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Population Growth and Its Effects on Water Demand in Arvada, Colorado

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ABSTRACT

The purpose of this study was to observe the effects of population growth on water demands in Arvada Colorado. An issue known as water crowding is the main concern for the conduction of the research and to determine whether Arvada will be able to support the raising population's consumption rates of water. Regression Analysis was the main statistical test that was used in the study. The variables that are compared include: years and annual precipitation, years and population, water consumption per year, and population's consumption rates. For the annual precipitation, dry and wet years are determined. Dry years consists of having low amounts of rain fall with the minimum being 13 inches of rainfall; wet years have upwards of 27 inches of rainfall. Over the course of time population increases in Arvada started slow until the 1950's where the data starts showing a significant increase. With the growth in population in Arvada, the consumption rates start increasing as well. It was found that the month of June was where most water is consumed. The results show that as the years progress with the increase in population, consumption rates increased at higher quantities but the residuals from year to year were larger. A positive correlation was found with the population versus consumption and a linear line was fitted. Residuals are found for the correlation and plotted against the population. The results visually showed the amount of water consumed above and below the fitted line. The same residuals were then divided by the population for that year and plotted against the population again giving smaller value ranges. The new residuals are plotted against the precipitation determining wet and dry years. The conclusion for the study was found that Arvada is capable of supporting the increasing population demands for water.

Keywords: *Water, Consumption, Population, Arvada, Colorado, Regression Analysis, Precipitation.*

INTRODUCTION

There has been speculation whether the world will be able to support the up coming population (Hughes, 2005). In the case of the town of Arvada, Colorado, the effects of the growing population's demand on the water supply are causing a problem known as water crowding. Water crowding happens when there is a higher usage of water than availability of water (Falkenmark, 2008). According to the U.S. Census Bureau, the population of Arvada has grown rapidly in the last 30 years. Arvada spreads out across 22,570.51 acres or 35.55 square miles of land at the base of the foothills of the Rocky Mountains (Arvada, 2008).

Water supply for the Arvada area is from snowfall and snowmelt that runs down the eastern slope of the Rocky Mountains to reservoirs that supply the city (Cronin et al, 2007). The sources for drinking water include rivers, lakes, streams, ponds, reservoirs, and wells. Water travels across the surface of the land and through the ground, where it dissolves naturally occurring minerals (The City, 2008). The Arvada drinking water supply comes from two surface water sources: year-round the Denver Water Department's Moffat system, and in the summer Clear Creek (The City, 2009). When the warmer months of spring and summer arrive the demand for water is higher, and so water is then diverted from Clear Creek. Approximately 25% of the water supply is diverted from Clear Creek and stored in Arvada/Blunn Reservoir (The City, 2009). The snow melt and mountain water is collected from Fraser River and the South Boulder Creek Basins, and it then is transported to the Ralston Reservoir (The City, 2009). In the Arvada, Colorado 2008 Community Profile (2008) Arvada's reservoir water exceeds the strict standards of the State of Colorado and EPA. The drinking water is processed through two water treatment plants for purification and disinfection before reaching the consumer (The City, 2008).

Regression analysis, defined as modeling and analysis of data consisting of values for a dependent variable and one or more independent variables, was used in comparing data. Population and water supply were analyzed in comparison to each other along an independent variable of time. Then water consumption is compared to the population of Arvada and the water supply. Regression analysis gives a projected estimate of future population and water consumption, presenting a problem that could be prevented.

After the results are found, the data collected can be used to create a proposal to help prevent shortages and restrict the usage of water in the Arvada area. This is crucial for future population growth, because if the demand exceeds the supply of water the problem of limited water will be at hand. The data obtained can be used as a tool for water conservation and to put restrictions on water demand

(Gato at el, 2007).

MATERIALS AND METHODS

Water consumption has become a problem for the city of Arvada, Colorado, due to the growing population in the area. The change in population is a problem for Arvada because the demand for water is exceeding water supply. Climate change could impact the projected future of the water supply in Arvada. Regression analysis is used as the tool to project the future of the water supply, population growth and water usage.

Population records were collected from the U.S. Census Bureau. The U.S. Census Bureau (2007) reported Arvada's population records for each decade beginning with 1900 and every year from the year 2000 which is graphed. Data of projected population growth is also compared with the water supply and expected climate used from the U.S. Census Bureau (2009).

