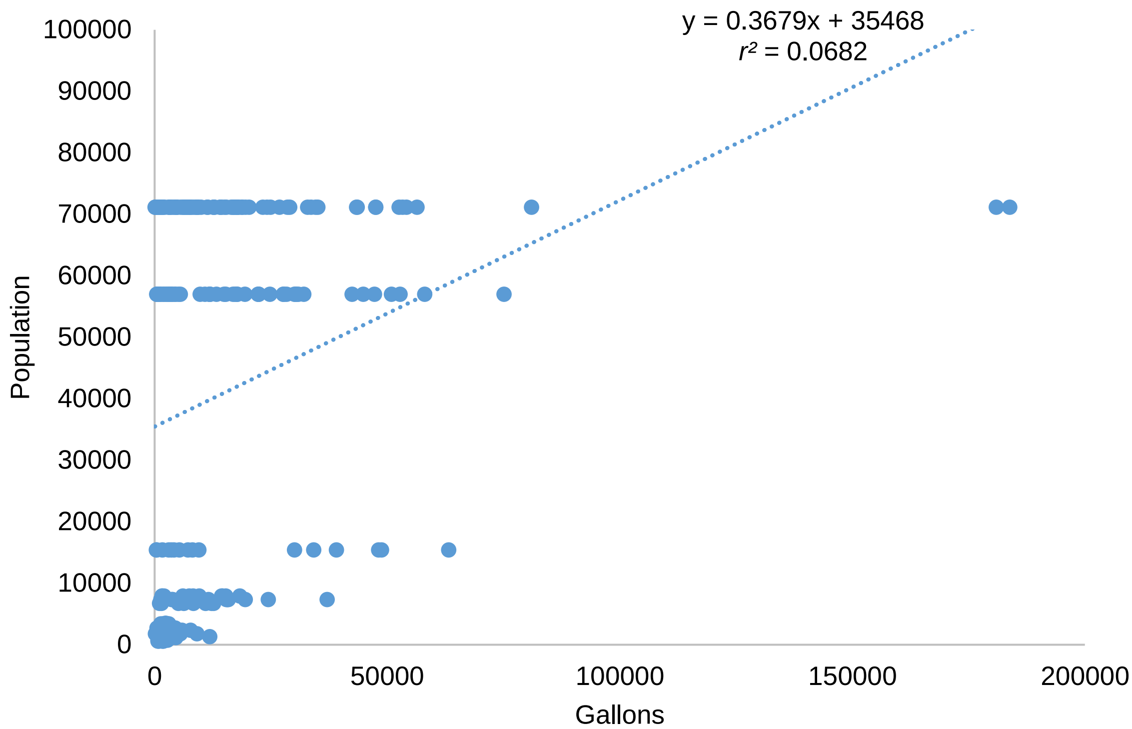

Figure F5. Average monthly water use per bank account (gallons).

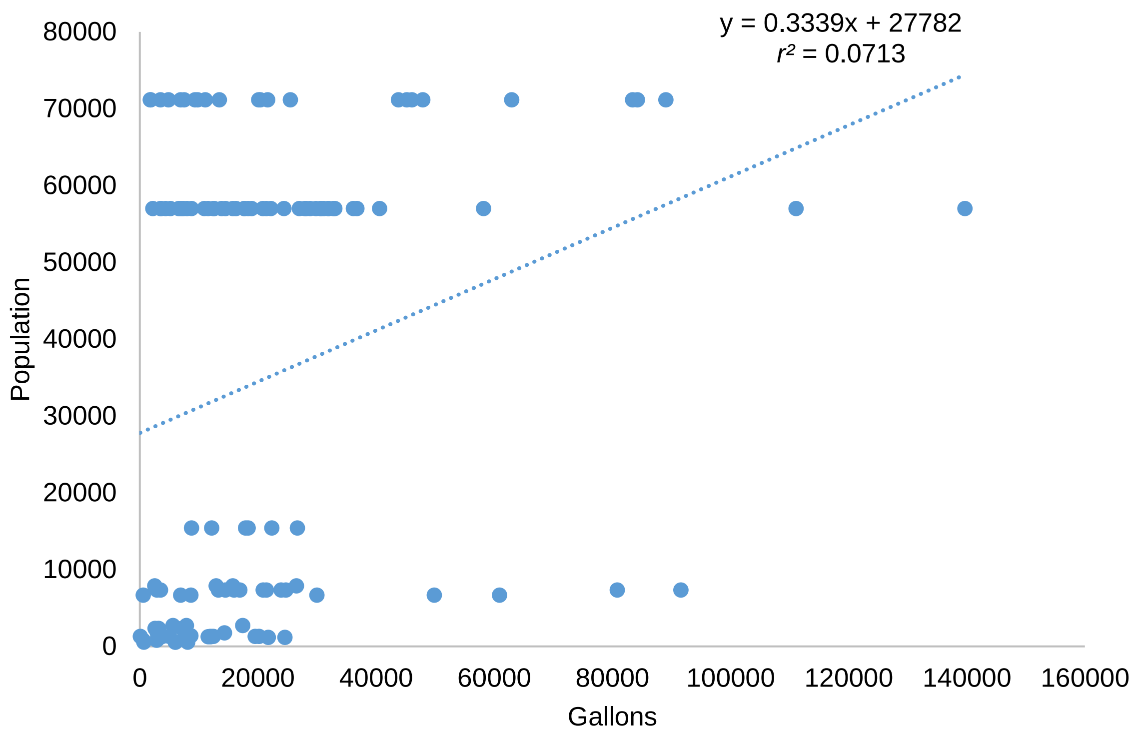

Figure F6. Average monthly water use per bar account (gallons).

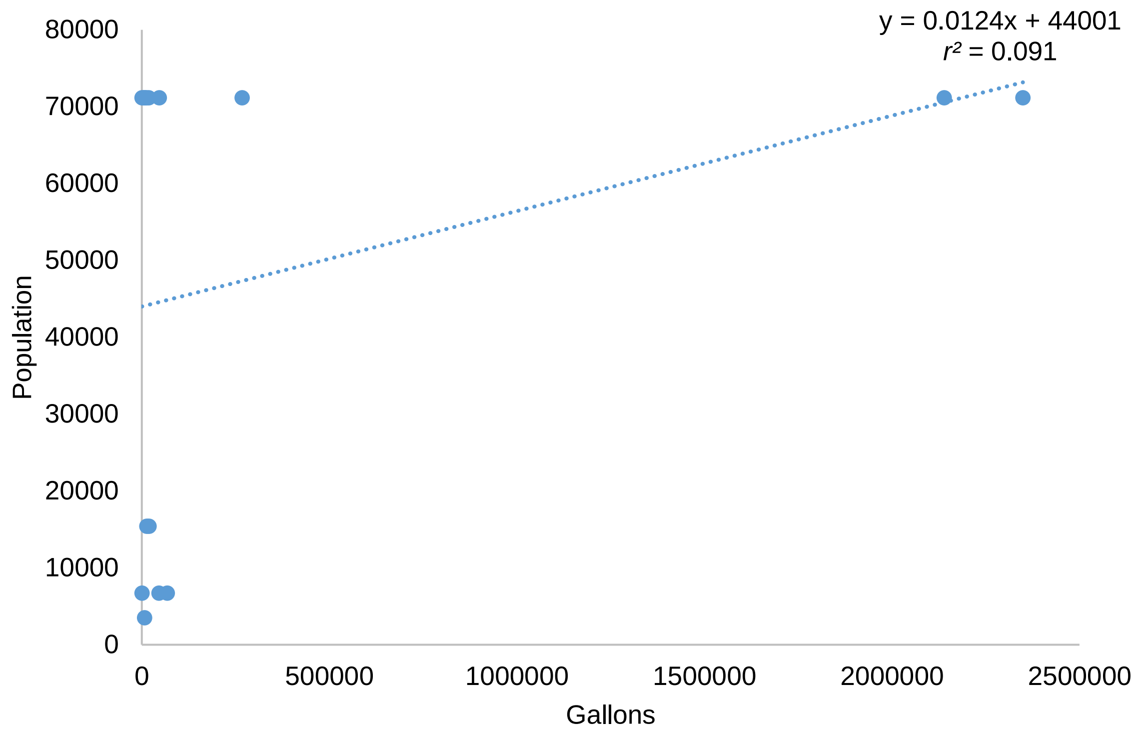

Figure F7. Average monthly water use per beverage maker account (gallons).

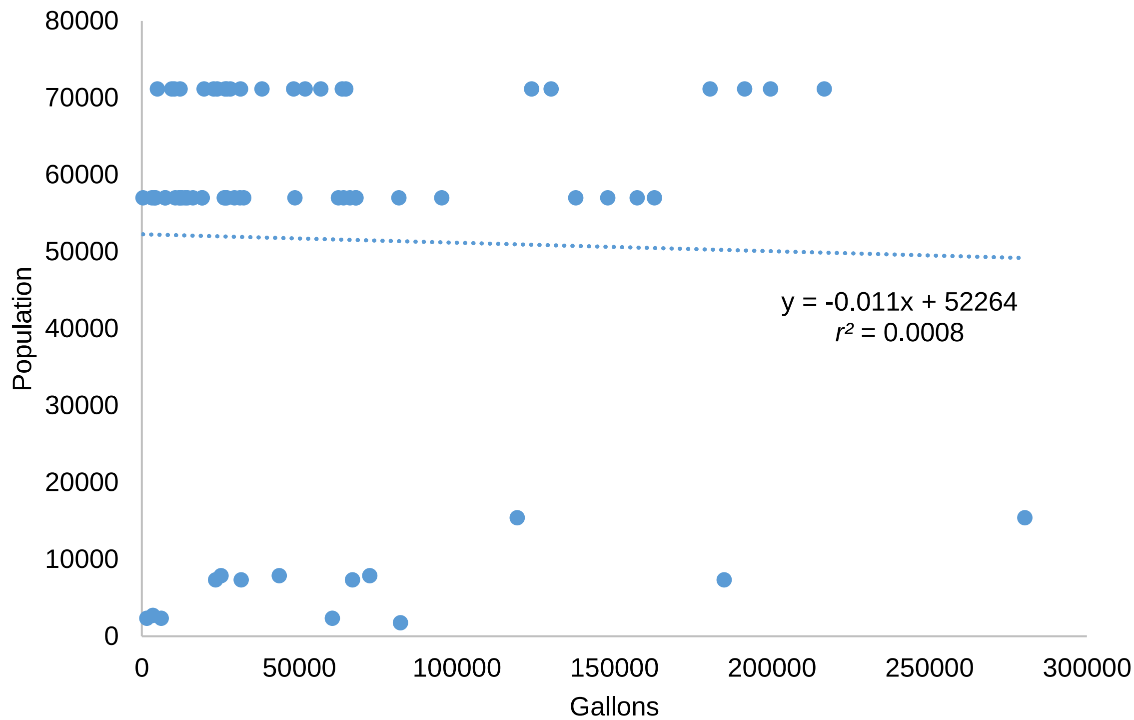

Figure F8. Average monthly water use per big box store account (gallons).

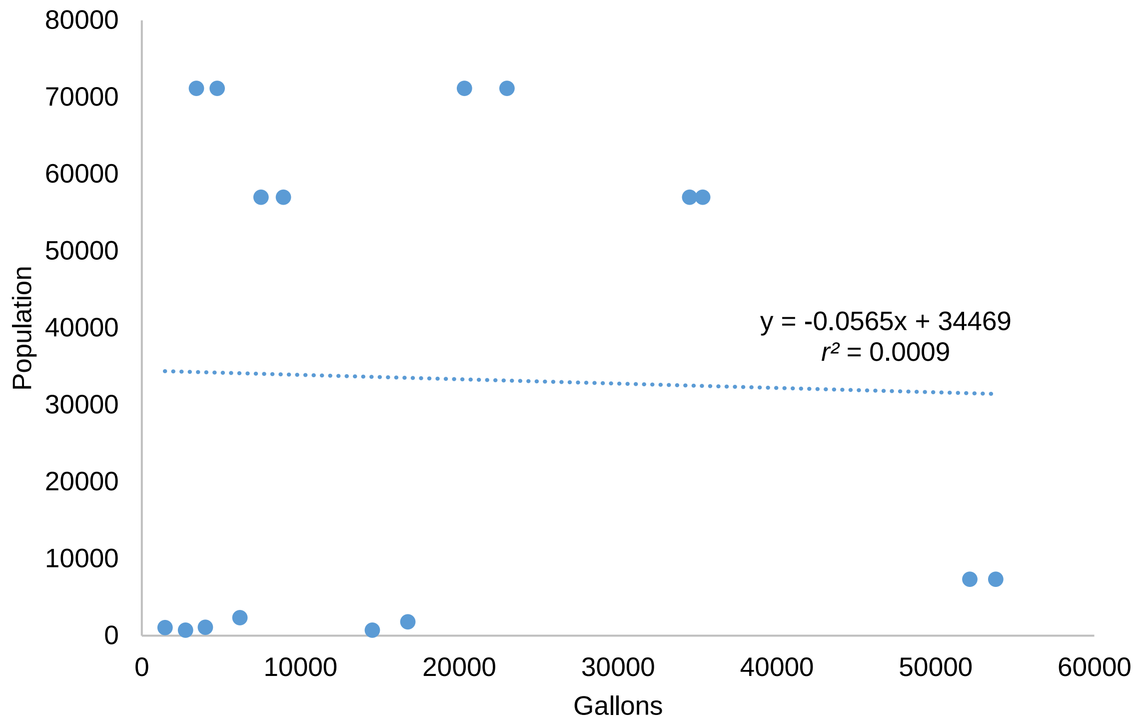

Figure F9. Average monthly water use per butcher account (gallons).

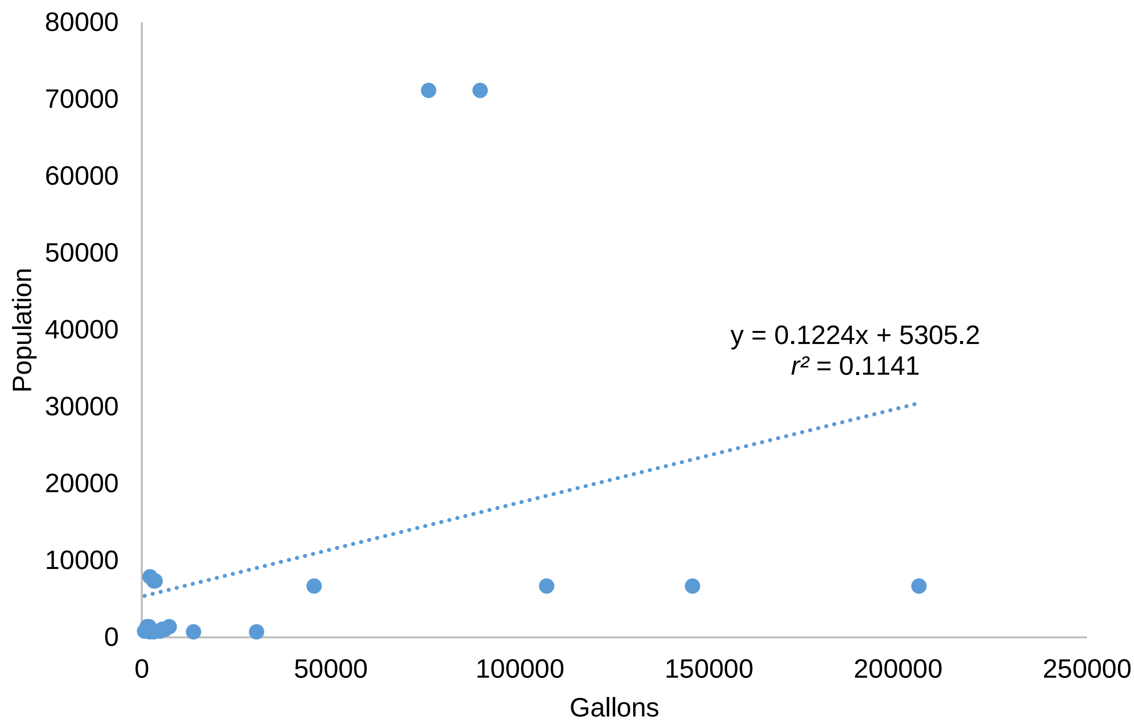

Figure F10. Average monthly water use per campground account (gallons).

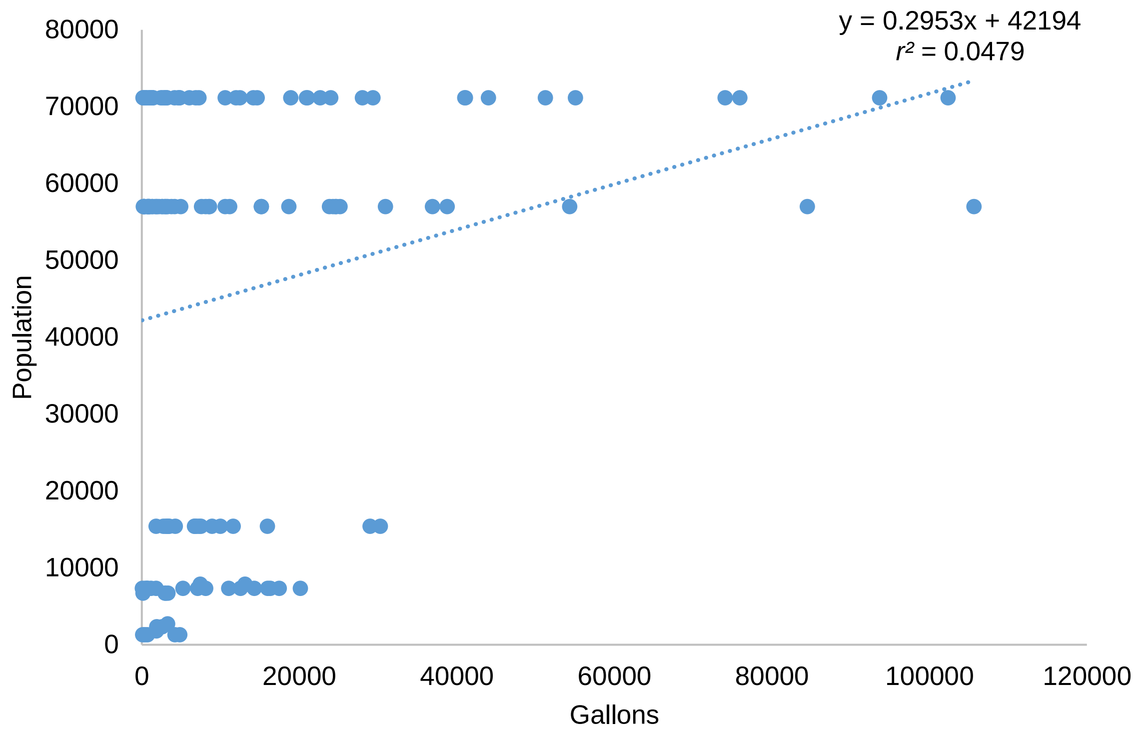

Figure F11. Average monthly water use per car dealer account (gallons).

