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Introduction

For three years (1995-1998), the Palo Alto Regional Water Quality Control Plant (RWQCP) collected influent and effluent concentration data for copper, nickel, and zinc on a weekly basis. The purpose of this document is to examine some of the factors that may influence these concentrations. Determining potential influences on the influent and effluent concentrations of these constituents will provide the RWQCP with a planning tool for implementing measures to control the concentrations of these constituents entering and leaving the plant.

Discussion of Methods

To assess the importance and relationship of various factors to the influent and effluent concentrations of copper, nickel and zinc to the RWQCP, several statistical methods were employed: correlations, regressions, and analysis of variance (ANOVA). Correlations and regressions apply to continuous independent variables and ANOVA was used for nominal independent variables such as day of the week and season. The following lists the type of analysis used for each factor:

Correlations and Regressions

- Influent concentration comparisons
- Rainfall and antecedent conditions
- Water supply information

ANOVA

- Day of the Week
- Month
- Season
- Plant operations

The following sections discuss the analyses in more detail and describe how results were interpreted for significance.

Correlations and Regression

Correlations and regression analyses can both be used to determine the relationship between two continuous variables. Regression is used when it is suspected that one variable (independent variable) can be used to predict the other variable (dependent). Correlation analyses are used when a relationship between two or more variables is suspected, but one variable is not considered likely to predict the other variable. For example, a relationship between copper and zinc influent concentrations was suspected, but it is not likely that the copper concentration would predict the zinc concentration or visa versa. Both analyses were used to examine the headworks data, but correlation analyses were much more suitable to the data being examined and are discussed in more detail in this report.

To determine whether or not two or more variables are related, a correlation coefficient can be calculated. Data that is considered normally distributed and is naturally paired can be compared in a correlation matrix. The matrix describes the Pearson Product Moment correlation coefficient for all combinations of a variety of factors. For an analysis of data that violates the assumptions of the correlation matrix, a nonparametric comparison, such as the Spearman Rank correlation, can be conducted. The Spearman Rank correlation coefficient is more robust to the distribution of the data. For all comparisons, a correlation matrix was calculated. Correlation coefficients that appeared significant were investigated in more detail and Spearman correlation coefficients calculated as necessary.

Correlation coefficients have a value between –1 and 1. A correlation coefficient of 1 or –1 indicates a perfect positive or negative correlation between the two variables. Correlation coefficients were considered significant if they were greater than 0.5 or less than –0.5.

ANOVA

For nominal variables (variables that can only take on certain values), an analysis of variance was conducted. The values that the nominal variable can take, for example the days of the week, are used to divide the influent or effluent concentration data into categories. The variance within each category is then compared to determine if there are significant differences among the categories. An F value is calculated which represents the likelihood that the differences among the categories represent actual differences. A P value is then calculated that is used to determine the likelihood that the F value demonstrates a significant effect on the independent variable from the nominal variable.

P values range from 0 to 1. The closer the P value is to 0, the more likely the differences demonstrated represent actual influences on the dataset. If the P value was less than 0.1 in the initial analysis, additional tests were conducted to examine the influences. In the additional tests, the P value was considered significant if it was less than 0.05. A P value of 0.05 represents a significant difference between the factors at a 95 percent confidence level.

Summary of Results

The following table summarizes the significant influences determined from the statistical analyses conducted. Detailed descriptions of the results are provided in the following sections.

Table 1. Summary of Analysis Results

	Influent Copper	Influent Zinc	Influent Nickel	Effluent Copper	Effluent Zinc	Effluent Nickel
Influent Zinc	Positively correlated					
Influent Nickel	NSR	NSR				
Effluent Copper	NSR	NSR	NSR			
Effluent Zinc	NSR	NSR	NSR	NSR		
Effluent Nickel	NSR	NSR	NSR	NSR	NSR	
Influent Flow	Slight negative correlation	Slight negative correlation	NSR	NSR	NSR	NSR
Day of the Week	NSR	NSR	Sunday significantly lower	NSR	Sunday significantly lower	NSR
Month	Monthly differences observed	Monthly differences observed	Monthly differences observed	Monthly differences observed	Monthly differences observed	Monthly differences observed
Season	Seasonal differences observed	Winter significantly lower	Seasonal differences observed	Seasonal differences observed	Seasonal differences observed	Winter significantly lower
Rainfall	NSR	NSR	NSR	NA	NA	NA
Groundwater Infiltration	Significant differences	Significant differences	NSR	NA	NA	NA
Tap Water pH	Negatively correlated	NSR	NSR	NA	NA	NA
Water Supply pH and Alkalinity	Negatively correlated	NSR	NSR	NA	NA	NA
Plant Operations	NA	NA	NA	NSR	NSR	NSR

NSR No significant relationship observed.
NA Analysis not conducted for these factors.

The results of the correlations, regressions, and ANOVA analyses on the influent and effluent concentrations are presented in the following sections. Of most interest were the influences on the influent concentrations, and these are discussed first. The effluent concentrations were examined in relationship to plant operations, day of the week, month, season and to each other and are discussed in the second section.

Influent Data

Weekly influent concentrations for copper, nickel, and zinc were examined and compared to a variety of factors to determine potential influences on these concentrations. Each constituent was compared to the other constituents to assess any relationships between them. Then, the day of the week, month, and season were examined to assess differences in the influent concentrations. Rainfall data was used as a factor to assess the influence of weather on the concentrations, and water supply data was collected to assess the impacts that the pH and alkalinity of the water may have on influent concentrations. The results of these analyses are discussed in detail in the following sections.

Comparison of Influent Concentrations

The first step in the analysis was the examination of the influent concentration data. Many statistical tests rely on the assumption that data is normally distributed and has certain other characteristics. Descriptive statistics were generated and tests run to assess the distribution of the data. Additionally, visual inspections of time plots were conducted to assess possible relationships between the influent concentrations and look for potential outliers in the data set. Finally, correlations were conducted to assess relationships between the three constituents.

Descriptive Statistics

Descriptive statistics provide a general description of the data set and allow first cut comparisons between the data. Table 2 lists the mean, median, standard deviation, and coefficient of variation for the influent concentrations of the three constituents.

Table 2. Summary Statistics for Influent Copper, Nickel, and Zinc

	Influent Copper	**Influent Zinc**	**Influent Nickel**
Mean	52.2	159	6.1
Median	50.2	150	5.5
Standard Deviation	16.4	46.1	3.2
Coefficient of Variation	0.32	0.29	0.53

As demonstrated by the coefficient of variation, the influent copper and influent zinc concentrations have similar variability and are less variable than the nickel concentrations. The nickel data contains a few very high concentrations that represent potential outliers. Because the nickel outliers may represent dumping incidents that are likely to continue to occur and statistical methods did not justify the removal of the values, the potential outliers were kept in the data set for the analysis.

Next, the influent concentrations were tested for normality by comparing the percentiles of the dataset to the percentiles of a normally distributed dataset with the same mean and standard deviation. The logarithms of the copper and zinc concentrations were determined to be very clearly normally distributed. Nickel concentrations did not fit the normal distribution nearly as well, even using logarithmic transformations and the removal of outliers. The fit was close enough for the lognormal data that the assumption of a normal distribution is not likely to be violated during the statistical analyses. However, tests that do not require a normal distribution were also performed on the nickel data and the copper and zinc data without the logarithmic transformation for comparison purposes. Figures 1 through 3 show the relationship between the data and a normal distribution.