Information about precipitation and climate change in Arvada was provided by the National Oceanic and Atmosphere Administration (NOAA) found at the National Weather Service Weather Forecast Office's Monthly Precipitation Totals (2009). NOAA is a government agency that records temperature, precipitation, and means and extremes of all climatological data, including daily, monthly, and annual results. This information gives evidence supporting the climate trends.

Collected data for the precipitation that occurred during the years being studied is the other component of the research. The data collected for precipitation is needed to compare to the water used. This concept is related to water crowding, in which more water is demanded than is available. Obtaining the precipitation for the area around Arvada gave estimates for how much water was present and how much could be provided. However, the amount of water supplied to Arvada can only be based on estimates due to the fact that each area can receive different amounts of precipitation based on its location (Annual, 2009). Because the amount of precipitation will not change a lot over time, but population will grow, the amount that will be available per person will illustrate a strong decrease. Reports collected from NOAA are additional information to strongly support the evidence of precipitation and annual water availability.

The final component for the research is the consumption for water in Arvada. These data are compared to the population in Arvada to show the amount consumed by each individual. The data were collected by contacting the Arvada Water Resources for the years 1954 to the present (Essert, 2009).

When all the information from population growth, precipitation, and consumption of water has been gathered, the data are then graphed. The graphed data of the consumption for water compared to the population will show how the changes have affected the amount of water the population is using. Comparing the amount of precipitation to the consumption of the water shows how the effect of a growing population changes the water amount used in this area. Over all, the data collected will go toward an effort to show the effects of population growth on water demand and to examine whether there will be enough water supply to support the rising population.

RESULTS

Performing linear regression analysis for the correlation between years and annual precipitation in Arvada, Colorado indicated that the data sets a p-value of 0.027 indicating that there was a significant difference between the distribution curve and the slope of the points. This evidence indicates that there is an increasing amount of precipitation as the years progress. The power for these variables are below the desired power of 0.800 being at 0.258. Since normality failed, the Spearman's Correlation was run giving a coefficient of 0.176, and a p-value of 0.142 concluding a significance difference.

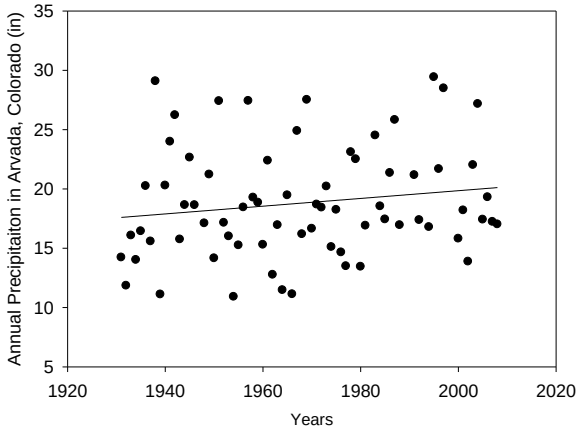

Figure 1. The annual precipitation in Arvada, Colorado per year from 1932 to 2008 is fitted with a linear line (above). However, there is not a strong correlation between the two sets of data.

A linear regression was performed between the years and population and a high R-squared value was obtained of 0.9974. A high R-squared value closer to one indicates that the fitted line closely fits the compared data sets and there is less of a difference between the points and the sigmoid curve. This data can be observed in Figure 2.

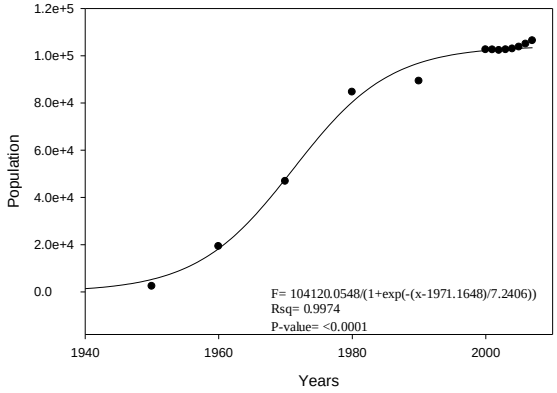

Figure 2. The relationship between the population growth in Arvada over the past decades is indicated in the equation of the sigmoid curve located in the Figure above starting at 1950 and proceeds to 2007.

A nonlinear regression analysis was used to start comparing the water consumption for each year. An R-squared value of 0.8431 was obtained from the fitted curve determining that predictions for future estimates will have smaller residual differences. The curve that was fitted to the data provided the equation which is viewed in Figure 3.

