ESM 121

Water Science and Management

Exercise 1:

Current and Future Population and Water Demand

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Objective

The objective of this exercise is to provide examples of methods to estimate future population, as well as estimating current and future water demand and urban water use. For this purpose, we are going to use data for the city of Watsonville California, which is located in the Monterey Bay (Figure 1).

Figure 1 - Watsonville City
Population

Open the file Ex_1_Data.xls. Go to the red tab named Population (Figure 2). Please take a look at the population of the City of Watsonville from 1860 to 2010. Excellent data¹! Don’t you think?

![Data Table]

Figure 2 – Historic population data

Now let’s start analyzing the data. First of all, let’s plot the data to see what it looks like. Use a scatter chart (X-axis for years and Y-axis for Population) to plot the data (Figure 3). Notice how the population has grown, from almost 400 people in 1860 to around 51,000 inhabitants in 2010. Now, Click on the data, then right-click and select “Add a Trendline …”. (Figure 4).

Select the “Power” regression type, and check the boxes of “Display Equation on Chart” and “Display R-squared value on chart” that are located at the bottom of the dialogue box (Figure 5). Click Close
Click on the label for the Equation and R-squared, then right-click to select “Format Trendline Label …” (Figure 6).
A dialogue box will open. Select the Number section; then, in the Category menu select “Scientific” and type 4 decimal places. (Figure 7). Close the dialogue box.

![Figure 7](image)

Now the equations should match Figure 8, and can be written as follows:

\[ y = (2.6401 \times 10^{-175}) \times x^{54.292} \]

\[ R^2 = 0.96496 \]

![Figure 8](image)

Notice that the value of \( R^2 \) (\( R^2 = 0.96496 \)) is close to 1 which is quite high, meaning that there is a good correlation between the historic data and the equation selected. Remember that the variable “X” refers to the year values and “Y” refers to the population values so plugging any year value into the equation will give you the population value at that point.

Select cell C6 and type the regression equation (Figure 9) as follows:
“=\((2.6401\times10^{-175})\times A6^{54.292}\)”

Copy this formula for the rest of column “C” (Figure 10) up to 2050. Now we have a regression using all the data available.

It doesn’t look bad, now we have an equation that simulates the population growth since 1860!!! But, what is the coefficient of determination \((R^2)\) since 1970? Go to cell C28 and
estimate the coefficient of determination ($R^2$) using the Excel command “RSQ” (Figure 11) as follows:

```
=RSQ(B17:B21,C17:C21)
```

Now let’s plot only the data from 1970 to 2010. Copy and paste the chart that we’ve been working with onto the Population tab. Right-click on the chart data to “select data” from 1970 to 2010 and select a “Linear” regression (Figure 12). The chart, regression equation and coefficient of determination ($R^2$) should look like this:
The regression equation should look like Figure 13, or in other words:

\[ y = 939.82 \times \text{Year} - 1837306.8 \]

\[ R^2 = 0.9915 \]

Figure 13

Remember that the y-variable represents population and the x-variable represents years. Notice that the coefficient of determination for the 1970-2010 regression equation (\(R^2=0.9915\)) is higher than for the entire period of 1860-2010 (\(R^2=0.9704\)). This means that the linear equation is better “capturing” the behavior of the population growth than the equation for the entire period. Now, let’s type the 1970-2010 regression equation into cell “D17” (Figure 14) as follows:
“=939.82*A17-1837306.8”

Let’s copy this formula for the period 1980-2050 (cells D18-25) and estimate the Coefficient of determination for the 1970-2010 regression equation in cell D28 (see Figure 15).
Plot the data for: historic data, regression 1860-2010 and 1970-2010 (Figure 16) in the second chart that we’ve been working on. How does it look? Do you think the “Whole Period” regression data looks better? The 1970-2010? What do the coefficients of determination tell you?

To be turned in: (a) the chart with the three data sets plotted and (b) describe the two regressions and explain which of the two you will select to project future population? Based on what criteria?

Now, to double check that we have selected the right equation, let’s estimate the average decadal growth. Go to cell E18 and subtract the population of 1970 from 1980 (Figure 17) as follows:

“=B18-B17”

Figure 16
Do the same for the following decades (Figure 18).

Figure 18

Calculate the average decadal population growth in cell E29 (Figure 19) as follows

Figure 19

Now, let’s do the same procedure to obtain the decadal growth for the 1970-2010 regression equation.
The average decadal growth for the historic data (9,158 inhabitants/decade) and for the 1970-2010 regression equation (9,398 inhabitants/decade) are very similar. A peculiar characteristic of the population growth in California is that since 1950 the growth has been linear. Some scenarios are considering this growth population pattern for the future².

