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BOD5 AND COD DATA ANALYSIS FROM THE NORTHWEST AND ROBERT R. BUSTAMANTE WASTEWATER TREATMENT PLANTS, USING DESCRIPTIVE STATISTICS AND BASIC STATISTICAL PROCESS CONTROL

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By

Juan Carlos Adame Meléndez

2012

DEDICATION

I dedicate this thesis project to my beloved wife Rosa, my sons David & Alan.

Also to my dear parents Oscar and Sara as well.

S.D.G.

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By

JUAN CARLOS ADAME MELÉNDEZ, B.S. PHYSICS

THESIS

Presented to the Faculty of the Graduate School of

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of the Requirements

for the Degree of

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ABSTRACT

The objectives of this thesis are to explore the use of basic Statistical Process Control in a Wastewater Treatment Plant with secondary treatment. Additionally, to describe statistical behavior and review normality of some reportable parameters, also to analyze mainly parameters like BOD5 (Biological Oxygen Demand), Electrical Conductivity, and COD (Chemical Oxygen Demand) with seasons of the year and days of the week, using data from the Northwest (NW) and Robert R. Bustamante (RRB) Wastewater Treatment Plants from El Paso Texas.

The scope of this analysis is to understand how Statistical Process Control can help to predict peak and valleys of certain parameters, patterns of behavior, and find if the wastewater treatment show linear relationships to improve performance by anticipating adverse behaviors.

The methodologies used in this thesis are Non-experimental, longitudinal (trend), quantitative in nature. There are few statistical models used for Statistical Process Control and descriptive Statistics. That includes tools like Correlation Matrices, scatter plots, trend line insertion, review of the $R^{2,}$ time series graphs, and few tests using Capability Studies on a parameter to check capability index.

El Paso Water Utilities collected all the samples of wastewater and treated water, analyzed them using the methodologies, instrumentation, and other technical requirements as per the TPDES and EPA Agencies. EPWU collected water in regular intervals for twenty-four hours, creating a time-weighted average is part of their process. Both automated samplers and personnel from WWTP were involved in the sampling process. Performance of the Statistical Analysis involved SPSS® 19 (IBM SPSS® Statistics software) and Minitab 16, while Microsoft Excel became mainly a storage for database.

El Paso Water Utilities (EPWU) provided processed data used in this analysis. The period covered by the data was from January 1 2008 to December 31 2011 of parameters such as flows (incoming and outgoing) from the wastewater plants, including BOD5 and COD among others.

Outliers are included in the statistical analysis due to ethical reasons. There were no logbooks or records explaining the occurrence of special cases. This measure affected the Capability tests for most of the parameters since outliers were outside the upper limit. Based on the four rules applicable to control charts most of the process is statistically not controlled, thusly no C_{pk} assessment applies to them. A C_{pk} study using segments of timeline with varying results is part of the results.

The conclusions are that Statistical Process Control is applicable to the control of WWTP secondary treatment in the basic level. Furthermore, despite the process is continuous, mostly non-linear and dynamic, Statistics applied to Process Control described the process signaling the "out of control" alerts. All the variables tested are Statistically Normal fulfilling the basic requirements using Shapiro-Wilk as the Normality Test, except RRBInBOD5, and NWeffTHard.

The parameters reviewed are BOD5, COD, Electrical Conductivity, Total Suspended Solids, Total Phosphorus, TKN, NO_{2}, and NO_3. There are few points for the NO_2 parameter. In addition, of all the explored linear correlations done in this study, there were few significant correlations found.

An analysis of Descriptive Statistics yielded interesting behavior patterns. Electrical Conductivity behavior patterns from RRB showed cyclic peaks during the fall of each year, EPWU WWTPs are non-linear systems, household wastewater and industrial wastewater are two different universes detected in the analysis, COD and BOD5 peak on several days of the week for each Wastewater Treatment Plant are instances discussed in this thesis.

The limitations are that lack of available time prevented from testing more Statistical Process Control tools to assess limitations of the Statistical Process Control. In addition to that, the temperatures used from NOAA were maximum and minimum both extreme temperatures. This is a limitation since the average does not represent the temperature that prevailed during the day. Applicability of results is for all parameters that met the normality requirement. Finally, analysis of the raw data collected by EPWU on a daily basis was not available at the time of writing up this thesis. The use of time-weighted averages on most of the parameters resulted in

the loss of details that might have provided additional behavior patterns on the load arrival to the Wastewater Treatment Plant.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND INFORMATION

The El Paso-Juarez region shares common environmental problems due to geographical closeness. Problems such as air quality and water availability are major concerns to both sides of the border. The Aquifer "Hueco" Bolson lies on both sides of the border with a global population of around two million persons and private industrial facilities that use water in their processes. This special situation requires planning and allocation of financial resources to keep both cities running.

The City of El Paso Texas is concerned with supplying and conserving water for the use of its residents and private industry. The El Paso Water Utilities (EPWU) is an organization guided of the Public Service Board, composed by seven members. The Public Service Board was established in 1952 to develop a system that manages, treats and operates drinking water and wastewater from domestic and Industrial use .

Since then, the Public Service Board has developed a network of surface water and Wastewater Treatment Plants, among them, the Northwest (NW), and Robert Bustamante Wastewater (RRB) treatment plants. Both Wastewater Treatment Plants can be located in Figure A. The NW and RRB facilities have undergone expansions to meet the growing demand of water for daily use. In addition to that, as part of the growing challenges to comply with the law, EPWU motivated to meet compliance and requirements from Federal and State laws, has invested financially. Training to technical personnel and state of the art technology are other forms of assets to achieve those goals. In this thesis, we will focus on the performance of the Northwest and Robert R. Bustamante WWTPs from the Process Control point of view.

The Northwest (NW WWTP), shown in Figure Q[1], has the capability of treating 17.5 million gallons per day (MGD) of wastewater from residential and industrial sources. The sectors served by the Northwest WWTP are located in the west and northwest parts of the city. This plant treats water with an extended aeration activated sludge treatment plant (secondary treatment).

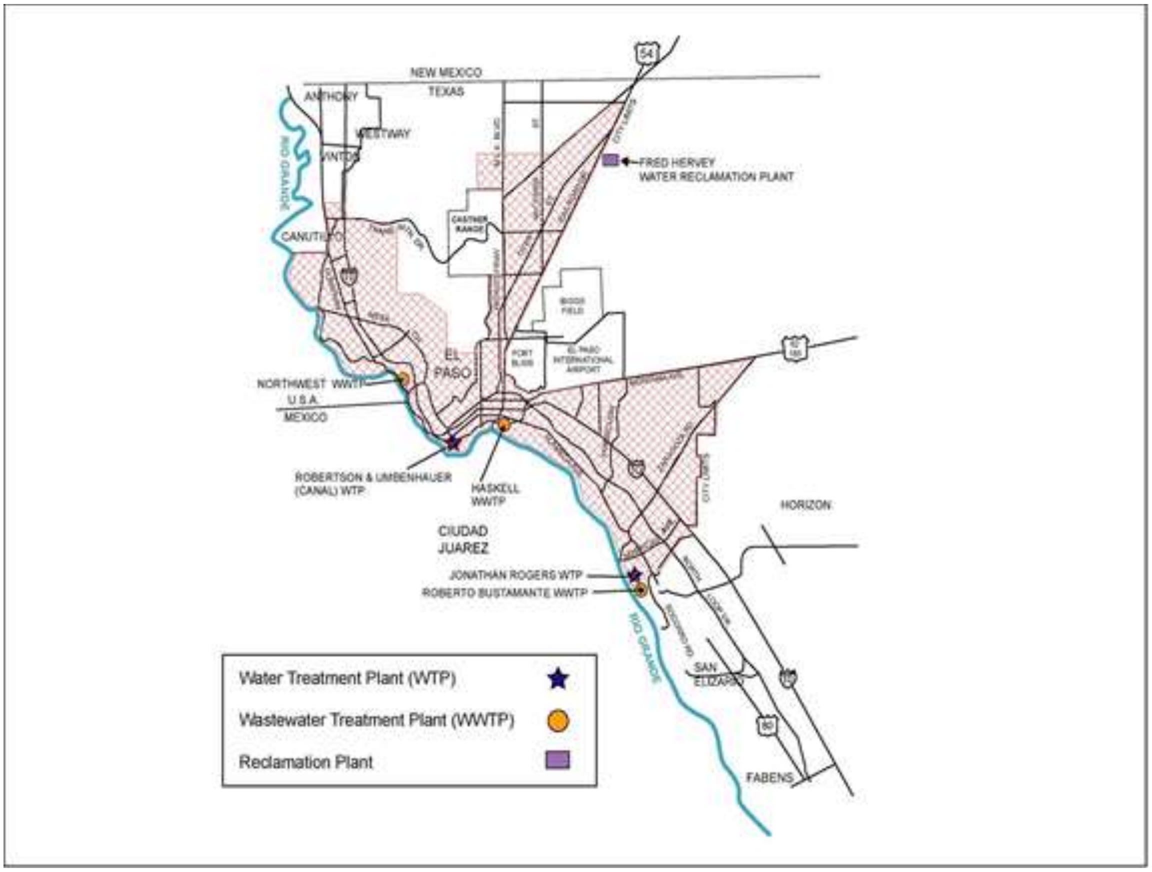

Figure A. Map showing location of all water treatment plants from El Paso Water Utilities.

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[1] Please got to Appendix Section Exhibit A

The Northwest Wastewater Treatment Plant has won numerous awards[2], such as 1st Place National USEPA Operations and Maintenance Excellence Award for Large Advanced Plant in 2008. In addition to that, the NW WWTP has received a total of 5 National Association of Clean Water Agencies (NACWA) Peak Performance Platinum Awards, 11 NACWA Gold Awards, and 6 NACWA Silver Awards. The Water Environment Federation's has awarded the prestigious award George W. Burke Award for Safety to the Northwest WWTP.

The Robert R. Bustamante Wastewater Treatment Plant (RRB WWTP), operations shown in Figure R[2], serves the sectors of the east and southeast of El Paso Texas and Lower Valley, and has a treatment capacity of 39 Million Gallons per Day (MGD). This Wastewater Treatment Plant is a secondary treatment plant with state-of-the-art extended aeration activated sludge processes.

In this case, the Robert R. Bustamante (RRB) plant, according to Mr. William Quinn, discharges to either the Riverside Canal or the Riverside Drain. The use for the treated water from RRB to the Riverside Canal is for irrigation, while water discharged to the Riverside Drain goes to the "Rio Bosque Wetlands Preserve." The ripean species of the area benefit from the treated water.

The Robert R. Bustamante WWTP has also received numerous awards in recognition to its performance. The EPWU website mentions[3] the awards it has received are number 1 National Association of Clean Water Agencies (NACWA) Peak Performance Platinum Award, 17 NACWA Gold Awards, and 2 NACWA Silver Awards. In 1994, the plant was second place in the nation in the USEPA Operations and Maintenance Excellence Awards. The Water

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[2] Please got to Appendix Section Exhibit B

Environment Association of Texas also judged this plant as the Municipal Wastewater Treatment Plant of the Year for 2005.

The objective of this thesis is to explore the applicability of basic Statistical Process Control methods in the process of wastewater plant with secondary treatment, analyze statistical behavior of some parameters, and point out significant statistical relationships.

1.1.1 REGULATORY ASPECT

The Clean Water Act (CWA)[4] is the most important Law in the United States of America, pertaining surface water pollution regulation. It establishes the limits of toxic substances discharged into rivers, open channels, and canals, ensuring that its waters would meet standards necessary for human recreation and sports, and guarantees survival of indigenous water life exposed to that water as well.

The Clean Water Act does not address groundwater contamination. Groundwater protection provisions are included in the Safe Drinking Water Act, Resource Conservation and Recovery Act, and the Superfund act.

1.1.1.1 REGULATED SOURCES

The Clean Water Act of 1972 created the National Pollutant Discharge Elimination System (NPDES), which is a system for regulating non-moving generators of pollution, called "point sources" of pollution. The above-named sources include industrial facilities (such as manufacturing, oil and gas extraction, and service industries), government facilities (such as municipal and military bases), and some agricultural facilities (such as milk processing plants and animal feedlots).

Point sources, such as the ones previously mentioned, may not discharge polluted water to surface waters without a permit from the National Pollutant Discharge Elimination System

(NPDES)[5]. This system is under the supervision and management by the United States Environmental Protection Agency (USEPA) in association with State Environmental agencies. EPA has authorized 46 states to issue permits directly to the discharging facilities. In our case, the Texas Commission on Environmental Quality (TCEQ) has authorization from EPA to issue discharge permits for regulated point sources located within Texas territory.

Texas, under the provisions of the NPDES system, and authorized by EPA, has the legal responsibility to issue discharge permits since September 14, 1998. The permits issued by TCEQ are administering though a program called Texas Pollutant Discharge Elimination System (TPDES) [6] to regulate over discharges of pollutants to Texas surface waters.

Both wastewater plants under consideration, namely the Northwest and Robert R. Bustamante, must comply with the NPDES permits criteria, through the TCEQ program. The Northwest Wastewater Treatment Plant has TPDES permit number WQ0010408009, while the TPDES permit number WQ0010408010 is for the Robert R. Bustamante.

1.1.1.2 EFFLUENT CHARACTERISTICS FOR BOTH WASTE WATER TREATMENT PLANTS

The TPDES permit Number WQ0010408009 for the Northwest[2] WWTP and the WQ0010408010 for the Robert R. Bustamante[7], define specific values for the BOD5, Total Suspended Solids, Ammonia Nitrogen and E. Coli discharge limits as shown in Table 1. Testing of all other parameters, such as COD, Nitrates, and Nitrites concentrations based upon the bio-monitoring provisions in the permit. This is by exposing indigenous species to different concentrations of pollutants of the effluent to demonstrate survival and tolerance of species to a given level of exposure to a pollutant.

Table 1 Effluent characteristics required for both Wastewater Treatment Plants. Effluent limits drawn from the TPDES permits.

Effluent Characteristics	Discharge Limitations					
	7-day Average mg/L		Daily Average mg/L		Daily maximum mg/L	
	Northwest WWTP	Robert R. Bustamante	Northwest WWTP	Robert R. Bustamante	Northwest WWTP	Robert R. Bustamante
Flow Million Gallons per Day MGD	Report	Report	N/A	N/A	Report	Report
Carbonaceous Biochemical Oxygen Demand (5-day) BOD5	10	20	15	30	25	45
Total Suspended Solids	15	20	25	30	40	45
Ammonia Nitrogen	4	5 April-October	6	7 April-October	10	10 April-October
E. Coli CFU	126	126	N/A	N/A	394	394

1.1.1.3 ADDITIONAL PROVISIONS FROM TPDES DISCHARGE PERMIT

As part of the requirements from the permit, there is a provision of "Minimum Self-Monitoring" in which the Measurement Frequency and sample type are covered. On Table 2, the

reader shall find some of the requirements from the TPDES permit for each Wastewater Treatment Plant.

Table 2 Minimum Self-Monitoring Requirements reported for both Wastewater Treatment Plants NW and RRB.

Effluent characteristic	Daily Average Measurement Frequency		Daily Maximum Sample Type	
	Northwest WWTP	Roberto R. Bustamante WWTP	Northwest WWTP	Roberto R. Bustamante WWTP
Flow	Continuous	Continuous	Totalizing meter	Totalizing meter
BOD5	One/day	One/day	Composite	Composite
Total Suspended Solids	One/day	One/day	Composite	Composite
Ammonia Nitrogen	One/day	One/day	Composite	Composite
E. Coli Colony Forming Units (CFU)	Daily	Five/week	Grab	Grab

1.1.1.4 USERS OF THE WASTEWATER TREATMENT PLANTS

The wastewater being treated by these two plants are contributions of regular customers with effluents from regular household use, any business, and the bigger contributors such as the private industry, all of them within the city limits. On Appendix Exhibit C, the reader will find a detailed list of the Industrial users registered over the Water Utilities from El Paso Texas whose waters are treated by either the Northwest or Robert R. Bustamante WWTP. The amounts described on the list are an estimate based upon the annual water consumption of each Industrial facility.

It is worthy to point out, that the customer "Western Refining Company" is the most important contributor in terms of volume of wastewater generation. The estimated amount for this particular customer is 1,366,430 gallons per day. The Wastewater Treatment Plant that receives the whole contribution is the Robert R. Bustamante WWTP.

The second largest contributors are the Unifirst Holdings with 134,072 gallons per day (GPD) being the receptor of the wastewater the Robert R. Bustamante WWTP, while the LPD and Sumitomo Electric Wiring Systems with contributions in the order of 130,162 gallons per day to the Northwest. Please see LIST OF CUSTOMERS AND WWTP TREATING THEIR EFFLUENTS (EXHIBIT C).

The relevance of these amounts from one contributor is that if the flow is laminar on the way to the Wastewater Treatment Plants, it is highly likely that the flow can arrive in pockets of high concentrations of contaminants. This event is called plug flow[8, 9], and it shows up as outliers or even special cases. When the concentrations are considerable or the size of the pocket is bigger than usual, they tend to disrupt data distribution of measured parameters and operations of the WWTP. If that happens, then data set changes from a statistically normal distribution, into a skewed histogram with bars located outside the distribution.

In addition to that, the Wastewater Treatment Plants considered in this thesis do not have pretreatment that will dilute those concentrations or flag the personnel that before entering the WWTP. There is one exception to this; there are remote sensors that detect on the Northwest Plant has hydrogen sulfide (H_2S) to monitor in the headwork. As far as the Robert Bustamante Plant concerns, it also has those same sensors in addition to LEL sensors at one of the lift stations upstream of the plant to monitor discharges from Western Refining. This is in consideration of some special cases that might cause safety concerns to the personnel or property.

1.1.2 DATA COLLECTION FROM THE EL PASO WATER UTILITIES (EPWU)

As per the TPDES, permit conditions El Paso Water Utilities collects data of parameters of different variables. Such as Biological Oxygen Demand 5-day (BOD5), Total Suspended Solids (TSS), Flow, E. coli, and Ammonia Nitrogen using the criterion described on Table 1. The type of sample and frequency previously mentioned on Table 2 are conditionals for reporting purposes. The TPDES permits on page four for each plant, describes the Monitoring and Reporting requirements.

Requirements for the calibration of automatic flow meters, recording device, and totalizing meters are in the permits to ensure accuracy as often as necessary or at least one a year, whatever comes first. The Manager of WWTP must keep verification sheets in file for a period of three years for auditing purposes by the Texas Commission of Environmental Quality, also known as TCEQ.

Samples of pollutants shall be collected using approved analytical methods have to be used, and all results shall be included in reporting and calculation sheets. Documentation and reporting of any deviation from the permit's instructions is part of the compliance process.

Typically, there are two sample types, grabs, and composites. The grab is an instantaneous sample collection. The composite is either proportional to the flow or time

weighted sample. The collection of composites is by an automatic sampler (auto-sampler) or manually. The frequency is every 2 hours over a 24-hour period. See "Standard Methods for the Examination of Water and Wastewater," 21st Ed. 2005, Section 1060 B[10] for further explanation.

1.1.2.1 OCCURRENCE OF SPECIAL CASES AND OUTLIERS

The focus of the wastewater treatment on this thesis is as a sequence of operations that have the goal to produce treated water as final product, using the legal limits as standards of the process.

Under the concept of process, variability in the product is a natural event. What generates special concern is the occurrence of special cases that are distant from the target. The likelihood of this type of events is higher under the wastewater treatment process.

A step to insure compliance is the quality control of the measurements, the permitting system requires accuracy in the measurements with the aid of control charts. That is standard practice for El Paso Water Utilities in the laboratory that analyzes all samples. The use of standard solutions for calibration purposes is part of the process in Wastewater Treatment Plants. The noise generation during the measuring stage is due to drifting of the process in physical-chemical characteristics of raw water. At one moment, the concentration of a given parameter will be low and a sudden spike in concentration will require the equipment calibrated for another set of values. This type of behavior was frequent in the dataset used in this thesis.

This situation puts the Wastewater Treatment Plant in disadvantage since they have to meet compliance even though the variability of the raw material is high[11].

One must keep in mind that since the generation of wastewater comes from all sorts of point sources, the final characteristics are extremely variable and not totally controlled. There are events such as non-point sources like water runoff that might have the same effect as illegal

dumping of waters with physical-chemical characteristics above the effluent limits is likely any moment[12]. This type of events will show as special cases and outliers on histograms and in descriptive statistics analysis.

Variability on any industrial process within legal limits is part of the event as well [13]. The contrast between the wastewater treatment process and the one in the private industry will help us to understand that high variability and outliers are part of the WWTP process. In the wastewater treatment process, variables are not controllable, while a manufacturing process industry will reject the batch that is not within specs.

Circumstances such as an industrial customer might have unusual operating conditions; the evaporation rate of water is high on sunny days causing higher concentration of pollutants and higher turbidity. Furthermore, if the water used on a given day comes from treated water from the Rio Grande or from ground water are possible factors of the outlier and high variability characteristics of raw water. Thus, the quality of the raw material (wastewater) is not possible to keep within certain limits before receiving it into a Wastewater Treatment Plant.

The El Paso Water Utilities in an effort to prevent dumping of hazardous waste and high concentration of regular pollutants into the sewage[14], issues limits of some chemicals in the effluent of industrial facilities. This is to control the incoming quality characteristics of wastewater entering the wastewater facilities. Unfortunately, events like human errors from industrial personnel and illegal dumping from private citizens is part of the raw water collection process.

1.2 PURPOSE AND SCOPE OF THE STUDY

The purpose of this thesis is to put to a test basic Statistical Process Control applicability to a Wastewater Treatment Plant with secondary treatment. Consequently, the normality test to variables involved in this WWTP process applies. Statistical Process Control requires that in order to subject the variables to a test, they must be normal variables from the statistical point of

view. Descriptive statistics to find interesting behavior from several parameters is part of the scope as well. The lapse of time covered by data made available by the El Paso Water Utilities from the above-mentioned plants is from January 1 2008 to December 31 2011. It is noteworthy to point out that the parameter concentrations for all physical-chemical characteristics available are on a weekly basis, except for the incoming and outgoing flow. The data made available is part of the reporting spreadsheets submitted use to fill out the TCEQ reports. The concentration units for most parameters are mg/L, µmhos/cm (µSiememns/cm) for Electro-conductivity and NTU for Turbidity.

The plants covered by this thesis are the Northwest and the Robert R. Bustamante Wastewater Treatment Plants. This is to explore the use of statistical process control with traditional tools.