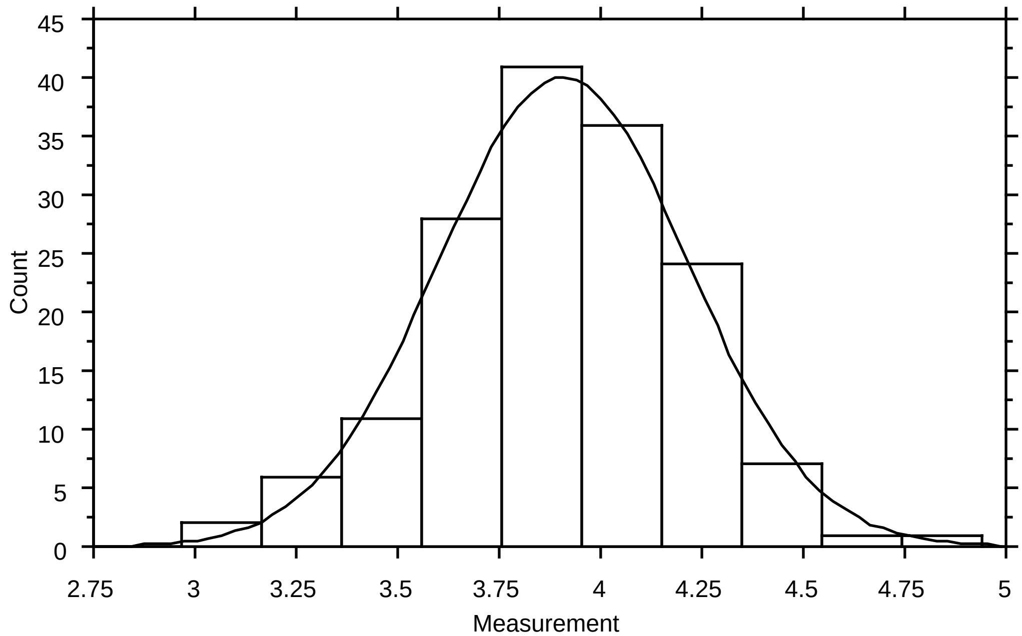

Figure 1. Comparison of Influent Copper Concentrations to Lognormal Distribution

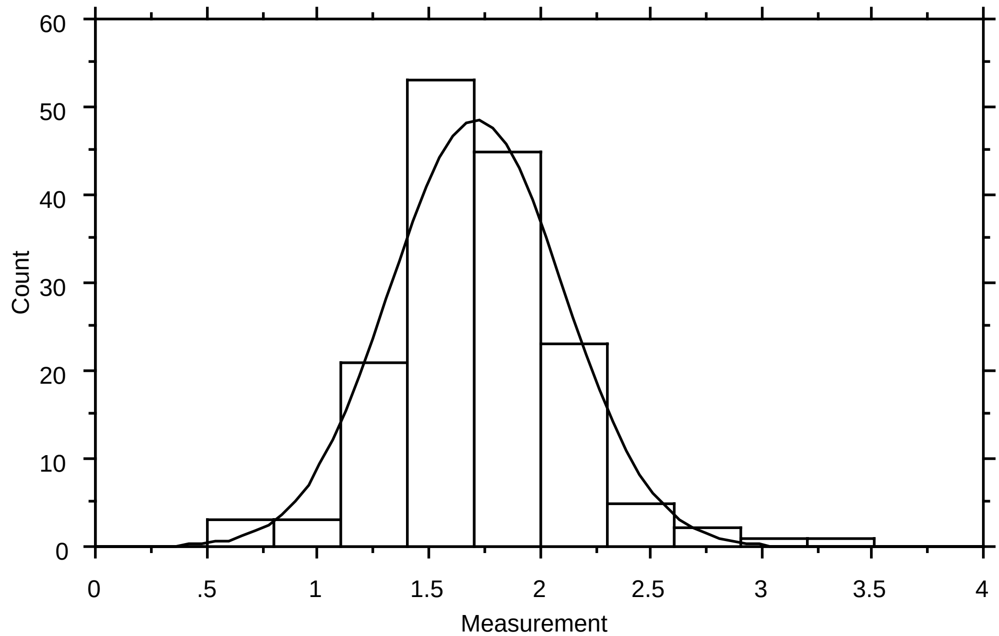

Figure 2. Comparison of Influent Nickel Concentrations to Lognormal Distribution

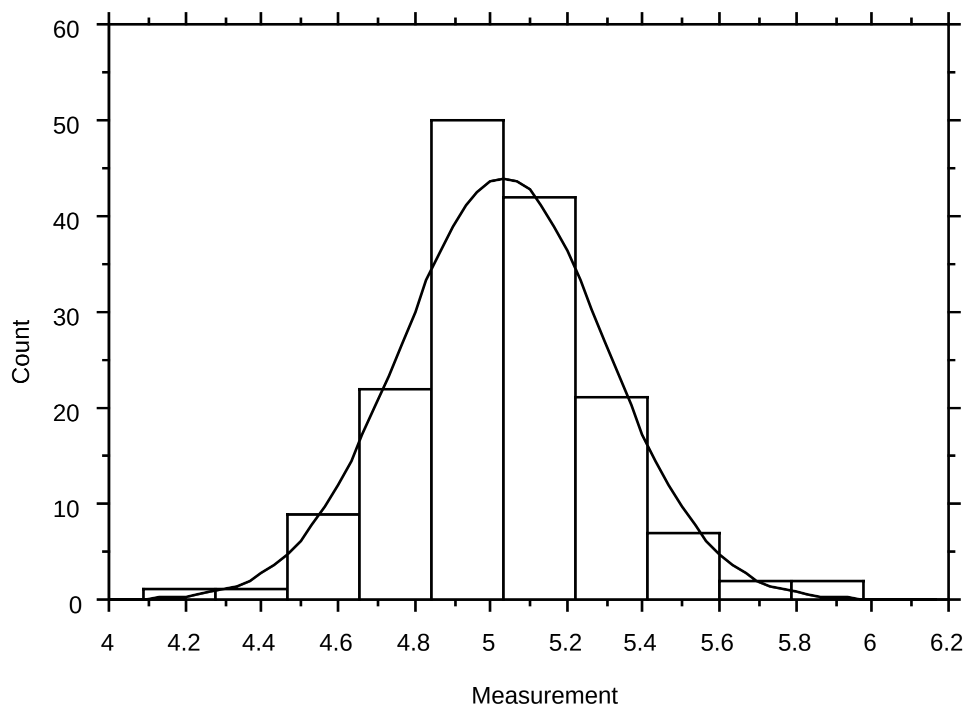

Figure 3. Comparison of Influent Zinc Concentrations to Lognormal Distribution

Time Plots

Time plots graph the change in variables over time. Time plots are a simple way to observe data for possible relationships. Because the influent concentrations of the three constituents were suspected of being related, the data were plotted over time. Figure 4 shows the plotted influent data with nickel plotted on a second y-axis to adjust for the lower nickel concentrations. The figure clearly shows the outlier nickel concentrations. Additionally, copper and zinc influent concentrations appear to be related, with peaks and valleys in concentrations generally occurring at the same time. Nickel does not follow the pattern quite as well and appears to have different patterns than copper and zinc.

