Example #1: The Power of Excel in Engineering

ENGN 178 – Introduction to Engineering

(Individual assignment distributed across three classes)

You have just started an internship at a local engineering firm. The company you work for has developed a design for a dam that will be constructed across Kerr's Creek here in Lexington, VA. Your supervisor has just let you know that in an effort to increase the city's renewable power resources, a turbine and generator system will be added to the dam. The new hydroelectric dam will take the water built up behind the dam and allow it to flow through a series of pipes, through a turbine, and out to the other side of the dam. The water will turn the turbine, making electricity with a generator. The power generated from the turbine will be transported to the city's electrical grid.
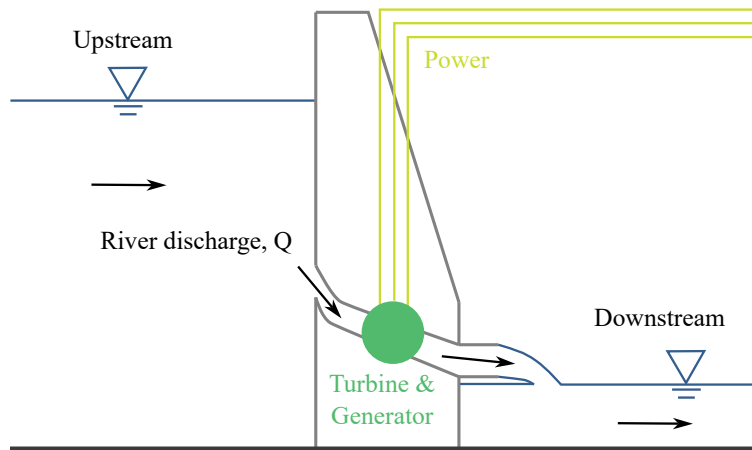

Figure 1: Cross-section schematic of a hydroelectric dam

However, before the dam is built, the city would like to know how much power they should expect the system to generate. You know from your fluid mechanics class that the power generated from steady fluid flow under idealized conditions (neglecting viscous work and heat transfer) can be calculated with,

$$P = (\rho Q g h_t)\, e,$$

where P is the electric power generated by the turbine in Watts ([W]), ρ is the density of the water in kilograms per cubic meter ([kg/m^3]), Q is the amount of water flowing through the turbine, or the river discharge, in cubic meters per second ([m^3/s]), g is the acceleration due to gravity in meters per second squared ([m/s^2]), h_t is the turbine head in meters ([m]), and e is the efficiency of the turbine (or the amount of power from the flow converted to electrical power, which is unitless).

Your supervisor has given you the following specifications from the manufacturer of the turbine:

Parameter	Value
Turbine head, h_t	79.8 [m]
Turbine efficiency, e	0.85 [-]

You also know that the density of water, ρ, changes with temperature, but your supervisor wants you to assume that the water temperature is always 21 [°C].

With this information, you can almost calculate the amount of power generated from the turbine. The only missing information is the amount of water flowing through the turbine, Q. During lunch, your friend who is taking a geology course lets you know that the United States Geological Survey (USGS) measures daily mean river discharge and publishes the values online.

She does a quick search for you and discovers that the USGS, in fact, has the river discharge data from Kerr's Creek! She shared the link with you: https://waterdata.usgs.gov/nwis/dv/?site_no=02022500.

Your plan is to take the data found on this website and calculate the average amount of power the hydroelectric dam can generate for each day in the past four years. **Represent this data in a spreadsheet, similar to the one shown in Figure 2, to show to your supervisor.**

Figure 2: Roughly, what your power-calculating spreadsheet will look like.

Hints:

1. You can generate the river discharge data by following the USGS link, selecting the output format as "Table", choosing the dates you want, and clicking "Go." The website will generate a table of data, and you can copy the URL and paste it into the "Get Data From Web" search bar in Excel.

2. Besides the river discharge data, which values in the power equation are you missing? Where could you find this information?