1.3 IMPORTANCE OF THE STUDY

Understanding the statistical behavior of a Wastewater Treatment Plant will help eventually to develop tools to aid control of the process and make the task of abiding to legal effluent limits easier to achieve. Once control of the process is achieved, other opportunities will be feasible such as eventual involvement of analyzers and sensors to reduce the delay of acquisition of physical-chemical characteristics of the parameters[15]. Other control strategies [16] are emerging using sensors, PID (Proportional-Integral-Derivative)[17], and specialized hardware and software are part of an integral solution.

1.4 RESEARCH OBJECTIVES

The research general objective is to detect statistical behaviors that might affect the performance of the Wastewater Treatment Plants of the study. In regards to the specific objective is to test applicability of basic SPC adequate to the operational conditions of the Wastewater Treatment Plant with secondary treatment.

CHAPTER 2: LITERATURE REVIEW

Literature review discusses published articles and publications related to the application of Quality Assurance criteria applied to the management, treatment, and control of Wastewater Treatment Plants using the database Academic Search Complete (EBSCO), PubMed, SciVerse AWWA, WorldCat, WEF and ASCE databases. The keywords used in the search are wastewater treatment, quality, control, General Linear Model, Multivariate, secondary treatment, simulator, simulation, BOD, BOD5, COD, EPWU, and model. There were several sources for the articles, journal, e-books, pamphlets, and proceedings. About a hundred and fifty primary sources are part of this literature review. The software used for reference management is Endnote X6. Additional reference management websites are RefWorks, Endnote Web, Google Academic, and Wiz Folio. Secondary sources are e-mails exchanged with Mr. William Quinn from EPWU. Discussion of relevant references is as follows.

(Spindler & Vanrolleghem, 2012)

The title of the article is "Dynamic mass balancing for wastewater treatment data quality control using CUSUM charts." Article published in Water Science and Technology. In this article, the authors talk about quality control of the acquired data by using mass balance equations in wastewater treatment. This system uses CUMSUM charts, which are control chart that used to graph the cumulative sum to detect changes based on mass balance operations. This chart will help to track the changes in input values. The contribution of this article is the application of basic concepts of Statistical Process Control (SPC) but with a significant twist, DYNAMIC conditions. This system is in opposition to basic SPC concepts, since it assumes static conditions.

(Sándor, Papp, Kosáros, Hegedűs, & Csengeri, 2012).

"Potential effects of Pharmaceuticals and their residues in aquatic environment." It was published on Studia Vasile Goldis Seria Stiintele Vietii (Life series), in which calls the attention to the resilience of the pharmaceuticals in aquatic media and the increasing concern it has become to society. The Wastewater Treatment Plants efficiency in removing such type of chemicals is low. This type of micro pollutant is a form of COD. Understanding what contributes to the concentration of CODs will help to make intelligent proposals in the quality control of the treatment and strategy to achieve it, are components of an integral solution to remove that type of chemicals from wastewater.

(Phillips et al., 2012)

"Combined sewer overflows: an environmental source of hormones and wastewater micro pollutants", published in Environmental Science and Technology, explores all the factors involving the variability of the concentrations of the above mentioned contaminants and their characterization as Chemical Oxygen Demand (COD). The impact of this paper in the present thesis consisted in acknowledging that uncontrollable factors like run off and careless disposal of pharmaceuticals can dramatically contribute to develop special cases in which the treatment train will experience reduction in efficiency of removal of contaminants. Runoff will transport the contaminant into the flow of water headed to the Wastewater Treatment Plant.

(Jensen, Spiild, & Toftum, 2012)

"Implementation of multivariate linear mixed effects model in the analysis of indoor climate performance experiments." The publication of this article was in the International Journal of Biometeorology. It discusses the use of linear models in the characterization of time series similar to the one used in this thesis.

(Garrido-Baserba, Reif, Rodriguez-Roda, & Poch, 2012)

"A knowledge management methodology for the integrated assessment of WWTP configurations during conceptual design," article published in Water Science and Technology. This article contributes with the concept of design reliability should considered all possible scenarios of need and growth of the eventual growth of the population being served. Therefore, at the time of expansions, it will maximize the benefit. A flexible and integral design should be under consideration. Different configurations and capabilities of automation should be the product of a well-structured methodology. A control strategy is a supplement to a design that is reliable and flexible. Once these parts have been implemented, management of the daily and seasonal variability of the incoming pollutants.

(Zuoyi, Huiping, Martin, & Chuanhai, 2011)

"Inferential Models for Linear Regression", from the Pakistan Journal of Statistics & Operation Research," served as a guide in the selection of variable considered in the analysis. It provided some information of current statistical methods nowadays.

(Zhao, Fu, Lei, & Li, 2011)

"Multivariate analysis of surface water quality in the Three Gorges area of China and implications for water management" from the Journal of Environmental Science, used several models, including the non-parametric statistics. It also reviewed the applicability spatial-temporal relationships of the variables analyzed. The use of multivariate analysis applied to wastewater analysis provided ideas applicable to the subject of this thesis.

(Pathak & Limaye, 2011)

On Pathak et al. article "Study of Seasonal Variation in Groundwater Quality of Sagar City (India) by Principal Component Analysis," talked about temporal relationships between water parameters, seasons of the year and monsoon season. Although he used clusters as his methodology of analysis, we can see that it is technically feasible to conduct an analysis using

seasons of the year as a reference in water related issues. Again, time series are the focus of this article. It provided some ideas in the use of seasons and graphs.

(Rahmat, Samsudin, Wahab, Sy Salim, & Gaya, 2011)

In "Control Strategies of Wastewater Treatment Plants," the authors review control strategies in wastewater treatment control. The focus is automation and use of PID (Proportional /Integral/Derivative) as one possible application in the dissolve oxygen and nitrate control with multivariable configuration for monitoring and controlling, also artificial neural networks are the common choice for modeling and prediction purposes. The authors recommend a Benchmark Simulation Model No. 1 as an alternative to understand primary and secondary treatments. From this model, we learn that the behavior of some unit operations is not linear.

(Krishnamoorth, 2011)

"WHAT, WHY, AND HOW: The importance of statistical thinking for Six Sigma" explains the need of statistical thinking in engineering issues. The author recognizes that the empirical thinking of engineering is necessary for manufacturing applications and by extension to any process, which produces a final product. Wastewater treatment is a process that generates a very valuable product, reusable water. This process needs a form of statistical control different from the traditional one used in regular manufacturing processes. It is a fundamental assumption to this thesis, that an adequate statistical methodology, along with other control strategies fitted to the needs of wastewater treatment processes. The implementation of a statistical model requires experience on both the process and statistics.

(Reynolds & Richards, 1996)

"Unit Operations and Processes in Environmental Engineering", in Chapter 3, page 42, the authors discuss the ideal Plug Flow Model, characterizing this flow as a piston flow, in which the elements of a given fluid, enter the system at the same time flow and travel at the same velocity. In other words, small volumes of the fluid will travel at the same velocity (with the

same mean time), creating a situation in which there is no dilution of the pollutant being transported by the wastewater at certain points. This means that pockets of high concentration of pollutants might enter the Wastewater Treatment Plant. This explains the special cases in the histogram of concentration of a given pollutant.

(Warren Viessman & Hammer, 1998)

In their book "Water Supply and Pollution Control," Warren and Hammer, discuss in Chapter 8, section 8.5, page 320, Water Quality Models, and their Reliability. One underlying assumptions of this thesis, is that Reliability of the process control and the product, depends on the Reliability of the design and supplementary tools such as strategies for control, data acquisition of concentrations through sensors and statistical tools that detect that the product is not meeting the physical-chemical and biological characteristics for its use. The authors of this book acknowledge that due to the complexity of this process, there is the need of simplifying assumptions that might create problems in the predictability of the output of the model. They claim that all models are rough approximations to the reality of this complex process, wastewater treatment.

(American Public Health, American Water Works, & Water Environment, 2005)

The analysis of the parameters are conducted on the Northwest and Robert R. Bustamante Wastewater Treatment Plants using "Standard Methods for the Examination of Water and Wastewater" compiled, reviewed and written by several Joint Task Groups that overlook the development of methods and approved by the EPA. Also the American Water Works Association, Water Environment Federation, and the committee on Laboratory Standards and Practices of the American Public Health Association. This work is the result of hundreds of specialists, and its gradual development extends for more than a hundred years. It is worthy to mention that in the introduction part, it considers the statistics involved in the process of

measurement and data acquisition. It recommends the use of Control charts of three types. The means chart for standards, means chart for background or reagent blank results and range chart for replicate analyses. These charts are necessary quality control tools in data acquisition. In Statistical Process Control, there are seven tools to track and control quality of a process. The preceding charts resemble the control of variables charts that are applicable to a process that can be ran on batches. A laboratory is that type of process, but the wastewater treatment done on a continuous flow fashion is a different story. That is, the Wastewater Treatment Plant has a control over some conditions, as opposed to controlled conditions and sampling from batches in the laboratory. The problem of the process consists in the control of the characteristics of the incoming wastewater. These conditions are NOT the product of careless users. Environmental conditions and circumstances contribute to highly variable physical-chemical and biological characteristics of the incoming wastewater, to the point of becoming outliers or special cases.

(Sadik & Gruenwald, 2011; Barnett & Lewis, 1984)

The following articles deal with issues with outliers and data acquisition. Sadik et al. wrote, "Online outlier detection for data streams," proposing Adaptive Outlier Detection for Data Streams (A-ODDS), for analysis of stream of data and ways to detect outliers. It considers the uncertainty related to that type of databases. The EPWU provided four years of data (January 1 2008 to December 31 2011), some of them already processed. Large amount of data creates different problems, among them of quality control and fitting to existing model. This article also deals with data streams such as meteorological in nature. The present thesis acquired temperature data from the National Climatic Data Center NOAA for four years, with same days as the EPWU data. This database created some technical problems, reason why this article and the IDEAS (Database Engineering & Applications Symposium) and consulted an organizer to address some specific issues. On the other hand, the "Outliers in statistical data" by V. Barnett and T. Lewis, 1994, 3rd edition was the basis for the Quality control considerations on the

"Standard Methods for the examination of water and wastewater." It addresses similar problems related to outliers.

(Singh, Basant, Malik, & Jain, 2010)

"Modeling the performance of "up-flow anaerobic sludge blanket" reactor based Wastewater Treatment Plant using linear and nonlinear approaches--a case study." Singh et al. used several linear and non-linear models to characterize a Wastewater Treatment Plant with biological treatment (secondary Treatment), analyzing BOD5, and COD with the results that the nonlinear models (MPR, ANNs) performed relatively better than the linear ones. According to the authors, "these models can be used as a tool for the performance evaluation of the WWTPs." This means it is feasible to describe data with a reasonable margin of error as a linear system. The nonlinear model used on this article presented a better alternative to describe better a secondary treatment process.

(Noori, Sabahi, Karbassi, Baghvand, & Taati Zadeh, 2010)

Noori et al. presented in their article, "Multivariate statistical analysis of surface water quality based on correlations and variations in the data set" used a multivariate analysis, and principal component analysis (PCA) technique and canonical correlation analysis (CCA) to determine relationship between physical and chemical water quality parameters. This article served as a case study of similar parameters analyzed in this thesis, with different outcomes. This article establishes specific goals for future consideration as a follow up to this thesis.

(Keskitalo, Jansen, & Leiviska, 2010)

Among the models being used to understand and control a secondary treatment is done employing a modified ASM1 (Activated Sludge Model 1).This model is used as part of the process of the design and control of Wastewater Treatment Plants. The ASM1 model characterized the secondary treatment as nonlinear. There are subsequent versions of that software used in different applications. This thesis relies in some findings produced by using the

above-mentioned model. This article also deserves special consideration as the follow up to this thesis. The model covers secondary treatment similar to the EPWU unit operation.

(Keskitalo et al., 2010)

The title of the article ¨Calibration and validation of a modified ASM1 using long-term simulation of a full-scale pulp mill Wastewater Treatment Plant¨ describes how the ASM1 (Activated Sludge Model No.1) can be adapted to specific applications and become a ¨pre-deterministic modeling in practical applications¨ for the pulp and paper effluents. This means that the models derived from the ASM1 being applied to a specific type of effluent, needs adaptation of the model to apply it to EPWU conditions.

(Hu, Shao, & Palta, 2010)

"Variability explained by covariates in linear mixed-effect models for longitudinal data" explains variability by covariates assesses the importance of covariates for dependent outcomes. In this paper covers longitudinal data under linear mixed models similar to the data considered in this thesis. Consideration of this article was due to a longitudinal study with time dependent variables included. In the website IWA Task Group on Benchmarking of Control Strategies for WWTPs [18], there is an explanation of both models. It also implicates secondary treatment in this paper.

(Ostace, Cristea, & Agachi, 2009)

"Model Predictive Control of the Wastewater Treatment Plant Based on the Benchmark Simulation Model No.1-BSM1 with Reactive Secondary Settler" is an interesting paper that incorporates some ideas discussed in this thesis. BSM1 is a dynamic model that intends to predict the changes of dependent variables based on the changes of the independent variable. Usually is employed in linear systems, but it also has adaptability to nonlinear systems such as ours. This model of process control is useful to understand and control complex dynamical systems. As we expect it uses sensors and PID (Proportional/Integral/Derivative) controllers.

The involvement of sensors is crucial for the control of the process. They should be the first line of detection of highly concentration of pollutants. Technically speaking should not be part of the pretreatment, since the location should be before reception of the wastewater and outside the facilities. A Wastewater Treatment Plant should have detection of pockets of concentration of pollutants before entering the WWTP since once it is inside the facilities; it is not an option to pump that water outside the plant. Furthermore, when using the sensors of specific parameters, the Wastewater Treatment Plant will have time to react to sudden increases of concentration of certain parameters, thus keeping the process within certain range of values of the incoming parameters. EPWU, based on a statement made by Mr. William Quinn, there are some sensors in the headworks of the WWTPs to detect certain chemical compound such H_2S ("NW Plant has hydrogen sulfide monitors in the headworks. RB Plant has those same sensors in addition to LEL [Lower Explosive Limit] sensors at one of the lift stations upstream of the plant to monitor discharges from Western Refining"…as per Mr. William Quinn) which is highly flammable and poisonous.

(Field, 2009)

"Discovering Statistics using SPSS® third Edition" was the Statistics reference books along with the Montgomery Statistics book were the guideline in the Statistical considerations. In the case of the Andy Field's book, it also served as user's manual for the SPSS® software. In the present thesis the statistical software used were SPSS®, Minitab and Excel/ This last one with very limited application.

(Montgomery & Runger, 2011)

"Applied statistics and probability for engineers" is the second book used in the Statistical field as reference book.

(Belia et al., 2009)

"Wastewater treatment modeling: dealing with uncertainties" introduces the concept of uncertainty in the modeling arena. It emphasizes that in every step of the treatment process of wastewaters there is a small contribution in the increase of uncertainty. That is, the model will always will be an approximation, unlike in chemical and industrial process in which there is a strict control of the concentration of the incoming and outgoing parameters. What called the attention of this consideration is that it intends to generate a discussion in the limitations of models, yet we need to consider them necessary to use in the design and functioning of the Wastewater Treatment Plant.

(Aizenchtadt, Ingman, & Friedler, 2009)

"Analysis of the long-term performance of an on-site greywater treatment plant using novel statistical approaches" introduces among other things, the use of different statistical methods for the quality control of the Wastewater Treatment Plant. In order to apply control measures, dynamic regression SPC (DRSPC), SPC (statistical process control) with variable control limits is necessary. DRSPC described underlying long-term trends in most cases. These algorithmic technique using treated water parameters provide meaningful and diagnostic red flags that are far superior to the X-r and R charts, or other control charts. The relevance of this approach is the introduction of dynamicity of the process and discarding the univariate approach for one that handles more than one variable. The conception of Multivariate Statistical Process Control has already been used and the chemical industry, pharmaceuticals and so on. Variable control limits are developed and employed. A chart X-r chart is assembled using this data. After removing the outliers, using Minitab 16 six-pack, a dialog box requires the mean, minimum, and maximum values to calculate among other things the C_{pk}, yielding a negative value of 1.78. This flag indicating that process was out of control. Checking the required limit, the process was

under compliance. This discrepancy was evident, that despite the process was achieving the desired result, and the typical statistical system was unable to detect it.

(Flores-Alsina, Gallego, Feijoo, & Rodriguez-Roda, 2010)

"Multiple-objective evaluation of Wastewater Treatment Plant control alternatives" is an article that invites the reader to consider the economic, microbiological, and legal implications and possible scenarios as part of the criteria in the design process. The authors used the model BSM2 for this evaluation.

(Thomann, 2008)

"Quality evaluation methods for Wastewater Treatment Plant data" proposes the detection of systematic errors in data sets through redundant mass balance approach by analyzing several different mass balances with the aid of Shewhart control-chart or process-behavior charts. This tool is widely used in statistical process control. Control charts are a tool to determine if a manufacturing process is in a state of statistical control. In the data received from the EPWU it was evident that there was a lot of noise introduced in the measurement of the parameters. There was a problem in the automatic samplers and in the flow meters.

(Rao, Kumar, Prakasham, & Hobbs, 2008)

"The Taguchi methodology as a statistical tool for biotechnological applications: a critical appraisal" proposes the application of the Taguchi methodology in a multivariate way to handle noise in a controllable way. Applying the signal to noise ratio becomes useful to focus on the "main effects," reducing the impact of the noise of the measurements. This is a relevant approach since the data provided by the EPWU presented a lot of noise and made difficult the interpretations and implementation of some tests. Taguchi's methods are a strong candidate to control the wastewater process statistically.

(Oliveira & Von Sperling, 2008)

"Reliability analysis of Wastewater Treatment Plants" presents reliability analysis for Wastewater Treatment Plants from Brazil, evaluating unit operations using the concept coefficients of reliability (COR) using the legal target of removal of parameters such as BOD and COD. This article support one of the basic assumptions that a design should be reliable in configuration, unit operations, and operational components from the process and so on. The concept of reliability and quality control of process is under adaptation in the wastewater treatment process.

(Oke, 2008)

"Utilization of Weibull Techniques for Short-Term Data Analysis in Environmental Engineering" implements the extreme value distribution concept in the wastewater treatment for the determination of design parameters with great success. Using extreme value distributions, the author was able to determine successfully BOD, financial and design characteristics. This article contributes to the idea of applying statistics in the design and process control of Wastewater Treatment Plants.

(Goode, LeRoy, & Allen, 2007)

"Multivariate statistical analysis of a high rate biofilm process treating kraft mill bleach plant effluent" article applied the multivariate analysis in the form of principal component analysis (PCA) and partial least squares (PLS) modeling with the purpose of explaining and predicting changes in the BOD output of the biological reactor. The use of statistics analysis applied to this topic confirms the use of statistics in predicting the performance of a unit operation of a Wastewater Treatment Plant.

(Flores, Comas, Roda, Jimenez, & Gernaey, 2007)

"Application of multivariable statistical techniques in plant-wide WWTP control strategies analysis" is an article that applies multivariable statistical techniques in Wastewater

Treatment Plant control strategies analysis using cluster analysis (CA), principal component analysis/factor analysis (PCA/FA), and discriminant analysis (DA). This novel approach used with Benchmark Simulation Model No 2 (BSM2) proposes strategies as an aid to control the operation of a Wastewater Treatment Plant. Cluster analysis seems to be appropriate to the complex case of groups with similar behaviors. The article gets technical but the basic idea of multivariate analysis can describe better a Wastewater Treatment Plant with secondary treatment than regular univariate SPC.

(Boccelli, Small, & Diwekar, 2007)

"Drinking Water Treatment Plant Design Incorporating Variability and Uncertainty" addresses the variability as part of water treatment. Also acknowledges the uncertainty inherent to this process. The article itself is not available in the sources used.

(Batzias, Efthymiadou, Siontorou, Simos, & Maroulis, 2007)

"A Knowledge Based System Offering Consultation for Enhancing Semi-Natural Wetland Functionality" uses methodologies to a wetland applicable as well to the design of a Wastewater Treatment Plant. Knowledge base is an artificial intelligence system in the decision process. It incorporates techniques useful in the decision process before and during the design process.

(Azman & Kocijan, 2007)

"Application of Gaussian processes for black-box modeling of biosystems" uses the Gaussian process model to identify nonlinear models, namely to a bioreactor. The impact from this article and the BSM1 and its modified versions is that a Wastewater Treatment Plant with secondary treatment (biological) is as nonlinear model. This article fits the needs of a biological process using statistical modeling.

(Aguado, Ferrer, Ferrer, & Seco, 2007)

"Multivariate SPC of a sequencing batch reactor for wastewater treatment" applies a SPC multivariate analysis using batch reactors. In this study, the authors propose an efficient MSPC scheme of the process. The first stage was to try to remove the nonlinear behavior of the sequence of reactors by different linear approaches. The success was limited, but the nonlinear behavior remained with less intensity. Each stage is part of the solution. From all the proposed models, after consolidating them a unique model is proposed. This model was able to find the seasonal process "drifts" and impacts of new operational conditions. The author state: "…This is of great importance for monitoring processes that exhibit a non-stationary behavior in order to provide reliable monitoring charts and avoid many false alarms…"

(Ho, 2006)

"Handbook of univariate and multivariate data analysis and interpretation with SPSS®" is the source of information of how SPSS® works. It was a valuable tool in the analysis of data.

(Clement, Thas, Vanrolleghem, & Ottoy, 2006)

"Spatial-temporal statistical models for river monitoring networks" is an article that explains why Space-time models are not applicable to this type of situations. The author talks about state-temporal models as an alternative to this type of scenarios.

(Oliveira-Esquerre, Seborg, Bruns, & Mori, 2004)

"Application of steady-state and dynamic modeling for the prediction of the BOD of an aerated lagoon at a pulp and paper mill: Part I. Linear approaches" presents several linear models that are able to predict the BOD from incoming flow and effluent. Microbial processes and interactions are not the exception, since they are time dependent. Models characterizing biological processes are time consuming to develop. The linear models are multiple linear regressions (MLR) and partial least squares (PLS) regression to develop predictive models. Prediction of BOD values was possible using this model and measurements along with process

information used to predict BOD at the inlet and outlet of an aerated lagoon of a pulp and paper mill. Linear steady state and dynamic models are able to predict inlet and outlet BOD.