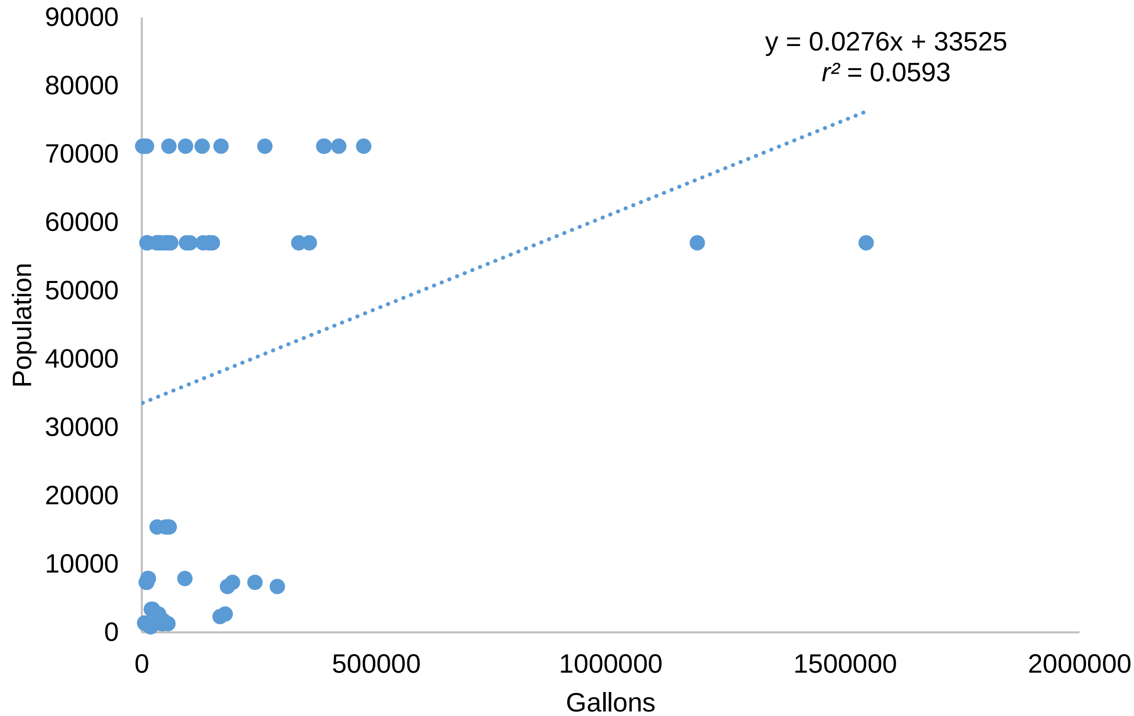

Figure F12. Average monthly water use per carwash account (gallons).

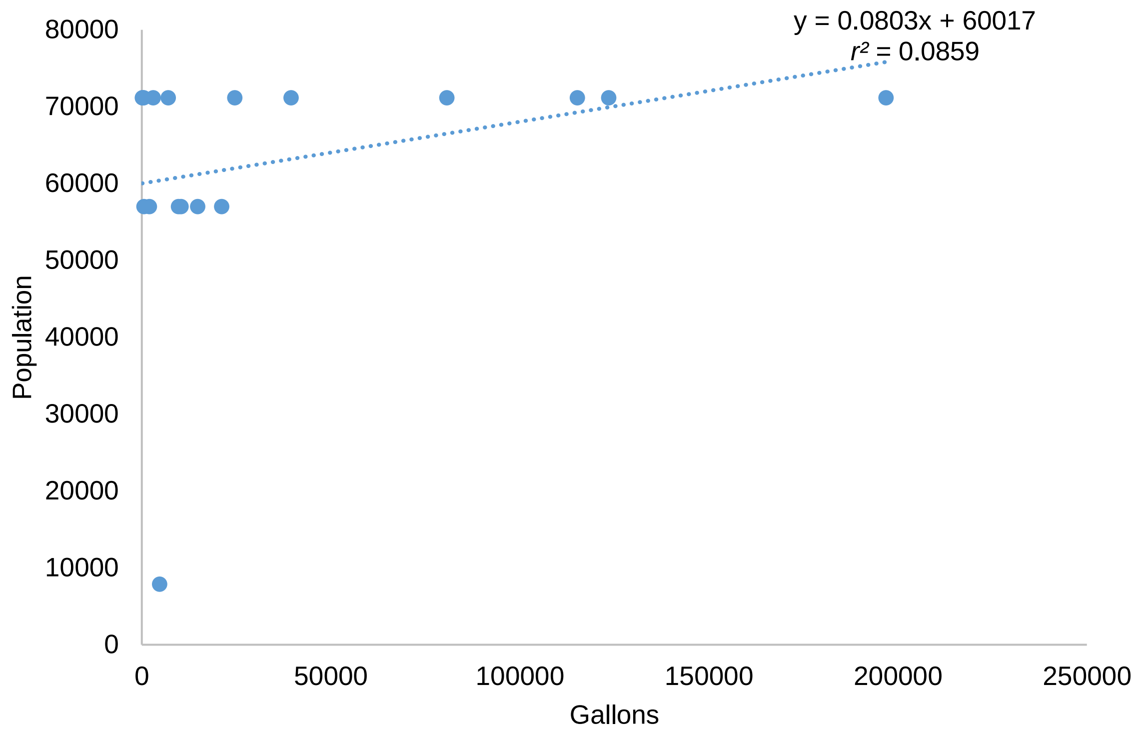

Figure F13. Average monthly water use per cemetery account (gallons).

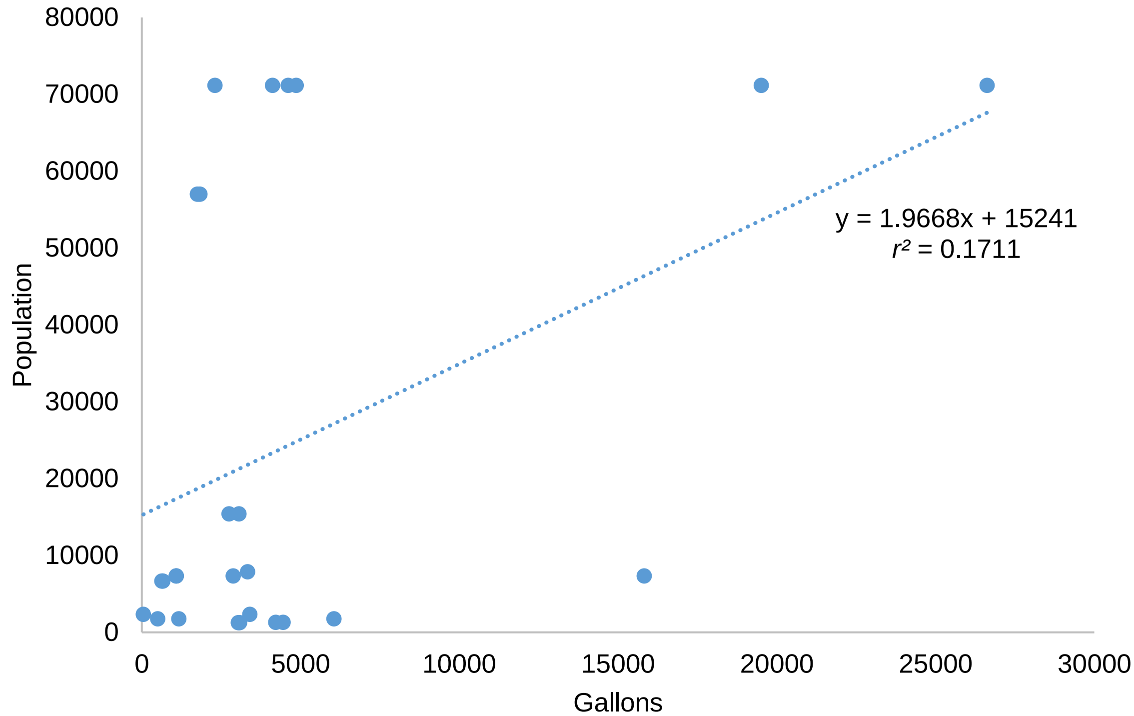

Figure F14. Average monthly water use per chiropractor account (gallons).

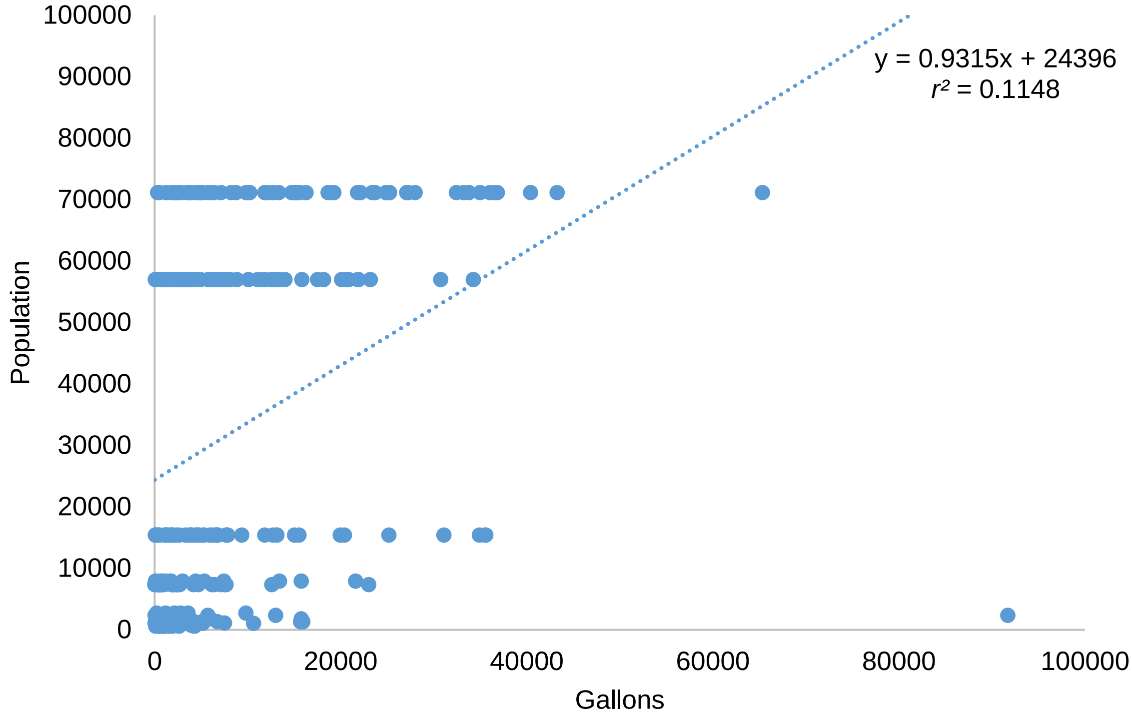

Figure F14. Average monthly water use per church account (gallons).

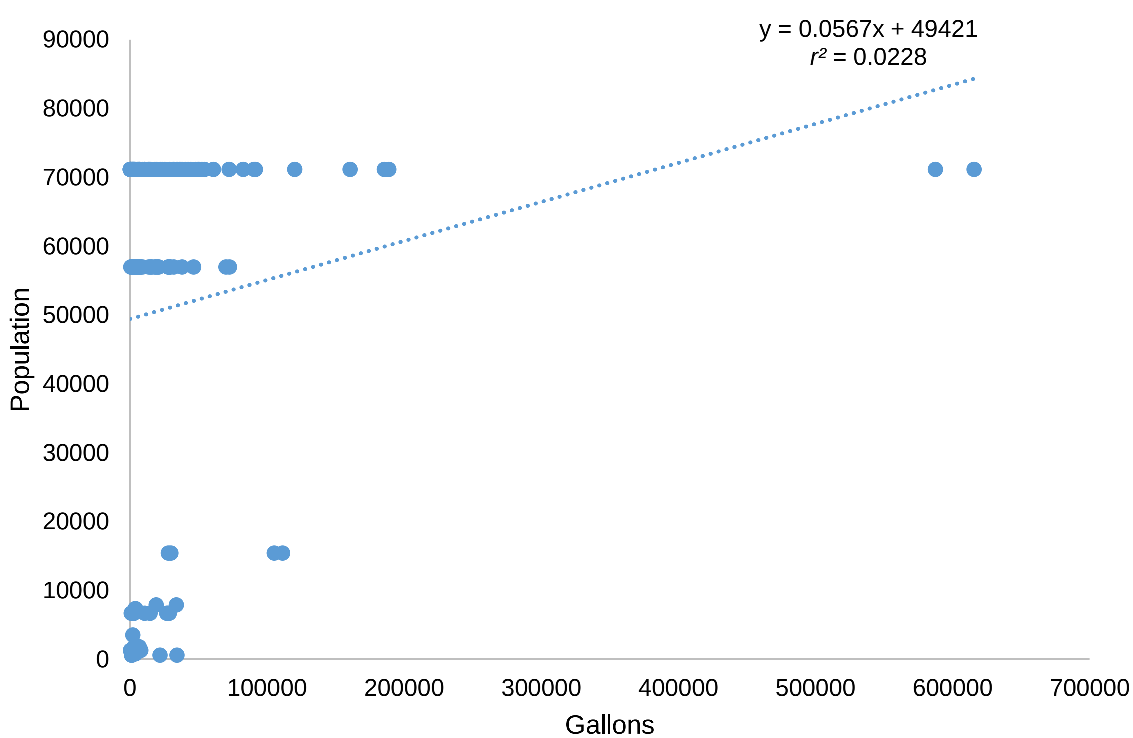

Figure F15. Average monthly water use per clinic account (gallons).

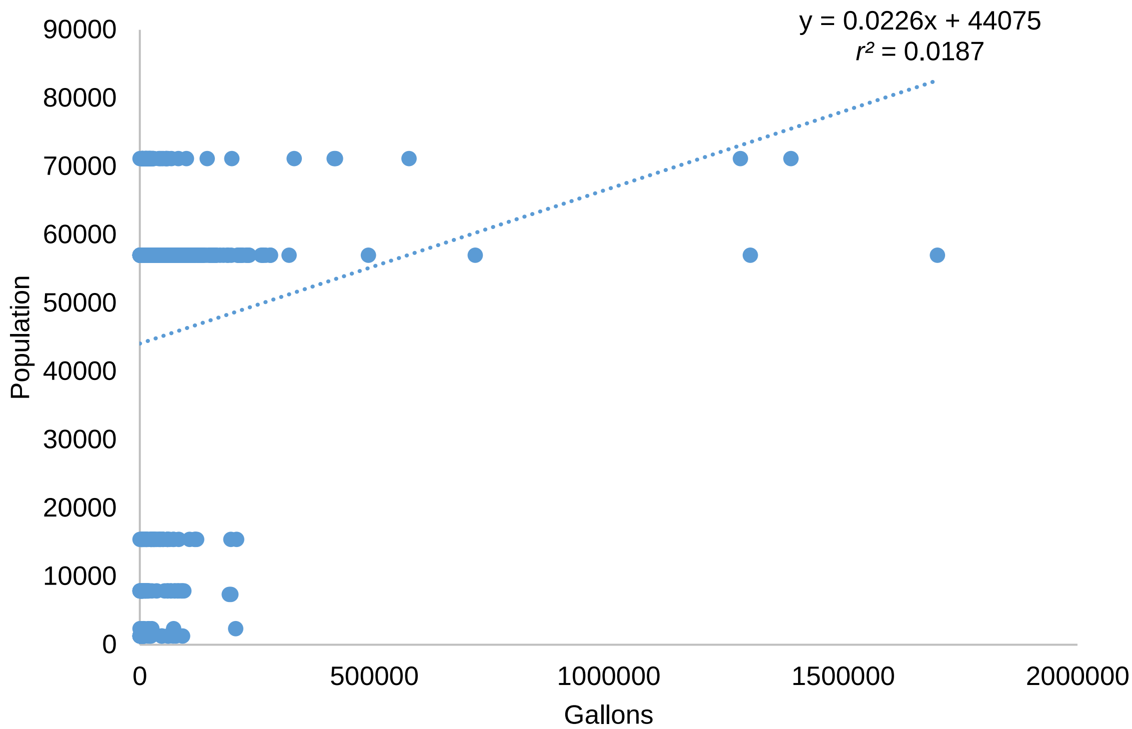

Figure F16. Average monthly water use per college account (gallons).

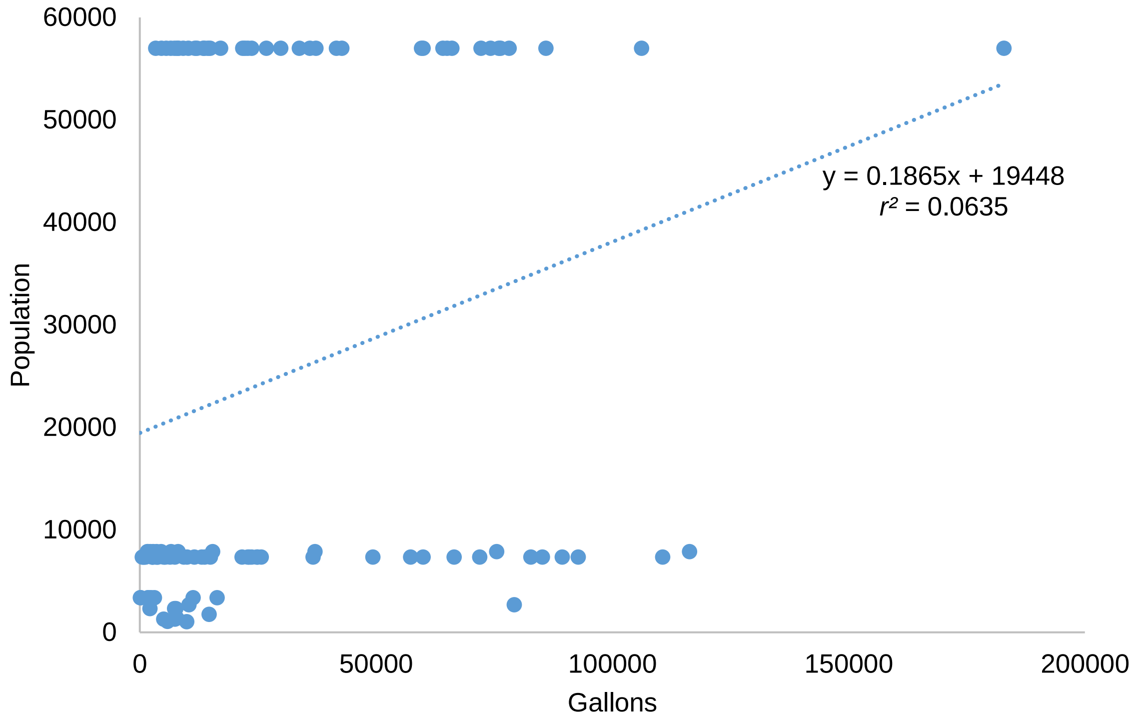

Figure F17. Average monthly water use per combo account (gallons).