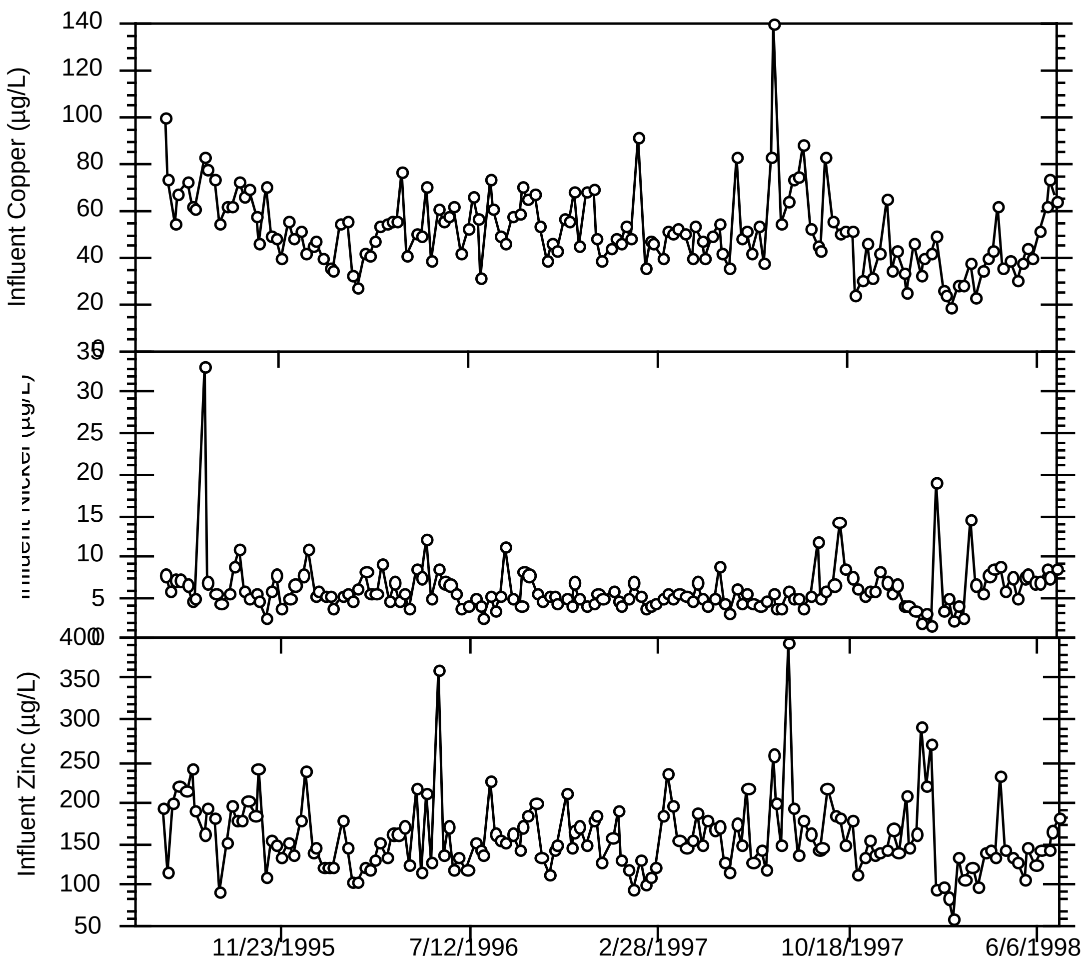

Figure 4. Influent Concentrations of Copper, Nickel, and Zinc Over Time

The time plot graphed in Figure 4 shows that the influent concentrations of the three constituents appear to have remained relatively constant over time. There appears to be a slight decrease in concentrations from the middle of 1995 to the end of 1995, but after that there is no clear increase or decrease in concentrations for any of the constituents.

Influent Concentration Correlations

Because the influent concentrations for the three constituents were expected to be related, but not necessarily predictors of each other, a correlation analysis was conducted. Table 3 shows the correlation matrix for the three influent concentrations (logarithmic data) and influent flow.

Table 3. Influent Concentration Correlation Matrix*

	Influent Copper	Influent Zinc	Influent Nickel	Influent Flow
Influent Copper	1.00			
Influent Zinc	0.5	1.00		
Influent Nickel	0.26	0.11	1.00	
Influent Flow	-0.36	-0.38	0.039	1.00

*Value greater than 0.5 or less than –0.5 is considered significant

Influent zinc and influent copper appear to be correlated, as suspected from the time plots of the data. A regression analysis on the copper and zinc influent concentrations does not indicate that either constituent concentration will predict the other. However, a peak copper concentration will likely correspond to a peak zinc concentration and visa versa.

Influent zinc and copper also appear to be slightly negatively correlated to the influent flow. The calculated correlation coefficient is not very high, but the correlations have a P value of less than 0.0001 that demonstrates a potential significant correlation. The correlation makes sense when the values are considered as concentrations. Assuming a constant mass of copper and zinc in the influent flow, as the flow decreases, the concentration of the two constituents will increase.

Nickel concentrations do not appear to be correlated to influent concentrations of copper or zinc or to influent flows.

Day, Month and Season Relationships

Influent concentrations for copper, nickel and zinc were analyzed to determine if differences in concentrations could be observed depending on the day of the week, month, or season in which the sample was taken. ANOVA analyses were used to assess differences and significant differences were examined in more detail using Fisher's PLSD, Scheffe's S test and other methods. These tests determine which categories (i.e. months or days) are significantly different from each other at a 95 percent confidence level. Box plots were generated for these relationships to demonstrate significant differences. In the plots, days, months or seasons are significantly different from each other at a 95 percent confidence level if the boxes in the plot do not overlap.

Samples of the influent to the RWQCP were collected on Monday, Tuesday, Wednesday, Thursday, or Sunday of each week. No samples were taken on Friday or Saturday, and therefore comparisons could not be made for all days of the week. All ANOVA results for day of the week need to be interpreted in light of the fact that data from only five out of seven days of the week were examined. Additional influences may be present or calculated influences may not be as strong if data were available from Friday and Saturday.

Day of the Week

To determine potential influences, the F and P values from the ANOVA analyses were examined. Table 4 summarizes the results of the ANOVA analyses for day of the week.

Table 4. ANOVA Results for Influent Concentrations vs. Day of the Week*

Constituent	F-Value	P-Value
Influent Copper	1.377	0.2447
Influent Zinc	1.097	0.3601
Influent Nickel	3.03	0.0194

* P-value less than 0.1 is considered significant for further analysis.

The P-values indicate that day of the week may be a significant influence on nickel concentrations, but differences in copper and zinc concentrations based on the day of the week are not significant. Additional analyses were performed on the influent nickel data to determine what days were significantly different.

The additional tests performed varied in how conservatively they interpreted differences between the days of the week. All tests demonstrated a significant difference between influent nickel concentrations observed on Sundays and concentrations observed on Tuesdays. Several other tests showed significant differences between Sunday influent nickel concentrations and concentrations observed on other days of the week (Monday, Wednesday, and Thursday). Therefore, Sunday influent concentrations of nickel appear to be significantly lower than concentrations observed on Monday, Tuesday, Wednesday and Thursday.

The following figures show the box plots for the three constituents. A box plot is a graph for displaying the 10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th} percentiles of a variable. Box plots are useful for comparing variable distributions, or showing the distribution of a single variable. Each box plot is composed of five horizontal lines that display the 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles of a variable. All values for a variable above the 90^{th} percentile and below the 10^{th} percentile are plotted separately, so box plots are useful for displaying outliers. Potentially significant differences between the variables are observed when the boxes in the plot do not overlap.

