Modernizing Water and Wastewater Treatment through Data Science Education & Research

TECH BRIEF

Data Science Summer Fellows Program

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Denver Water: Foothills Treatment Facility

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SUMMARY

Clean drinking water represents one of the most important hallmarks of public infrastructures. Not only do individuals, families, and businesses rely on easy access to drinking water, but the quality of water itself is one of the greatest predictors of health within an area. The Foothills treatment facility operated by Denver Water serves it's community by providing easy access to quality drinking water. The process of cleaning, filtering, and treating water can be a long and complex process. This brief focuses on how Denver Water utilizes filtration at the Foothills treatment facility.

INTRODUCTION

There are 16 filters in the Foothills facility. The media within the first three filters have been replaced this year, and the remaining 13 filter medias were not replaced. Filter's 1-3 were compared to filter's 4-16 to investigate whether media replacement increased filter performance. Additionally, each filter was tested to determine if some filters perform better than others.

FACILITY SYSTEM DESCRIPTION

The facility utilizes a combination of chemicals, basins, and filters to remove waste and treat water. Water flows from the Strontia Springs reservoir and passes through flocculation and sedimentation basins to remove large pieces of debris. Multiple chemicals are added to treat the water and then the water moves into one of 16 filters. The filters include smaller basins to catch remaining debris, called floc, and then passes through a thick layer of anthracite coal. After the water completely filters through the coal. At the end of the filter the clean water moves onto a disinfectant basin, and the left-over wastewater is discarded. Once the filter has completely filtered the water (a process that takes approximately 10 hours) additional water is run through the filter to clean it in a process called backwashing.

DATA DESCRIPTION

The datasets provided by Denver Water contained information on all 16 filters. Each filter had its own dataset with five different variables: datetime, head loss, total effluent flow, turbidity, and filter runtime. Data is collected at five-minute intervals for each filter. Turbidity, measured in NTU's, describes the clarity of filtered water; therefore, acts as a sufficient measure of filter performance. There were no missing values within the dataset; however, there were many zero readings due to filter downtime and maintenance. To focus the analysis on only times when the filters were operations these zero values were removed, an important step to obtain the most accurate results about filter performance.

EXPLORATORY DATA ANALYSIS

Exploration of the dataset began with creating time series plots for all 16 filters to compare the flow rate over time (figure 1). This showed that filter seven was not operational and therefore was excluded in the analysis. A correlation plot (figure 1) was constructed to determine if a linear relationship exists between the variables within each filter.

Figure 1

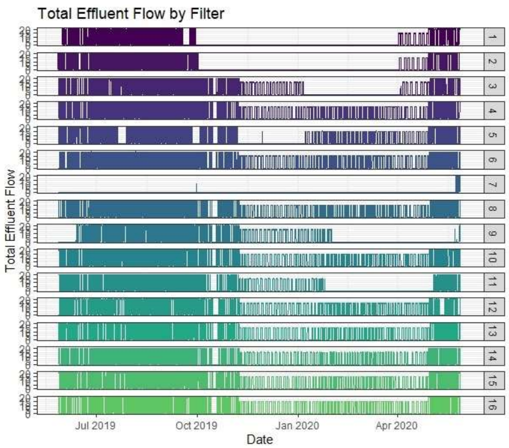
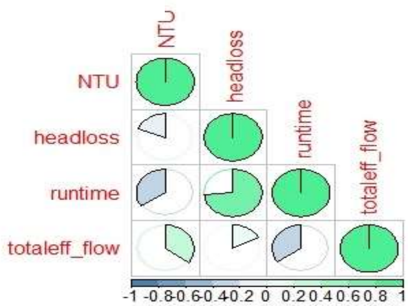


Figure 2

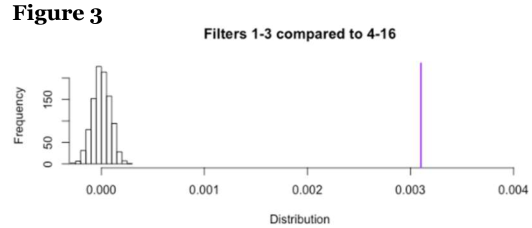


Turbidity, measured in NTU's, was chosen to measure filter performance because of it is a response variable with high correlation to total effluent flow and runtime. The turbidity of each filter was measured, and then the combined dataset of all 16 filters was separated by date into two categories: pre filter replacement and post filter replacement. Plots of the turbidity over time from the pre replacement data were compared to the post replacement. To determine the difference between the replaced filters and the non-replaced filters we used a preliminary test, Welch's t -test, to compare the mean amount of the all the post replacement turbidity in filters 1-3 to the mean amount of turbidity in filter's 4-16 from the same time frame.