(Yoo, Vanrolleghem, & Lee, 2003)

"Nonlinear modeling and adaptive monitoring with fuzzy and multivariate statistical methods in biological Wastewater Treatment Plants" proposes a new approach to nonlinear modeling and adaptive monitoring using fuzzy principal component regression (FPCR) and then applied to a real Wastewater Treatment Plant (WWTP) data set. The authors use principal component analysis (PCA) to remove collinearity from collected data. Then using adaptive credibilistic fuzzy-c-means method the system is monitored (operating conditions) based on the PCA score values. The third step is the Takagi-Sugeno-Kang (TSK) fuzzy model application to model the relation between the PCA score values and the target value. FPCR method is applied to predict the output variable, based on the result we can say it has the ability to model the nonlinear process and diverse operating conditions. From this article, we can conclude that by fuzzy principal component regression (FPCR) with some additional steps can model nonlinear systems such as secondary wastewater treatment.

(Rosen & Lennox, 2001)

"Multivariate and multiscale monitoring of wastewater treatment operation" talks about the limitations PCA related to wastewater plant monitoring situations. Since variables are dynamic in a Wastewater Treatment Plant, this condition is a limits the applicability of PCA. In the case when studying time dependence (one time-scale), PCA is adequate. Disturbances in a Wastewater Treatment Plant occur in different time-scales. These limitations make unsuitable for WWTP monitoring. A way to overcome this limitation is by use of adaptive PCA. This is possible by "adjusting continuously using an exponential memory function," the authors say. They suggest using variable mean, variance, and co-variance to adapt to the dynamic conditions. A solution to the problem is using a multiresolution analysis (MRA) in combination with PCA.

From the primary and secondary information sources, we can establish a framework: ¨It is feasible to model a Wastewater plant with secondary treatment using statistical models. The use of SPC tools in Wastewater Treatment Plant is in use in the Laboratory Standard Procedures but not in the WWTP process. Normality is a requirement of the variables involved in the implementation of the SPC and Xbar-r is a tool to review if the process is under control.¨

CHAPTER 3: METHODOLOGY

The methodology used on this thesis it is Quantitative, non-experimental, using a time sequence, longitudinal (trend), with a scope of explore and describe, using season and day of the week over flow and other dependent variables[18].

The targeted population is BOD5, COD, TSS, Electrical Conductivity, Total Phosphorus, Total Kjeldahl Nitrogen (TKN), and NO_2 and NO_3 parameters from the Northwest and Robert Bustamante Wastewater Treatment Plants. In addition, performance of a test for seasonality for Electrical Conductivity for both plants is included in this thesis. The methodology of collecting data abided to the requirements of the TPDES criterion applicable to each Wastewater Treatment Plant, including the Standard Methods for the Examination of Water and Wastewater, 21st Ed. 2005[10], Section 1060 B instructions. According to Mr. William Quinn´s e-mail sent on November 12 2012, ¨Typically we have two types of samples, grabs, and composites. The grab is an instantaneous sample collection. Either the composite is a flow proportional or time weighted sample. The collection of the composites is either by auto sampler or by manually compositing samples collected every 2 hours over a 24-hour period.¨

There is no description of the instrumentation used to collect, analyze and keep water samples in the EPWU facilities. Regarding the software used to analyze data is SPSS® (Statistical Package for the Social Sciences) and Minitab 16. Data was in Microsoft excel spreadsheets at the time of the reception from EPWU. The array of the received data was by Wastewater Treatment Plant, by calendar year and month. In addition to that, data grouped in categories like Flow of raw water, and effluent Flow. The parameters are: Alkalinity, Ammonia, BOD5 (Biological Oxygen Demand five day test), Bromine (Br), Calcium (Ca), COD (Chemical Oxygen Demand), Chlorine (Cl), Electrical Conductivity (EC), Fluoride (F), Potassium (K), Magnesium (Mg), Sodium (Na), Nitrite ion (NO_2)), Nitrate ion (NO3), Orthophosphate o-PO4, Silicon Dioxide (SiO_2), Sulfates (SO_4), TKN (Total Kejeldahl Nitrogen), Total Phosphorus

(Total P), TDS, Hardness, Total Suspended Ash (TSA), Total Suspended Solids (TSS), Turbidity, and VSS (Volatile Suspended Solids). The values provided, except for the flow, are not on a daily basis. They are on a weekly basis. That is, that one value for every seven days. The units for flow data are in Millions of Gallons per Day (MGD) and collected on a daily basis. A transformation of the above-named flows into cubic meters per day took place for the use in this thesis. In regards to the physical-chemical parameters, they also were collected mostly on a daily basis, except for Electrical Conductivity. The permission to use the information in the spreadsheets with the above-mentioned parameters was implicit when EPWU through Mr. William Quinn e-mailed them to my mailbox. Minitab, Inc. granted copyright permission to use screens from their product. In addition, IBM Corporation granted copyrights permission with some conditional for using SPSS® screens at the time of submitting this thesis.

All outliers remained on the dataset used on this thesis. The decision based on ethical grounds. Test of Normality and detection of outliers were part the first step taken before using SPC. Logarithmic Transformation of data (which was not useful) to adjust skewness is the second step.

After that, performance of descriptive analysis using both SPSS® and Minitab® is the third step. In SPSS® under Analyze, you can create a histogram to review normality. (IBM acquired SPSS® Inc. in October 2009). When fitting the histogram with a normal curve, outliers are visible outside the normal curve. In SPSS® when the cursor is over the bar laying outside the distribution and clicked over it, the case number will appear.

Once identified the case, manual removal is possible. The scenario of removal of outliers does not apply to this thesis for reason already explained. After removing outliers as preparation for the Capability test or I-MR, a histogram will show a symmetrical distribution.

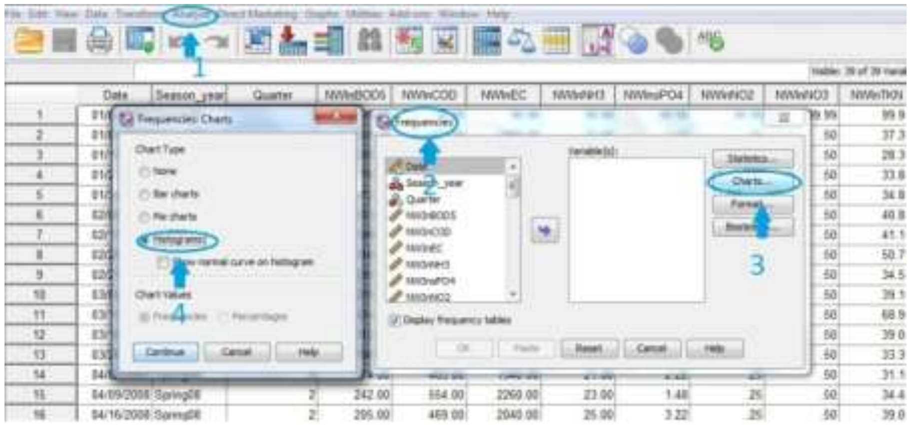

Figure B Frontal views of the SPSS® dialog boxes showing sequence of steps to get a histogram[3]

After confirmation normality of data, perform the analysis takes place. Collect the statistical parameters minimum, maximum, and mean. Feed these values to Stat Quality tools, Capability Six-pack, Normal (Minitab). In options, the number of subgroups should be one for the Capability test. The C_{pk} measures how close the process is to a target and consistency around an average value. Red flags appear in the form of red points. During most of the time, the effluent was within statistical target. In the literature review stage found that, Multivariate SPC, and Principal Component Analysis (PCA) along with moving mean and variance are an alternative tools fit to the set of conditions of a WWTP with secondary treatment.

The testing plan applied to the hypothesis "Statistical Process Control can help to predict peaks and valleys, patterns that data from the WWTP signal as negative behavior to the performance of the process" is by directly analyzing the data first for normality, then using charts like the I-MR and test the C_{pk} to see how data behaves and the type of results we get in the output of the analysis[13]. In addition to that, the use of correlation matrices, correlation plots, and scatter plot analysis will help to understand the process.

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[3] Reprint Courtesy of International Business Machines Corporation, © International Business Machines Corporation

Now, if using SPSS® click on the box plot and select Normality plots with test and histogram by placing check marks on both small squares. Press on the Continue button to close the Explore Plots Dialog Box. Then press on the OK button located at the bottom of the Explore Dialog Box (as shown on Figure C). Once the sequence of steps follows the number system from one to five, a series of results will show up in the Output screen.

Figure C. Sequence of steps followed to perform Normality Test in SPSS®.[4]

The Central University of Michigan and SPSS® offers tutorials to use that software as a guide to conduct several statistical tests [19, 20].

To have the Normality Test using the Minitab 16 you go to the Menu bar, click on Stat, then to Basic Statistics, finally select Normality Test on the drop down box. A dialog box will appear, a list of variables will show up, select the variable you want to test, click twice on it or click on the Select button on the bottom of the screen. On the bottom right hand, there will be a list of three options to choose from Anderson-Darling, Kolmogorov-Smirnov, and Ryan-Joiner

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[4] Reprint Courtesy of International Business Machines Corporation, © International Business Machines Corporation.

(similar to Shapiro-Wilk). Check on any of the circular clear bullets on the left of the options. Once you have selected the test option, click on the OK button. A graph with a diagonal line in blue and the set of points of the parameter under consideration will show. In addition to that, a box on your upper right with the results will indicate mean, standard deviation, number of points, initials of the normality test used, and the p-value. If the p–value is less than 0.05, then the null hypothesis of the test will apply. In this case, it will mean that your set of points is Normal.

As part of the descriptive part of the thesis, application of descriptive analysis aids to find out more about how parameters behave. This includes of course BOD5, COD, and Electrical Conductivity among others. Both Minitab 16 and SPSS® 19 were graphing tools as part of this project. The quality of the graph for publication purposes is a crucial criterion for the selection of which software to use. In addition to that, independent variables like temperature, days of the week, date and flow are in the pool at the time of putting together the graphs.

In the exploratory aspect of the thesis, references provided possible models to analyze and control our Wastewater Treatment Plant with secondary treatment. Multivariate SPC [21], MRA and PCA [22, 23], and BSM1 [24] are models that after calibrating to the conditions that prevail at the Northwest and Robert R. Bustamante may help to establish control strategies to improve already good performance.

SPSS® is instrumental to achieve the analysis using categorical variables like “day of the week.”[25] Furthermore, the reduction of the number of variables used in this thesis was necessary to decrease the complexity of the analysis. Minitab® was very useful with the panel graph function, I-MR, and C_{pk} features.

Originally, the design involved more than one hundred dependent variables. The drawback is at the time of interpreting all the results of that first analysis, the excess of output became confusing and difficult to process. The validity of the results never became an issue. In this analysis, the independent variables are season of the year, temperature measured over El

Paso International Airport (in °C) and day of week. The temperature provided by NOAA had maximum and minimum temperatures. The temperature used was the average of the two. El Paso-Juarez area is an extreme temperature region during the same day. During extreme weather days, the average does not represent the prevailing temperature.

As part of the Descriptive Analysis correlation matrices, scatter plots, plots over time, descriptive tables with basic statistical characteristics, and insertion of trend lines with the R^2 in the plots are part of the set of analysis tools.

The lack of the daily values prevented this thesis from providing patterns that were present when outliers and special cases appeared, thusly the ability of predicting. Furthermore, the use of a time-weighted average prevented this thesis from understanding the diurnal behavior of the incoming water.

Description of relevant results is in the Results and discussion Section.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 RESULTS

This section presents the results from document review and statistical analysis of the Incoming flow and Effluent data from the Northwest and Robert R. Bustamante for the BOD5, COD, TSS, Electrical Conductivity, Total Phosphorus, TKN, and NO_2 and NO_3. As mentioned previously, the software used is SPSS®19 and Minitab16 [6]. In this chapter, the presentation of findings related to the statistical behavior using tools from Statistical Process Control basics follows in this section.

Before we continue with the presentation of the results, an explanation about the notation used on the data is necessary. The prefix NW relates to the Northwest WWTP, whereas the RRB indicates that the Robert R. Bustamante WWTP. For the segment of the word "Eff," it relates to the Effluent (treated water), while "In" indicates relation to the incoming flow (raw water) of any two of the plants under consideration. As an example, we have the following, when the parameter NWInBOD5 is under consideration that means that BOD5 of raw water from the Northwest Wastewater Treatment Plant is under scrutiny. The same logic applies to all of the parameters statistical tags used in this analysis.

In regards to the grounds of the decision of inclusion of outliers in this analysis are for ethical reasons. In some manufacturing plants, a logbook is part of best practices in the industry. It contains historical record keeping of outliers and extreme cases. Also includes root cause analysis and details related to the solution. EPWU does not have a logbook to keep track of special cases and outliers. For a Wastewater Treatment Plant, not having a logbook recording those types of events in not wrong. Both Wastewater Treatment Plants under consideration are award-winning WWTPs. However, from the Statistical point of view, and from the perspective

of Statistical Process Control it matters if alterations on collected data before an analysis with any real justification.

Table 3 Descriptive Statistics for the Northwest WWTP Incoming flow.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic
NWInBOD5	208	82.70	374.00	208.5298	62.49400	.535
NWInCOD	208	284.00	1080.00	521.9087	109.05229	.998
NWInEC	195	1660.00	2650.00	2040.8205	118.33616	.269
Valid N (listwise)	195					

Descriptive Statistics

	Skewness	Kurtosis	
	Std. Error	Statistic	Std. Error
NWInBOD5	.169	-.025	.336
NWInCOD	.169	2.974	.336
NWInEC	.174	3.483	.346
Valid N (listwise)			

The confidence interval used is every statistical analysis in this thesis have a 95%, is an indicator of reliability an estimate of refers to the percentage of all possible samples that can include the true population parameter. The P-value of 5% applies to the acceptance of the null hypothesis of a particular test. In the Normality tests, having significance (Sig.) of 0.05 or less, means that the data set analyzed is normal.

When analyzing the Figures with the Normality charts for some of the parameters, the reader will notice that the KS acronym will show up. That means that the charts used the Kolmogorov-Smirnov results for displaying the Normality results. Those charts do not contradict the Shapiro-Wilk results in this thesis. In the Annex Section, **Table 12** shows that all the parameters used in this thesis are Normal.

Table 4 Results of Normality Tests for the Incoming Flow of the Northwest WWTP.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
NWInBOD5	.063	195	.058	.976	195	.002
NWInCOD	.070	195	.021	.952	195	.000
NWInEC	.073	195	.014	.960	195	.000

a. Lilliefors Significance Correction

The Kolmogorov-Smirnov statistic is a nonparametric test (not Normal), showing the significance of 0.058, enough to reject the hypothesis of normality for the NWInBOD5. On the other hand, the Shapiro-Wilk test yields that the parameters come from a normal distribution. According to the Nornadiah Mohd Razali et al, in their article "Power Comparison of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors, and Anderson-Darling Tests," published in Journal of Statistical Modeling and Analytics, volume 2, number 1, 21-33, 2011 concludes that the most powerful test is the Shapiro-Wilk normality test. Therefore, we will choose the Shapiro-Wilk (SW) test as the measure of Normality of our data.

Table 5 Results of Normality Tests for the Incoming Flow of the Northwest WWTP.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
NWeffEC	.048	191	.200*	.979	191	.005
NWeffBOD5	.354	191	.000	.448	191	.000
NWeffCOD	.130	191	.000	.855	191	.000

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

In regards to the Normality Test, we have the following. For the RRB WWTP BOD5 Incoming flow does not have outliers. The median and mean are off about four units relative to

each other. COD and EC do have several outliers. Standard deviation for all three parameters is big. Usually standard deviation of one unit or less is acceptable. For the Electrical Conductivity is 133 units, while for the BOD5 is in the order of 40 units. Skewness is negative for EC and BOD5, whereas for COD is positive. Kurtosis is less than three for BOD5, which indicates that is flatter than a normal distribution, having a wider peak. On the other hand, we have EC close to three and a value of ten for COD. For the Normality Test Table for all parameters please see Annex Exhibit E, Table 12 has the Kolmogorov-Smirnov and the Shapiro-Wilk p-values.

Up to this point, we have considered an analysis on incoming water characteristics from Northwest and Robert R Bustamante. Now we proceed to address the outcome of the treatment. For the Effluent of the Robert R. Bustamante plant, BOD5, COD, and Electrical Conductivity are Normal. As shown on Table 6.

Table 6 Results from the Normality Test for the RRB Effluent with BOD5, COD, and EC.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
RRBeffBOD5	.103	194	.000	.899	194	.000
RRBeffCOD	.091	194	.001	.960	194	.000
RRBeffEC	.088	194	.001	.980	194	.006

a. Lilliefors Significance Correction

The only non-normal parameter found according to Shapiro-Wilk is RRBInBOD5, and NWeffTHard.

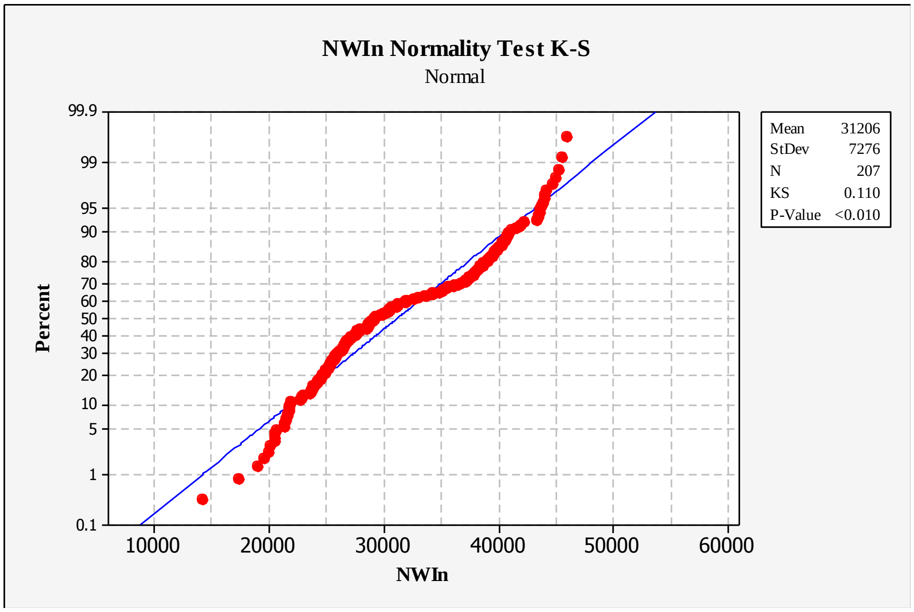

Figure D Normality Test result for the Incoming Flow for the Northwest WWTP.

The Incoming Flow for the Northwest plant is Normal according to the KS and SW Test.

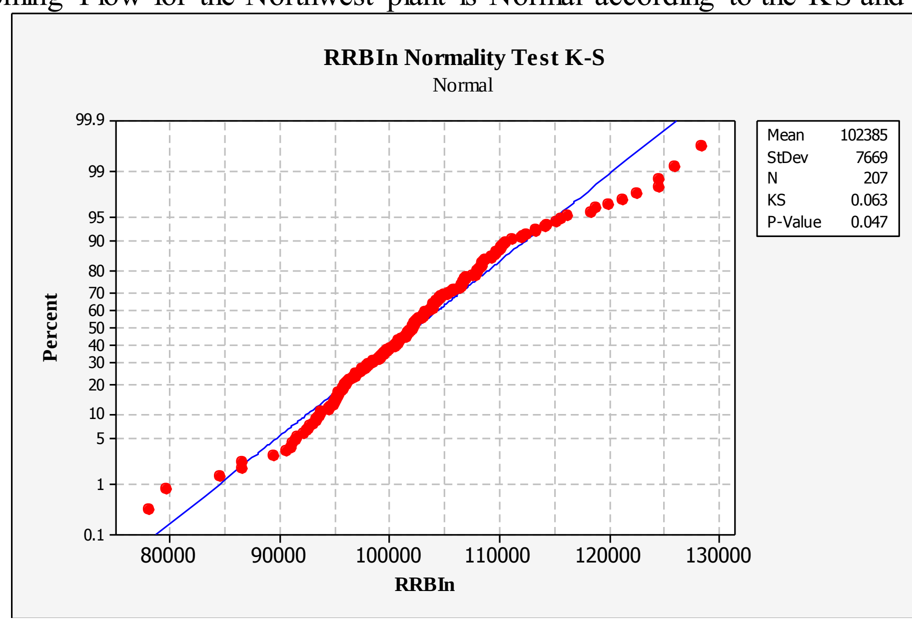

Figure E Result for the Normality Test for the incoming flow for the Robert R. Bustamante WWTP.

The incoming flow for the Robert R. Bustamante is Normal according to KS and SW Normal with departure from the blue line at both ends.

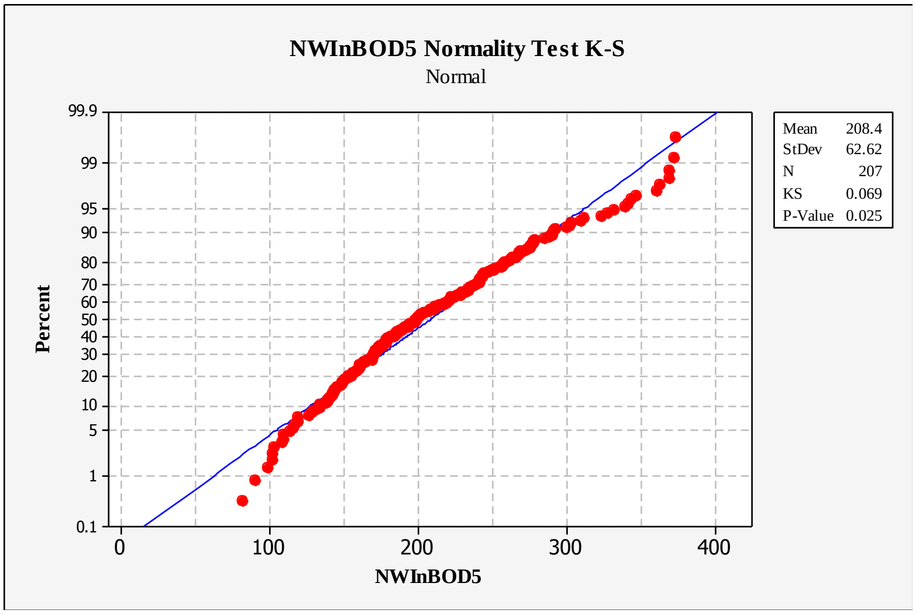

Figure F Normality test result for the BOD5 from the incoming flow of the Northwest WWTP.

BOD5 for incoming flow of the NW WWTP is normal as per the KS and SW test.