3. Make sure your units are consistent. It is usually a good idea to convert all the values you use in a calculation to the same type before performing the operation. You can find information on unit conversion online or ask Prof. Woodruff about how dimensional analysis works if you are unsure how to convert complex units, such as $[\text{ft}^3/\text{s}]$ to $[\text{m}^3/\text{s}]$.

4. Use absolute and relative referencing to calculate the daily mean power for each day.

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Now that you have a spreadsheet containing the river discharge and hydroelectric power data, your supervisor wants you to make sense of the data. You decide to make some plots to visualize the data and see if there are any trends. The first thing you are curious about is whether or not the daily mean river discharge is similar year-upon-year. You know that with seasonal changes, there is usually more rain during certain times of the year, which might lead to larger river discharge. **Create a plot that shows the river discharge over time.**

After making the plot, examine the results. Is there a pattern between years? If there are many outliers, you should copy the plot, and make a new one that uses a logarithmic scale on the y-axis. You can do this by double-clicking on the axis, selecting Axis Options, Axis Options, then selecting Logarithmic scale. Does there appear to be a pattern between seasons now? **Show this new plot in your Excel file.**

So far, you have made two assumptions: (1) The amount of rain, or precipitation, that falls will predictably vary with the seasons; (2) the more precipitation you have, the higher the daily mean river discharge will be. You want to make sure that these assumptions are supported by evidence. To do so, you plan on collecting data about precipitation in the Lexington area. You consult with your friend in geology, and she tells you that the National Centers for Environmental Information through the National Oceanic and Atmospheric Administration (NOAA) has a geographic-information system (GIS) that contains historical precipitation data for various locations in the United States (https://www.ncei.noaa.gov/maps/daily-summaries/). Your friend tells you that, like most databases, the website is tricky to use. She offers you the following advice:

1. Open the URL in your browser. Click on the "Map Tools" icon (the wrench in the upper, left-hand corner). Under "Daily Observation Tools," select "Location."

2. Select a location type to find Lexington, VA 24450 (Note: In Virginia, cities, such as Lexington, are considered counties).

3. Once you find Lexington on the map, you should see a list of stations on the left-hand side of the screen. Find the station for Lexington, VA US – Station ID GHCND:USC00444876. Select "View Station Details."

4. You will need to request the data that NOAA will send to you via email. To do so, select "Add to Cart," then open the cart. Select the output format as a CSV file. Choose the date range that corresponds to the river discharge data you found earlier (it is okay if some of the data is cut off, since the NOAA data are less up-to-date than the USGS data). Select "Continue."

5. You only need the liquid precipitation data (nothing to do with snow), so remove any information about the station, location, or data flags. Choose the units you want ("Standard" is inches per day, "Metric" is millimeters per day – notice the bias).

6. Give the website form your email address, and submit the order. You will need to wait a few minutes for the request to be process, but eventually NOAA will send you an email containing the precipitation data. Download the CSV file, and save it somewhere on your computer.

7. You can access the data in Excel either by opening the CSV file directly or by importing the file with the Excel Get Data From Text/CSV Tool. You should now see a spreadsheet containing the data and precipitation data in the unit requested.

You now have the precipitation data. Add these data to your spreadsheet containing the river discharge data as a new column. **Plot these data as a time series.** Do you see a pattern between seasons? Perhaps not. A little frustrated, you remember that there are other plots that let us see meaning from data. You decide to see if there is a relationship between the amount of precipitation in a day and the daily mean river discharge. **Create a scatter plot with precipitation as the x-values and daily mean river discharge as the y-values.** Do you see a trend between these two values?

Hints:

1. Make sure your plots follow the Golden Rule of plotting. Make sure your plots are readable and the axes fit the data.

2. When choosing the bounds on an axis defining dates, the number you see is the number of days since January 1st, 1900 (it actually counts the number of days since December 31st, 1899, since Microsoft decided to leave in a bug that counted 1900 as a leap year, which it was not). You can convert a date to this number of days by changing the data type from Date to Number.