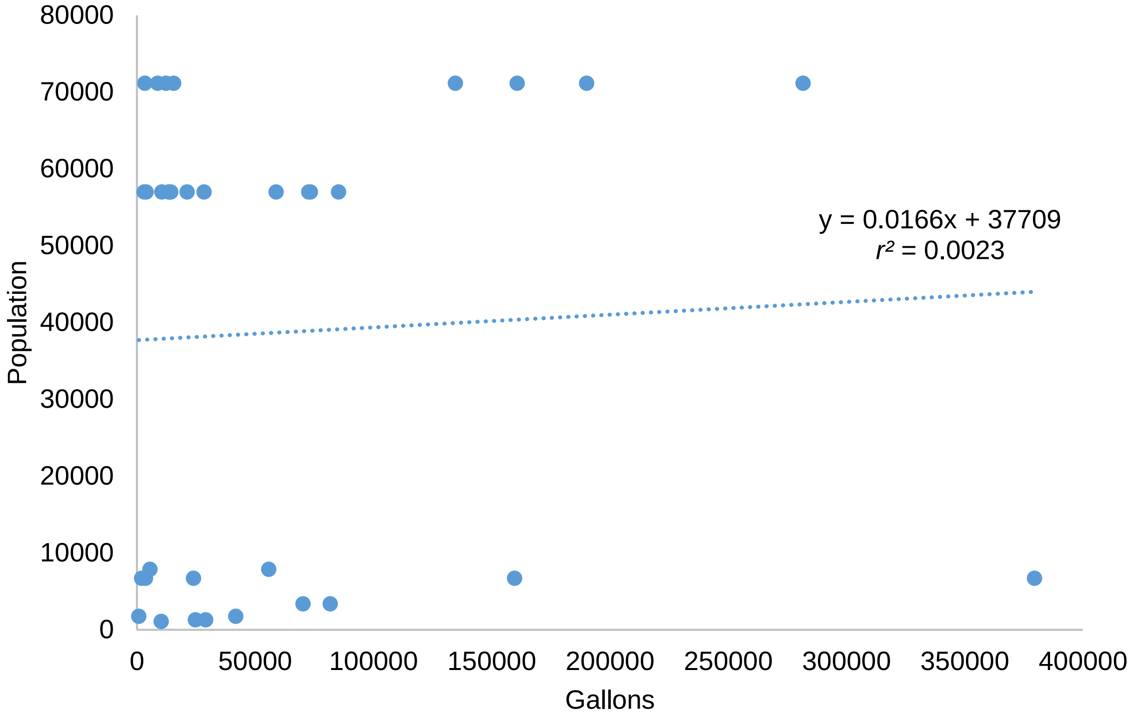

Figure F18. Average monthly water use per concrete batch account (gallons).

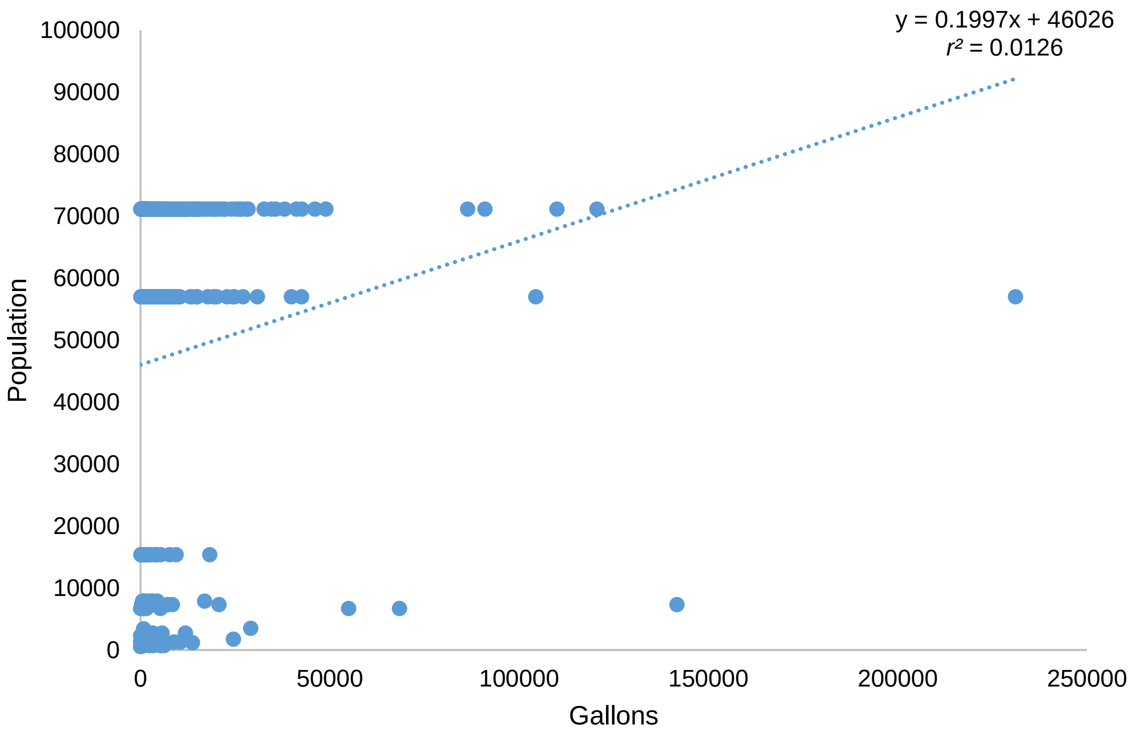

Figure F19. Average monthly water use per construction and contractor account (gallons).

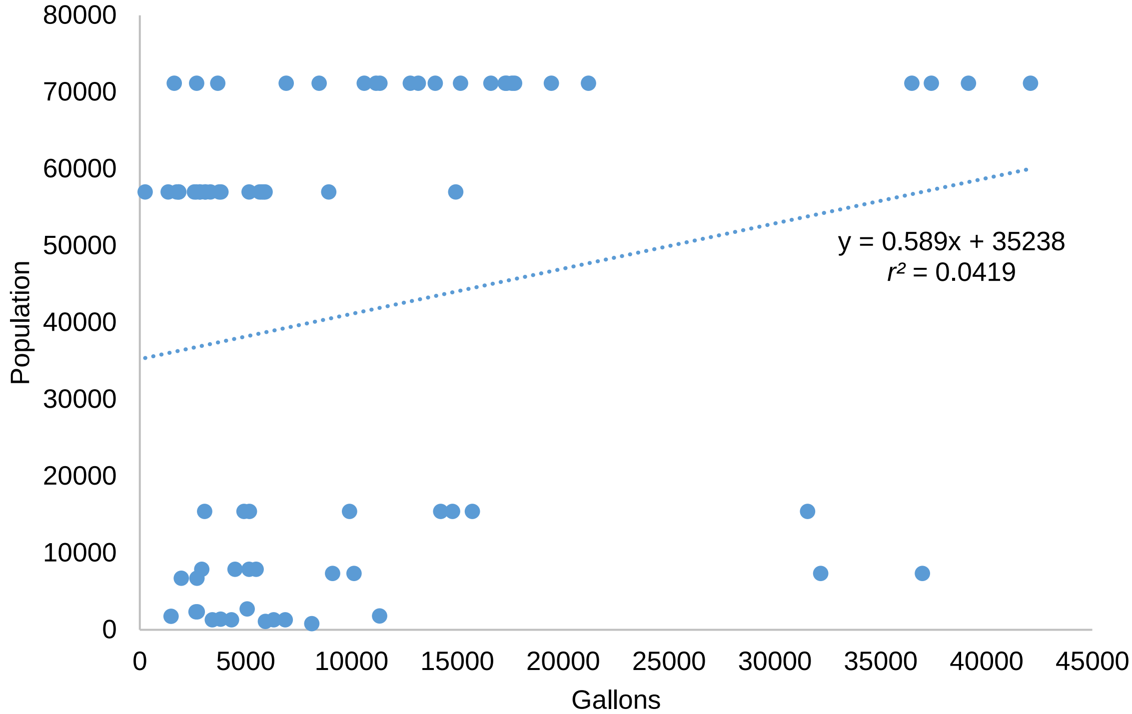

Figure F20. Average monthly water use per dentist account (gallons).

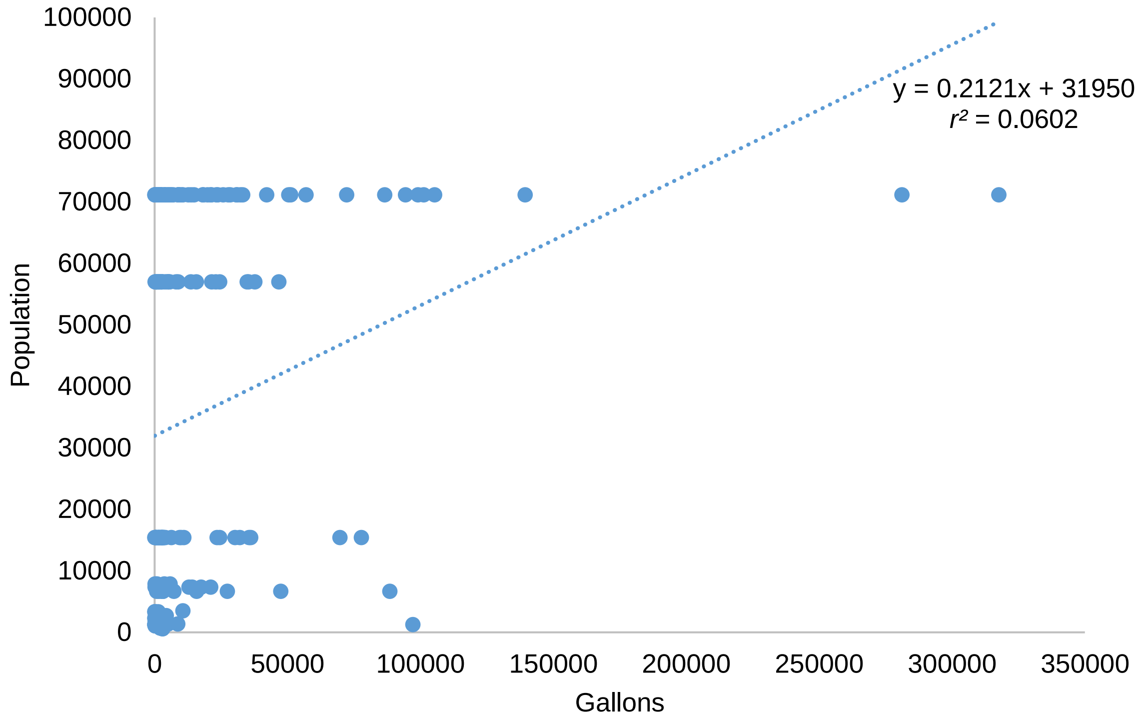

Figure F21. Average monthly water use per entertainment account (gallons).

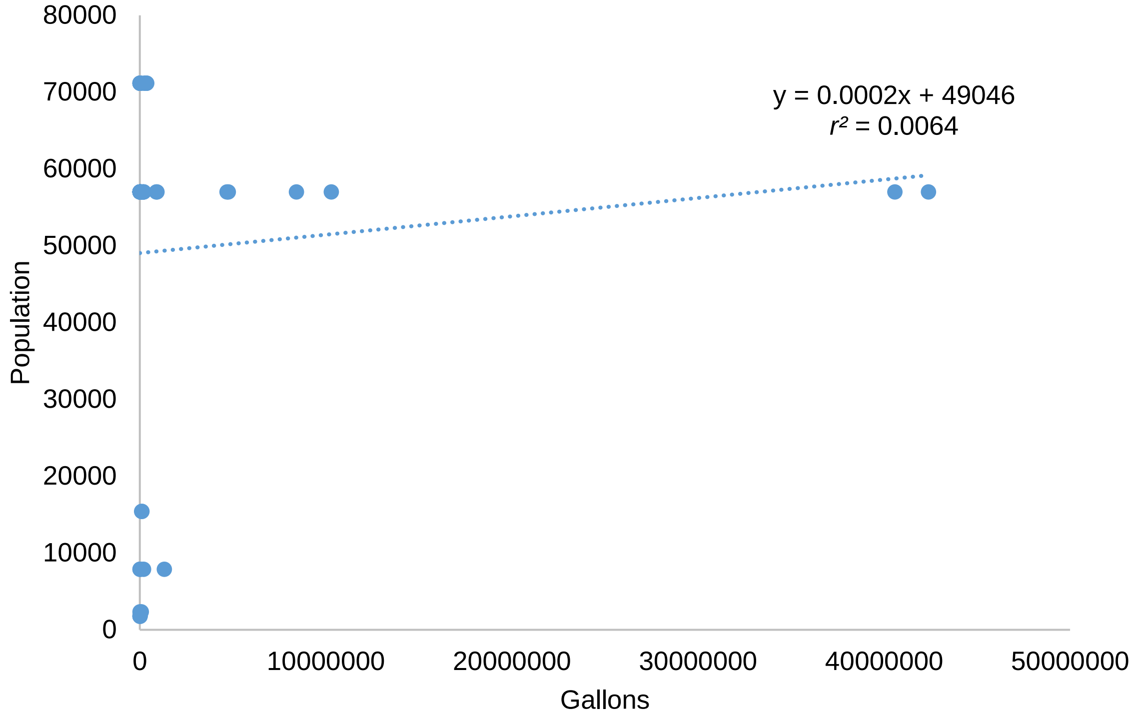

Figure F22. Average monthly water use per food processing account (gallons).

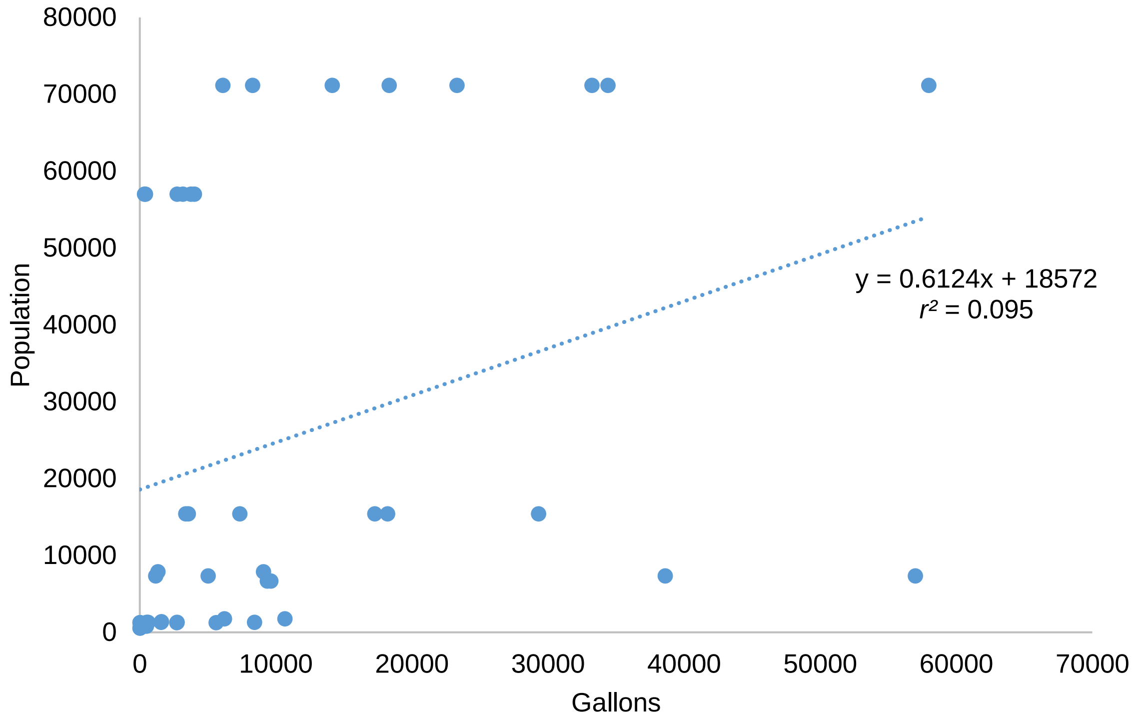

Figure F23. Average monthly water use per funeral home account (gallons).

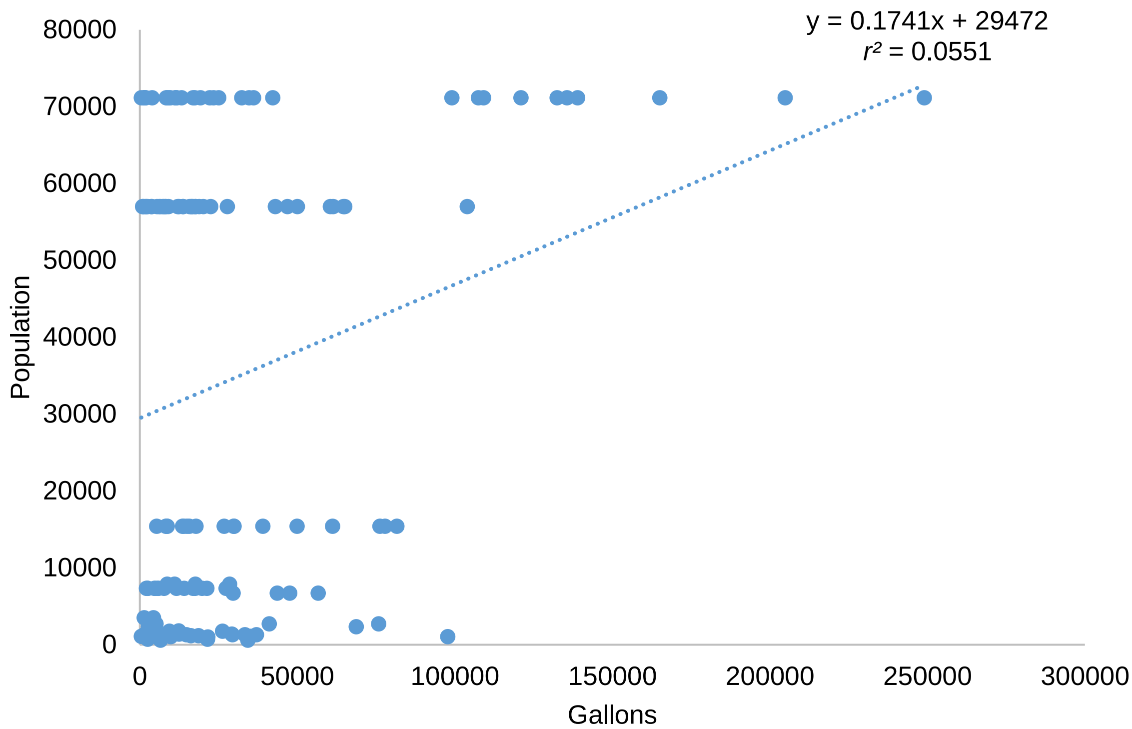

Figure F24. Average monthly water use per gas station account (gallons).