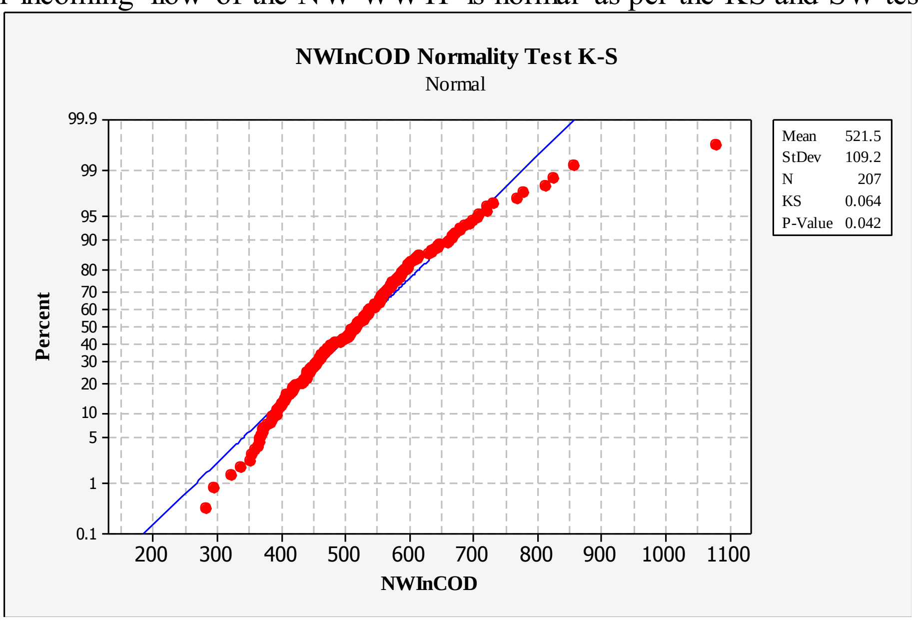

Figure G Normality test result for the COD for incoming flow for the Northwest WWTP.

COD for the incoming flow of the NW WWTP is Normal according to KS and SW tests.

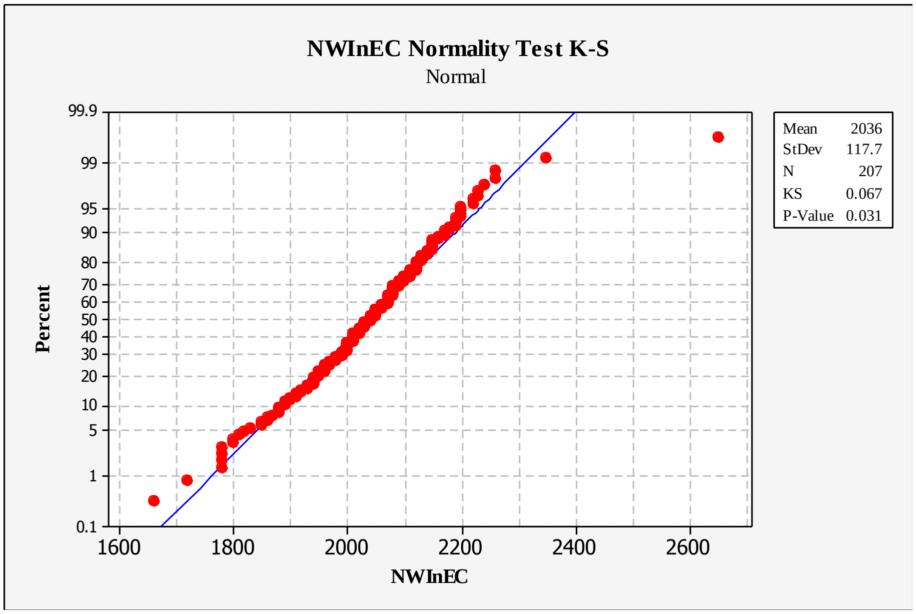

Figure H Normality Test for Electrical Conductivity of the incoming flow for the Northwest WWTP.

Electrical Conductivity for the incoming flow of the NW WWTP is Normal according to the KS and SW tests.

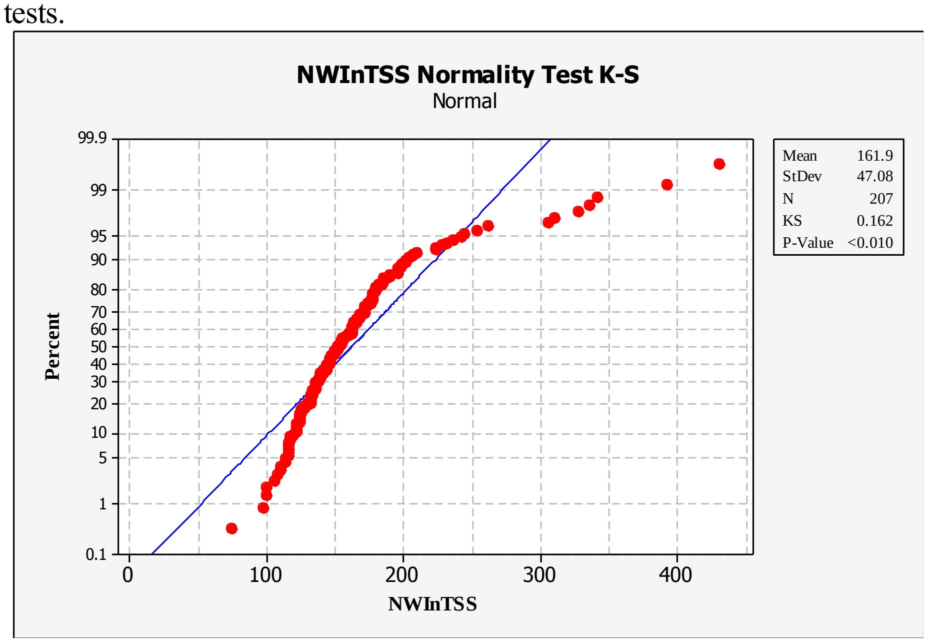

Figure I Results for the Total Suspended Solids of incoming water of the Northwest WWTP.

Total Suspended Solids for the incoming flow of the Northwest WWTP is Normal as per the KS and SW tests.

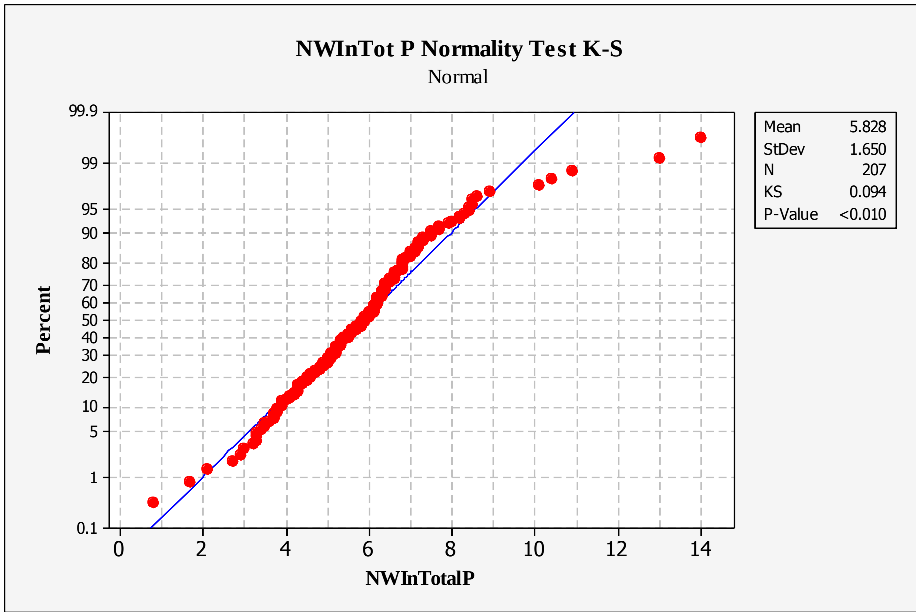

Figure J Results from the normality test for the Total Phosphorus from incoming flow for the Northwest WWTP.

Total Phosphorus for the incoming flow of the NW WWTP is Normal KS and SW tests.

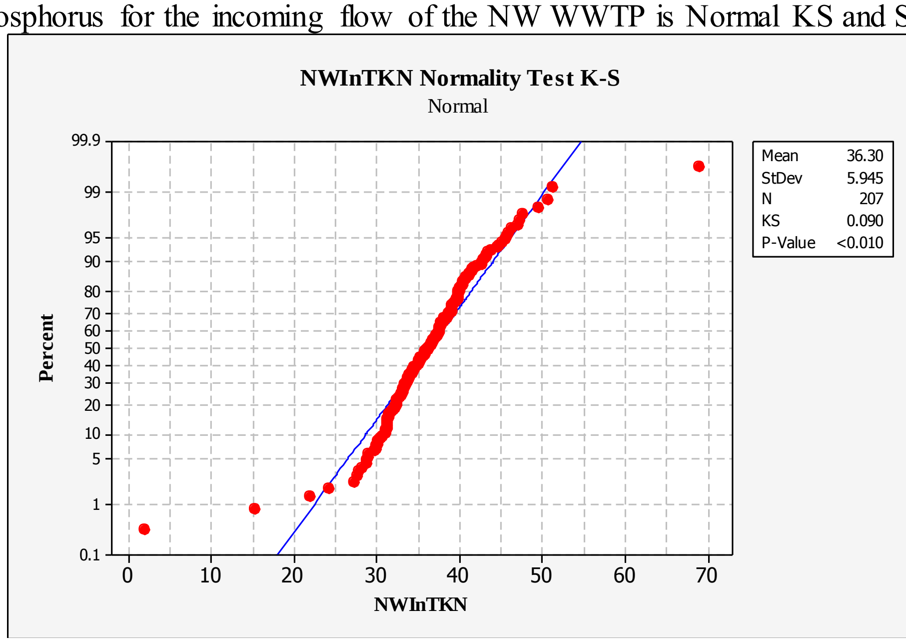

Figure K Results for the TKN of incoming flow for the Northwest WWTP.

TKN from incoming flow for the NW WWTP is Normal by the KS and SW tests.

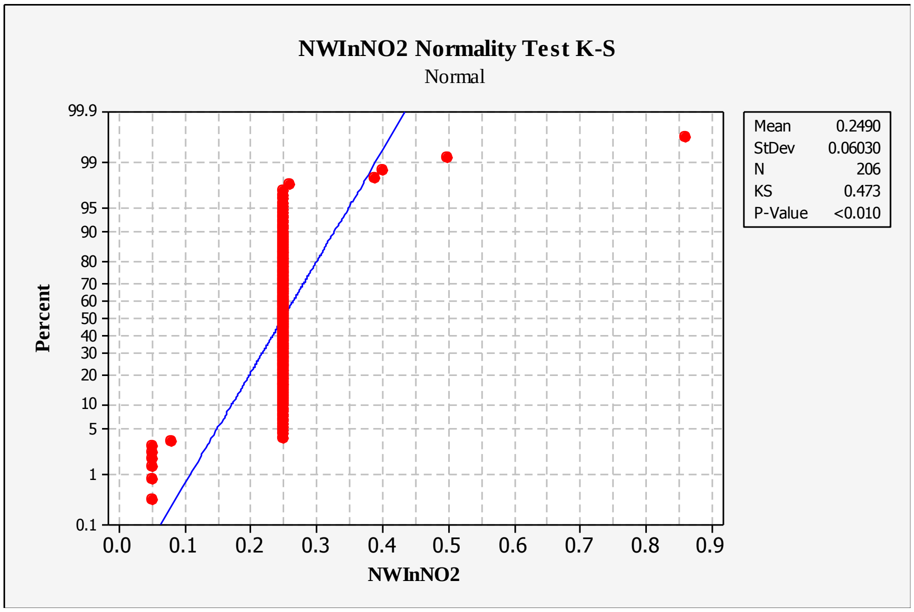

Figure L Normality Test results for the NO2 of incoming flow for the Northwest WWTP.

NO_2 from incoming flow of the Northwest WWTP is Normal as per KS and SW tests.

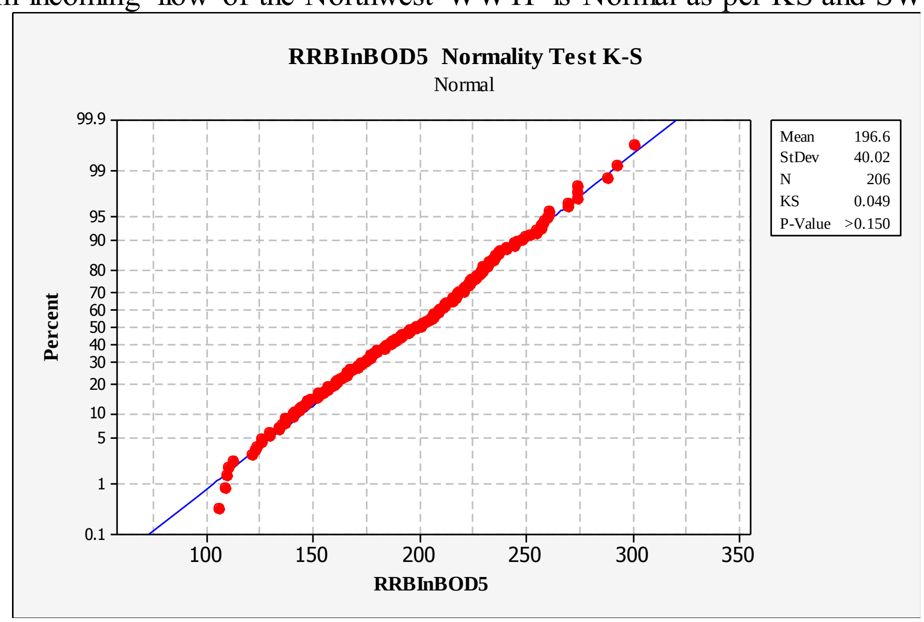

Figure M BOD5 Normality Test results of the incoming flow for the Robert R. Bustamante WWTP.

BOD5 from incoming flow of the Robert R. Bustamante WWTP is not Normal by the KS and SW tests.

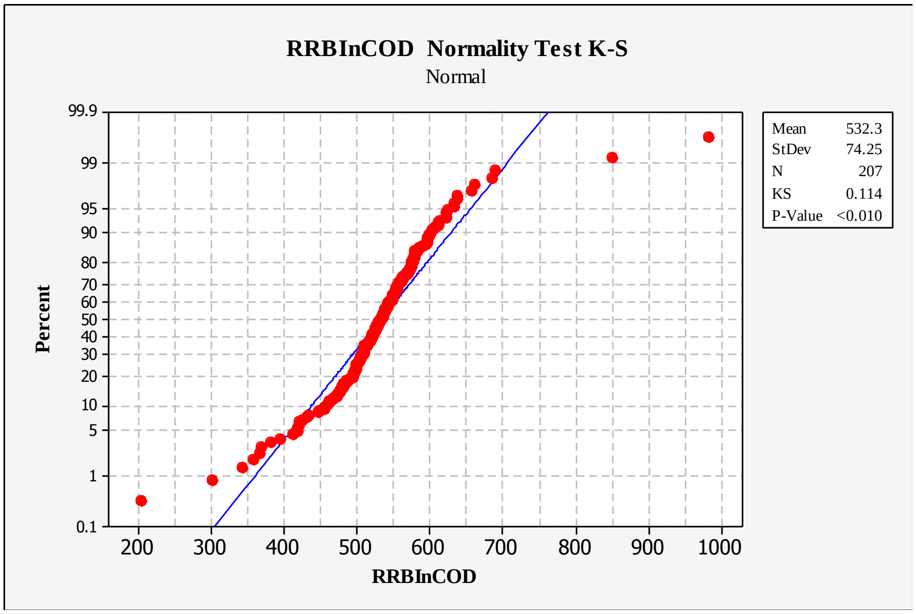

Figure N COD Normality Test results of incoming flow for the Robert R. Bustamante WWTP.

COD from incoming flow of Robert Bustamante WWTP is Normal by KS and SW tests.

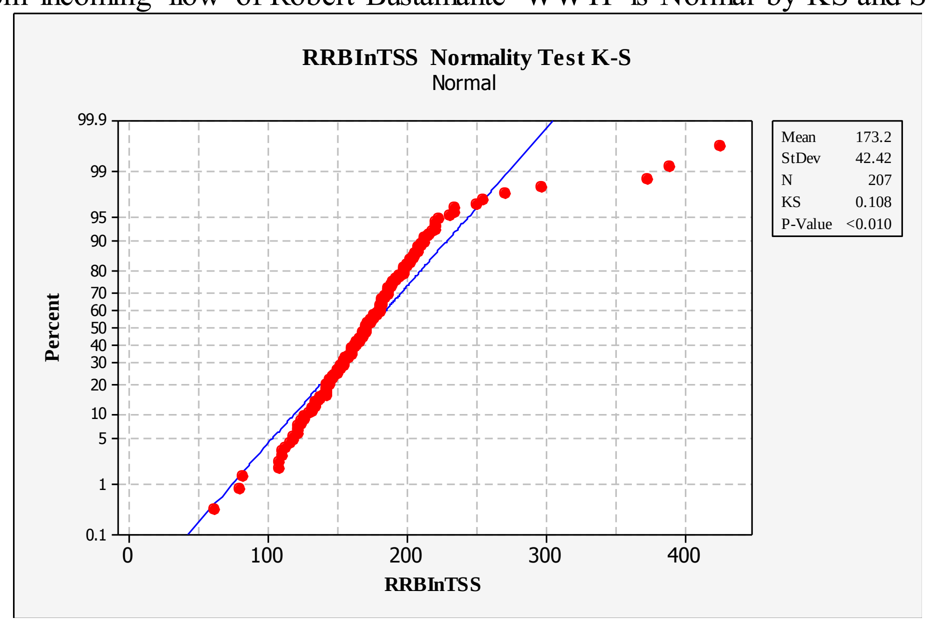

Figure O Normality Test results of incoming flow for TSS for the Robert R. Bustamante WWTP.

TSS for incoming flow of the Robert Bustamante WWTP is Normal (KS and SW tests).

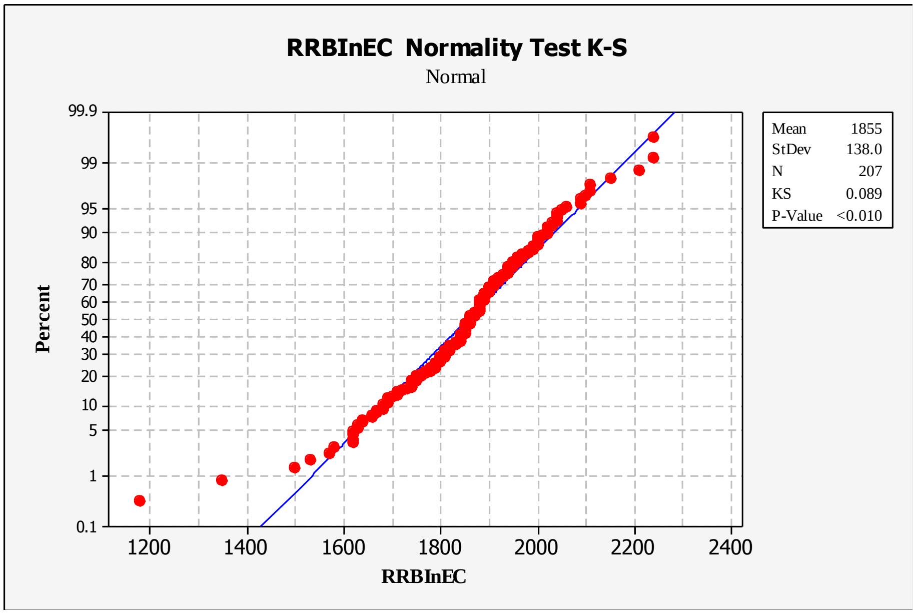

Figure P Normality Test results of incoming flow for EC of the Robert R. Bustamante WWTP.

Electrical Conductivity for incoming flow of the Robert R. Bustamante WWTP is Normal by the KS and SW tests.

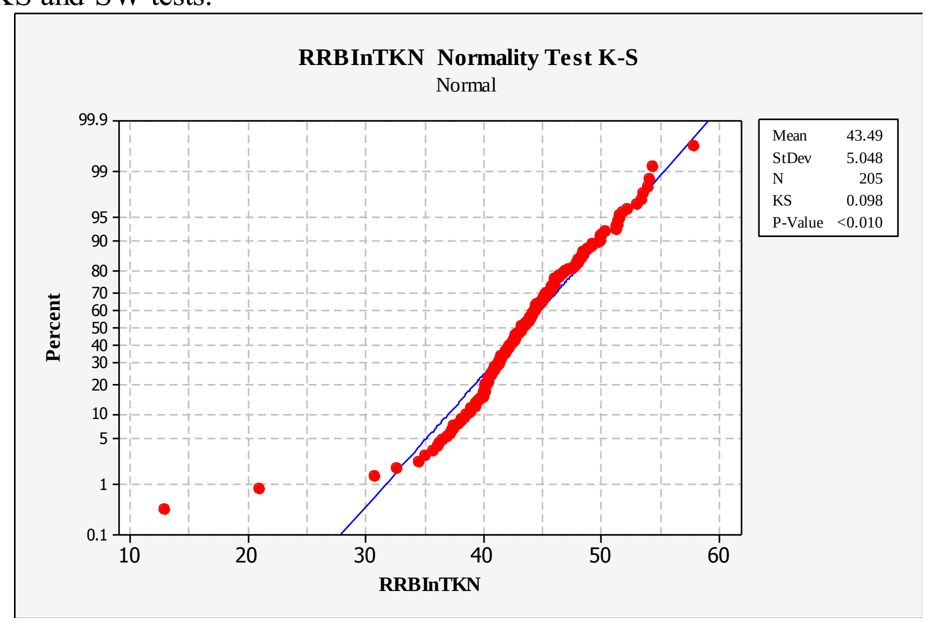

Figure Q Normality Test results for the TKN of the incoming flow for the Robert R. Bustamante WWTP.

TKN from incoming flow of the Robert R. Bustamante WWTP is Normal.