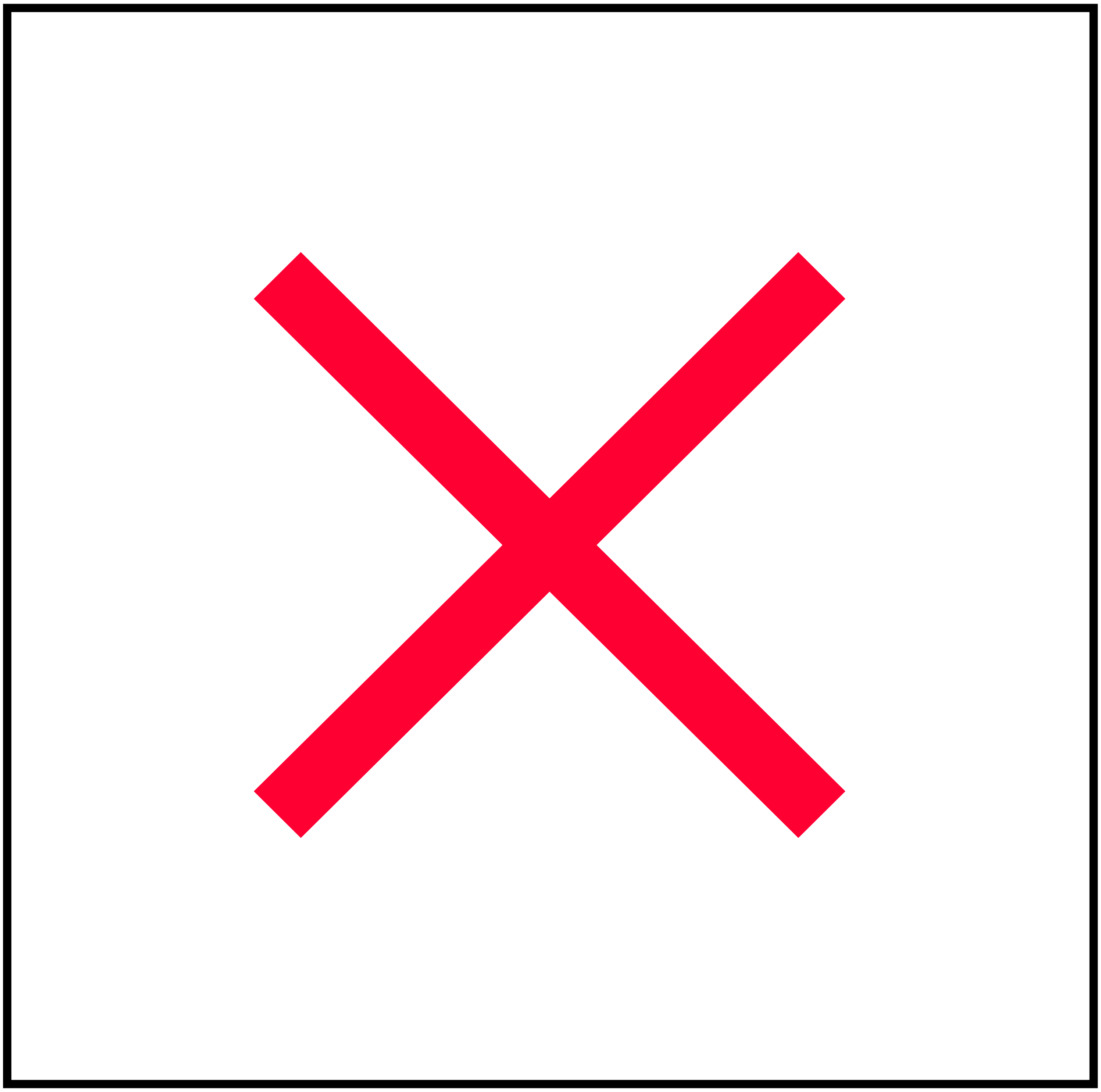

Figure 5. Box Plots of Influent Concentrations (Log) vs. Day of the Week

Weekday vs. Weekend

To test if differences could be observed between weekday and weekend concentrations, sample results collected on Monday, Tuesday, Wednesday, and Thursday (weekday) were grouped together and compared against sample results collected on Sunday (weekend). The results confirmed that weekend influent nickel concentrations were significantly lower than weekday concentrations. There was no significant difference observed in the copper and zinc concentrations between the weekdays and the weekend.

The results of this test may be altered if data from Friday and Saturday were included in the data set and the results should be interpreted with caution.

Month

The month in which the sample was collected appears to have a significant impact on all three constituents. Table 5 lists the F and P values determined from the ANOVA for each constituent.

Table 5. ANOVA Results of Influent Concentrations vs. Month*

Constituent	F-Value	P-Value
Influent Copper	5.281	<0.0001
Influent Zinc	3.927	<0.0001
Influent Nickel	1.872	0.0476

* P-value less than 0.1 is considered significant for further analysis.

Because the P-value for all three constituents was less than 0.05, additional tests were conducted for copper, nickel, and zinc to determine which months were significantly different than other months. The following box plots show the results of these analyses.

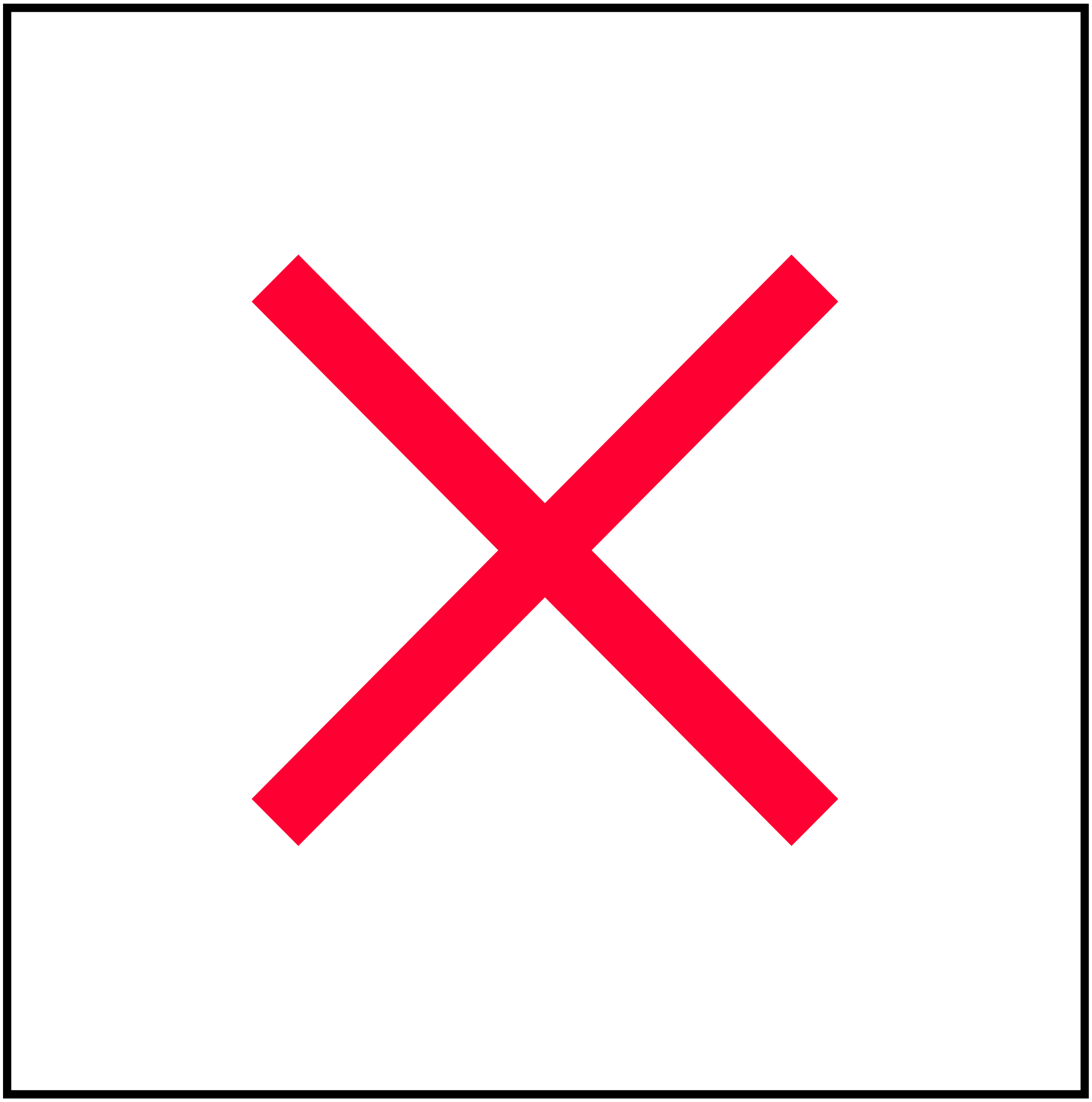

Figure 6. Box Plots of Influent Concentrations (Log) vs. Month

From these plots, January and February concentrations of nickel appear to be significantly lower than most other months. February concentrations of zinc are also lower than most other months of the year. Copper appears more seasonal, with July, August, and September being significantly higher than the other months of the year. During July, August, and September, almost all of the water used in the service area comes from the Hetch-Hetchy reservoir and has a lower pH than water received during other times of the year. The lower pH water may be a factor in the higher copper concentrations observed during these summer months.