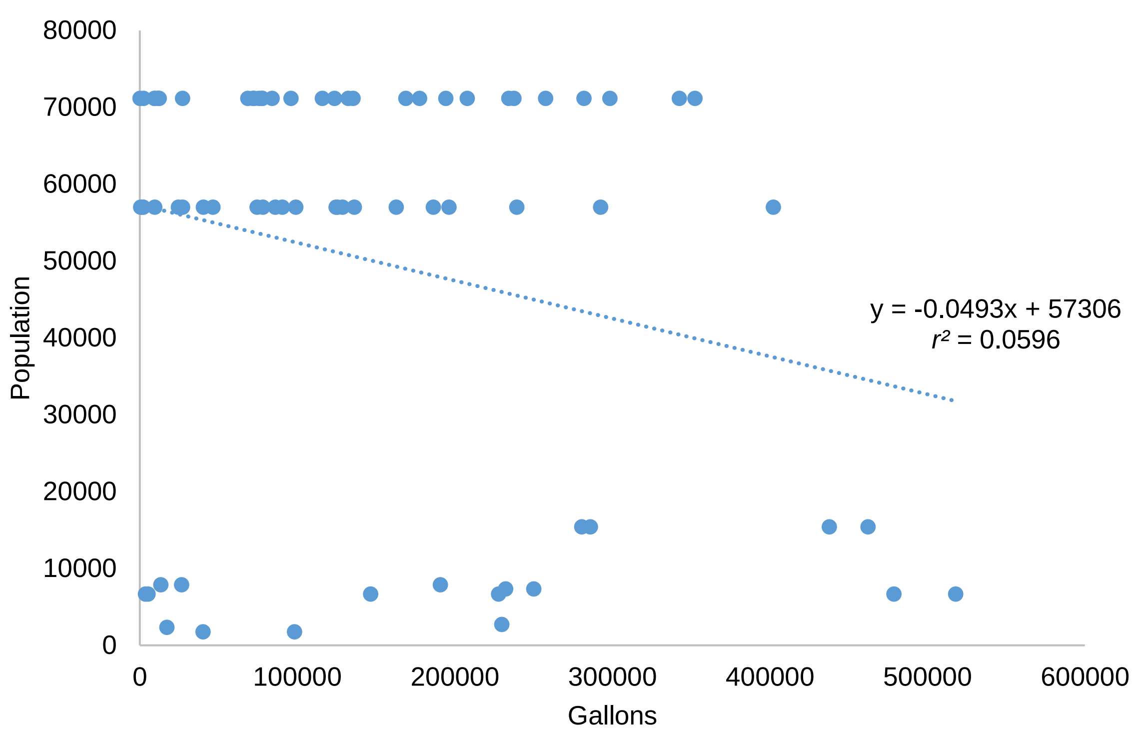

Figure F25. Average monthly water use per gas station with carwash account (gallons).

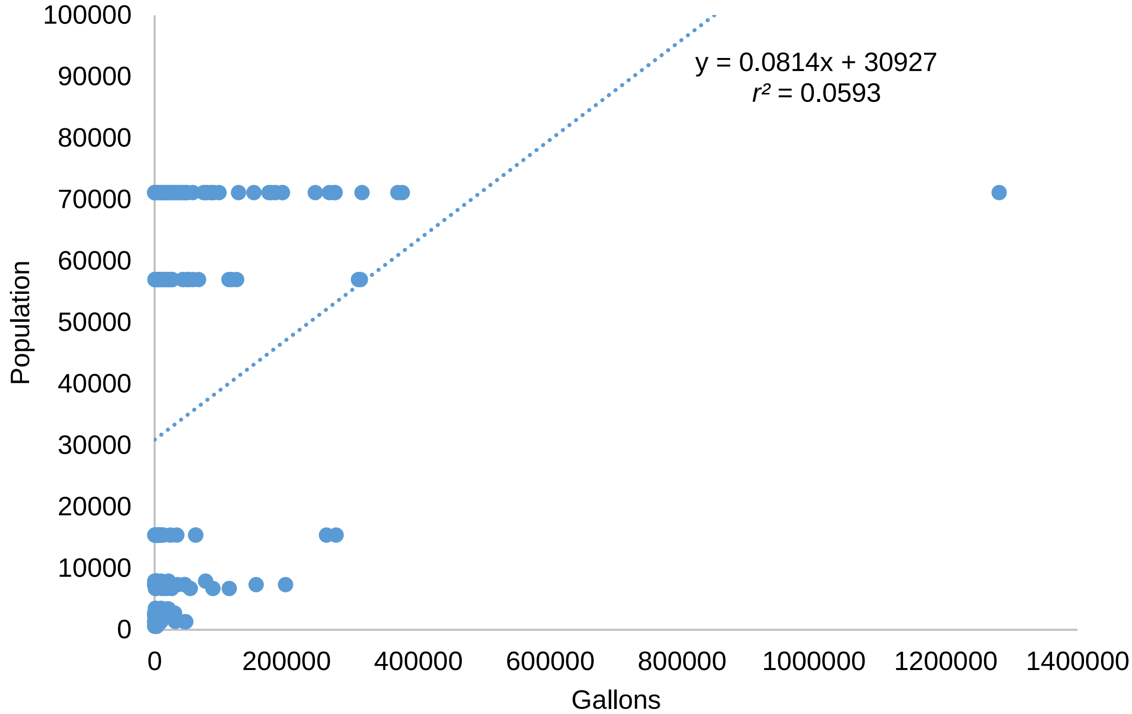

Figure F26. Average monthly water use per government account (gallons).

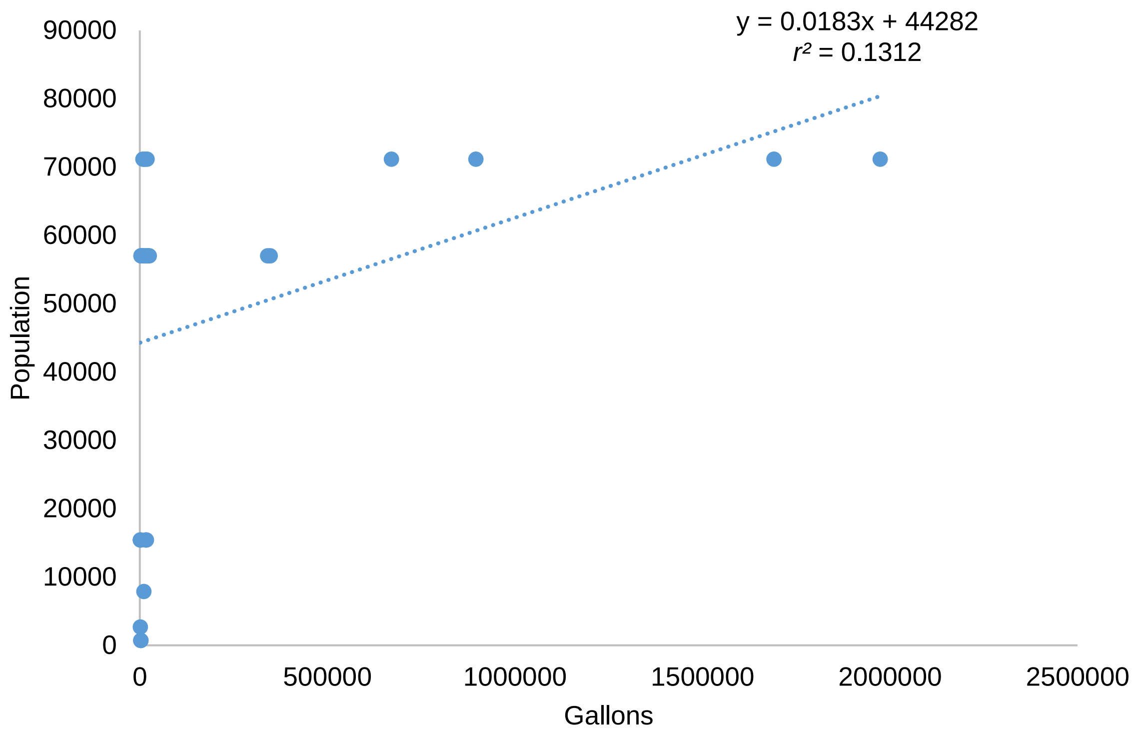

Figure F27. Average monthly water use per golf course account (gallons).

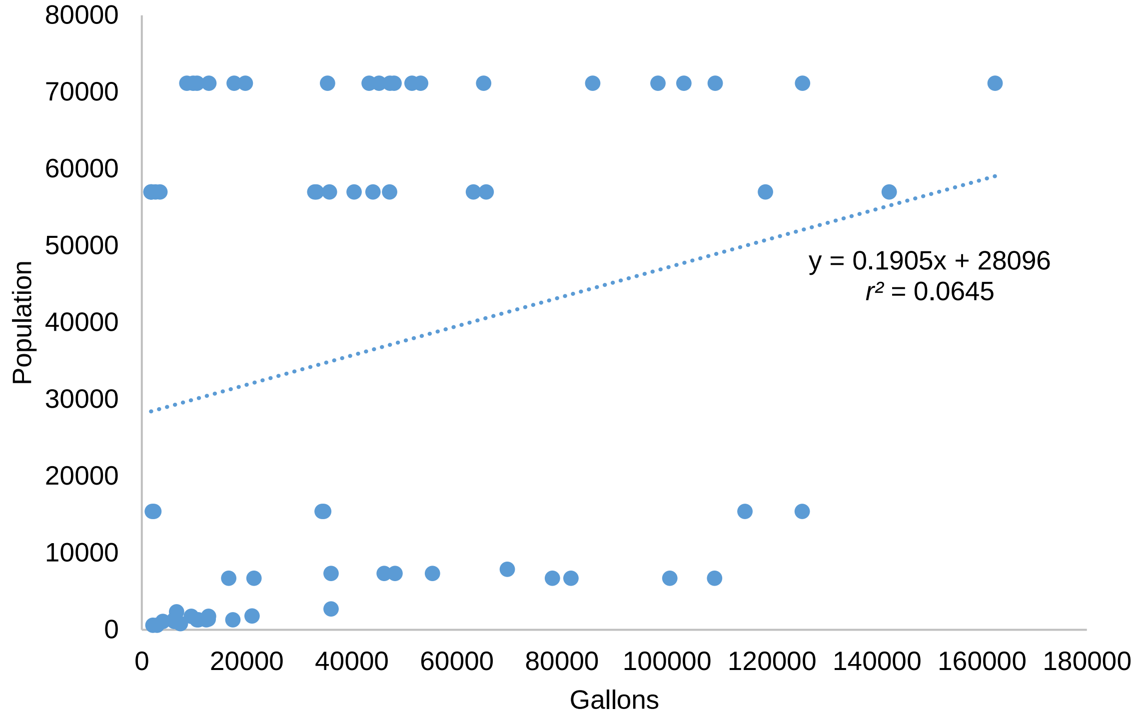

Figure F28. Average monthly water use per grocery store account (gallons).

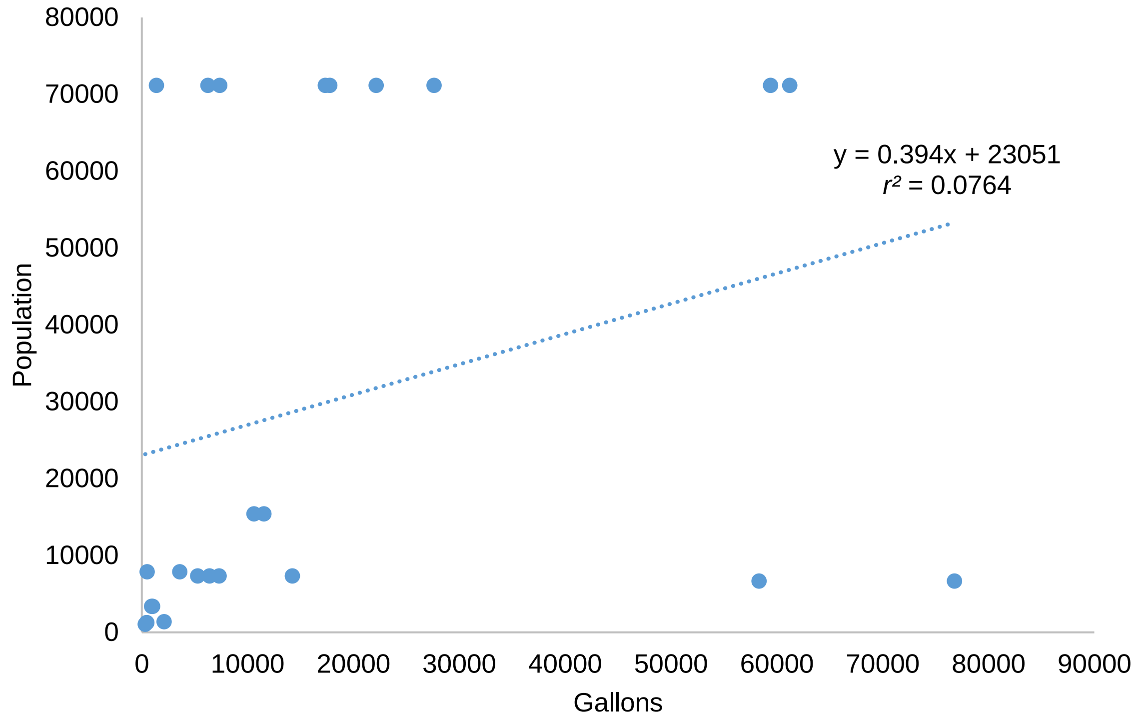

Figure F29. Average monthly water use per gym account (gallons).

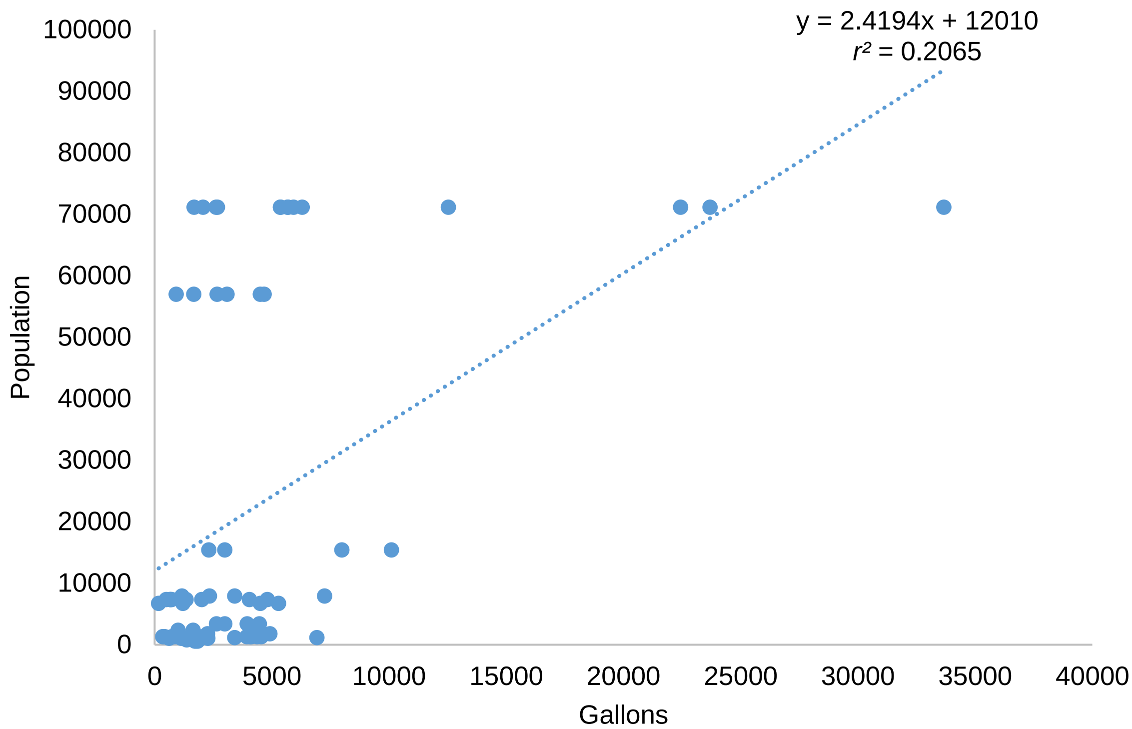

Figure F30. Average monthly water use per hair salon account (gallons).

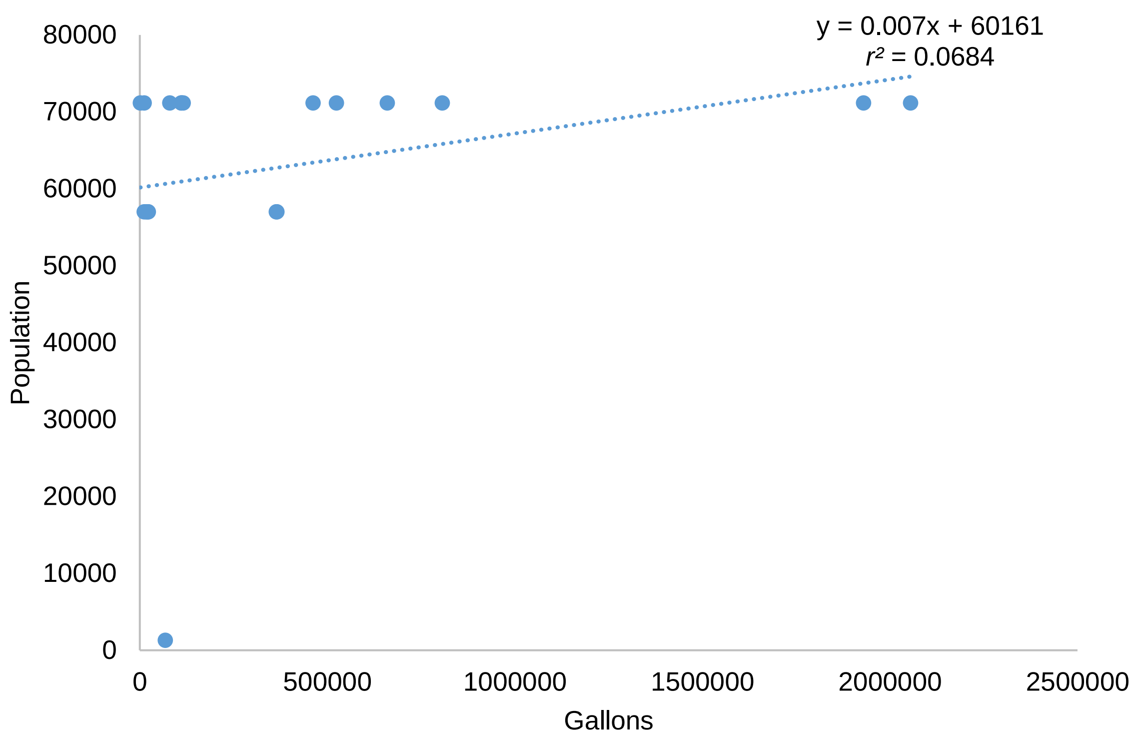

Figure F31. Average monthly water use per jail account (gallons).