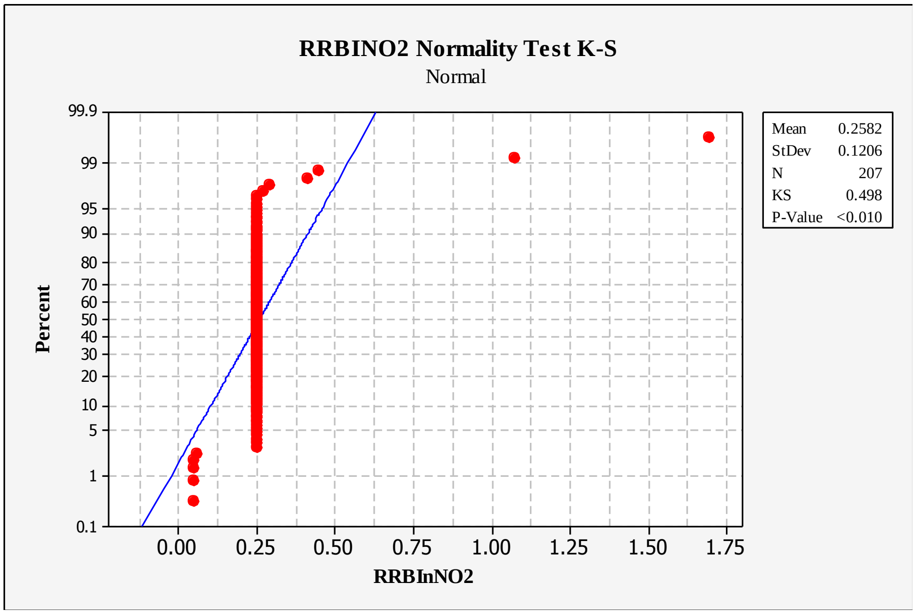

Figure R Normality Test results of the NO2 for incoming flow for the Robert R. Bustamante WWTP.

NO_2 from incoming flow of the Robert R. Bustamante is Normal.

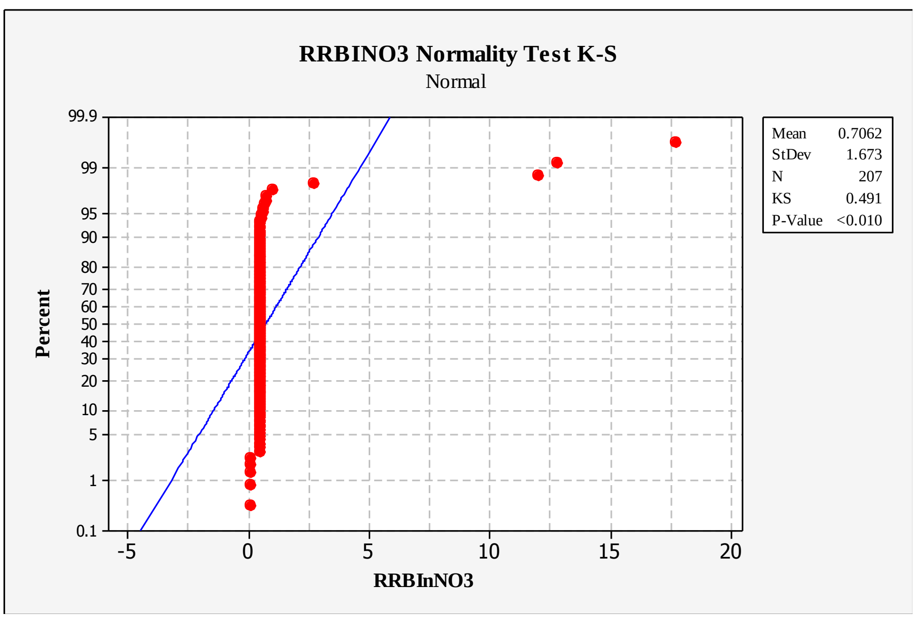

Figure S Normality Test results of the NO3 from incoming flow from the Robert R. Bustamante WWTP.

In Figure T shows, NO_3 from incoming flow of the Robert R. Bustamante WWTP is Normal by the KS and SW test.

Evidence of Normality for all variables took place in previous pages, now will proceed to examine the possible linear relationship between variables. Four Matrix Plots (Figure IIIII to Figure LLLLL in Appendix Exhibit E) explore the combination of two variables at a time, presenting a graph with the purpose of examining possible linear relationships. This serves as a visual aid to identify linear relationships between two variables. In addition to that, an analysis using bivariate correlation instead of limiting to a visual inspection only will supplement the analysis. Following the Plots, there will be matrix Pearson correlation coefficients with their respective p-values. The maximum value will be one following a sign. If the sign is negative means that if the x-axis variable increases, the other variable value will decrease. On the other hand, if the sign is positive then it represents an increasing linear relationship. That is, when the x-axis variable increases also the other variable value will increase. When the Pearson correlation coefficient is less than the cutoff of 0.05 (i.e., 5% probability that the observations are due to chance) that there is a statistically significant is linear relationship between both variables. Furthermore, everything said above about the r-value (Pearson correlation value) depends if the p-value is equal or less than 0.05. On the matrices with Pearson Correlation Coefficient whose r value around or above 0.300 and p-value 0.05 or less are in yellow. Some of those r coefficients with values about or above 0.300 with p-value equal or less than 0.05 are on Table 7. In Appendix Exhibit E, there is a supplement to the combinations between all of the variables from the database for further exploration in a subsequent study.

Table 7 Table showing part of the Pearson Correlation Coefficients.

Variable 1	Variable 2	Pearson Correlation Value r
RRBeffNO3	RRBeffNH3	-0.598
RRBeffTKN	RRBeffNO3	-0.516
NWeffTHard	NWEff	-0.486
RRBeffNH3	RRBInTHard	-0.485
RRBeffTHard	RRBeffNH3	-0.483
RRBInBOD5	Temp_avg_airport	-0.47
RRBeffNH3	Temp_avg_airport	-0.467
RRBeffNO3	RRBeffNO2	-0.448
RRBeffTKN	RRBInTHard	-0.425
RRBeffTHard	RRBeffTKN	-0.424
RRBeffBOD5	Temp_avg_airport	-0.422
RRBeffTHard	RRBInBOD5	-0.419

Variable 1	Variable 2	Pearson Correlation Value r
NWInTOTHARD	NWEff	-0.419
RRBeffTKN	Temp_avg_airport	-0.413
NWeffTotalP	NWEff	-0.402
RRBeffNH3	RRBInSO4	-0.397
RRBInTHard	RRBInBOD5	-0.392
RRBeffTHard	RRBeffNO2	-0.387
RRBeffNO2	RRBInTHard	-0.379
RRBeffNO2	Temp_avg_airport	-0.372
RRBeffNO2	RRBInSO4	-0.358
RRBInTKN	Temp_avg_airport	-0.315
RRBeffSO4	RRBInBOD5	-0.313
RRBeffTKN	RRBeffSO4	-0.309
RRBeffBOD5	RRBInTHard	-0.303
RRBeffTHard	RRBInTKN	-0.296
NWeffNO3	NWInBOD5	-0.281
RRBeffBOD5	RRBInSO4	-0.268
RRBInTDS	yearquart	-0.267
NWeffNO3	NWInCOD	-0.252
RRBeffTKN	RRBeffTDS	-0.25
RRBInTDS	YDATE	-0.248
RRBInCOD	Temp_avg_airport	-0.188
RRBInSO4	RRBInEC	0.288
RRBeffBOD5	RRBInBOD5	0.292
RRBInTotalP	RRBInTKN	0.292
RRBeffNO2	RRBeffCOD	0.293
NWInBOD5	NWEff	0.305
RRBInTotalP	RRBInCOD	0.322
RRBInTotalP	RRBInBOD5	0.327
RRBeffTKN	RRBeffNO2	0.327
RRBeffTKN	RRBInTKN	0.342
RRBeffNO2	RRBeffBOD5	0.351
RRBeffNO3	Temp_avg_airport	0.354
RRBInVSS	RRBInCOD	0.364
RRBeffTDS	RRBInTDS	0.380
RRBeffTHard	RRBInTDS	0.380
RRBInTSS	RRBInCOD	0.406
RRBeffNO3	RRBInSO4	0.423
RRBeffTKN	RRBeffBOD5	0.430
RRBInCOD	RRBInBOD5	0.437
RRBeffNH3	RRBeffBOD5	0.443

Variable 1	Variable 2	Pearson Correlation Value r
RRBeffNO3	RRBInTHard	0.453
RRBInNO3	RRBInNO2	0.480
RRBeffTSS	RRBeffBOD5	0.489
RRBeffVSS	RRBeffCOD	0.493
RRBeffCOD	RRBeffBOD5	0.495
RRBInSO4	RRBInTDS	0.510
RRBeffVSS	RRBeffBOD5	0.515
RRBInTHard	RRBInTDS	0.521
RRBInTHard	RRBInTDS	0.521
RRBeffTSS	RRBeffCOD	0.527
RRBeffSO4	Temp_avg_airport	0.531
NWInTKN	NWInBOD5	0.533
RRBInSO4	Temp_avg_airport	0.538
RRBeffTDS	RRBeffSO4	0.548
NWInTKN	NWInCOD	0.561
RRBeffTHard	RRBeffTDS	0.597
RRBInEC	RRBInTDS	0.648
RRBeffTHard	Temp_avg_airport	0.666
RRBeffTHard	RRBeffSO4	0.679
RRBInTHard	Temp_avg_airport	0.684
RRBeffTHard	RRBInSO4	0.712
RRBeffoPO4	RRBInoPO4	0.718
NWInCOD	NWInBOD5	0.737
RRBInTHard	RRBInSO4	0.773
RRBeffTKN	RRBeffNH3	0.845
NWeffTotalP	NWeffoPO4	0.874
NWEff	NWIn	0.900
RRBeffTHard	RRBInTHard	0.924
RRBeffVSS	RRBeffTSS	0.953
RRBInVSS	RRBInTSS	0.971

Table 8 depicts the combination between the left row variable and the column variable yields two numbers, r coefficient and the p-value. When the p-value is less or equal to 0.05 then the upper number applies. In the first example, a value of 0.437 is the r-coefficient and the p-value is 0.000 means there is a positive linear relationship between RRBInCOD and RRBInBOD5.

Table 8 Correlation Table for Incoming-Effluent of the RRB, BOD5, COD, NH3, ….

Correlations: RRBInBOD5, RRBInCOD, RRBInNH3, RRBInNO2, RRBInNO3, RRBInTDS, ...

	RRBInBOD5	RRBInCOD	RRBInNH3	RRBInNO2
RRBInCOD	0.437	← r-coefficient		
p-value →	0.000			
RRBInNH3	-0.007	0.131		
	0.922	0.059		
RRBInNO2	-0.098	-0.006	0.033	
	0.160	0.926	0.637	
RRBInNO3	-0.023	0.001	-0.026	0.480
	0.744	0.993	0.715	0.000
RRBInTDS	0.010	0.042	-0.015	0.034
	0.883	0.546	0.830	0.626
RRBInTKN	0.288	0.298	0.219	-0.023
	0.000	0.000	0.002	0.740
RRBInTSS	0.285	0.406	0.104	-0.072
	0.000	0.000	0.137	0.301
RRBInVSS	0.295	0.364	0.123	-0.072
	0.000	0.000	0.078	0.301
RRBInEC	0.189	0.099	0.107	0.114
	0.006	0.158	0.126	0.102
RRBInoPO4	-0.003	-0.010	0.005	-0.024
	0.970	0.884	0.947	0.727
RRBInSO4	-0.242	-0.075	-0.050	-0.033
	0.000	0.286	0.477	0.636
RRBInTotalP	0.327	0.322	0.117	-0.027
	0.000	0.000	0.094	0.701
RRBInTHard	-0.392	-0.138	-0.086	-0.011
	0.000	0.048	0.216	0.880
RRBeffBOD5	0.292	0.239	0.090	0.004
	0.000	0.001	0.200	0.960
RRBeffCOD	0.116	0.144	0.084	0.008
	0.099	0.039	0.232	0.905
RRBeffNH3	0.279	0.281	0.234	0.000
	0.000	0.000	0.001	0.996
RRBeffNO2	0.283	0.163	0.004	-0.019

	0.000	0.019	0.952	0.791
RRBeffNO3	-0.253 0.000	-0.133 0.057	-0.098 0.162	-0.201 0.004
RRBeffoPO4	-0.102 0.145	-0.007 0.925	-0.051 0.464	-0.082 0.239
RRBeffSO4	-0.313 0.000	-0.157 0.024	-0.040 0.568	-0.035 0.616
RRBeffTDS	-0.176 0.012	-0.144 0.040	-0.086 0.219	0.036 0.610
RRBeffTKN	0.285 0.000	0.212 0.002	0.133 0.058	-0.002 0.983
RRBeffTotalP	-0.018 0.801	0.090 0.198	0.009 0.896	0.003 0.969
RRBeffTHard	-0.419 0.000	-0.194 0.005	-0.126 0.071	-0.014 0.841
RRBeffTSS	0.081 0.265	0.057 0.431	0.067 0.359	0.021 0.773
RRBeffVSS	0.113 0.117	0.071 0.323	0.029 0.688	0.024 0.737

RRBInNO3 and RRBInNO2 have an r-correlation coefficient value of 0.480 and the p-value is zero. Another case is the RRBEffTHard and RRBInBOD4, their correlation value is -0.419 and p-value of zero (

Table 8). These are example of moderately strong correlations. One is increasing (positive) while the other decreasing (negative). Most of the linear relationships in this thesis are not statistically significant. Some of the correlations are weak linear correlations between 0.4 and 0.6. An example of strong correlation is RRBeffTKN and RRBeffNH3 in

Table 14 with 0.845 of coefficient of correlation and a p-value of 0.000. An additional strong correlation is in **Table 16** with NWEff and NWIn has a correlation coefficient of 0.900. This linear relationship is strong but it should be perfect (r-coefficient equals one) since the Water that enters the Wastewater Treatment Plant (NWIn) is treated to become the effluent (NWEff). It is true that residence time and other factors affect and that the incoming volume of raw water goes through the process and leaves the Wastewater Treatment Plant as treated water, but in the case of the Northwest WWTP some volume remains in the plant systematically.

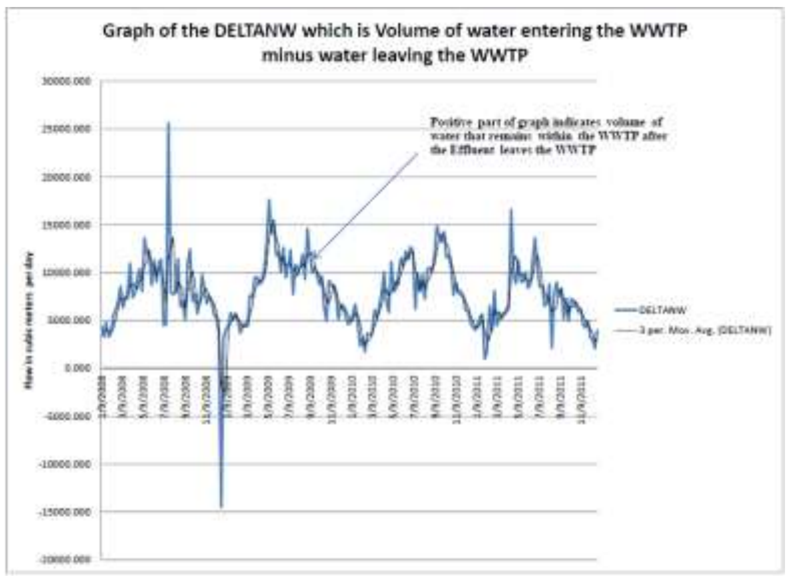

Figure T Graph that shows the difference between Incoming water minus Effluent per day.

Similar examples are the case for RRBeffoPO4 and RRBInoPO4, the coefficient is 0.718 and RRBeffSO4 and RRBInSO4 is 0.726 (both on

Table 10) RRBeffTHard and RRBInTHard with correlation coefficient of 0.924. The above-named interactions should be closer to one numerically.

The relationship of indicates RRBInVSS and RRBInTSS 0.971 have an almost perfect linear relationship (Table 9). Variables RRBeffVSS and RRBeffTDS have a coefficient of 0.953

(Table 15). We also have NWeffTotalP and NWeffoPO4 with a coefficient of 0.874 (Table 18). The rest of the relationships described in these correlation matrices are not as strong as the above described which is predominantly are weak correlations. The following matrices are for evidence and the ones that highlighted are with p-values of 0.05 or less.

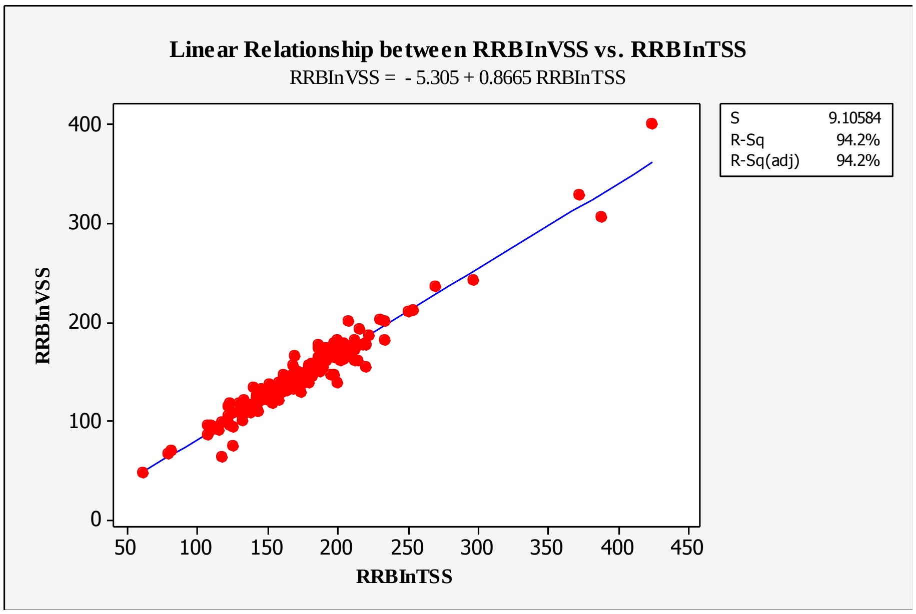

Figure U Graph showing a strong linear relationship between RRBInVSS and RRBInTSS.

From the relationships named previously which have a correlation coefficient above 0.800 and a p-value with 0.05 or less, there is the linear relationship of RRBInVSS and RRBInTSS with an estimate of goodness of fit of 94.2 % shown in Figure V. The coefficient of multiple correlations (R) is a statistical measure of how well the line approximates the real data points. In this case is one of the highest correlation coefficient from our correlation matrix.

Table 9 Correlation Table for Incoming –Effluent of RRB with TDS, TKN, TSS…

	RRBInNO3	RRBInTDS	RRBInTKN	RRBInTSS
RRBInTDS	0.017 0.805			
RRBInTKN	-0.059 0.398	0.063 0.367		

RRBInTSS	0.009 0.902	-0.061 0.384	0.288 0.000	
RRBInVSS	0.007 0.925	-0.081 0.246	0.269 0.000	0.971 0.000
RRBInEC	0.066 0.345	0.648 0.000	0.208 0.003	0.029 0.674
RRBInoPO4	-0.040 0.563	0.109 0.119	0.076 0.280	-0.135 0.052
RRBInSO4	-0.028 0.685	0.510 0.000	-0.154 0.028	-0.019 0.785
RRBInTotalP	-0.050 0.472	0.163 0.019	0.292 0.000	0.188 0.007
RRBInTHard	-0.013 0.856	0.521 0.000	-0.246 0.000	-0.115 0.100
RRBeffBOD5	-0.025 0.718	-0.095 0.177	0.231 0.001	0.143 0.041
RRBeffCOD	-0.054 0.445	-0.047 0.509	0.060 0.391	0.103 0.140
RRBeffNH3	-0.033 0.633	-0.111 0.112	0.341 0.000	0.123 0.079
RRBeffNO2	-0.046 0.511	-0.177 0.011	0.175 0.012	0.139 0.046
RRBeffNO3	-0.284 0.000	0.095 0.176	-0.161 0.022	-0.057 0.414
RRBeffoPO4	0.001 0.987	0.090 0.198	-0.038 0.593	-0.078 0.265
RRBeffSO4	-0.028 0.686	0.291 0.000	-0.200 0.004	-0.070 0.322
RRBeffTDS	-0.049 0.489	0.380 0.000	-0.109 0.121	-0.090 0.202
RRBeffTKN	-0.055 0.433	-0.104 0.141	0.342 0.000	0.092 0.190
RRBeffTotalP	-0.052 0.460	0.043 0.542	0.039 0.582	-0.024 0.728
RRBeffTHard	-0.020 0.775	0.347 0.000	-0.296 0.000	-0.126 0.071
RRBeffTSS	0.160 0.027	-0.063 0.391	0.103 0.159	0.070 0.337
RRBeffVSS	0.139	-0.066	0.134	0.110

	0.053	0.364	0.064	0.127

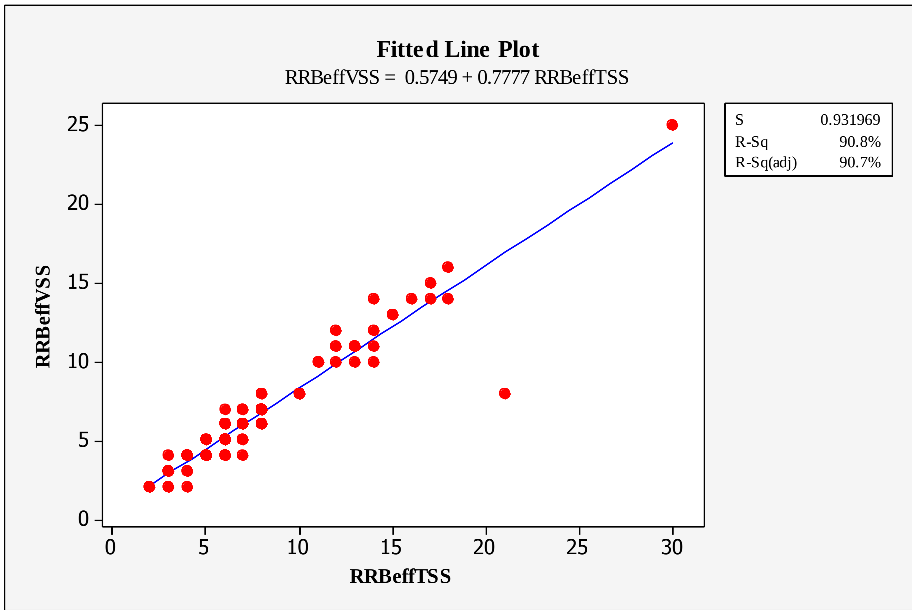

Figure V Graph showing a strong linear relationship between RRBEffVSS and RRBEffTSS.