Season

The monthly relationships become much clearer if the months are grouped into seasons. Winter includes December, January, and February. Spring is designated as March, April, and May. June, July and August make up the summer and autumn includes September, October, and November. The following table summarizes the significant seasonal differences observed for copper, nickel and zinc.

Table 6. Significant Different Seasonal Influent Concentrations

	Copper	Nickel	Zinc
Winter	Summer, Autumn	Spring, Autumn	Summer, Autumn
Spring	Summer, Autumn	Winter	Summer
Summer	Winter, Spring, Autumn	None	Winter, Spring
Autumn	Winter, Summer, Spring	Winter	Winter

Winter concentrations of all three constituents appear to be consistently lower than the corresponding autumn concentrations. For copper and zinc, summer concentrations are significantly higher than the corresponding winter and spring concentrations.

Rainfall and Antecedent Conditions

Because of stormwater infiltration into the sewer lines and potential “rainy day” activities that may occur in households and businesses, rainfall records from 1995-1997 were compared to influent concentrations to assess any influence the weather may have on concentrations. Several factors (antecedent conditions) can be examined related to rainfall data. Comparisons can be made to daily rainfall totals, weekly rainfall, time between storms, and cumulative rainfall to date. A time plot was generated with rainfall included to assess any obvious correlations between rainfall and influent concentrations and determine which antecedent conditions to compare. Figure 7 shows the time plot and demonstrates that no obvious correlations are present in the data as compared to influent concentrations. As a result, all of the listed antecedent conditions were examined for correlations.

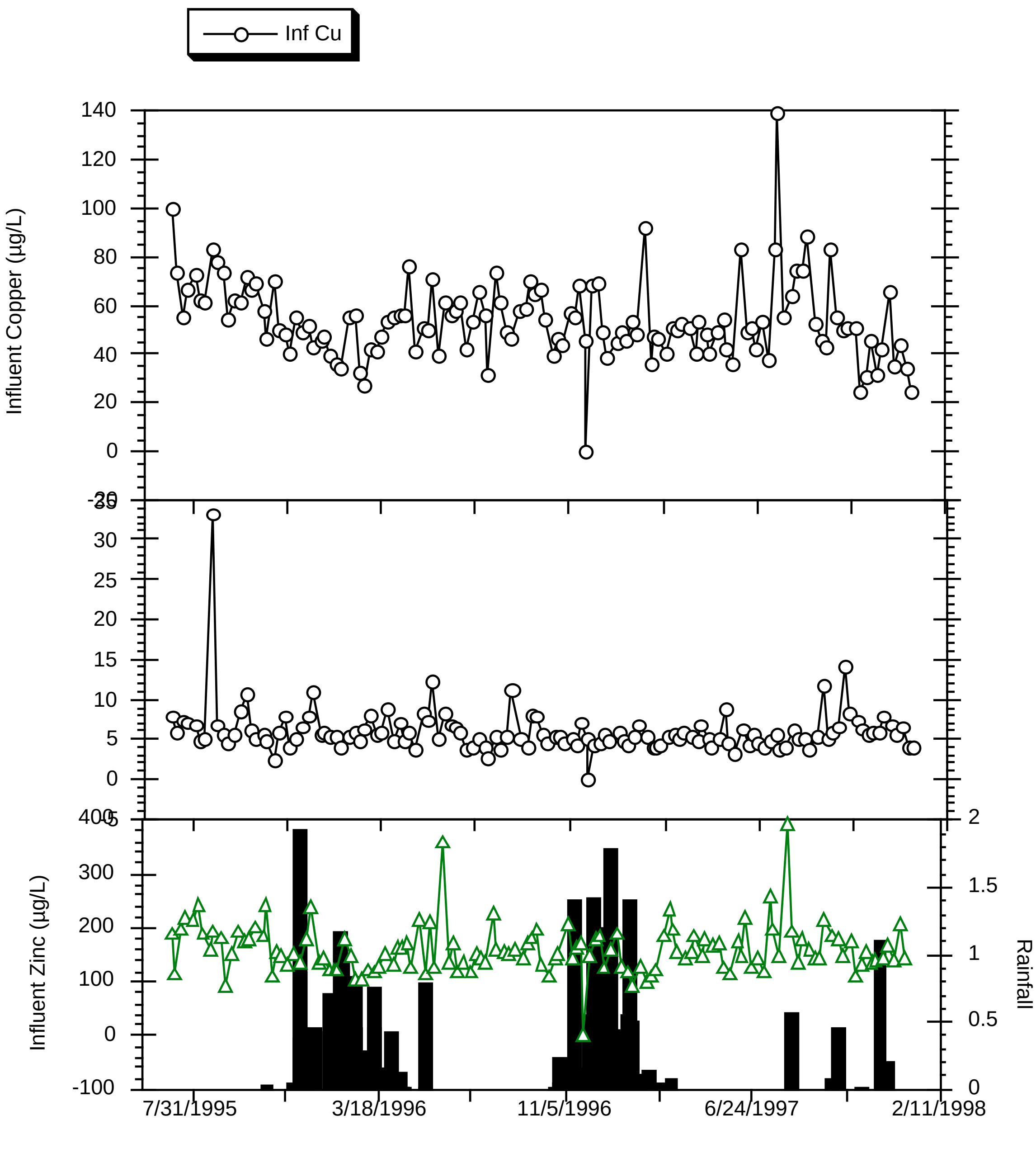

Figure 7. Influent Concentrations vs. Rainfall Over Time

Rain on day

Rainfall amounts occurring during the 24-hour period in which a sample was collected were compared to influent concentrations of copper, nickel, and zinc using a correlation matrix. No significant correlations were found between the amount of rain and the influent concentrations of any of the constituents.

A second analysis was conducted to compare days on which rain occurred with days with no rain, rather than comparing actual rainfall amounts. The results were similar and did not show any significant differences in concentrations for days with rain versus days without rain.

Rain during week

Because the 24 hour values often did not describe the rainfall conditions occurring during the week before the samples were collected that might influence concentrations, weekly rainfall totals for the week preceding the sample collection dates were compared to influent concentrations. Additionally, weeks with rain were compared to weeks without rain. Again, no significant correlations were found between weekly rainfall totals and influent concentrations for all three constituents. Weeks with rain did not have significantly different concentrations than weeks without rain.

Cumulative Rainfall and Days Since Last Rain

If stormwater concentrations are considered to be a significant source of these constituents in influent flows to the RWQCP, cumulative rainfall totals and days since the last rain should have some correlation to the influent concentrations. Build-up and wash-off of pollutants in stormwater is strongly correlated to the number of days between storms and the amount of rainfall that has occurred previous to the sampling event. For this reason, both the cumulative rainfall to date and the days since the last rainfall were compared to influent concentrations.

No significant correlation was found to the cumulative rainfall to date or to the days since last rain for any of the three constituents.