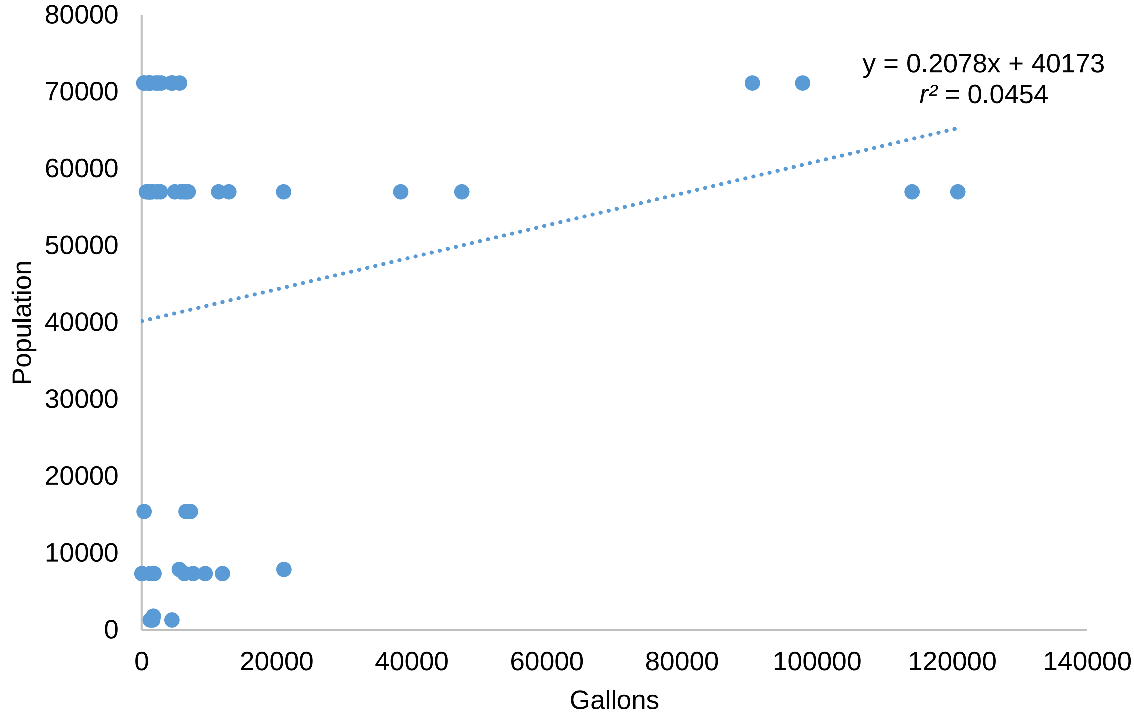

Figure F32. Average monthly water use per landscaping account (gallons).

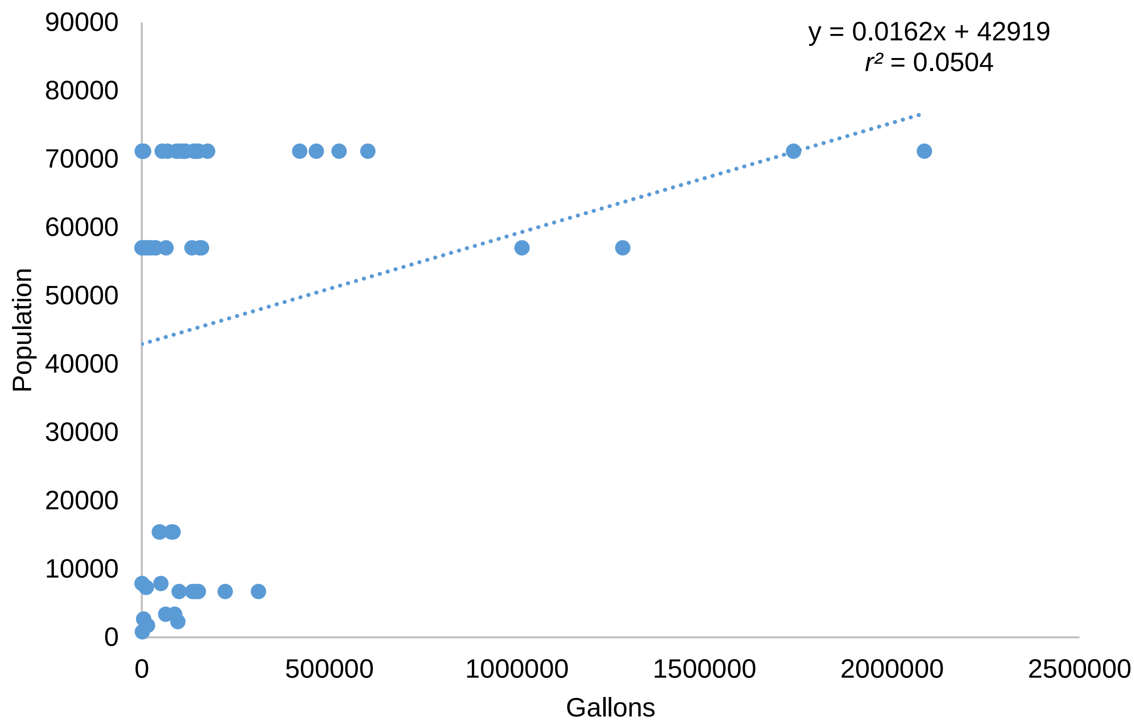

Figure F33. Average monthly water use laundromat and laundry service account (gallons).

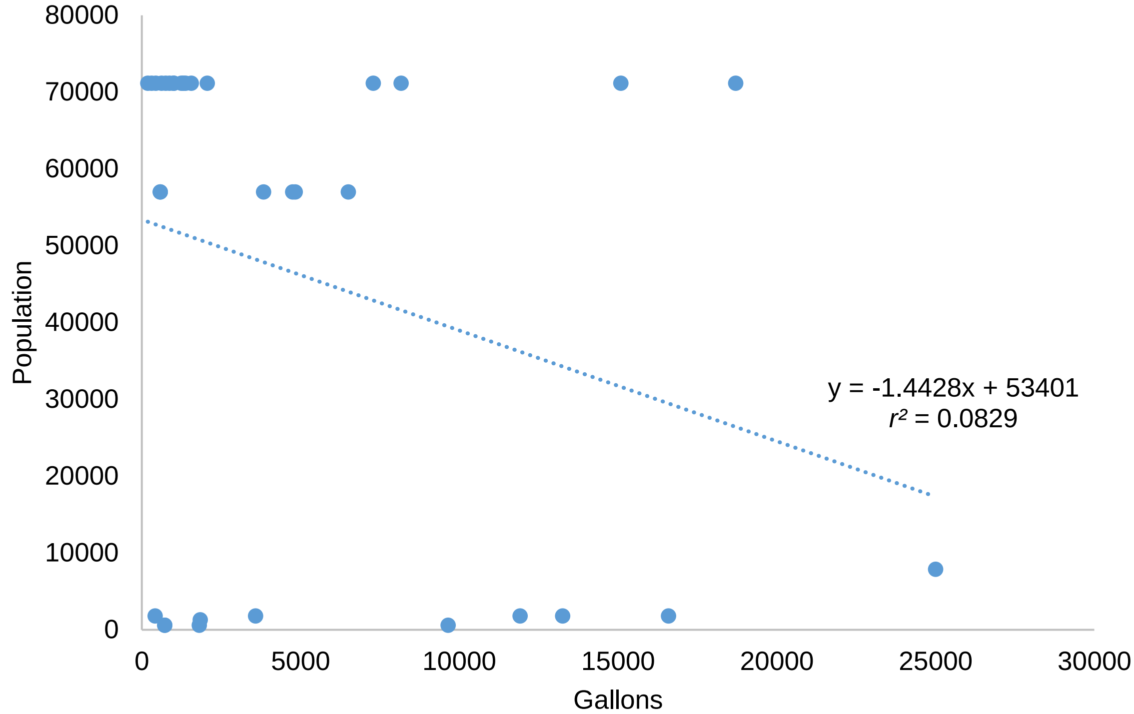

Figure F34. Average monthly water use per machine shop account (gallons).

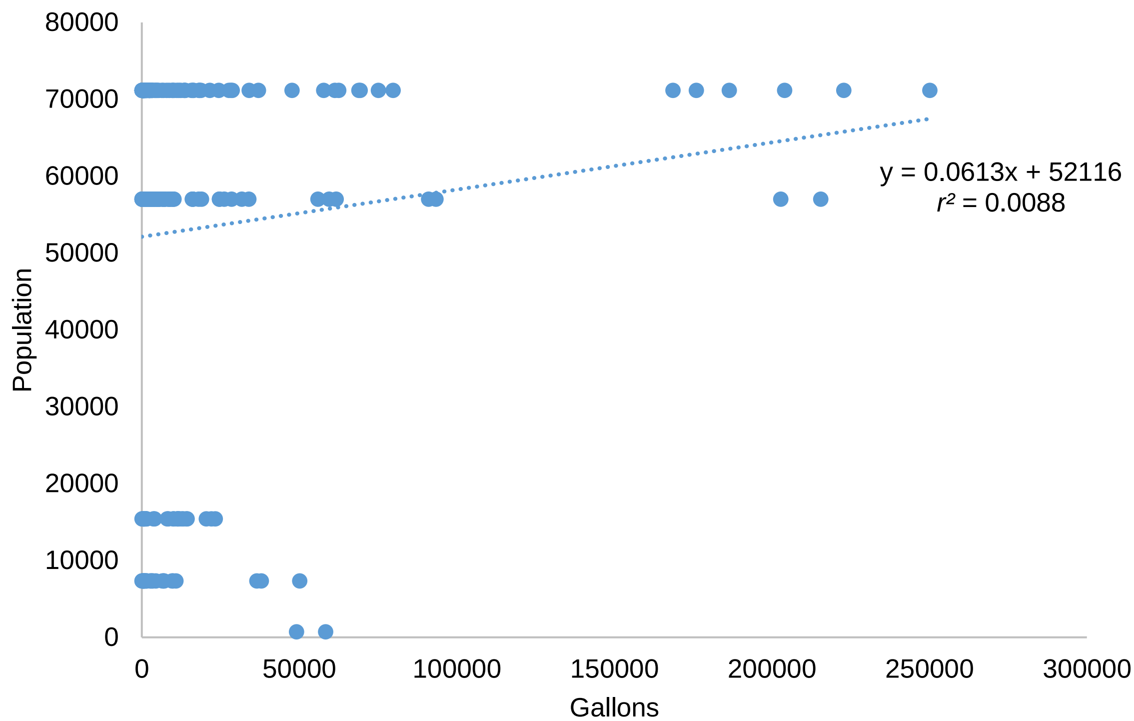

Figure F35. Average monthly water use per mall account (gallons).

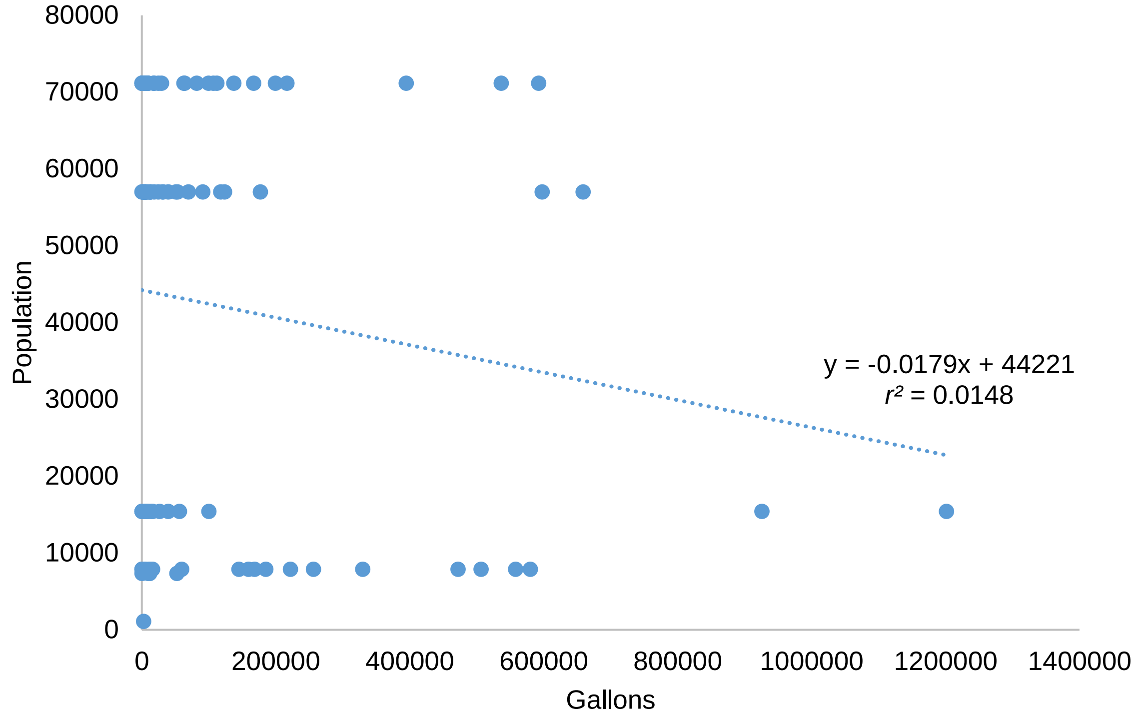

Figure F36. Average monthly water use per manufacturing account (gallons).

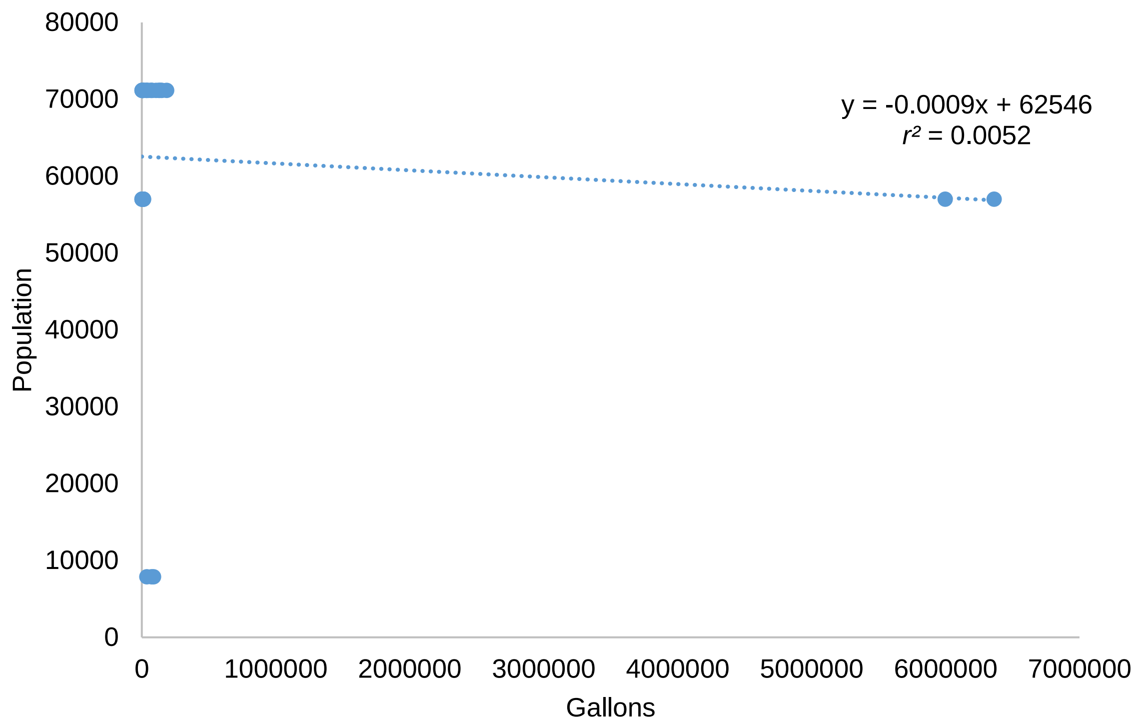

Figure F37. Average monthly water use per military account (gallons).

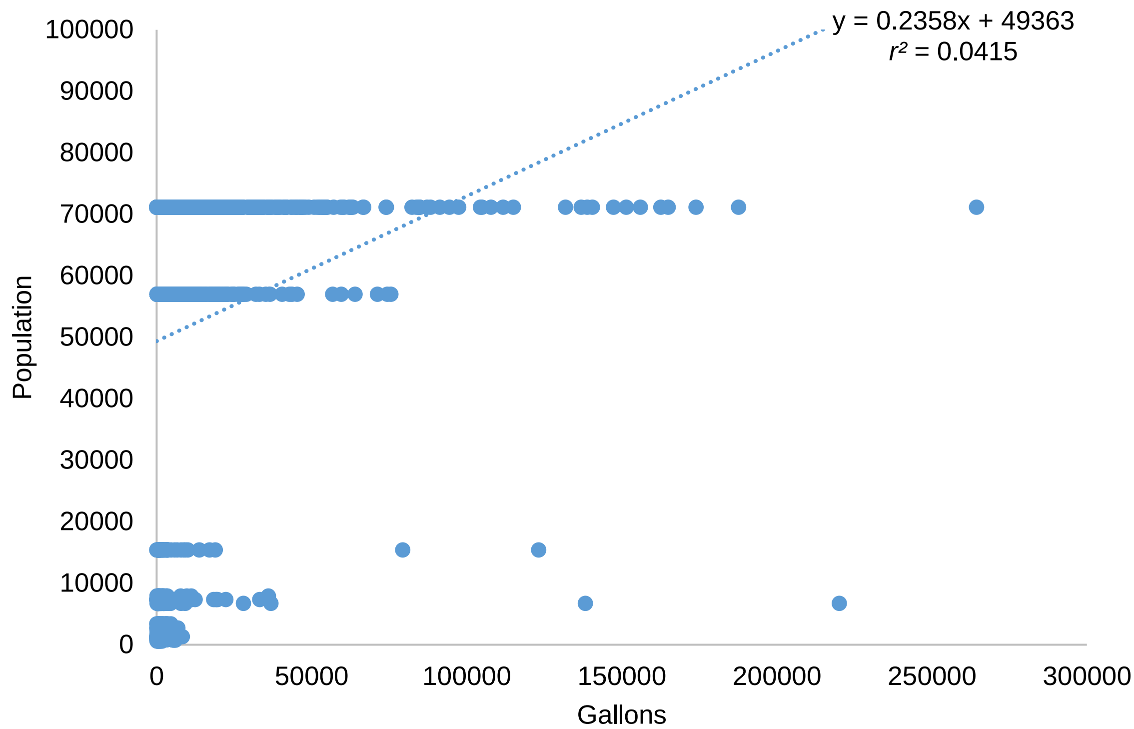

Figure F38. Average monthly water use per office building account (gallons).

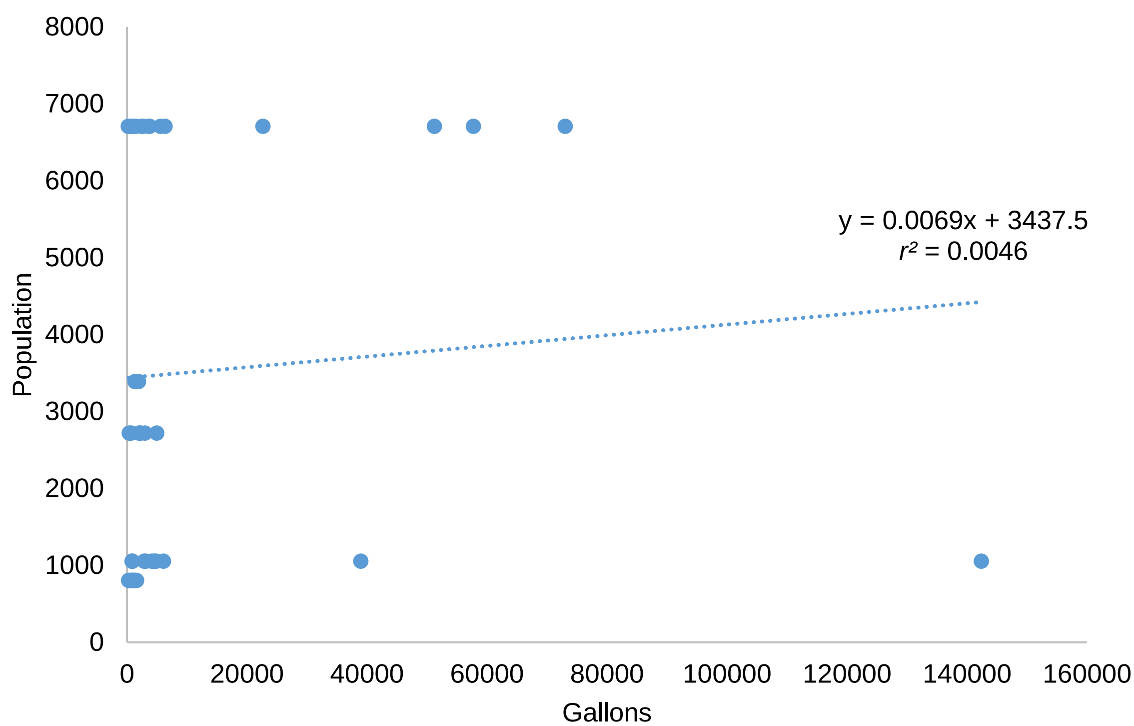

Figure F39. Average monthly water use per oilfield account (gallons).