The second highest coefficient of multiple correlations (R) is from the RREffVSS and RREffTSS relationship shown in Figure W. The value is of 90.8% still is a high value but affected by the outlier at the height of the x value of 20 distant from the blue line.

Table 10 Correlation Table for the Incoming- Effluent of the RRB EC, oPO4, SO4,…

	RRBInVSS	RRBInEC	RRBInoPO4	RRBInSO4
RRBInEC	0.028			
	0.694			
RRBInoPO4	-0.140	0.103		
	0.044	0.142		
RRBInSO4	-0.035	0.355	0.107	
	0.622	0.000	0.125	
RRBInTotalP	0.134	0.199	0.128	-0.056
	0.054	0.004	0.067	0.426

RRBInTHard	-0.139	0.288	0.088	0.773
	0.046	0.000	0.206	0.000
RRBeffBOD5	0.158	-0.019	0.033	-0.268
	0.024	0.782	0.635	0.000
RRBeffCOD	0.105	-0.027	0.108	-0.006
	0.133	0.701	0.122	0.937
RRBeffNH3	0.131	-0.051	0.044	-0.397
	0.061	0.465	0.527	0.000
RRBeffNO2	0.124	-0.118	0.089	-0.358
	0.075	0.092	0.204	0.000
RRBeffNO3	-0.070	0.039	-0.066	0.423
	0.316	0.574	0.349	0.000
RRBeffoPO4	-0.091	0.013	0.718	0.161
	0.195	0.858	0.000	0.021
RRBeffSO4	-0.074	0.188	0.084	0.726
	0.293	0.007	0.230	0.000
RRBeffTDS	-0.077	0.424	0.178	0.505
	0.272	0.000	0.010	0.000
RRBeffTKN	0.092	-0.031	0.020	-0.351
	0.191	0.658	0.776	0.000
RRBeffTotalP	-0.030	-0.035	0.057	0.073
	0.673	0.618	0.419	0.297
RRBeffTHard	-0.144	0.191	0.102	0.712
	0.039	0.006	0.144	0.000
RRBeffTSS	0.083	-0.056	-0.013	-0.038
	0.254	0.445	0.860	0.601
RRBeffVSS	0.126	-0.065	0.006	-0.063
	0.079	0.369	0.929	0.382

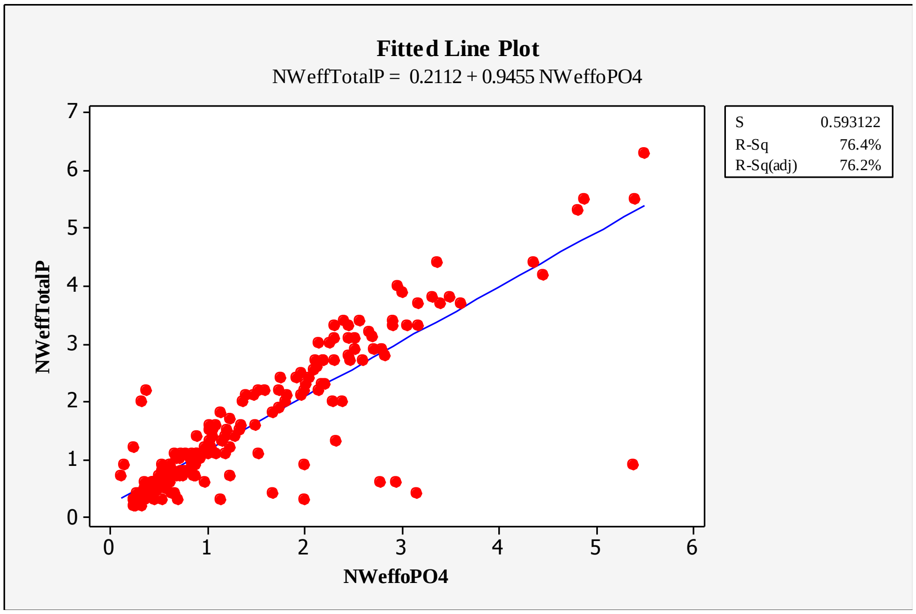

Figure W Graph showing a strong linear relationship between NWEffTotalP and NWEFFoPO4.

The third highest R squared factor is from the fitted line plot between the variables NWEffTotalP and NWEffoPO4 with a value of 76.4%. This linear relationship still is strong according to the ranges established above in previous pages. The outliers are numerous and this affects the R squared value.

In Figure Y, we find the fourth highest R squared value from the RRBEffTKN and RRBEffNH$_3$ relationship. It is of 71.3% which marginal in the sense that the set of points are not as close as the previous relationships. In this instance, we see more outliers or points that are distant from the blue line. This indicates that the projection of the line is not a good predictor for some points. Keep in mind that an R squared of 0.500 is a weak linear relationship; this is a correlation coefficient of 0.7071. In Table 7 highlighted in light blue, the reader will find the r-values that form a weak or strong linear relationship. That means that most of the values displayed in the correlation matrices are either non-linear or very weak linear relationships.

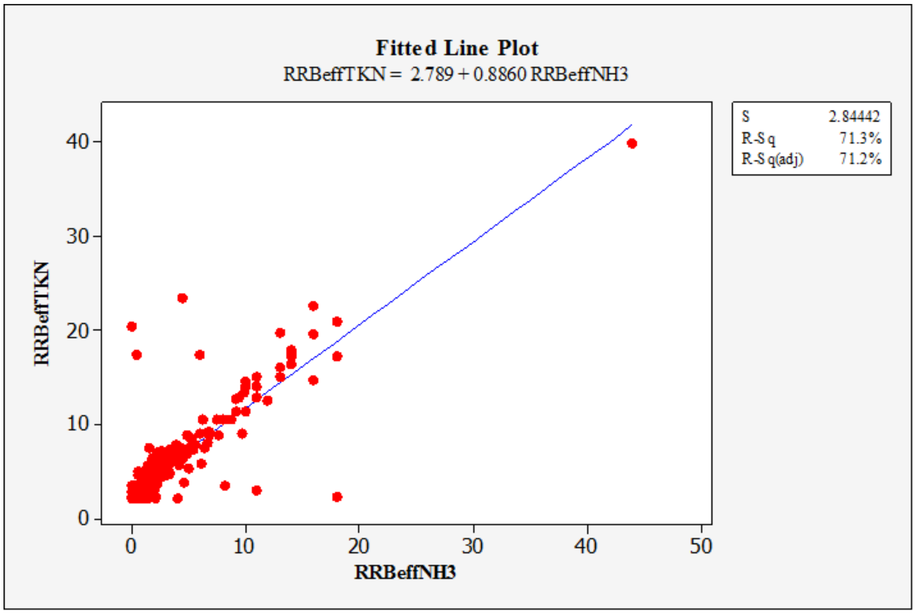

Figure X Graph depicts relationship between RRBEffTKN and RRBEffNH3.

In Figure X, there is another marginal linear relationship. The R squared is 71.3% and both variables are RRBEffTKN and RRBEffNH3. The same pattern shows with several points far from the blue line. As previously mentioned this type of patterns affects adversely the R squared value.

Using regression analysis approach we got the linear relationship between RRBIn and Temperature getting Equation 2 with an R squared of 39.3%. Details are as follows:

Regression Analysis: RRBIn versus Temp_avg_airport, YDATE

The regression equation is

Equation 1 RRBIn = - 263267 + 318 Temp_avg_airport + 8.95 YDATE

Predictor	Coef	SE Coef	T	P
Constant	-263267	40097	-6.57	0.000
Temp_avg_airport	318.22	46.88	6.79	0.000
YDATE	8.9478	0.9987	8.96	0.000

S = 6004.33   R-Sq = 39.3%   R-Sq(adj) = 38.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	4760437996	2380218998	66.02	0.000
Residual Error	204	7354608644	36052003		
Total	206	12115046640			

Source	DF	Seq SS
Temp_avg_airport	1	1866575033
YDATE	1	2893862963

Unusual Observations

Obs	Temp_avg_airport	RRBIn	Fit	SE Fit	Residual	St Resid
13	19.2	78122	96639	761	-18517	-3.11R
81	26.6	122483	103269	568	19214	3.21R
109	7.0	86601	98754	718	-12153	-2.04R
112	6.1	113247	98671	752	14576	2.45R
116	13.6	79674	101308	506	-21634	-3.62R
128	30.8	124527	107533	695	16993	2.85R
129	32.2	124489	108041	747	16447	2.76R
131	27.5	128387	106671	591	21716	3.63R
142	25.3	125927	106660	562	19267	3.22R
145	21.7	118395	105702	515	12693	2.12R
161	-11.9	92203	96012	1591	-3810	-0.66 X
205	0.3	116162	102650	1235	13511	2.30R
206	7.5	119871	105004	1013	14867	2.51R
207	5.3	121158	104351	1083	16807	2.85R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.

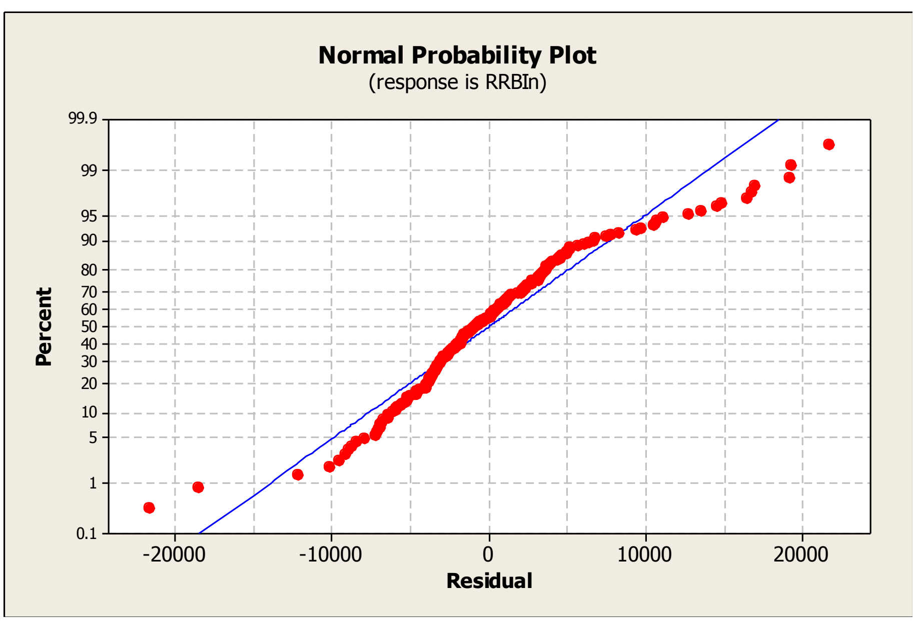

Figure Y Normal Probability Plot for the Robert R. Bustamante WWTP incoming flows.

Figure Y shows the Normal Probability Plot showing some deviation from the blue line. The data departs from the theoretical normal line from the tails of the data. As a reminder, the RRBIn parameter is Normal from the Shapiro-Wilk Test. In this instance more than 2% of data is distant from line.

Regression Analysis: NWEff versus Temp_avg_airport, YDATE

The regression equation is

Equation 2 NWEff = - 288477 - 516 Temp_avg_airport + 8.01 YDATE

Predictor	Coef	SE Coef	T	P
Constant	-288477	42579	-6.78	0.000
Temp_avg_airport	-516.25	49.79	-10.37	0.000
YDATE	8.009	1.061	7.55	0.000

S = 6375.92   R-Sq = 43.6%   R-Sq(adj) = 43.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	6417839975	3208919987	78.94	0.000
Residual Error	204	8293077914	40652343		
Total	206	14710917889			

Source	DF	Seq SS
Temp_avg_airport	1	4099208073
YDATE	1	2318631901

Unusual Observations

Obs	Temp_avg_airport	NWEff	Fit	SE Fit	Residual	St Resid
41	15.8	34661	21623	662	13039	2.06R
112	6.1	13832	30611	799	-16779	-2.65R
115	12.8	13576	27346	560	-13770	-2.17R
161	-11.9	27971	42651	1689	-14680	-2.39RX
170	25.6	39265	23822	720	15443	2.44R
178	29.1	35081	22412	844	12669	2.00R
179	28.6	35670	22752	834	12918	2.04R
180	30.8	35400	21672	901	13728	2.17R
184	27.8	37073	23445	839	13627	2.16R
185	33.0	37475	20791	993	16684	2.65R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.

A residual plot is a graph depicting the residuals (difference between theoretical value and the actual data point) on the vertical axis and the independent variable on the horizontal axis.

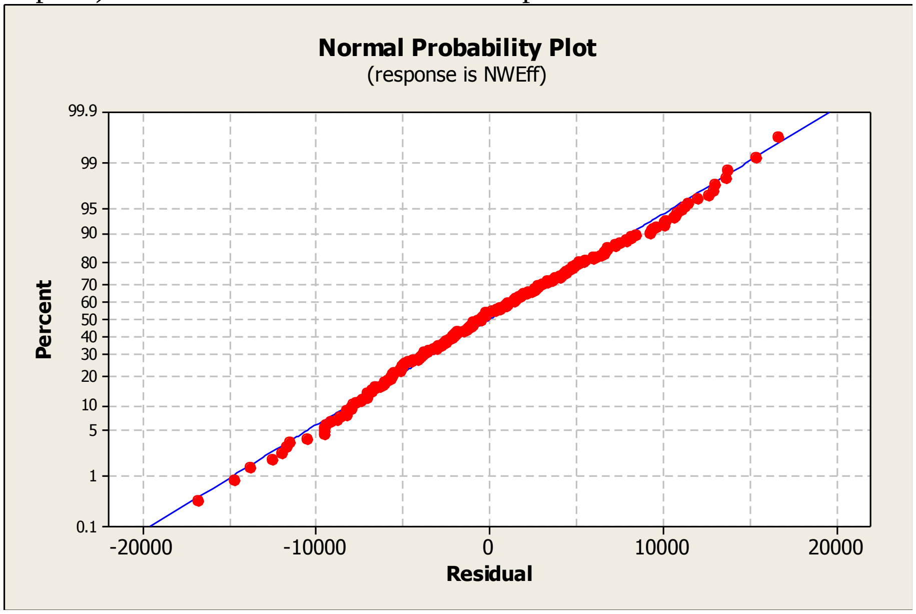

Figure Z Normal Probability Plot showing normality for the Effluent of the Northwest WWTP.

Figure Z shows the Normal Probability Plot for the Effluent of the Northwest Wastewater Treatment Plant. Notice that the flow is Normal with very small deviations from the blue line.

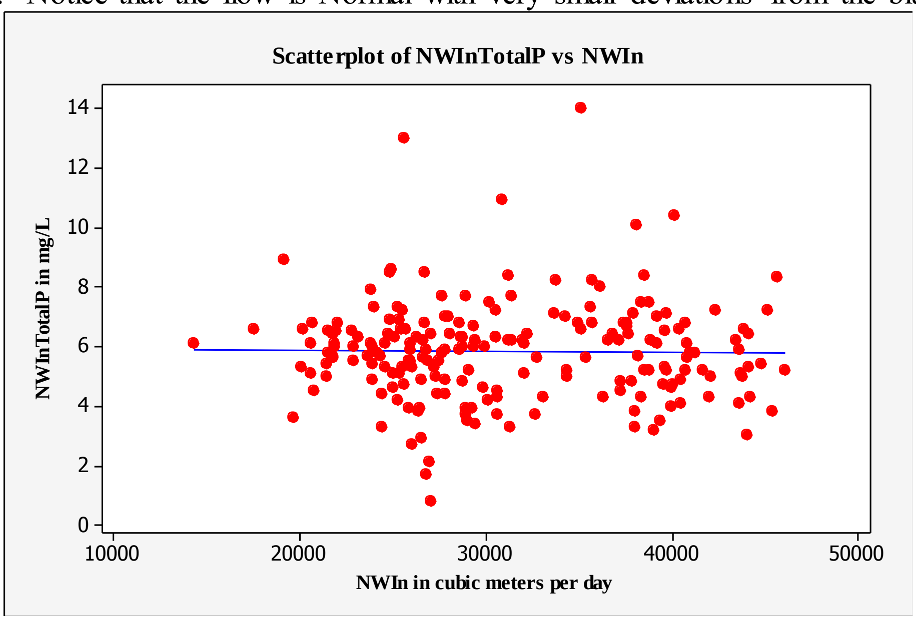

Figure AA Scatterplot of NWInTotalP vs. NWIn.

Figure AA shows a disperse array of points with a horizontal line as a trend line.

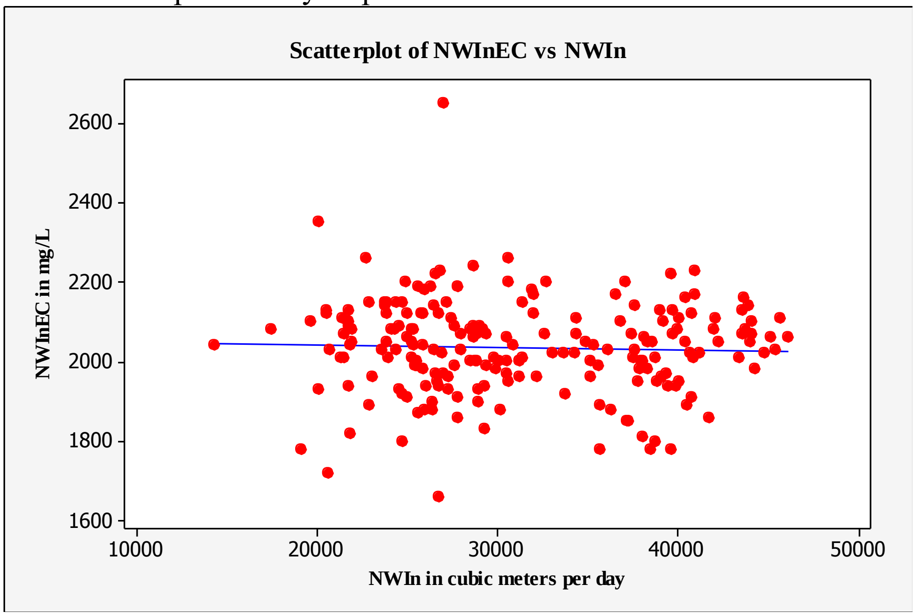

Figure BB Scatterplot of NWInEC vs. NWIn.

Figure BB shows another dispersed array of data points with a horizontal trend line.

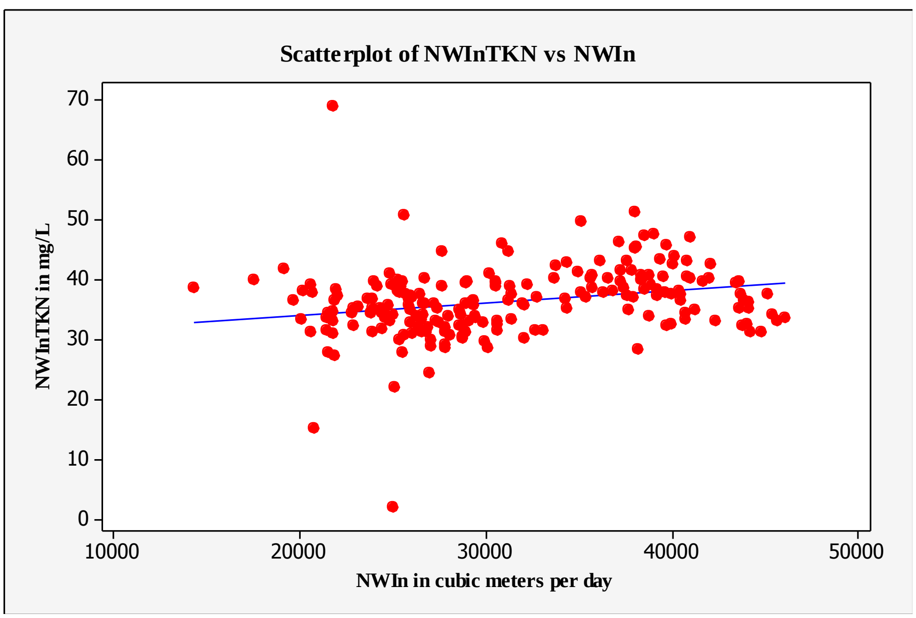

Figure CC Scatterplot of NWInTKN vs. NWIn.

Figure CC shows an R squared of 6.1%, which means that residuals are high and that the relationship is non-linear.

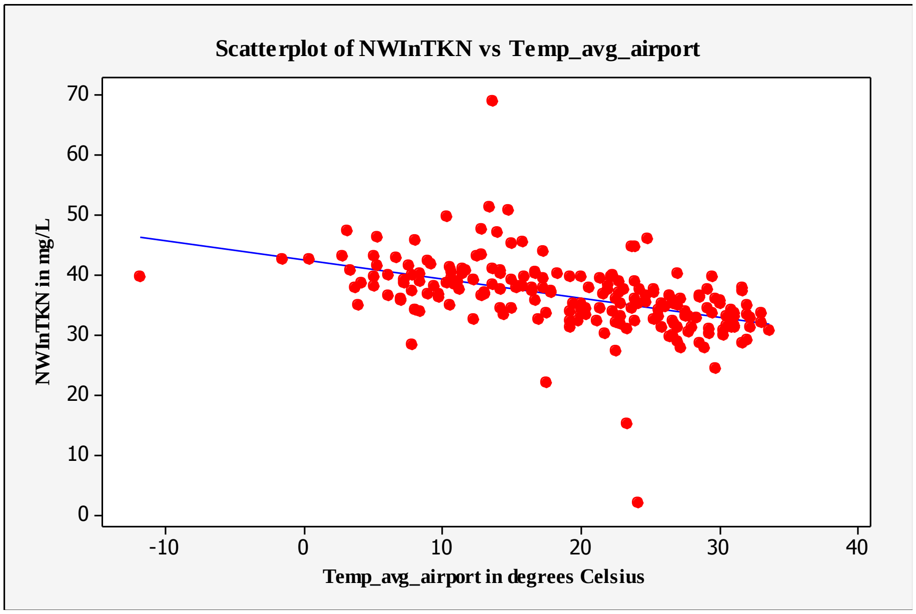

Figure DD Scatterplot of NWInTKN vs. Temperature.

Figure DD shows the graph for NWInTKN = 42.53 - 0.3219 Temp_avg_airport with an R squared of 23.4% with some of the residuals high in value.