Groundwater Infiltration

Rainfall also has an impact on the amount of groundwater that infiltrates into the pipes carrying wastewater to the treatment plant. During the wet season, rainfall saturates the ground and raises the level of the groundwater table. As more rain enters the groundwater, the water rises until it comes in contact with the pipes carrying wastewater to the RWQCP. Measurements of the groundwater table levels were not available for comparison to influent copper, nickel, and zinc concentrations. However, the amount of rainfall received compared to the influent flow to the RWQCP can be used to estimate the periods of time in which groundwater infiltration is a component of the flow to the RWQCP.

Higher influent flows were generally observed after between 5 and 10 inches of rain had fallen in the service area. Two ANOVA analyses were conducted using this information. Data gathered during the dry season in which the lowest influent flows were observed was compared to data collected after 5 inches of rain had fallen and to data collected after 10 inches of rain had fallen. The following table summarizes the ANOVA results found.

Table 7. ANOVA Results for Groundwater Infiltration

	5 Inches Cumulative Rainfall		10 Inches Cumulative Rainfall	
Constituent	**F-Value**	**P-Value**	**F-Value**	**P-Value**
Influent Copper	18.77	<0.0001	12.18	0.0008
Influent Nickel	0.063	0.8029	0.001	0.9711
Influent Zinc	10.93	0.0014	8.068	0.0057

* P-value less than 0.1 is considered significant for further analysis.

This analysis shows that influent copper and zinc are significantly different in samples collected after 5 and 10 inches of rainfall than those collected during the dry season. This indicates that groundwater infiltration may have an impact on the influent concentrations of these two constituents to the RWQCP. Based on this analysis, influent nickel does not appear to be influenced by groundwater infiltration.

From these calculations and the time plot of the data, it does not appear that rainfall or other antecedent conditions directly have a significant influence on influent concentrations of copper, nickel, and zinc to the RWQCP. Groundwater infiltration into the wastewater pipes resulting from rainfall raising the level of the groundwater table appears to have an impact on influent copper and zinc concentrations.

Water Supply

Limited information was available on the characteristics of the water supply for the RWQCP's service area. The San Francisco Water District (SFWD) supplies water to the Palo Alto area, but they obtain the water from different sources during different times of the year. Samples of the distribution water have been taken on an irregular, but approximately monthly basis, for pH, alkalinity, chlorine residual, temperature, hardness, turbidity, and conductivity. In addition, Palo Alto collects monthly information on tap water from 20 businesses and residences in the area.

Because both sets of water supply information are based on a maximum of one sample per month, assumptions had to be made about the data. The water supply and tap water values were considered to represent a monthly average value for the water supply. Values from the 20 tap water samples were combined to obtain an average tap water value for the month. The weekly influent concentrations were combined to obtain monthly averages for comparison purposes. Correlations to tap water and water supply concentrations are discussed in the next section.

Tap Water

Average monthly influent concentrations of copper, nickel, and zinc were compared to average monthly tap pH, conductivity, and turbidity. Tap alkalinity and hardness concentrations were not available. The following table shows the correlation matrix for tap water and influent constituent concentrations.

Table 8. Influent Concentrations vs. Tap Water Data

	Tap pH	Tap Conductivity	Tap Turbidity
Influent Copper	-0.63	-0.22	-0.070
Influent Zinc	-0.29	-0.37	-0.040
Influent Nickel	-0.013	-0.25	0.062

*Value greater than 0.5 or less than –0.5 is considered significant

Influent copper concentrations show a significant negative correlation to tap water pH. As pH increases, copper concentrations in influent to the RWQCP are likely to decrease. Because one source of copper entering the RWQCP is corrosion of pipes, the higher the pH, the lower the corrosivity of the water and the less likely copper is to be corroded from the pipes into the waste water entering the RWQCP.

Zinc shows a slight negative correlation to tap water conductivity. Because the correlation is greater than –0.5, the significance of the correlation is questionable. Additional nonparametric tests resulted in P-Values greater than those required for significance. As a result, tap water conductivity may play a role in influent zinc concentrations, but the statistical results do not indicate a significant influence.

Average influent nickel concentrations were not significantly correlated to any of the tap water characteristics.

SFWD Water Supply

Average influent concentrations for the three constituents were compared to the water supply pH, alkalinity, hardness, conductivity, and turbidity to determine if any significant correlations could be found. Table 9 lists the correlation coefficients for the comparison.

Table 9. Influent Concentrations vs. Water Supply Information

	Water Supply pH	Water Supply Alkalinity	Water Supply Hardness	Water Supply Conductivity	Water Supply Turbidity
Influent Copper	-0.49	-0.38	-0.46	-0.35	0.20
Influent Zinc	-0.36	-0.19	-0.26	-0.15	0.16
Influent Nickel	-0.16	-0.32	-0.37	-0.33	0.19

*Value greater than 0.5 or less than –0.5 is considered significant

Because water supply samples were not taken every month, a limited number of data points were available for use in the correlation analysis. As a result, higher correlation coefficients are needed to suggest a potential relationship between the variables. None of the correlation coefficients meet the criteria for significance described in the Methods section. Upon investigating further, influent copper and water supply pH and hardness show a potentially significant correlation. The remaining constituents show no significant correlations to any of the water supply characteristics.

Effluent Concentrations

Effluent concentrations of the three constituents were compared to each other; to influent concentrations; to day of the week, month and season; and to internal plant operations to assess potential influences on the effluent concentrations.

Description of Effluent Data

Descriptive statistics, time plots, and tests for normality were also conducted for the effluent concentrations to provide a general description of the data. Table 10 lists the mean, median, standard deviation, and coefficient of variation for the effluent concentrations of the three constituents.

Table 10. Summary Statistics for Effluent Copper, Nickel, and Zinc

	Effluent Copper	Effluent Zinc	Effluent Nickel
Mean (µg/L)	5.9	53.3	3.5
Median (µg/L)	6	50	3.3
Standard Deviation	1.3	12.3	0.94
Coefficient of Variation	0.22	0.23	0.27

The three constituents all appear to have approximately the same amount of variability in the effluent concentrations.

Comparisons of effluent concentrations to normal and lognormal distributions demonstrated that effluent nickel fit the lognormal distribution quite well. However, effluent copper and zinc concentrations were not normally or lognormally distributed. Because of the large deviation from normal distributions for copper and zinc effluent concentrations, methods that are robust to the distribution of the data were used for effluent concentration comparisons.

Figure 8 shows a plot of effluent concentrations over time from 1995 through 1998. From approximately the middle of 1996 through the middle of 1997, concentrations of all constituents (but primarily copper) appear to be very consistent as compared to other years of the data. Concentrations in 1995 appear to be higher than in later years, though concentrations appear to have increased to similar levels near the end of 1997. Overall, effluent concentrations appear to have remained relatively constant since the end of 1995.