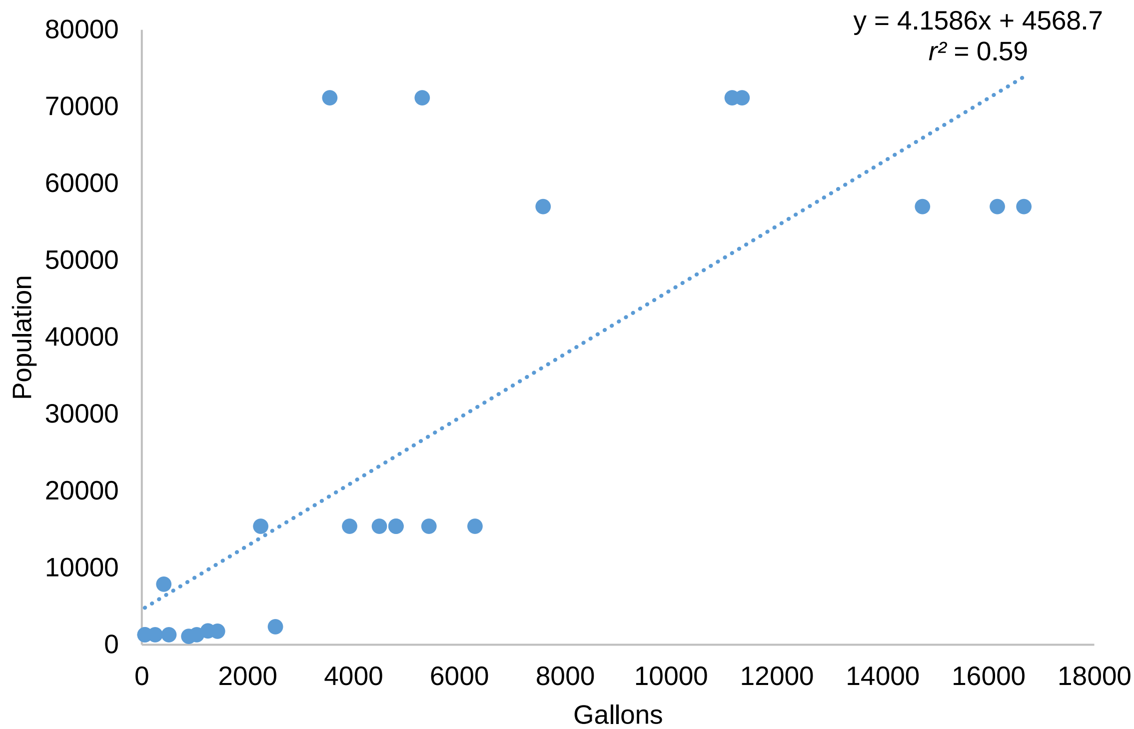

Figure F40. Average monthly water use per optical account (gallons).

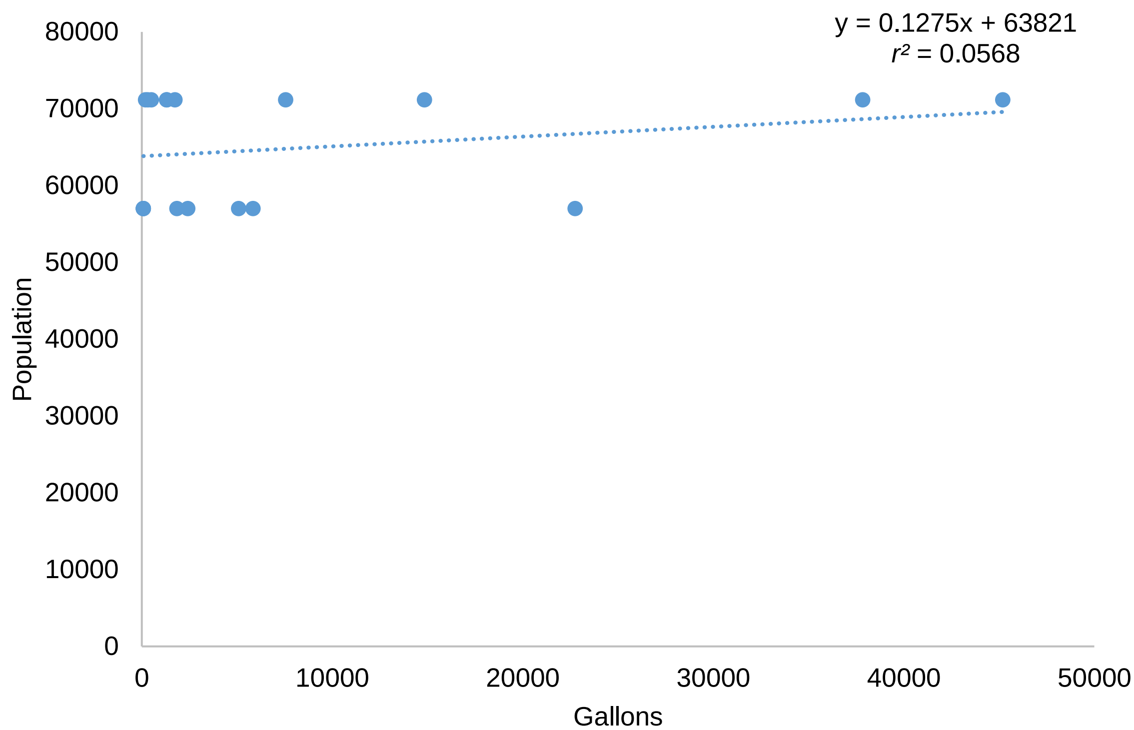

Figure F41. Average monthly water use per parking lot account (gallons).

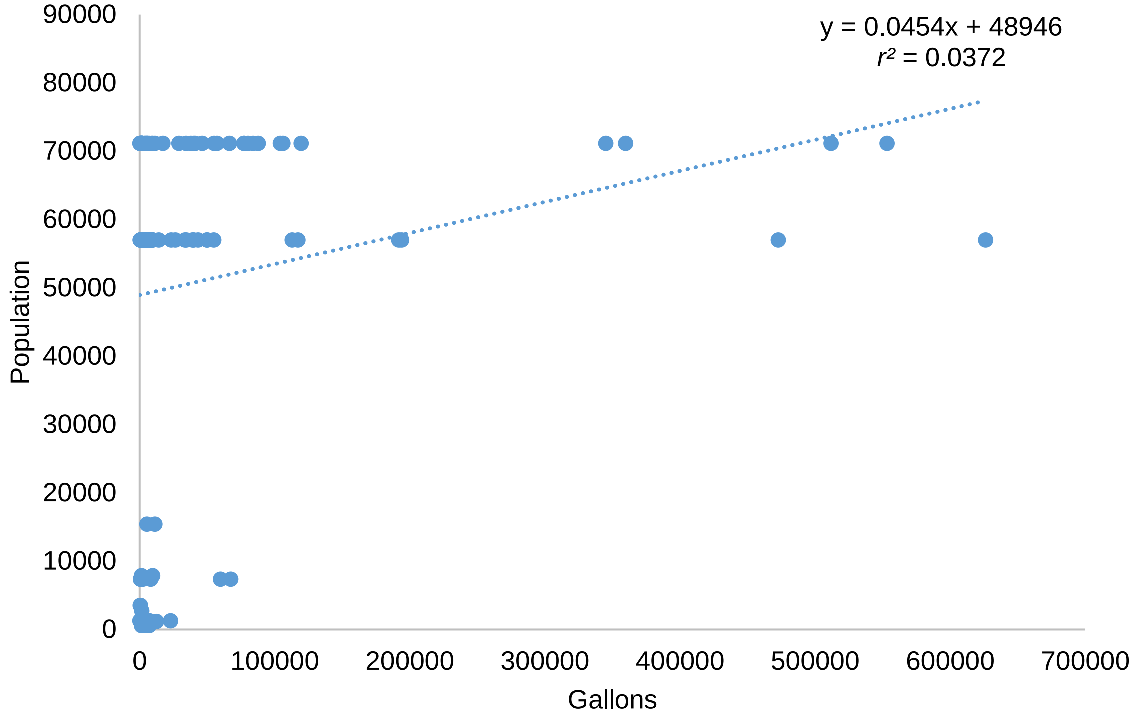

Figure F42. Average monthly water use per park account (gallons).

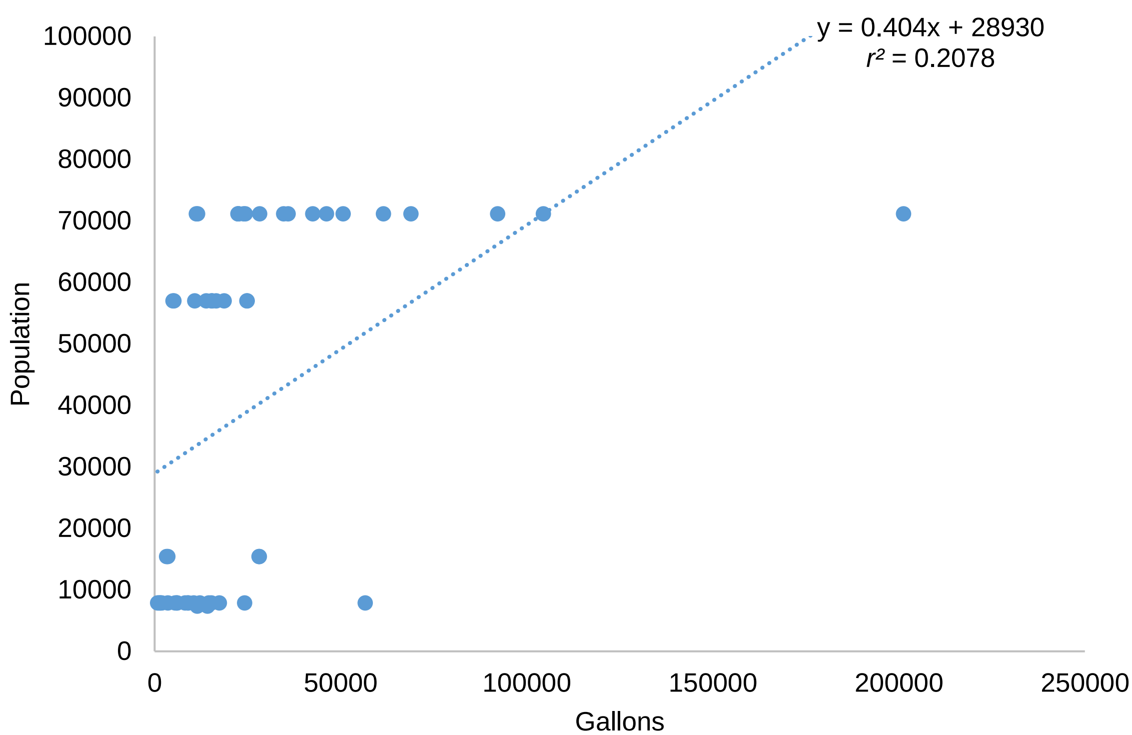

Figure F43. Average monthly water use per private school account (gallons).

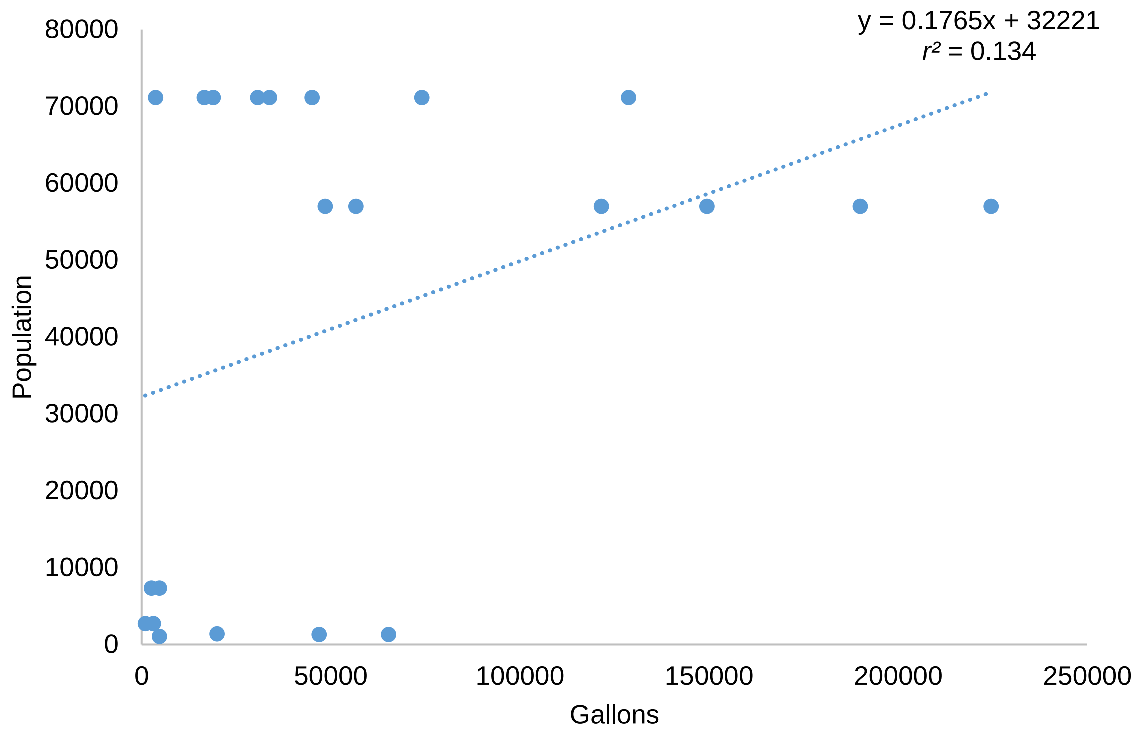

Figure F44. Average monthly water use per public pool account (gallons).

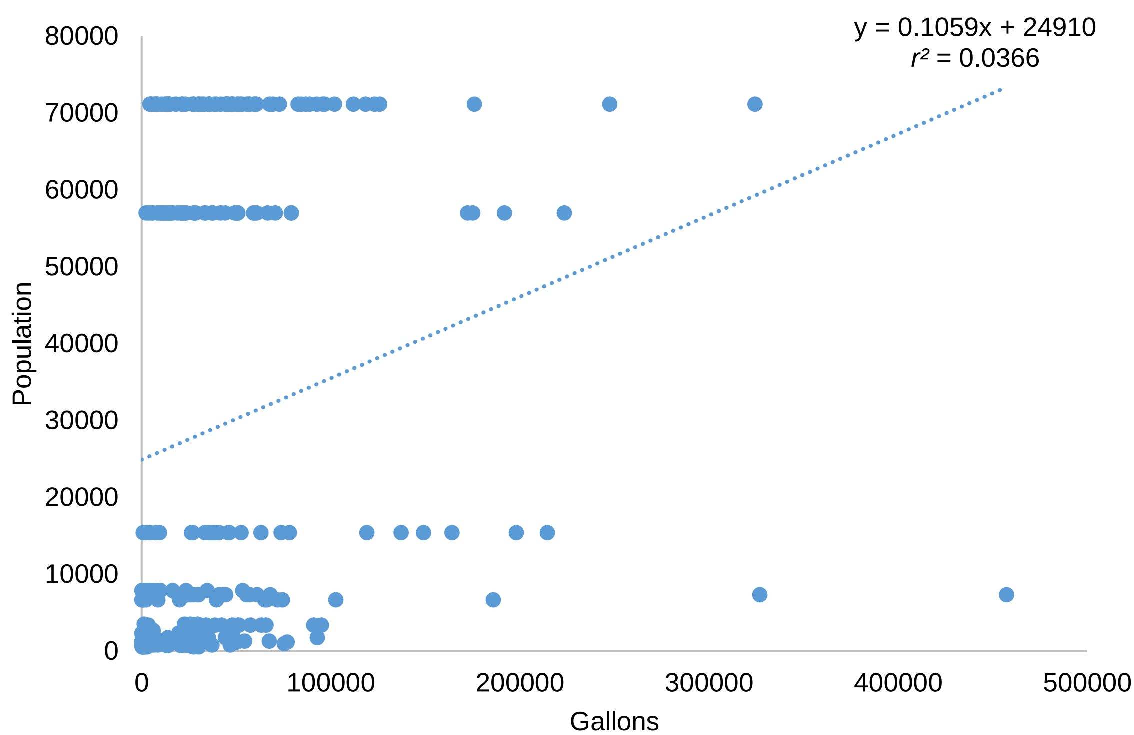

Figure F45. Average monthly water use per public school account (gallons).

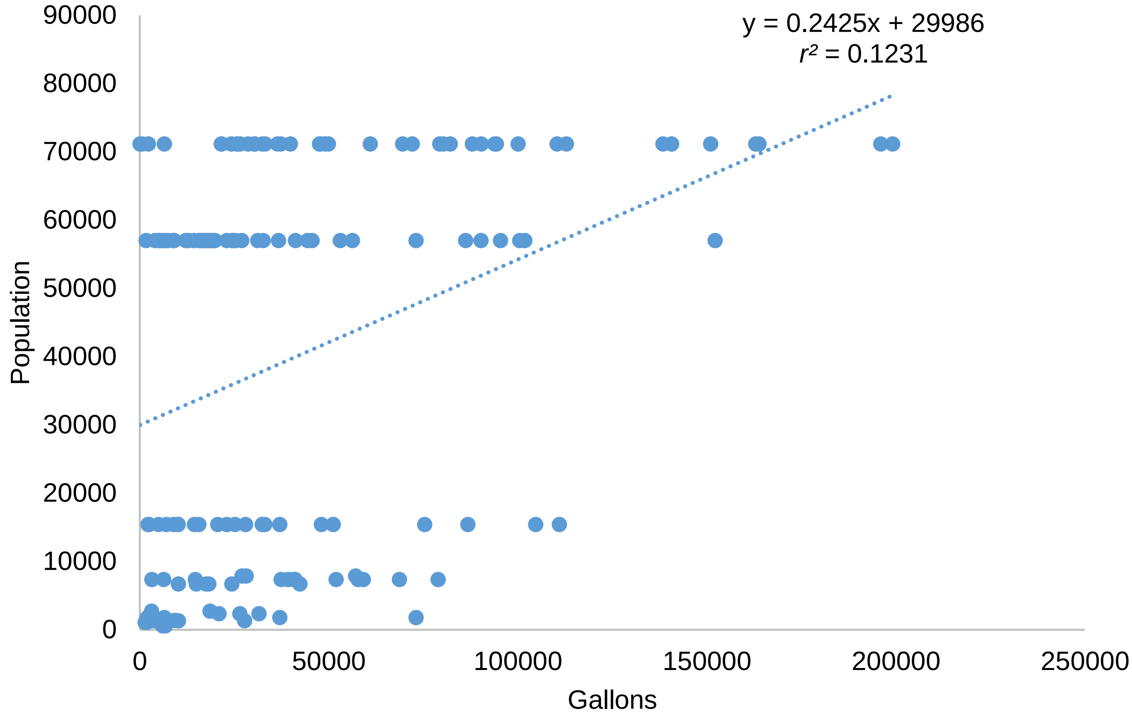

Figure F46. Average monthly water use per restaurant account (gallons).