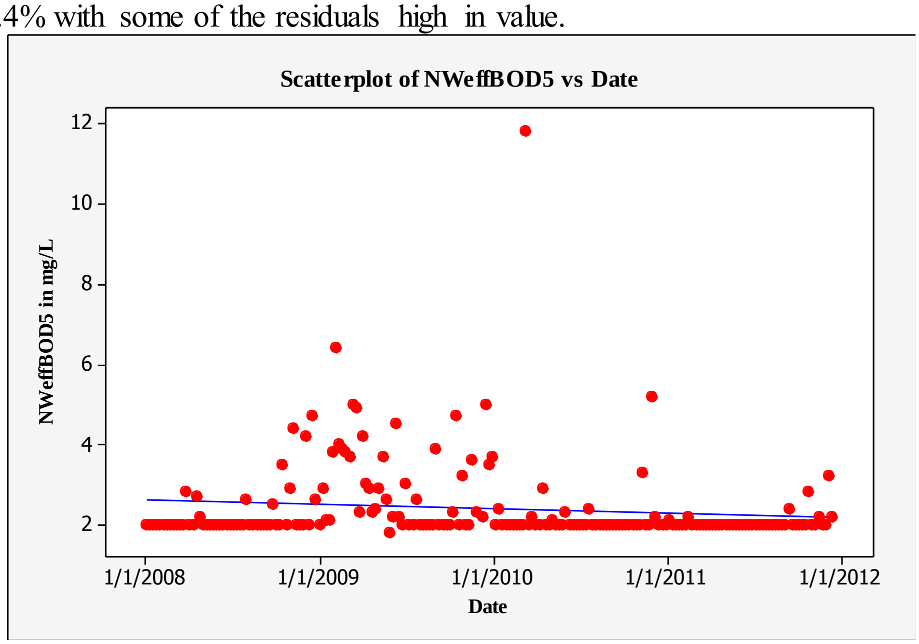

Figure EE Scatterplot of NWEffBOD5 vs. Date.

Figure EE shows the linear relationship NWeffBOD5 = 14.32 - 0.000297 Date with an R squared of 1.6%. The Seven Day Limit from TPDES is 15 mg/L.

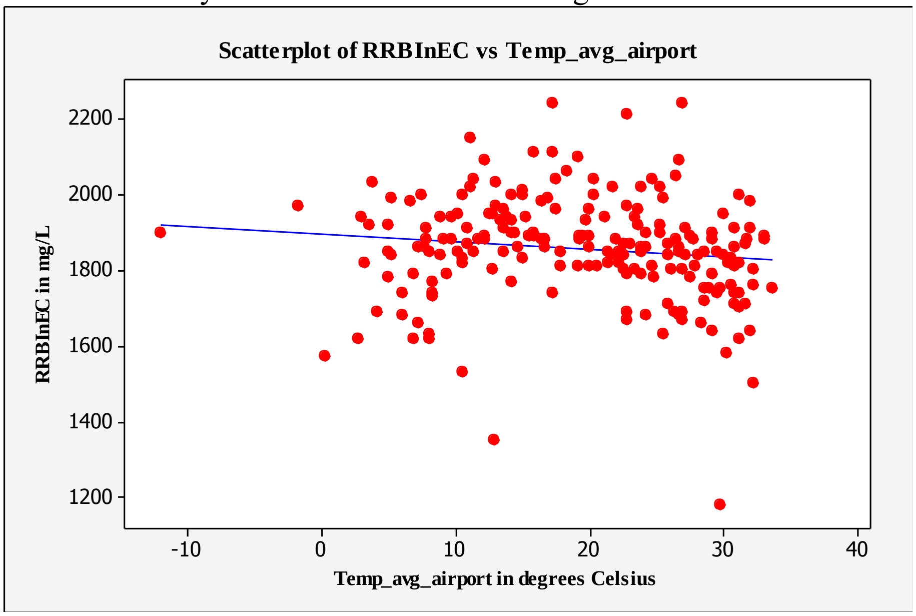

Figure FF Scatterplot of RRBInEC vs. Temperature.

Figure FF shows the linear relationship RRBInEC = 1896 - 2.108 Temp_avg_airport with an R squared of 1.9%.

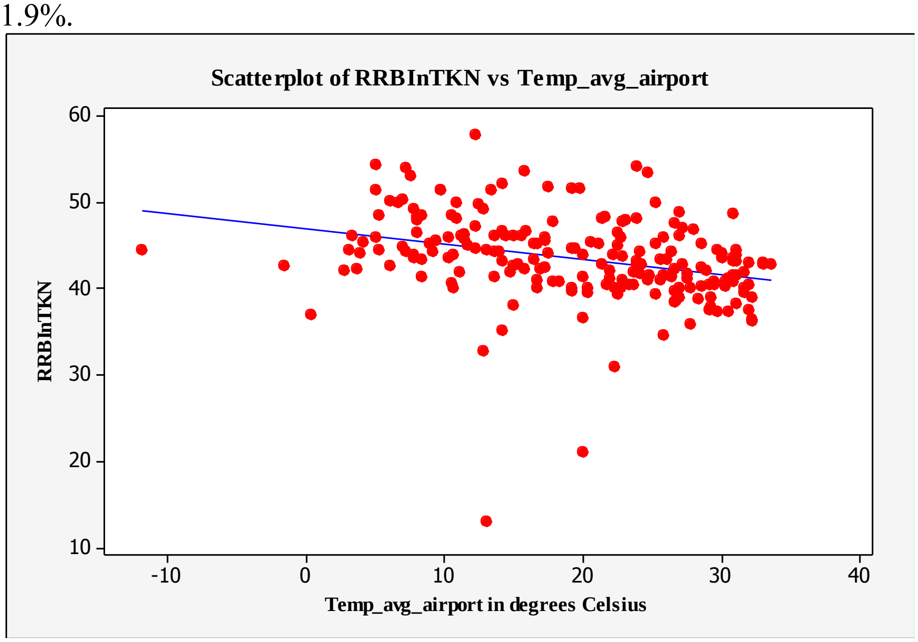

Figure GG Scatterplot of RRBInTKN vs. Temperature.

Figure GG shows the linear relationship RRBeffTKN = 10.80 - 0.2458 Temp_avg_airport with an R squared of 17%.

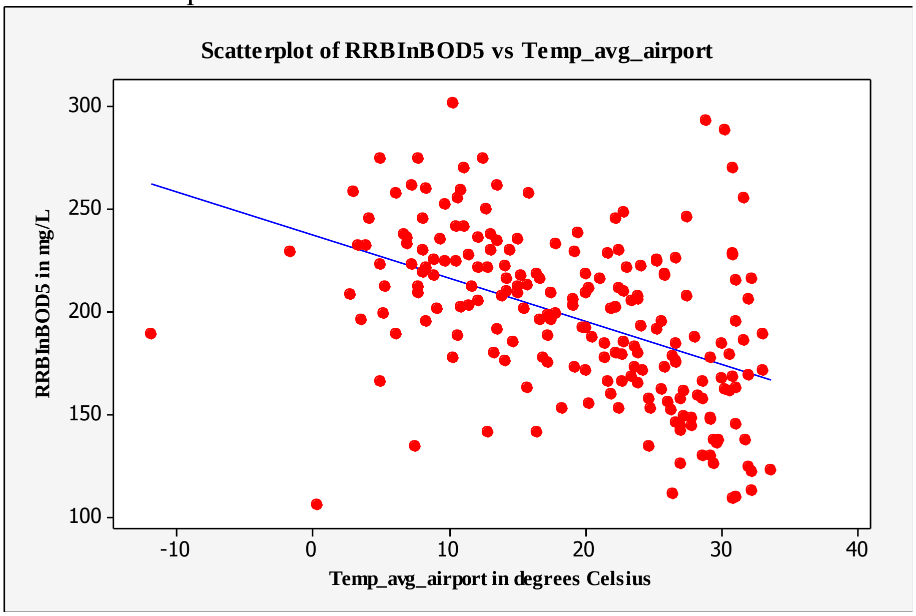

Figure HH Scatterplot of RRBInBOD5 vs. Temperature.

Figure HH shows the RRBInBOD5 = 237.3 - 2.102 Temp_avg_airport linear relationships with an R squared of 22.1%.

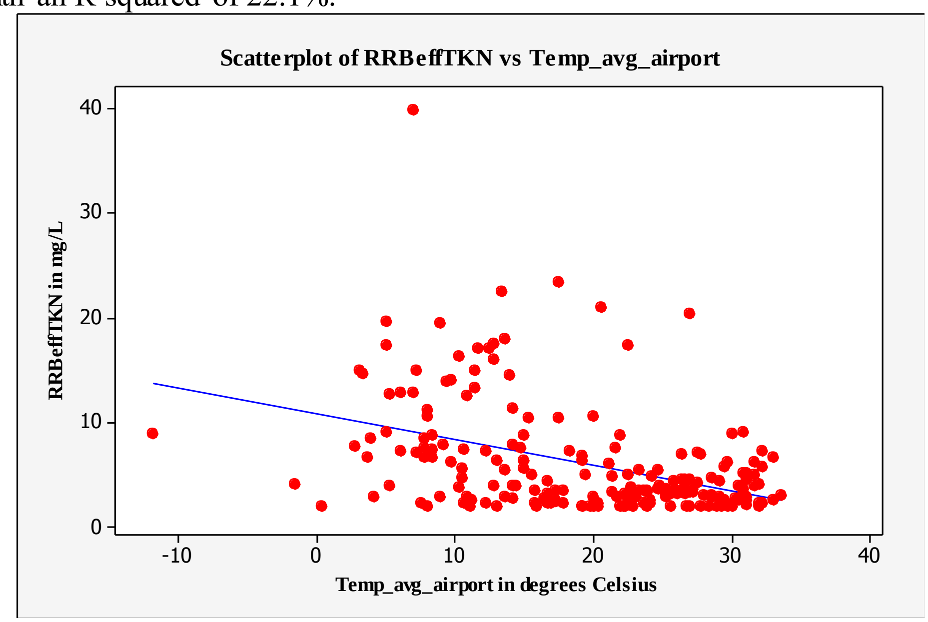

Figure II Scatterplot of RRBEffTKN vs. Temperature.

Figure II shows the relationship RRBeffTKN = 10.80 - 0.2458 Temp_avg_airport with an R squared 17%.

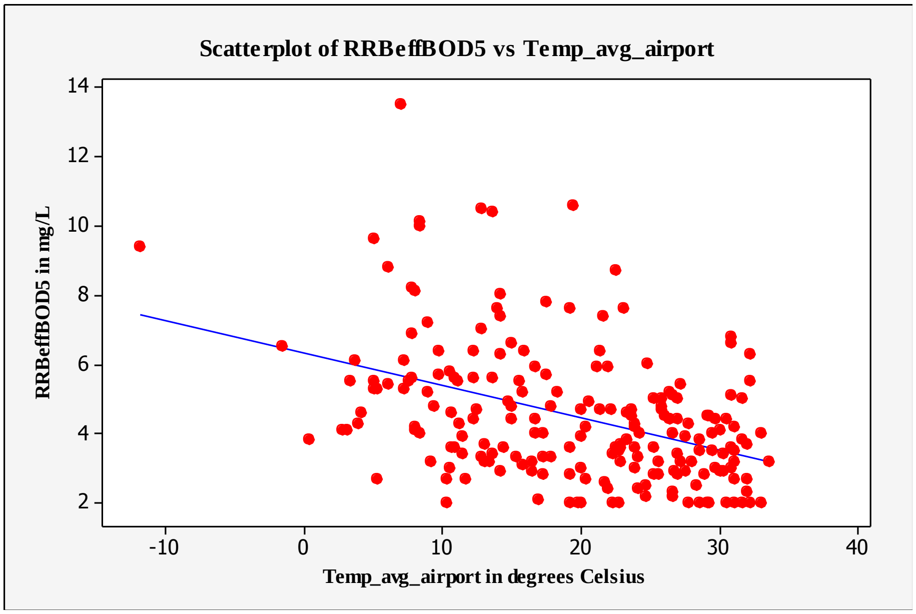

Figure JJ Scatterplot of RRBEffBOD5 vs. Temperature.

In Figure JJ scatter plot shows RRBeffBOD5 = 6.306 - 0.09305 Temp_avg_airport as the linear relationship of that set of points. The R squared is 17.8%.

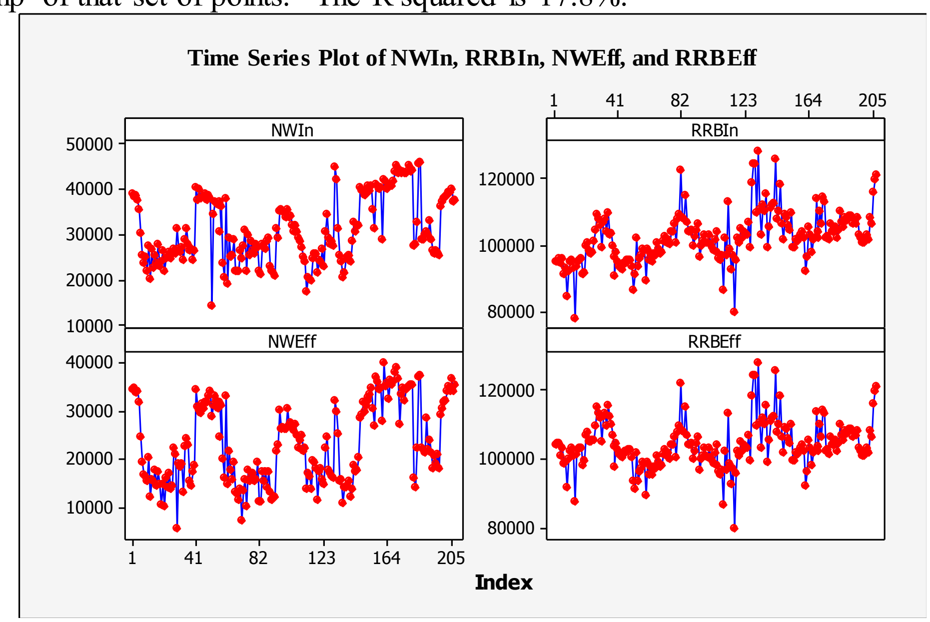

Figure KK Time Plot of NWIn, RRBIn, NWEff, and RREff.

Figure KK shows an index time series of incoming and effluent for both WWTP. It is noticeable that Effluent from Northwest WWTP is different from incoming flow.

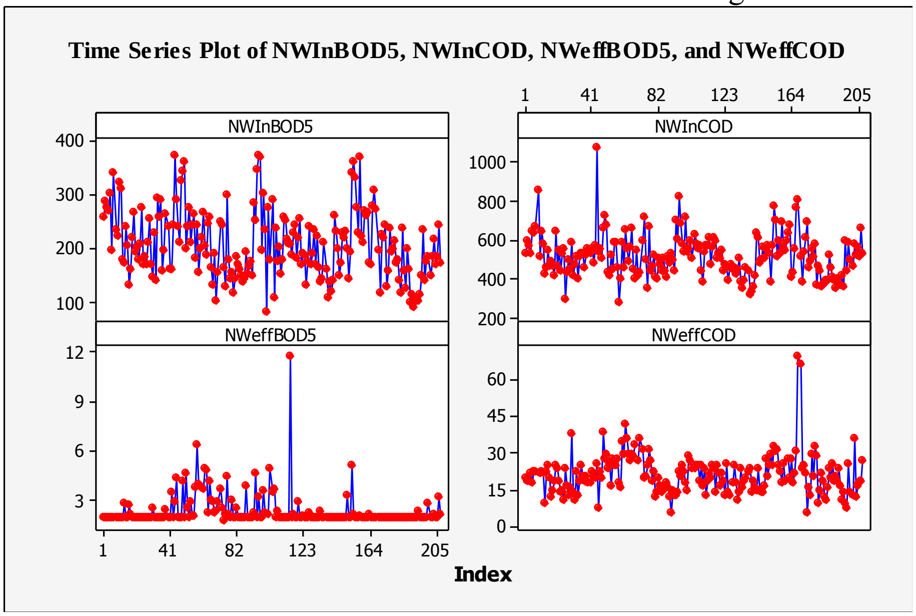

Figure LL Time Plot of NWInBOD5, NWInCOD, NWEffBOD5, and NWEffCOD.

Figure LL shows Incoming and Effluent concentrations for the BOD5 and COD for the Northwest plant. COD is as twice as the BOD5 incoming into the plant.

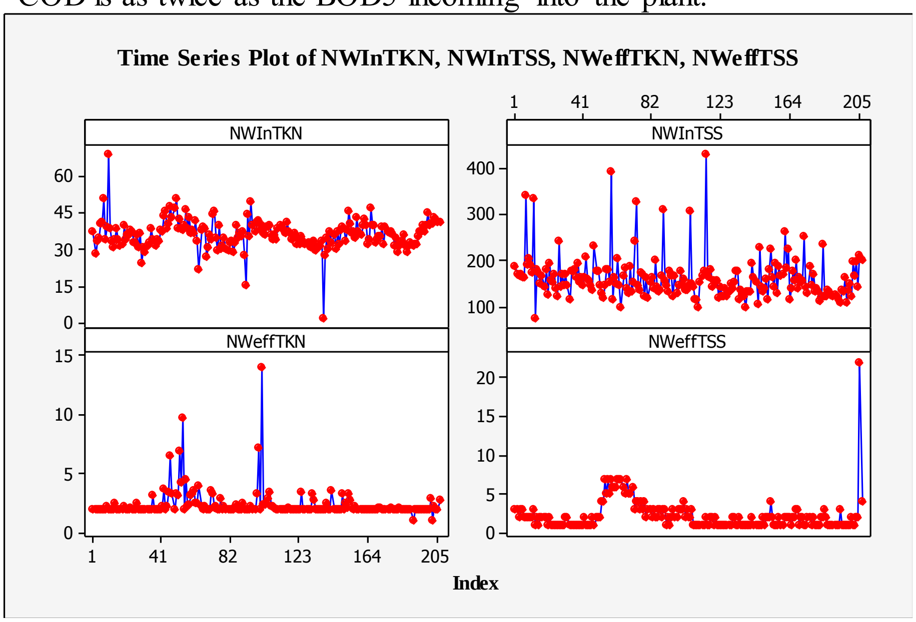

Figure MM Time Plot of NWInTKN, NWInTSS, NWEffTKN, and NWEffTSS.

Figure MM show that numerically the Northwest WWTP has less concentration in TKN and TSS than the Robert R. Bustamante.

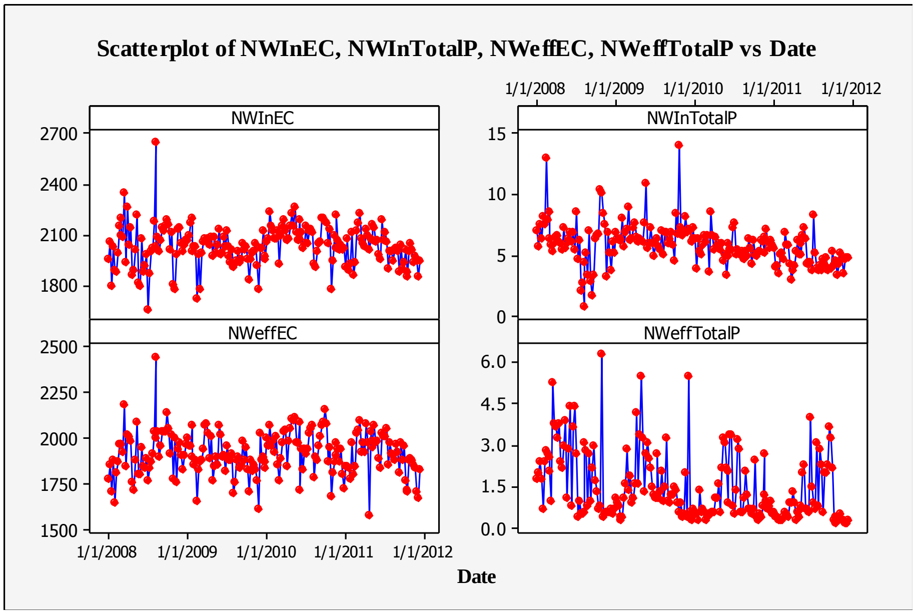

Figure NN Time Plot of NWInEC, NWInTotalP, NWEffTotalP, and NWEffEC.

Figure shows very small decrease in the EC for the Northwest WWTP, while the TotalP decreases numerically to half of original concentration.

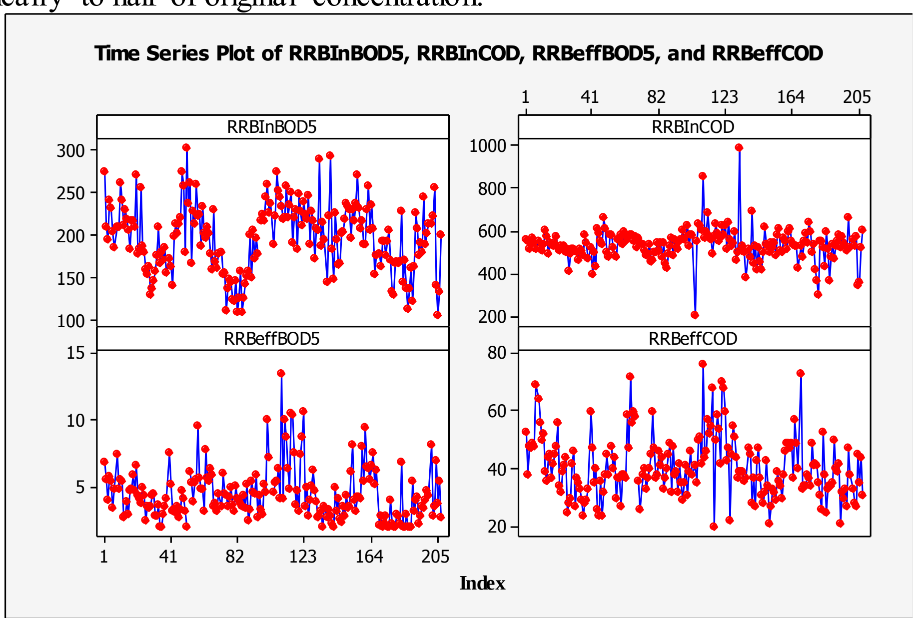

Figure OO Time Plot of RRBInBOD5, RRBInCOD, RRBEffBOD5, and RRBEffCOD.

COD concentration is higher than BOD5 incoming for the RRB, and BOD5 from the Effluent below the Seven-Day limit of 15 mg/L. COD effluent is very variable from day to day.