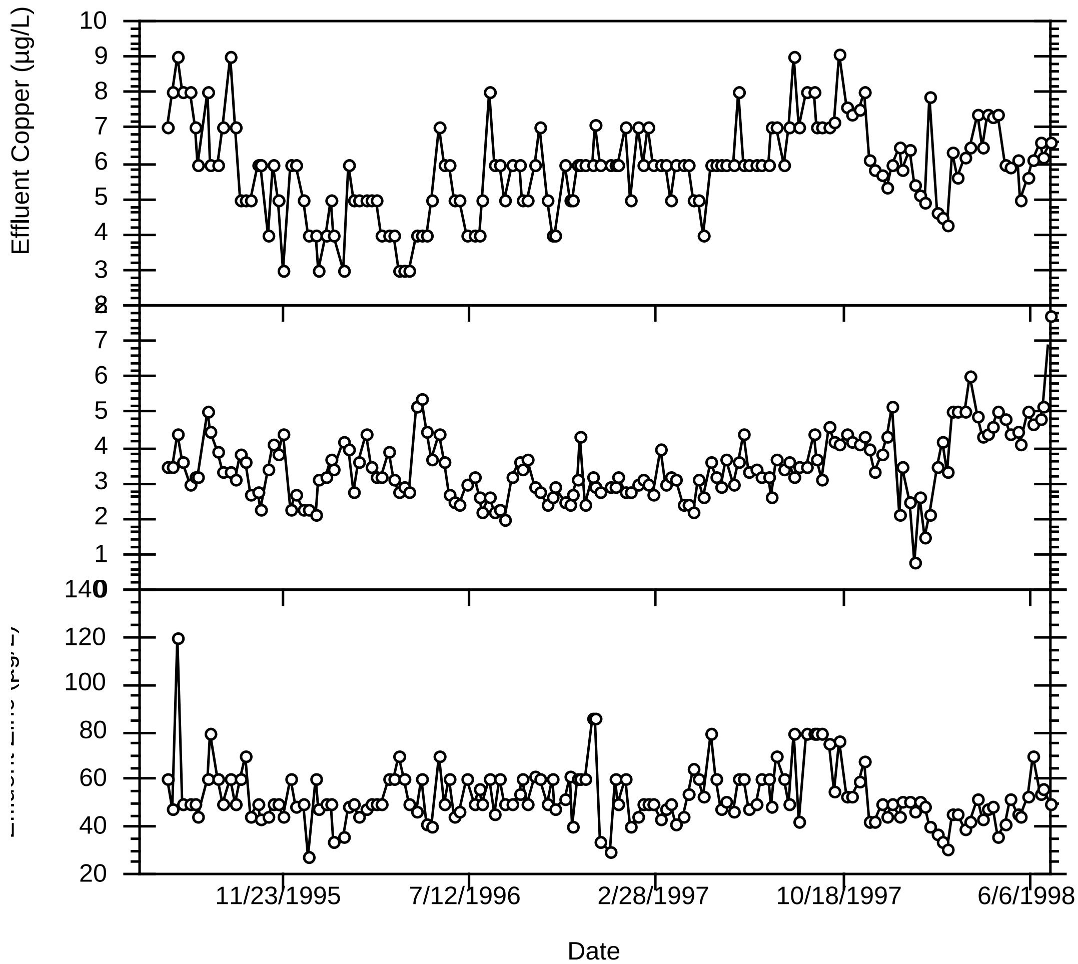

Figure 8. Effluent Concentrations Over Time

Relationship Between Constituents

Effluent concentrations were compared to each other, to influent concentrations and to influent flow using the Spearman Rank Correlation Coefficient. Table 11 shows the Spearman correlation coefficients for the various constituents.

Table 11. Effluent Concentration Comparisons

	Effluent Copper	Effluent Nickel	Effluent Zinc
Effluent Copper	1		
Effluent Nickel	0.26	1	
Effluent Zinc	0.26	0.026	1
Influent Copper	0.21	-0.079	0.35
Influent Nickel	0.20	0.40	0.063
Influent Zinc	0.15	-0.14	0.26
Influent Flow	-0.086	0.13	-0.34

*Value greater than 0.5 or less than –0.5 is considered significant

Effluent concentrations do not show any significant correlations to each other, influent concentrations of the various constituents or influent flow. Effluent and influent nickel have a P value for the correlation that indicates a potentially significant correlation, even though the correlation coefficient does not meet the established criteria for significance. Effluent concentrations of the constituents were compared directly to influent concentrations taken on the same day, without taking residence time in the plant into account. As a result, a stronger correlation may exist between influent and effluent concentrations if data were available to take residence time in the plant into account.

Plant Operations

The RWQCP conducts a wide variety of regular and irregularly scheduled activities that have the potential to impact concentrations of copper, nickel, and zinc in the Plant's effluent. Unfortunately, records for many of the activities were not readily available. As a result, effluent concentrations were compared to the concentration of mixed liquor suspended solids (MLSS) and temperature of the treatment chambers. The Spearman Rank Correlation coefficients were calculated to compare the plant operations to effluent concentrations. The following table summarizes the results.

Table 12. Effluent Concentrations vs. MLSS and Temperature

Constituent	MLSS	Temperature
Effluent Copper	-0.206	0.324
Effluent Nickel	-0.053	-0.022
Effluent Zinc	-0.194	0.369
MLSS		-0.798

*Value greater than 0.5 or less than –0.5 is considered significant

Effluent copper and zinc show slight correlations to the temperature of the treatment chamber, but not enough to be considered significant. MLSS and temperature are highly negatively correlated. Nickel does not show any correlations to the plant operations analyzed.

Day of the Week Comparisons

Effluent copper and effluent nickel concentrations do not vary significantly by day of the week. Effluent zinc concentrations, on the other hand, appear to be lower on Sundays as compared to the rest of the week. Table 13 shows the results of the ANOVA comparisons and Figure 9 shows the box plots for the effluent concentrations for the days of the week.

Table 13. ANOVA Results for Effluent Concentrations vs. Day of the Week*

Constituent	F-Value	P-Value
Effluent Copper	0.95	0.4371
Effluent Zinc	3.425	0.0103
Effluent Nickel	1.4	0.2366

* P-value less than 0.1 is considered significant for further analysis.