3. To save a plot in Excel as an image, simply right-click the plot border, and select "Save as picture."

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Now that you have collected and plotted the data about river discharge and precipitation in Lexington, you are ready to start analyzing the results and finding quantitative meaning in the numbers. To do so, you have four goals in mind:

1. Determine the strength of the correlation between daily precipitation and daily mean river discharge. Does rain predict how much water will flow through the river very well? If not, what other factors could affect the river discharge besides precipitation? Show a linear trend line and R^2 value for these data.

2. You want to create meaningful results for the City of Lexington to help them decide if building this hydroelectric dam will meet their needs and justify the additional cost to the design. Your first goal here is to calculate statistics on the daily power production data, reducing the large column of numbers to a small table of values, such as the one in Figure 3(a).

3. The second goal you have regarding the power production information is to see how much variation there is between months. The City is concerned that during months with low river discharge, the hydroelectric dam will not produce enough energy to justify costs. You plan on creating a table, such as the one in Figure 3(b) showing the monthly statistical values during 2019, a year with an exceptionally low daily mean river discharge rate.

4. Finally, you want to carefully consider the impact that building a hydroelectric dam on the river can have on people, places, and things besides your clients. Think of ways that building such a dam could be detrimental to the surrounding community or land. Might there be a better way of producing renewable electricity for the city?

(a)

Daily power production statistics from 09/12/2018 - 09/12/2022		
Average		[kW]
Median		[kW]
Standard Deviation		[MW]
Minimum		[kW]
Maximum		[MW]
Number of days less than 1 [MW]		[-]
Percent of days less than 1 [MW]		%
Number of days less than 0.5 [MW]		[-]
Percent of days less than 0.5 [MW]		%

(b)

	Daily power production statistics for 2019				
Month	Average [kW]	Median [kW]	St. Dev [kW]	Minimum [kW]	Maximum [kW]
January					
February					
March					
April					
May					
June					
July					
August					
September					
October					
November					
December					

Figure 3: (a) Example table summarizing daily power generation over the past four years. (b) Example table summarizing daily power generation for each month in 2019.

Hints:

1. The `COUNTIF()` function in Excel could be useful in calculating statistics such as "Number of days less than 1 [MW]." The documentation on how to use this function can be found here: https://support.micr osoft.com/en-us/office/countif-function-e0de10c6-f885-4e71-abb4-1f464816df34

2. There are two types of standard deviation. The one you should use is the sample standard deviation (not the population standard deviation).

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You now have a spreadsheet that shows you the amount of power that a hydroelectric dam would have created each day from the past four years, time-series plots that show the daily mean river discharge (both with a linear and logarithmic y-axis) and the daily precipitation amount, and a scatter plot showing the relationship between precipitation and river discharge. You will take these plots and data to create a report to show to your supervisor and the City of Lexington.

In your report, you will need to address the following:

- Describe, in your own words, the purpose of the report. What questions did seek to find answers to? Who should care about these answers?

- Describe your approach to answering the questions. What process did you follow? Where did you find data (cite the source using the APA 7th Edition citation style)? What equations did you use? What constants did you use (consider using your spreadsheet to make a table)?

- Show your results and discuss their meaning. What answers did you find? What answers did you not find? Do you have plots to support these answers? Are you unsure of any of your results, and why?

- Conclude your report by answering the following questions: What obstacles did you have to overcome when doing this work? What successes did you have when doing this work? How do you imagine Excel being useful in your future work, either in classes or at a job?

When answering questions, follow the statement-evidence-analysis model, where you answer the question with a statement, give evidence or an example to support that answer, and explain how the evidence is relevant to your answer. For instance,

> *The most difficult obstacle that I had to overcome while completing this assignment was figuring out how to use the USGS data tool. The website did not have clear instructions, and when I would generate the data, it would not always be in the column format I wanted. When using this tool, I would get frustrated and annoyed until I figured out how to get the data in the format I wanted.*

Look at the example report for formatting expectations. The length of the report does not matter as much as the thoroughness and concision of the writing. If you follow the statement-evidence-analysis model when answering questions, and your report is easy to follow, you will receive a good grade.