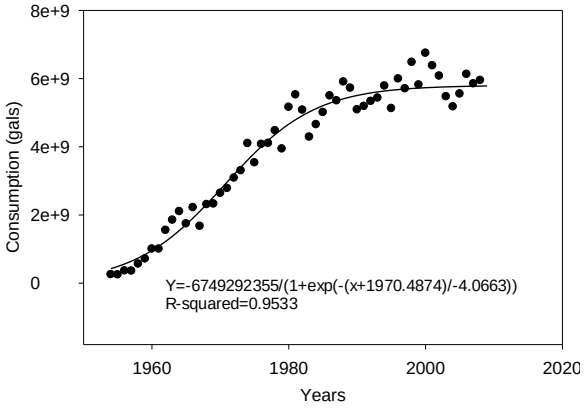

Figure 3. The annual consumption of water in Arvada increased over time. A sigmoid curve was adjusted to fit giving the equation displayed on graph.

A sigmoid dynamic fit line for the nonlinear regression was created to adjust to the points allowing predictions of future consumption for Arvada.

Discovering that the month with the most consumption was June, a correlation between the total consumption of the June months and years was done. Figure 4 shows the relationship between the two variables with a sigmoid fitted curve. The equation and R squared value can be observed in Figure 4.

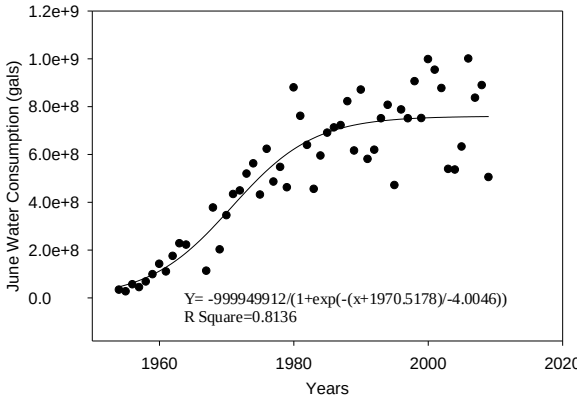

Figure 4. The graph above indicates that for every month of June, for each year, progressed where there are more water consumed at higher quantities and larger ranges from year to year.

To correlate the population and consumption for the amounts of each decade were used and a positive correlation was developed, Figure 5 shows the relationship.

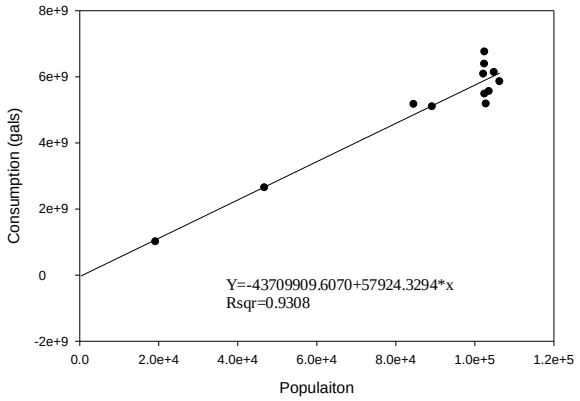

Figure 5. As the population increases over time a linear line was added to show the positive relationship between population and consumption.

With the fitted linear line on in Figure 5, the residuals can be found between the point and the line. The residuals are plotted versus population showing whether there is more or less residual difference, Observed in Figure 6.

To obtain a smaller range of points the residuals that were found are divided by the populations. This creates a per capita for the relationship between the residuals and the population. The per capita is graphed against the climate for each year to acquire wet and dry seasons, seen in Figure 7.

From the equations for each graph, predictions for the future populations and the water consumptions can be made.

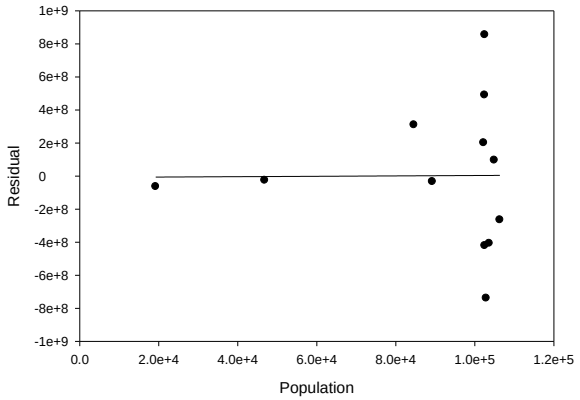

Figure 6. The residual difference, more or less water used, between the fitted line in Figure 5.