To be turned in: (a) Discuss why the average decadal growth in Watsonville is linear. (b) Did you select the linear growth equation as your population regression? (c) Was it necessary to estimate the average decadal growth and compare it? (d) How does the estimation of the average decadal growth help you support your decision to select a regression equation? Is this decision more supported because of this last calculation?

**Water Use Per Capita (WUPC)**

In this section we are going to analyze the Water Use Per Capita (WUPC) of the City of Watsonville using a very simple approach. Move to the “Water Use Per Capita” Tab (Blue tab). Let’s take a look at the urban water use data of the city of Watsonville (Figure 21).

<table>
<thead>
<tr>
<th>Year</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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<th>J</th>
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<tr>
<td>2004</td>
<td>Total (Gallons/year)</td>
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<tr>
<td>2005</td>
<td>Total (Gallons/Year)</td>
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Let’s create a stacked column chart to observe the Surface water and groundwater use of Watsonville from 1999-2010 (Figure 22). As you can see, most of the water supply for Watsonville comes from groundwater sources.

![Stacked Column Chart](https://via.placeholder.com/150)

**Figure 21**

Now, let’s estimate the total water use for each year. Add rows 5 and 6 for each year (Figure 23 and 24). Notice that the units of these rows are Acre-feet/year (AF/year). An acre-foot is a unit of water volume, with the area of an acre (~70 square yards) and the depth of a foot.
In the following conversion table (Figure 25) you can find that 1 acre-foot equals 325,851 gallons of water.

**CONVERSION FACTORS FOR WATER**

1 cubic foot ———— 7.48 gallons ———— 62.4 pounds of water  
1 cubic foot per second (cfs) ———— 450 gallons per minute (gpm)  
1 cubic foot per second (cfs) ———— 646,400 gallons per day ———— 1.98 acre-feet per day  
1 acre-foot ———— 325,851 gallons ———— 43,560 cubic feet ———— 1,233 cubic meters  
An acre-foot covers an acre of land to a depth of one foot.  
1 million cubic meters ———— 811 acre-feet  
8.1 AF (acre feet) ———— 1 hectare/meter  
1 hectare ———— 2.47 acres  
1 million gallons ———— 3.07 acre-feet  
1 million gallons per day (mgd) ———— 1,120 acre-feet per year  
10 cents per 1,000 gallons ———— $32.59 per acre-foot  

* The average annual rainfall is calculated on a 30-year average.  
** 2005 was defined as an above normal water year.  
*** Environmental water includes designated wild and scenic flows, instream flows,  
Sacramento-San Joaquin Delta required outflow, managed wildlife refuge water,  
and the Environmental Water Account. Theoretically, the number would also  
include water for riparian habitats; however, it is not quantified at this time.

Because the standard units used to express the urban water use per person is gallons per capita per day (gpc/day), we have to convert the acre-feet/year to gpc/day. First let’s calculate the gallons per year by multiplying the total water use (row 7) by the conversion factor (325,851 gallon per acre-foot) (Figure 26)
Let’s do the same for the whole row 8, it should look like Figure 27.

Now let’s calculate the gallons per day by dividing the gallons per year by 365 days (Figure 28). Let’s do this for each year (Figure 29).
Now we need to estimate the population in each of these years. We already know how to do that! We are going to use the population equation of the linear regression that we estimated in the previous part of this exercise:

\[
\text{Population} = 939.82 \times \text{Year} - 1837306.8
\]

On row 11, let’s calculate the population for each year as shown in Figure 30 and 31.

We have all the ingredients ready to estimate the water use per capita (WUPC): (1) the water use in gallons/day (row 9) and (2) the population per year (row 11). Let’s divide the total water use in gallons (row 9) by the population (row 11) for each year, as shown in Figures 32 and 33.
Now let’s create a column plot of the water use per capita (row 12) and the precipitation (row 3). Use secondary-axis for the precipitation data (right click on top of the precipitation series, then select “Format Data Series” and in Series options select Secondary Axis) and change the chart type to line with markers (right click on top of the precipitation series, then select “Change Series Chart Type …” and then select “Line with Markers” under the line section) (Figure 34).
Figure 34 – Water Use Per Capita Per Day and Precipitation

Figure 34 shows that there is not a clear correlation between low or high precipitation years with the WUPC. Notice that in the last 2 years, 2009 and 2010, the WUPC is 128 and 120 gpd/person respectively, which is 486 and 454 lpd/person (liters per day per person), respectively. Temperature is not driving the WUPC in this region, water use habits and appliances are the main drivers of the WUPC.