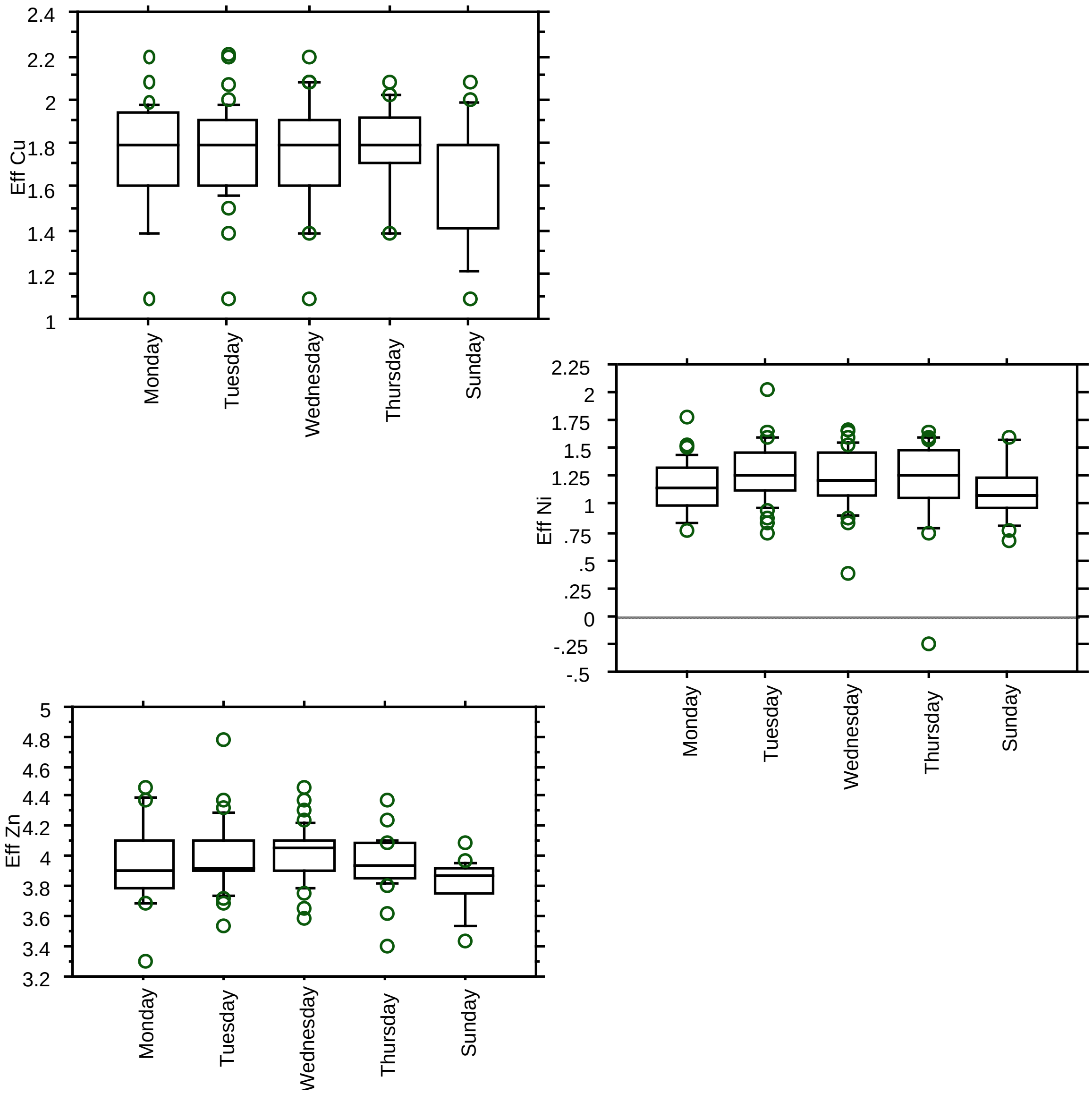

Figure 9. Box Plots of Effluent Concentrations (Log) vs. Day of the Week

Month and Season Comparisons

Effluent concentrations during each month were compared to effluent concentrations for the other months of the year for each of the three constituents. The following figure shows the months that showed significant differences from each other.

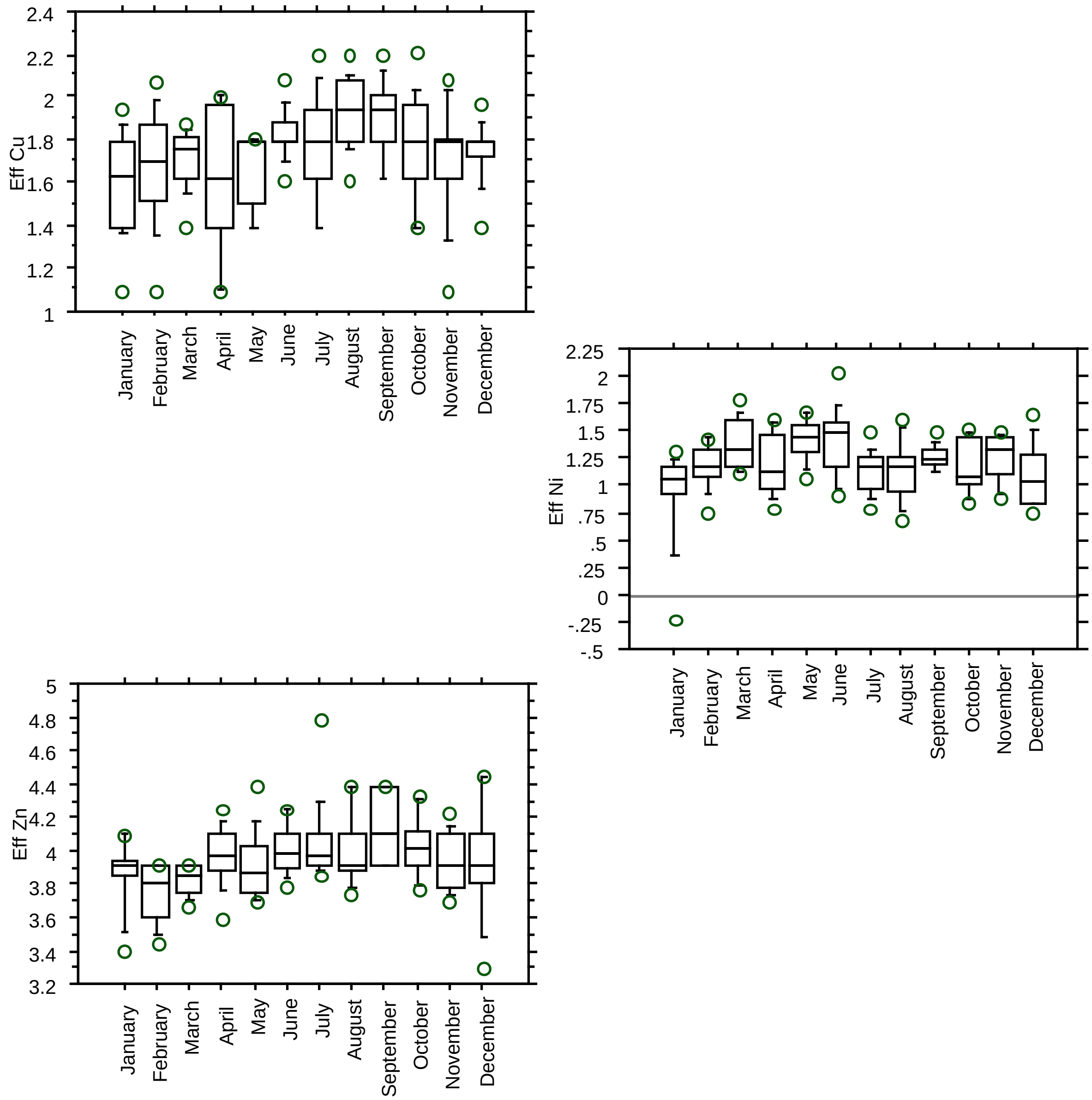

Figure 10. Box Plots of Effluent Concentrations (Log) vs. Month

January effluent nickel concentrations and January, February and March zinc concentrations appear to be significantly lower than most other months of the year. Copper concentrations appear to be more seasonal, with the summer and autumn months having significantly higher concentrations than the winter and spring months. Although the monthly comparisons differ somewhat, the influent and effluent concentrations have the same trends in significantly different monthly concentrations.

Seasonal comparisons for the effluent concentrations were also made. Table 14 lists the seasons that show significantly different concentrations.

Table 14. Seasonal Comparisons of Effluent Concentrations

	Copper	Nickel	Zinc
Winter	Summer, Autumn	Spring, Summer, Autumn	Summer, Autumn
Spring	Summer, Autumn	Winter	Summer, Autumn
Summer	Winter, Spring	Winter	Winter, Spring
Autumn	Winter, Spring	Winter	Winter, Spring

All three constituents appear to have higher concentrations in the summer and autumn than in the winter. Summer and autumn concentrations for copper and zinc are also higher than the spring concentrations. For nickel, winter concentrations are lower than all other seasons during the year.

Conclusions

- Copper and zinc concentrations in the influent and effluent seem to be more closely correlated to each other and other factors, while nickel often has very different patterns and correlations.
- Influent nickel has statistically lower concentrations on Sunday than throughout the rest of the week.
- Effluent zinc has statistically lower concentrations on Sunday than the rest of the week.
- Influent and effluent concentrations of copper, nickel, and zinc appear to have statistically different concentrations during some months and seasons of the year.
- Water supply and tap water pH, alkalinity, and hardness appear to influence the influent concentrations of copper to the plant.
- Rainfall and other antecedent conditions do not seem to have any correlation to influent concentrations.
- Effluent concentrations of the three constituents do not appear to be significantly correlated to each other or the plant operations examined.

Overall, the season, month, and day of the year appear to have the most influence on the concentrations of the three constituents entering and leaving the plant. Water supply characteristics play a role for some of the constituents, but other factors do not appear to significantly influence influent or effluent concentrations. However, additional statistical analysis that takes into account the influences the various factors have on each other could reveal some other influences on influent and effluent concentrations of copper, nickel and zinc to the RWQCP.