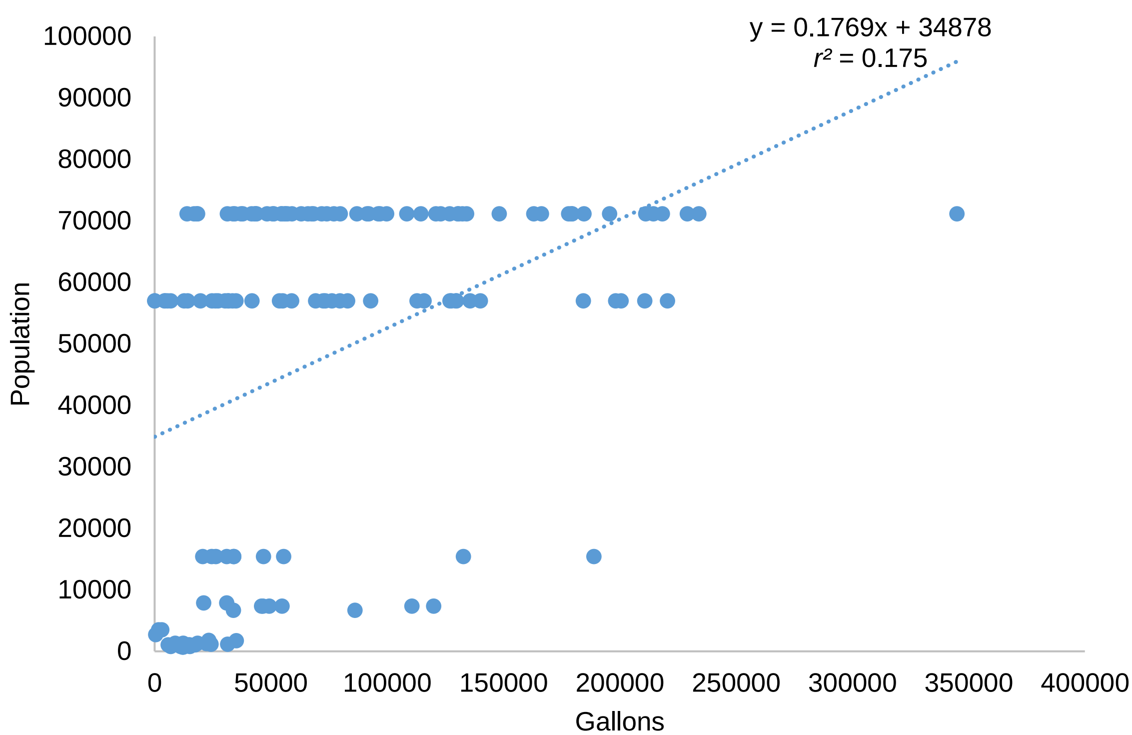

Figure F47. Average monthly water use per restaurant-bar account (gallons).

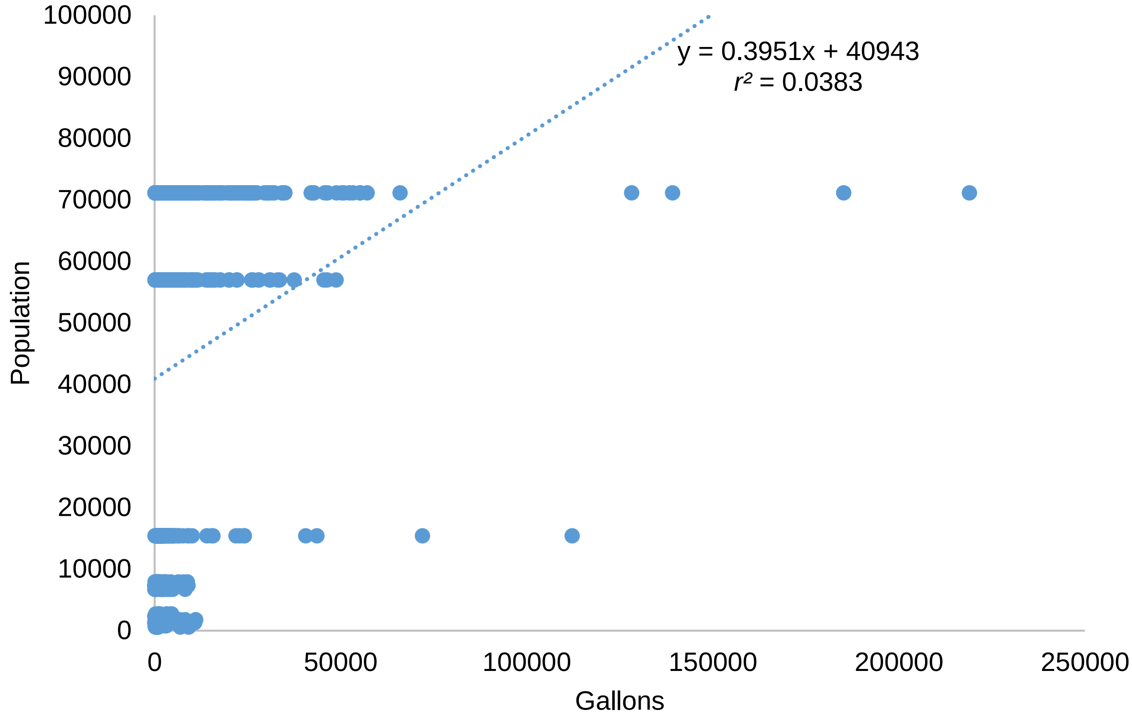

Figure F48. Average monthly water use per retail account (gallons).

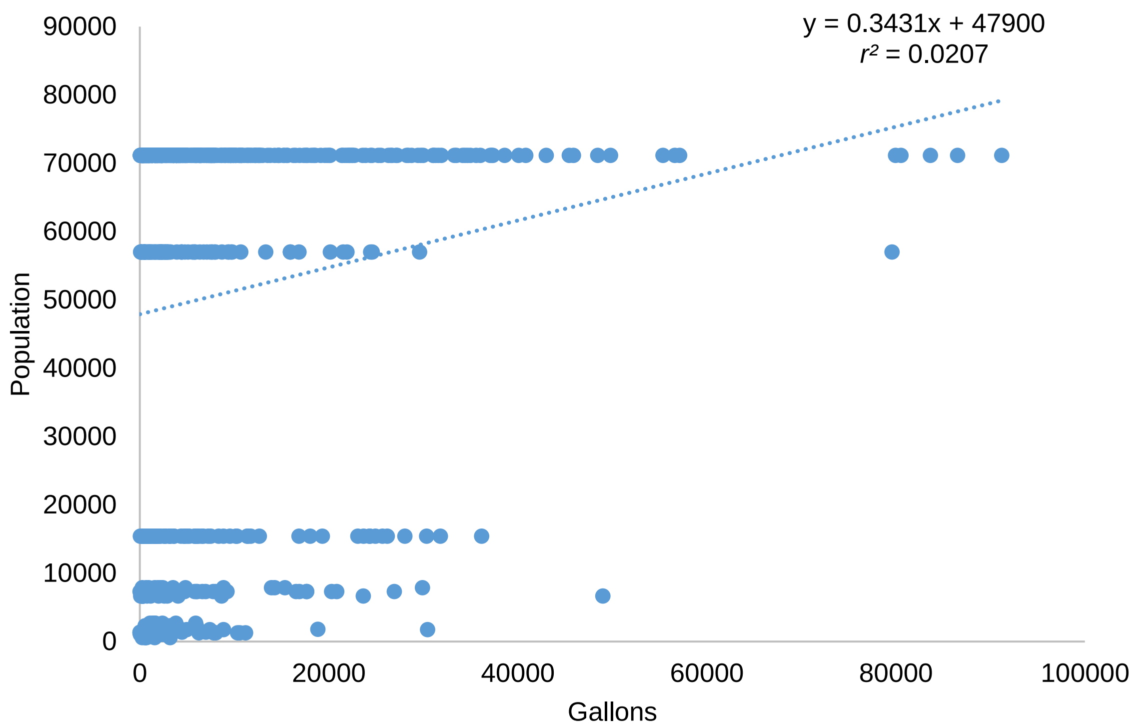

Figure F49. Average monthly water use per service account (gallons).

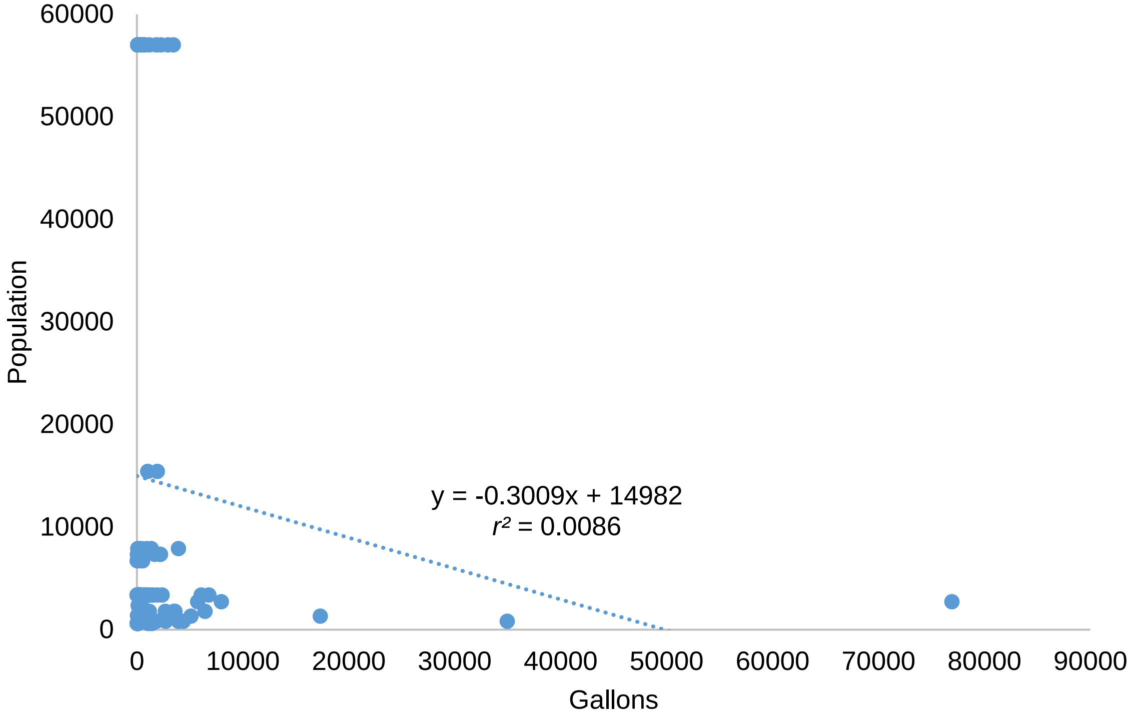

Figure F50. Average monthly water use per shop account (gallons).

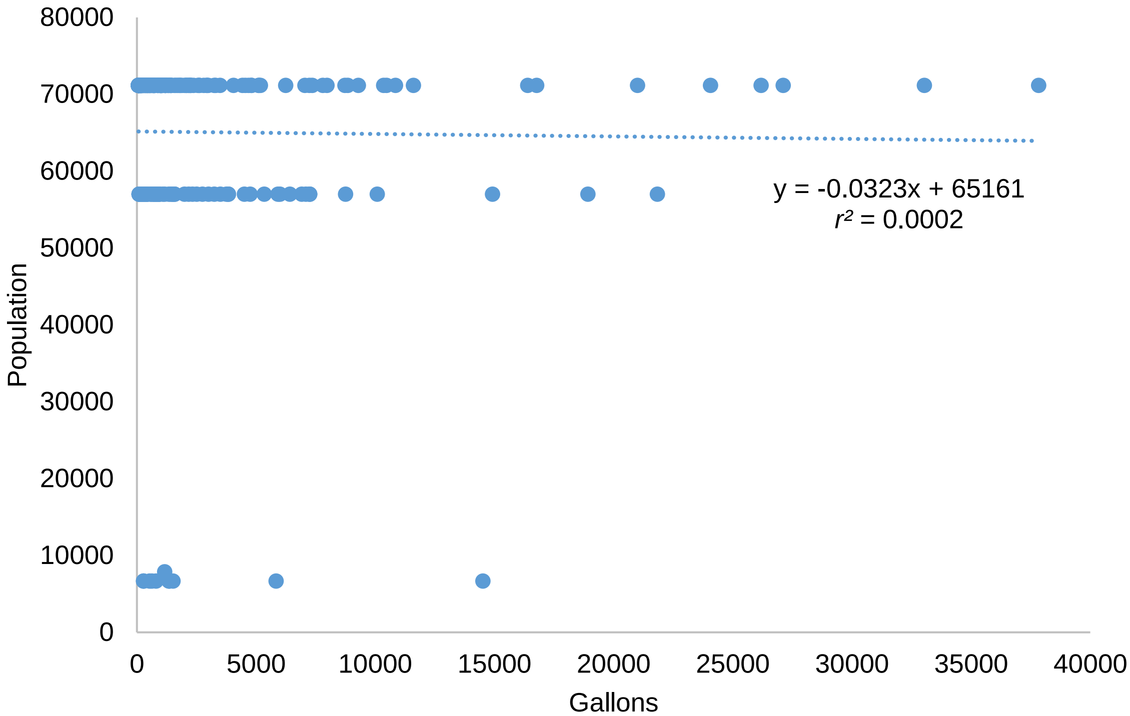

Figure F51. Average monthly water use per shop condo account (gallons).

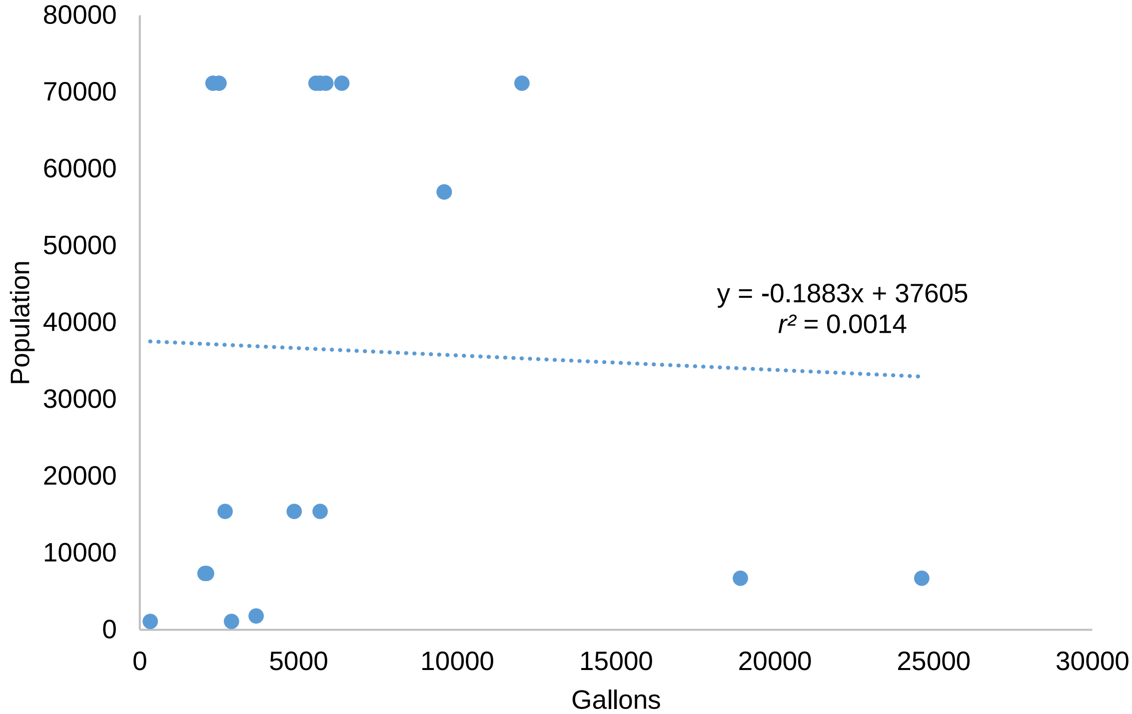

Figure F52. Average monthly water use per spa account (gallons).

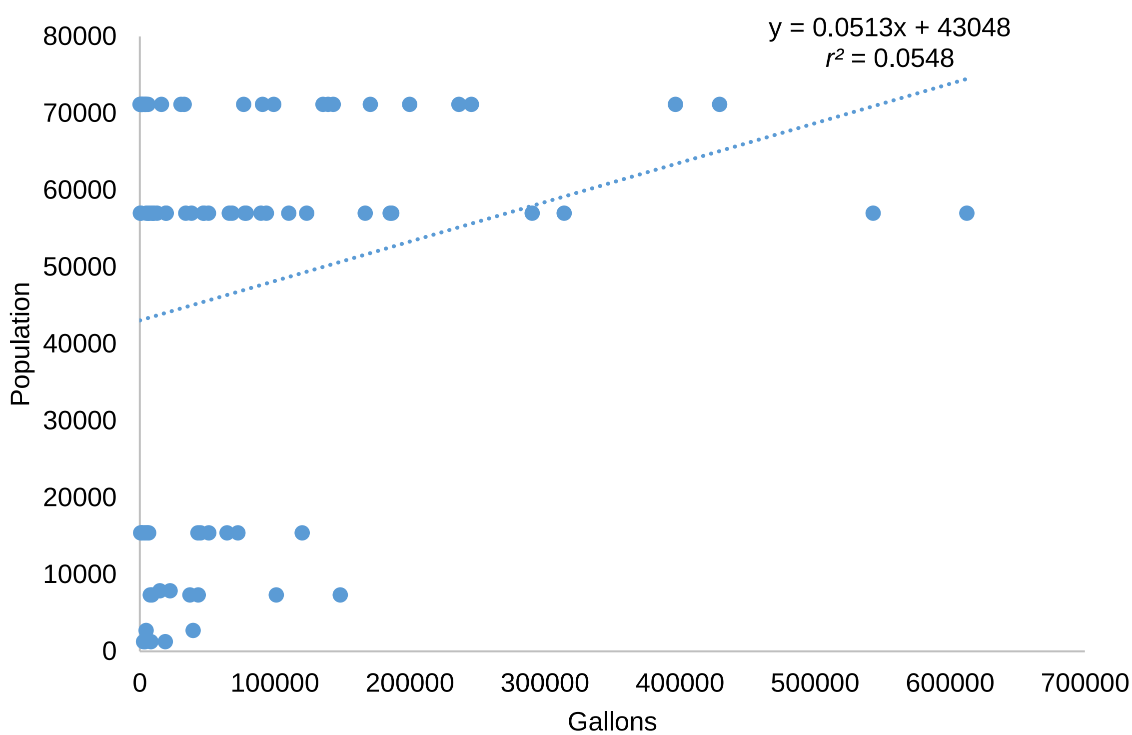

Figure F53. Average monthly water use per sports complex account (gallons).