To be turned in: (a) A column plot chart of the WUPC and precipitation, (b) Has the WUPC increased or decreased? (c) How has the program residential implemented in the last decade impacted the WUPC in the region? [http://www.pvwma.dst.ca.us/conservation/urban-areas.php](http://www.pvwma.dst.ca.us/conservation/urban-areas.php) (d) Is the WUPC (~125 gpd/person = 473 lpd/person) too much or too little? Take a look at the following picture and provide some discussion.
There are also rural communities close to Watsonville whose water supply comes from the same water source (groundwater) (Figure 36), but for these communities there is only data for 2010. Let’s follow the same procedure for these rural communities to obtain the water use in acre-feet per year (Figure 37), gallons per year (Figure 38) and gallons per day (Figure 39).
Once again, the ingredients are ready; we can estimate the WUPC by dividing the water use by the population (Figure 40), which is 132 gpd/person in 2010. Notice that this value is not very different from the value estimated for Watsonville city (120 gpd/person).
In summary:

Water Use Per Capita (WUPC):

Watsonville: ~120 gpd/person

In rural communities around Watsonville: ~132 gpd/person

To be turned in: (a) Provide a brief comment about why there is a slightly higher WUPC in rural communities than in the city. Hints: Leakage? No meters? Less sophisticated equipment and water saving devices to supply water?
Projected Water Demand

Ok, let’s analyze the data that so far we have:

- Population data until 2050 using a linear regression equation.
- Water use per capita (~120 gpd/person)

With this information it is possible to estimate the future water demand for the city of Watsonville. Move to the “Projected Water Demand” Tab (Orange tab). In column B, let’s recalculate the population for Watsonville using the linear regression equation that we’ve been using [Pop =939.82*Year - 1837306.8] (Figure 41 and 42).

Let’s insert the Water Use Per Capita (WUPC) (Figure 43) of the previous tab into this worksheet in cell “C3” and convert this value into liters per day per person by multiplying it by the conversion factor (Figure 44).
Now, let’s estimate the water demand in column C in gallons per year by multiplying the WUPC in cell “C3” by the estimated population of column B times 365 days (Figure 45 and 46). (Make sure to use “$C$3 so this value is set for all of column C)
Now let’s convert this data into acre-feet per year (AF/y). Divide the values in column C by the conversion factor (325,851 gallons = 1 acre-foot) (Figure 47 and 48).
Let’s create a column chart from the water demand in Column D (Figure 49). The water demand increases linearly with population. This is not always true, because implementing some water use efficiency policies (e.g. more efficient outdoor water use) and water savings policies (reducing the area of yard to be watered) may reduce the linearity between these two variables. These concepts will be explored in detail in next week’s exercise (water use efficiency and water savings).
Meanwhile, let’s consider a “Scenario” (Scenario = a policy that we are proposing to be implemented) where the WUPC is reduced 15% (from 120 gpd/person to 102 gpd/person) in the future, from 2020 to 2050. First, let’s just copy the water use before 2020 (Figure 50, 51 and 52).
Now let's calculate the water demand (in gallons per year) by multiplying the proposed water use per capita, 102 gpd/person, by the population in the future by 365 days (Figure 53 and 54).
Now let’s convert these values into acre-feet per year by dividing the values of column E by 325851, which is the conversion factor (Figure 55 and 56).
Let’s compare the results of the Scenario “Reduction in WUPC” with the constant WUPC as shown in Figure 57. Notice that the water demand between 2010 and 2020 does not increase. This is because the WUPC has been decreased, or in other words: “The population increased, but the water use per capita was reduced and thus the water needed for the population was the same amount”. Also notice that in 2030 the water demand starts to grow again. Thus, reducing the water per capita will help to solve the increase in water demand for a while, but as the population keeps increasing, a time demand will start to pick up. In the following exercise we will take a look at systems efficiency, water savings, future water demand and more scenarios.
To be turned in: (a) The plot of both water scenarios demand (Figure 57), provide your own comments about reducing the WUPC (b) A policy is proposed to reduce the WUPC arbitrarily by a certain percentage (15%). What kind of action would you propose to reduce the urban water demand? e.g. less water consumptive toilets? Harvesting rainfall water?