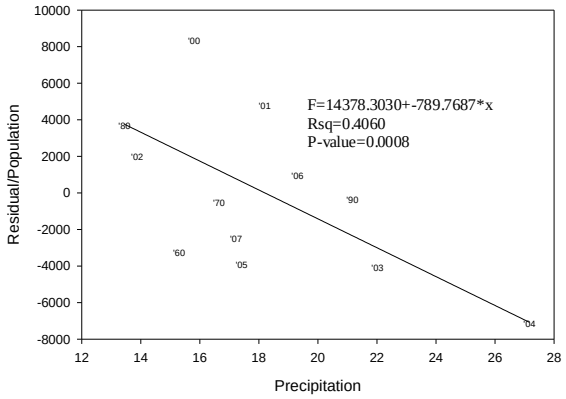

Figure 7. Used to determine the ranges of precipitation for wet and dry years with the residuals for previous populations.

DISCUSSION

The objective of this study was to observe the effects of population growth on water demand in Arvada, Colorado. The results show different relationships between the components in the research using a process called regression analysis. In this study data is collected including the population of Arvada, annual precipitation around the Arvada area, and annual consumption of water.

Precipitation is compared to years to uncover a pattern in the rainfall. As seen in Figure 1 no correlation between the points is discovered. There are slightly skewed points that range from a dry year containing around 12 inches of precipitation and up to 27 inches in a wet year.

The consumption in Arvada has a positive correlation with the years due to the fact that as the population increases over time, the amount of water used increases. The fitted curve for the analyzed data between consumption and the years can be seen in Figure 3 gives a line that can be used to project estimates for the future consumption of

Table 1- Years chosen to predict future values for wet and dry season water consumption ranges. 13 inches is the annual low and 27 inches as the annual high.

Year	Projected Population	Dry-13 Water Used (Gals)	Wet-27 Water Used (Gals)
2010	103634	6.385x10^9	5.239 x10^9
2011	103696	6.389x10^9	5.242 x10^9
2012	103751	6.392x10^9	5.245 x10^9
2015	103876	6.400x10^9	5.251 x10^9
2020	103997	6.407x10^9	5.257 x10^9
2030	104089	6.413x10^9	5.262 x10^9

Arvada. Realizing that a significant amount of water is used in the months of June consistently through the past years, the months of June are analyzed with the years to obtain a better correlation with the maximum amounts of water that is used. Discovering that multiple plotted points having residual differences between the fitted curve and the points shows an inconsistent use of water. The change in water usage is found to be influenced by the amount of precipitation for that year. During a wet year less water would be used causing the point to fall below the fitted curve compared to a dry season where more water was used plotting the point above the fitted curve. These differences can be explained by the abundance of parks and recreation areas there are in Arvada with the 140 parks and 2,000 acres of land that need maintenance in the summer months (City, 2010). These parks include multiple golf courses and two huge outdoor sport complexes using 135 acres alone (City, 2010).

Population was compared with the consumption of water in Arvada and a positive correlation was found, demonstrated in Figure 5. This correlation is explained by as the population increases the water usage increases. The residuals of these points are taken to then be compared to the population seen in Figure 6. Figure 6 shows how much water is used above and below the distribution curve in Figure 5. The residuals are divided by the population for that year to get the relationship between water usages for the population during specific years. The relationship is then analyzed against the population to see the amount of water that would be used in the population which is used to estimate for future population's residual water consumptions above and below the distribution curve.

The residual divided by population is compared with the amount of precipitation showing a Dry-Wet season comparison seen in Figure 7. This demonstrates that the higher amount of precipitation the less water that was used and lower precipitation causes the consumption of water to increase.

As seen in Table 1, the years that have been chosen are used to predict future population estimates and then those populations are used in the equation in Figure 7 to determine the projected amount of water consumption in wet and dry years would be. The data will help in determining whether the city is capable of supporting the amount of water usage that these estimates predict for future populations. According to The City of Arvada: 2008 Water Quality Report, the two water treatment plants in Arvada can produce and pump up to 52 million gallons of water a day. With the projected consumption data for either a wet or dry season, Arvada has the capabilities to support the rising population's water consumptions.

Arvada City Water Plants is capable of producing 52 million gallons of water per day. The annual consumption from 2007 was 5,850,466,453 billion gallons. When considering the 52 million gallons that can be produced a day by the water plants, 18,980,000,000 gallons is what would be produced each year. Clearly, Arvada has the equipment to support the growing population.

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