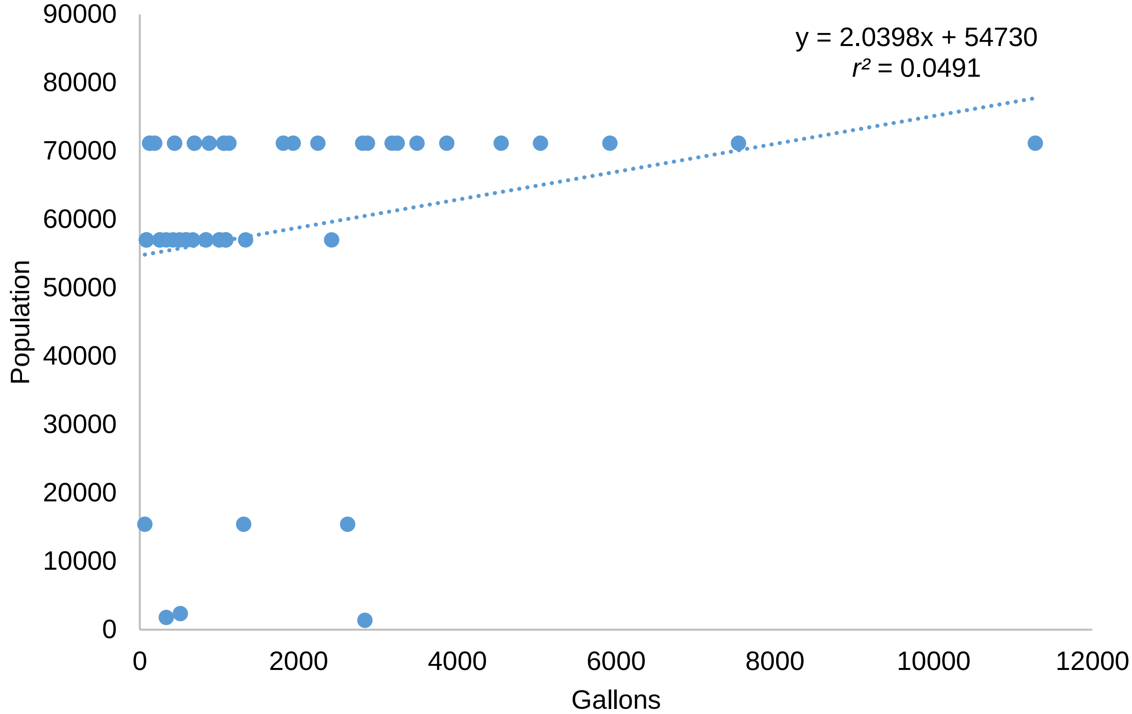

Figure F54. Average monthly water use per storage unit account (gallons).

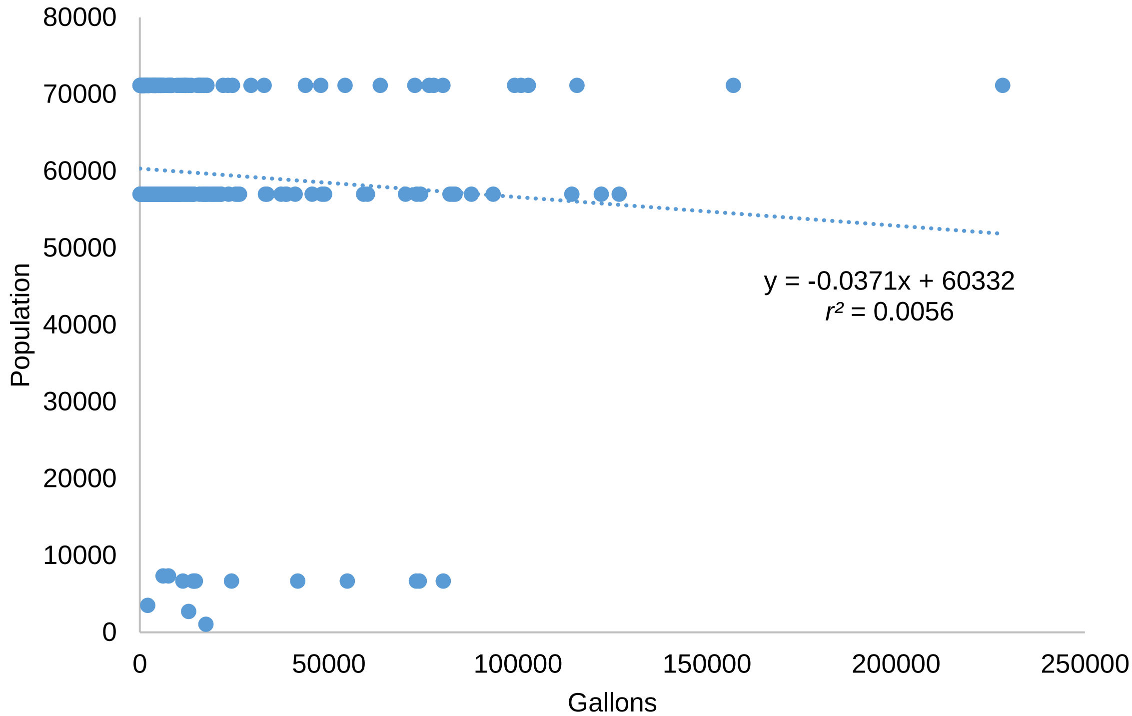

Figure F55. Average monthly water use per strip mall account (gallons).

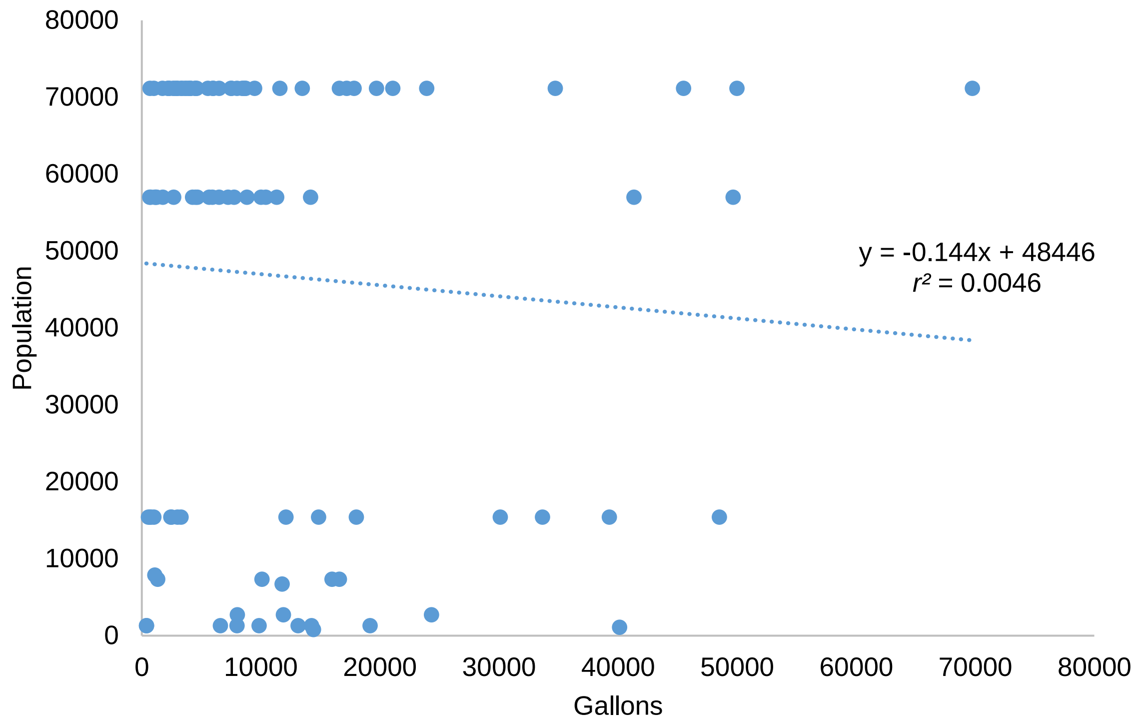

Figure F56. Average monthly water use per truck parks and service account (gallons).

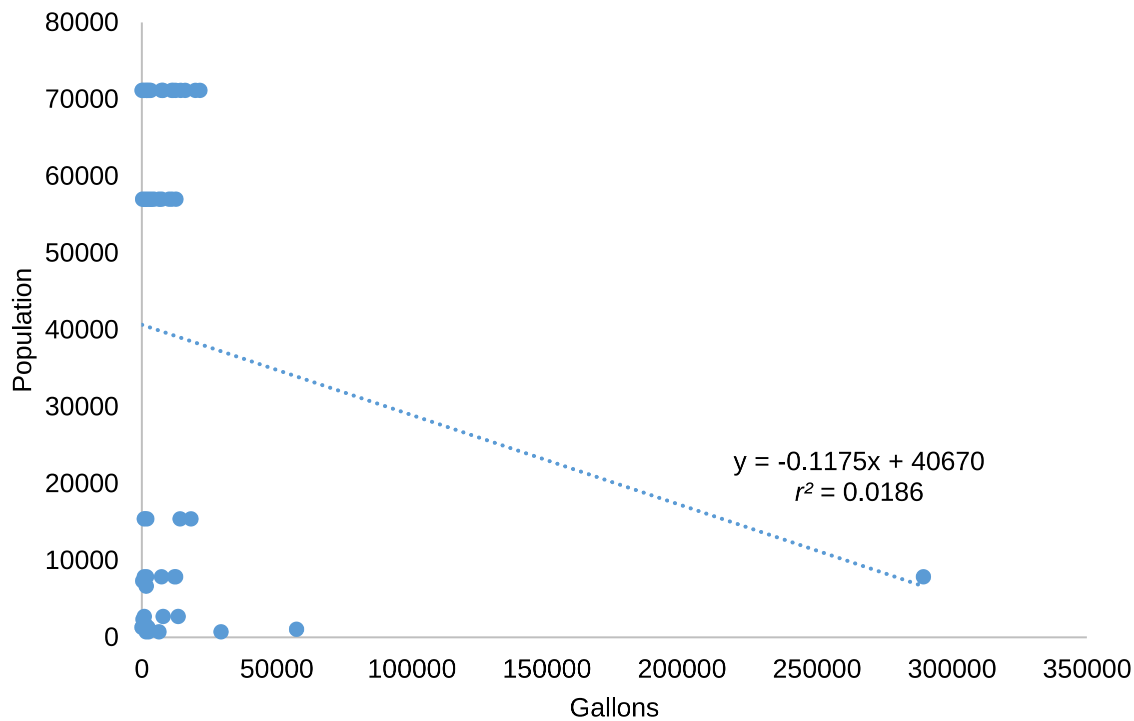

Figure F57. Average monthly water use per trucking company account (gallons).

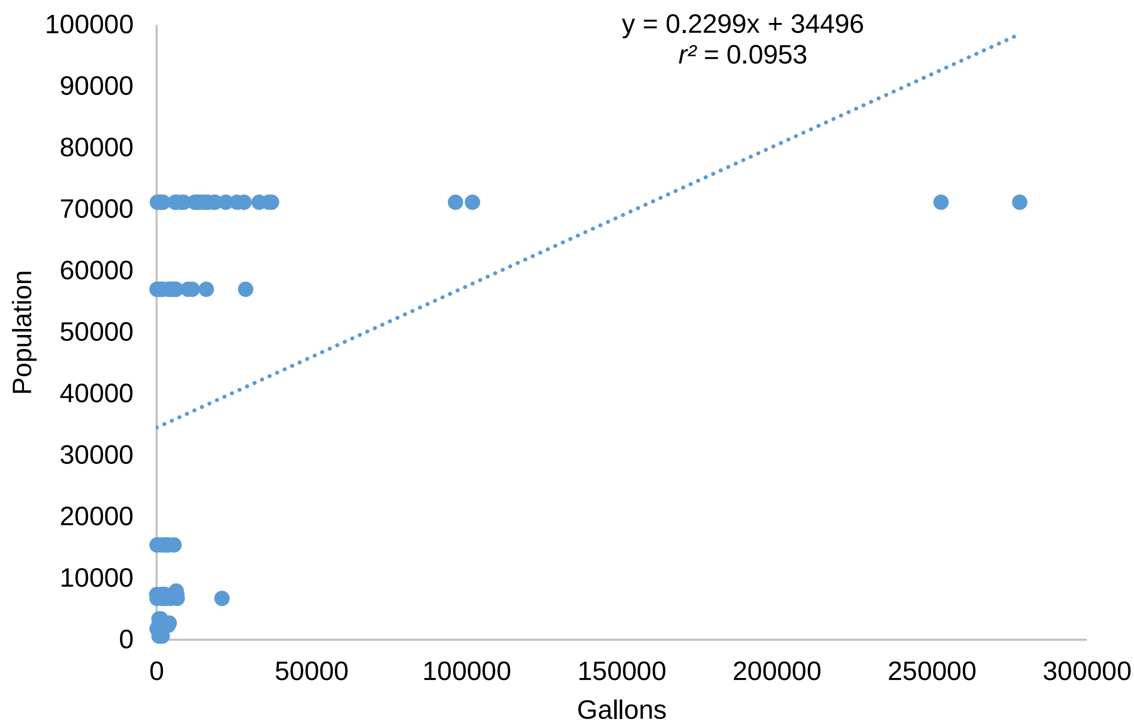

Figure F58. Average monthly water use per utility account (gallons).

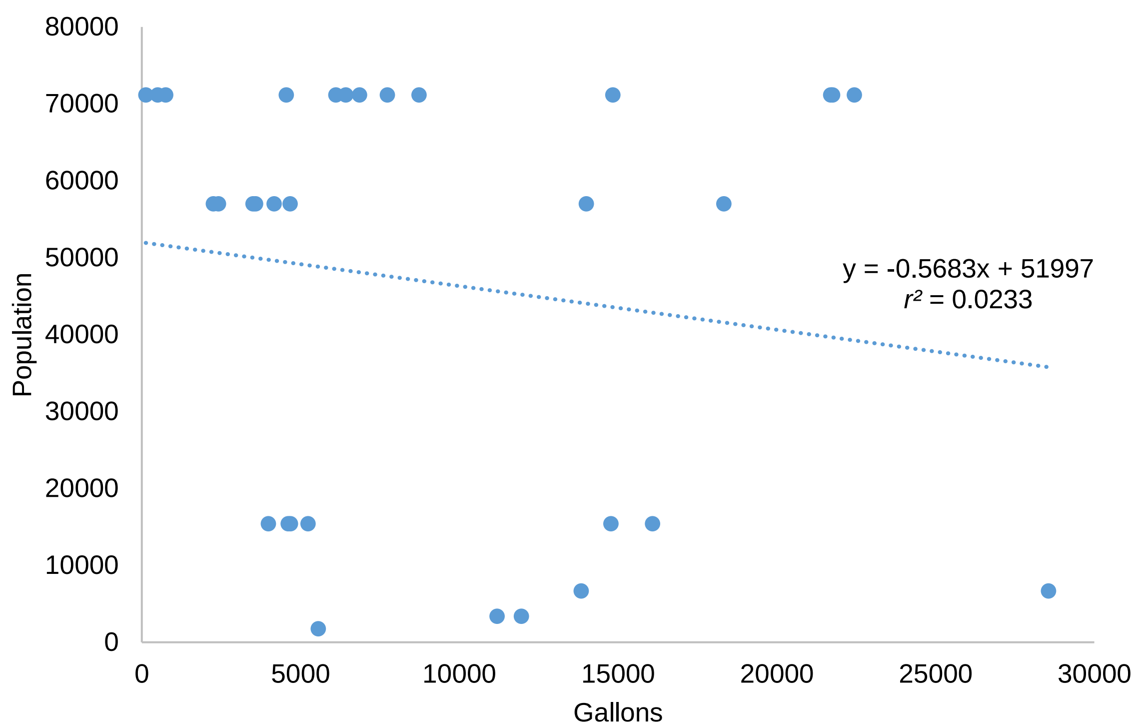

Figure F59. Average monthly water use per veterinarian account (gallons).

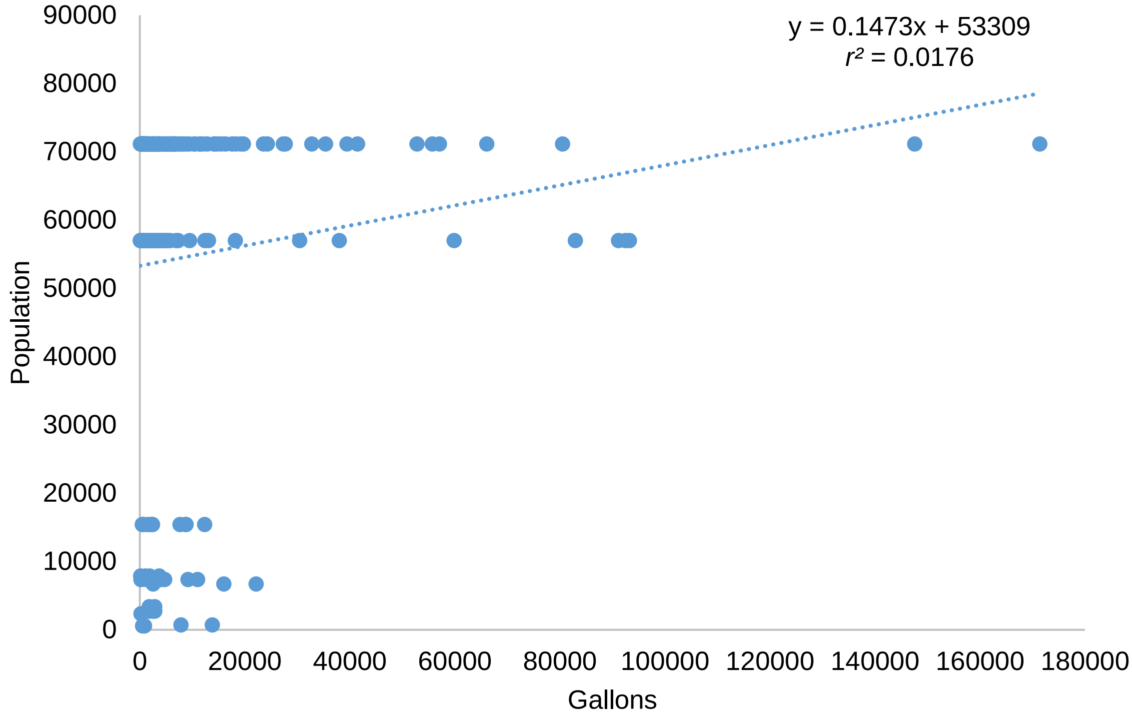

Figure F60. Average monthly water use per warehouse account (gallons).