STATISTICAL ANALYSIS and RESULTS

Permutation Test: A permutation test was used to analyze whether there was a difference in turbidity within each filter. Due to the size of the dataset, it was important to decrease sampling bias and randomize the sampling data while also testing every possible combination of samples. The permutation test then created a reasonable distribution of pre and post replacement data. The observed difference of turbidity was overlaid in the histogram above to determine if there was significant evidence to suggest that turbidity changed between pre and post media replacement. Our analysis showed that within filters 1-3 there was a significant difference between the turbidity pre filter replacement and the turbidity post filter replacement. Similarly, the permutation test (figure 2) showed that turbidity from the post filter replacement from filters 4-16 was significantly different compared to post filter replacement in the first three filters, as shown in the histogram.

Figure 3



T – Test: The permutation testing does not give a confidence interval or probability value for each test. Running a t-test determined whether there was a significant difference for turbidity between pre and post media replacement. Additionally, we tested to see if there was a difference between filters 1-3 and 4-16. Within filters 1-3, filter 1 showed the greatest decrease in turbidity from after replacement, with a p-value = 2.2e-16 and a 95% confidence interval of (0.0078 0.010), suggesting a significant. This result means that there is a significant difference, and that we are 95% confident the mean amount of turbidity is within the interval. Additionally, the mean turbidity post replacement is less than pre replacement confirming a decrease. Filters 2 and 3 show a change but the t-test indicating the mean amount of turbidity rose after replacement. Fortunately, in a comparison of all filters, the post replacement

NTU showed to be significantly less than the pre replacement NTU, with a p-value of 2.2e-16 and a confidence interval of (0.003, 0.004). Additional analysis show that filters 5,6, and 12 all increased turbidity over time and may benefit from filter replacement. Conversely, filters 11 and 8 appear to the least turbidity over the course of a year and are functioning optimally.

Outlier analysis: Upon exploration of turbidity in the dataset it became clear that there may be observations of turbidity that are outliers and may have occurred due to maintenance. Observations of turbidity that exceed 0.75 NTU are considered abnormally high and may be an outlier. After filtration is complete, water is pushed back into a filter to clean and prepare for the next filtration cycle. This process, called backwashing, has the possibility to leave sediments in the filter that read as excess turbidity within the first hour of the next filtration cycle. To account for this possibility, a function was created that could track backwashing within each filter and determine if an outlier reading of turbidity occurred during the first hour after backwash cycle. The results showed that only 25.9% of the turbidity readings above 1.0 NTU occurred within the first hour after a backwash. Similarly, only 27.2% of NTU readings above .75 occurred within the first hour after a backwash. The boxplot shows the mean amount of turbidity within each filter (figure 4). Most filters average around 0.05 NTU which is standard; however, there are many observations between 0.1 and 0.2 NTU which is extremely high. Further analysis is needed to determine why these high reading of turbidity occur, why there is such a large variation in turbidity, and whether or not a high turbidity is related to other variables within the dataset.

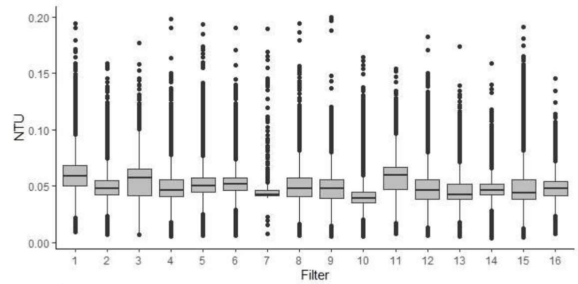


Figure 4

CONCLUSIONS

The analysis has revealed that overall the replacement of filters 1-3 has been successful at decreasing the amount of turbidity. Even though turbidity was not decreased within filters 2 and 3 when compared to a non-replaced filter, there was strong evidence to support a decrease in turbidity in filters 1-3 compared to 4-16. Through our analysis we also found that some filters may benefit from a replacement (filters 5,6, and 12) compared to filters that already function very well (filters 11 and 8). Moving forward the Denver Water team may want to investigate a possible correlation between backwashing and abnormally turbidity, as well as how the length of backwash effects filter performance.

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