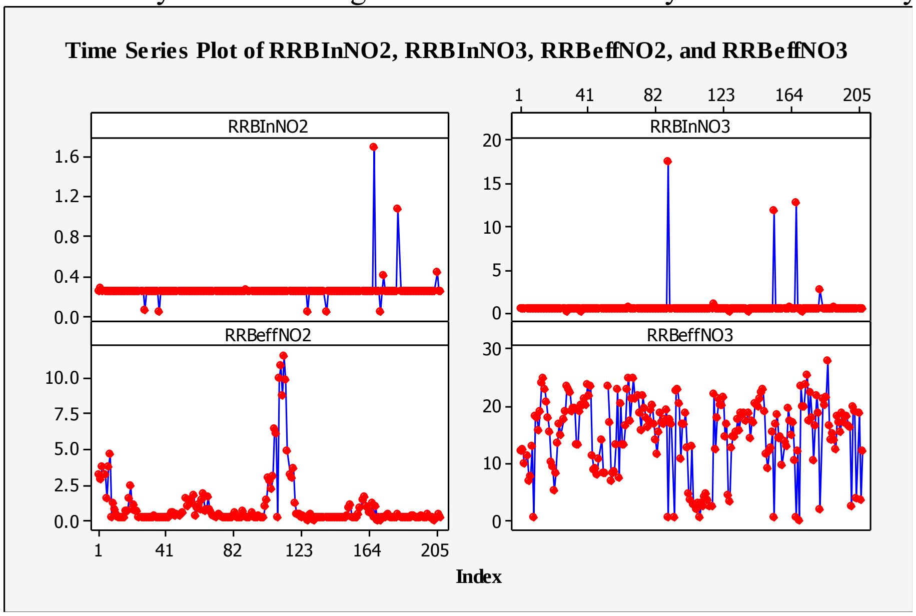

Figure PP Time Plot of RRBInNO2, RRBInNO3, RRBEffNO2, and RRBEffNO3.

The measured efficiencies of removal for NO_2 and NO_3 are negative. The highest value for NO_2 efficiency removal is -14 % and for the NO_3 the highest value is -122%. Figure QQ shows on both instances the increase in concentration of the NO_2 and dramatically for the NO_3.

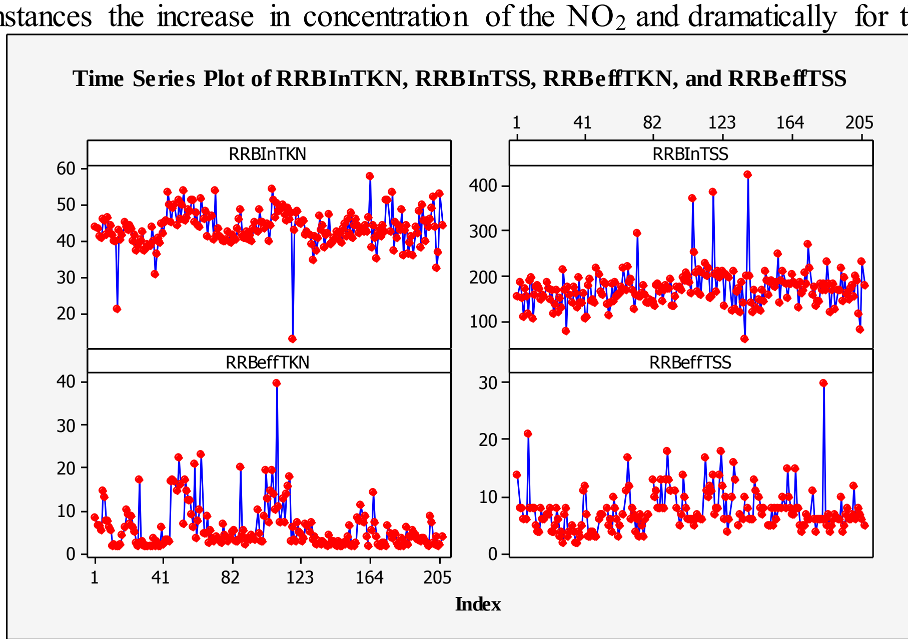

Figure QQ Time Plot of RRBInTKN, RRBInTSS, RBNEffTKN, and RRBEffTSS.

Figure QQ shows TKN Effluent concentrations above the Seven-Day limit of 7 mg/L.

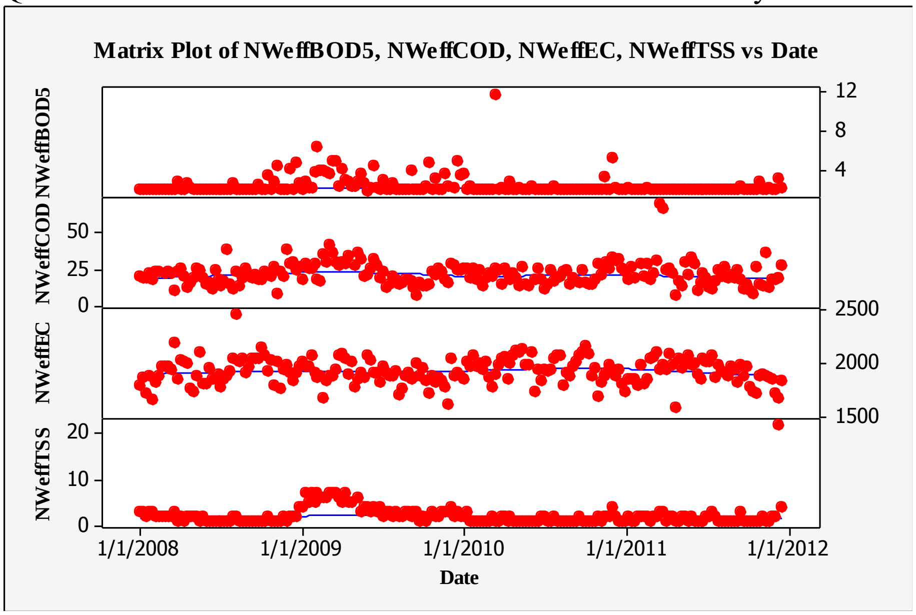

Figure RR Matrix Plot of NWEffBOD5, NWEffCOD, NWEffEC, NWEffTSS vs. Date.

Figure RR shows effluent below the Seven-Day limit for BOD5 (15 mg/L) and TSS (25 mg/L) for years 2008 to 2011 for NW WWTP. There is no limit set for COD and EC.

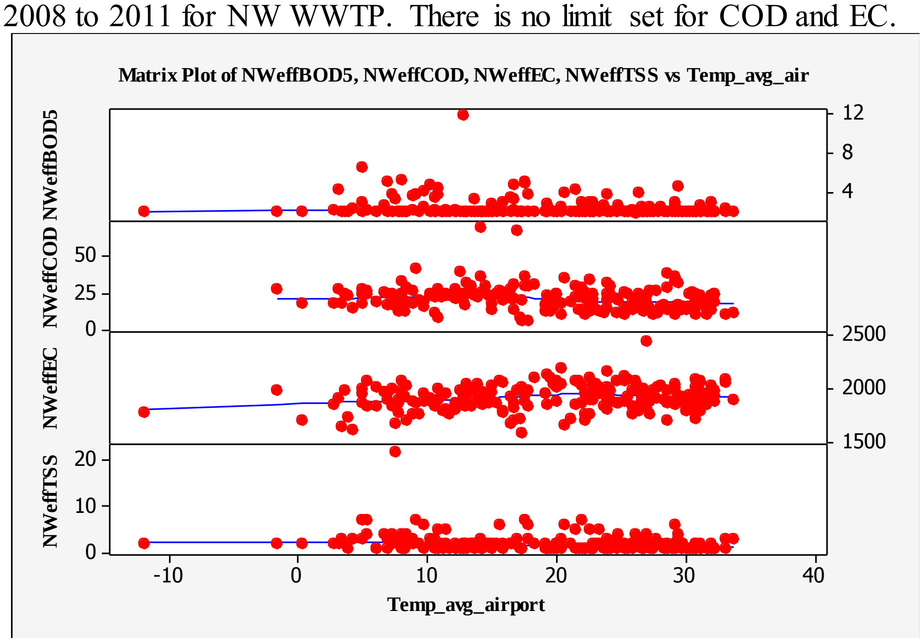

Figure SS Matrix Plot of NWEffBOD5, NWEffCOD, NWEffEC, NWEffTSS vs. Temperature.

Figure SS shows closer together for BOD5 as temperature increases for Effluent of NW Wastewater Treatment Plant.

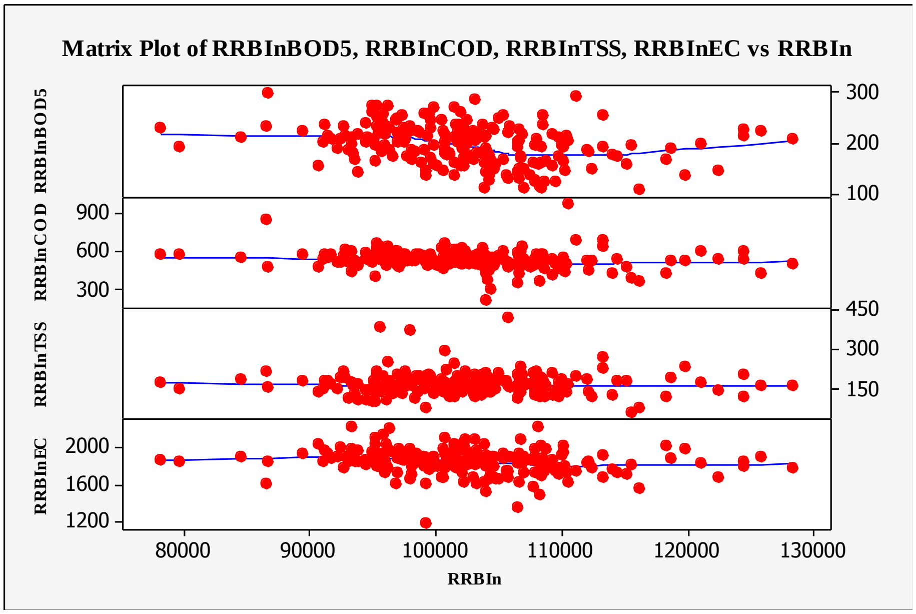

Figure TT Matrix Plot of RRBInBOD5, RRBInCOD, RRBInTSS, RRBInEC vs. RRBIn.

Figure TT shows that most of the cases concentrate between the flow of 90,000 to 115,000 cubic meters per day for BOD5, COD, TSS, and EC.

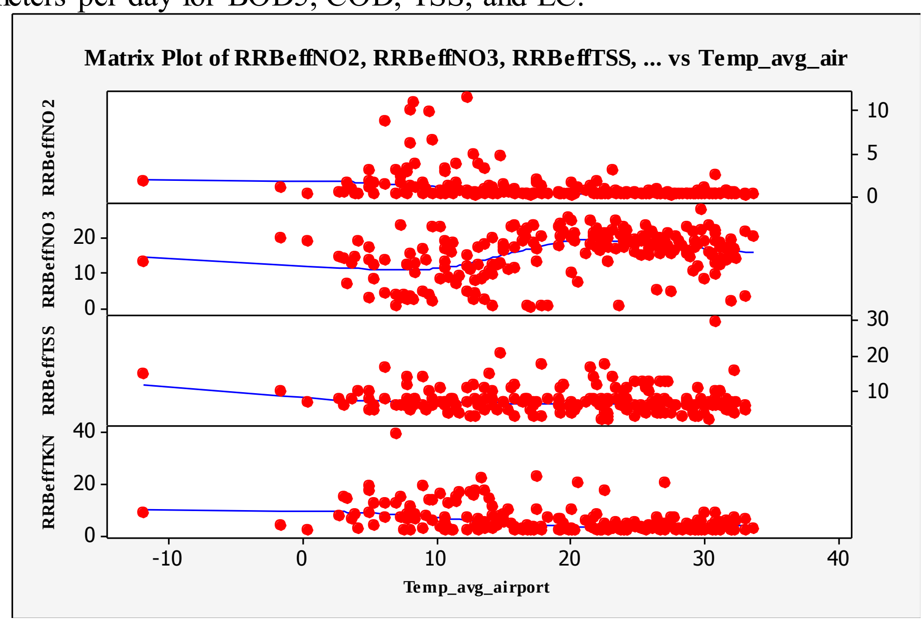

Figure UU Matrix Plot of RRBEffNO2, RRBEffNO3, and RRBEffTSS vs. Temperature.

Figure UU shows a maximum of concentration for NO_2 around 10°C.

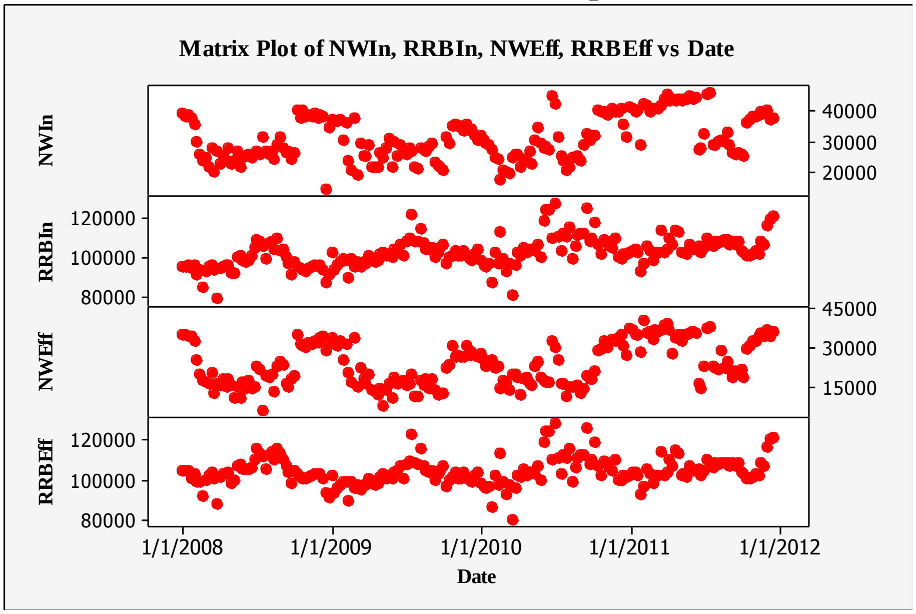

Figure VV Matrix Plot of NWIn, RRBIn, NWEff, RRBEff vs. Date.

Figure VV shows the flow in cubic meters per day of both WWTP with respect to time.

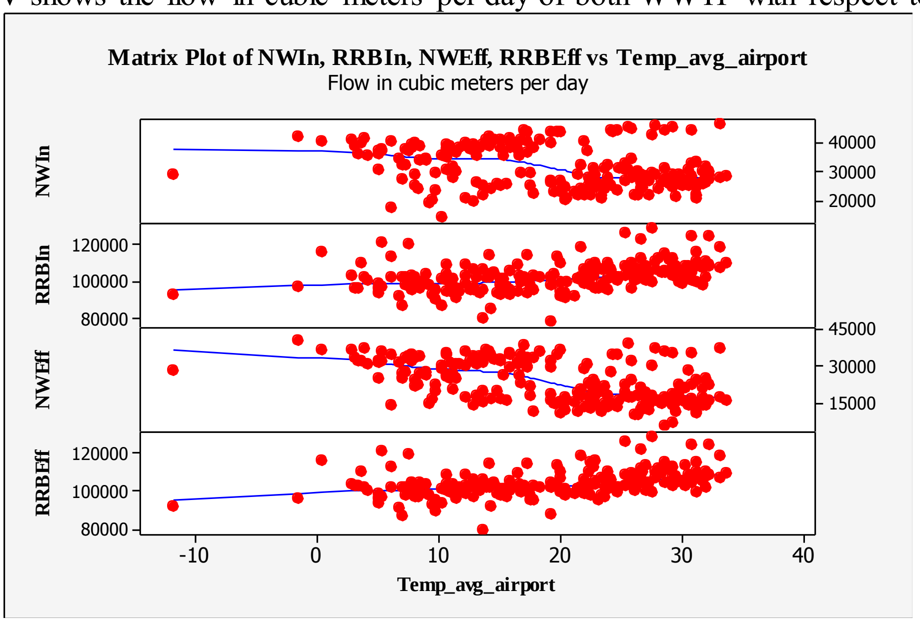

Figure WW Matrix Plot of NWIn, RRBIn, NWEff, RRBEff vs. Date.

Figure WW shows linear relationship NWEff = 32986 - 499.4 Temp_avg_airport with an R squared of 27.9% decreasing, and RRBEff = 97843 + 325.1 Temp_avg_airport with R squared

of 17.9% with positive slope.

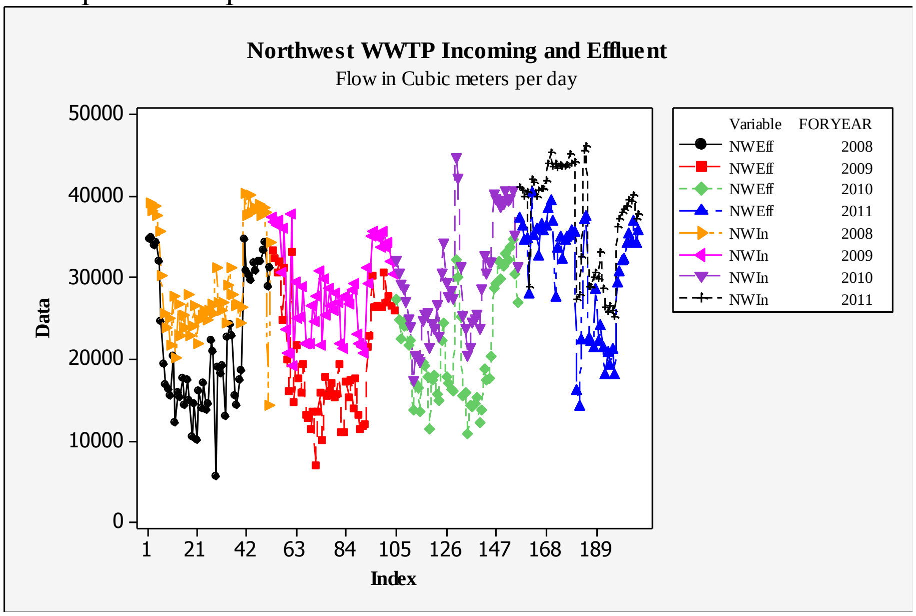

Figure XX Northwest WWTP Incoming and Effluent.

Figure XX shows the Incoming and Effluent for NW WWTP per year.

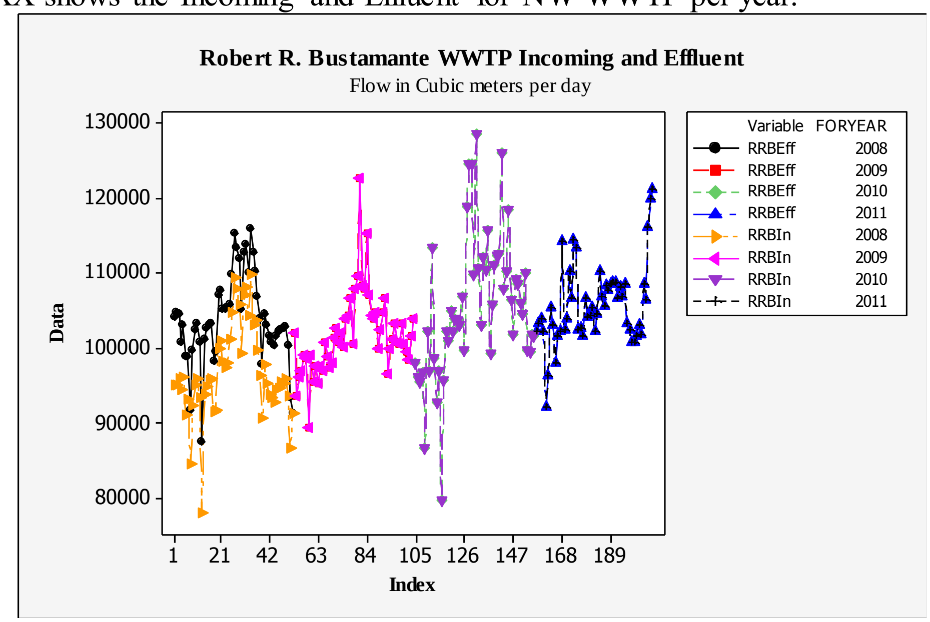

Figure YY Robert R. Bustamante WWTP Incoming and Effluent.

Figure YY shows the Incoming and Effluent for the RRB WWTP.

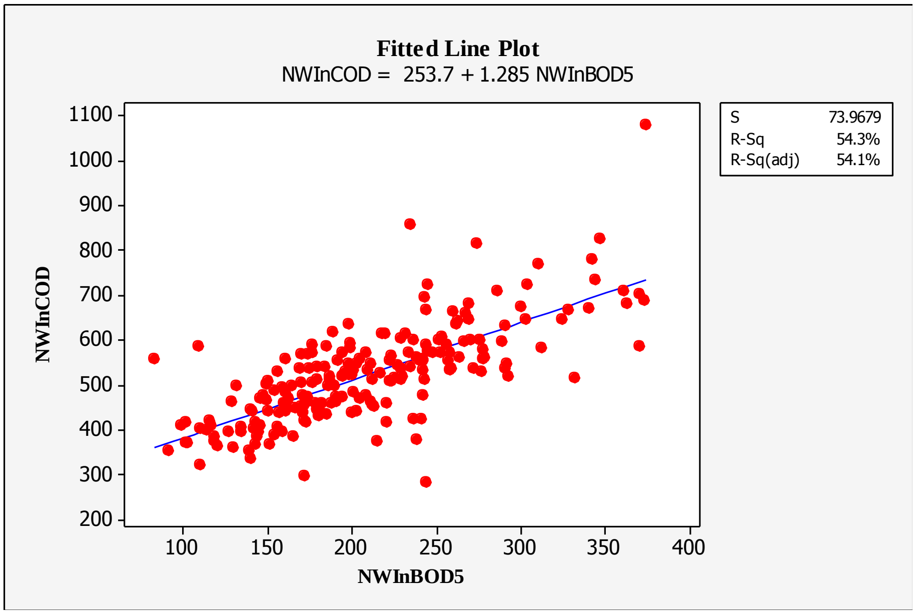

Figure ZZ Fitted Line Plot for NWInCOD as a function of NWInBOD5.

Figure ZZ shows the linear relationship between COD and BOD5for Incoming flow for the Northwest WWTP with an R squared of 54.3% and increasing as the NWInBOD5 increases.

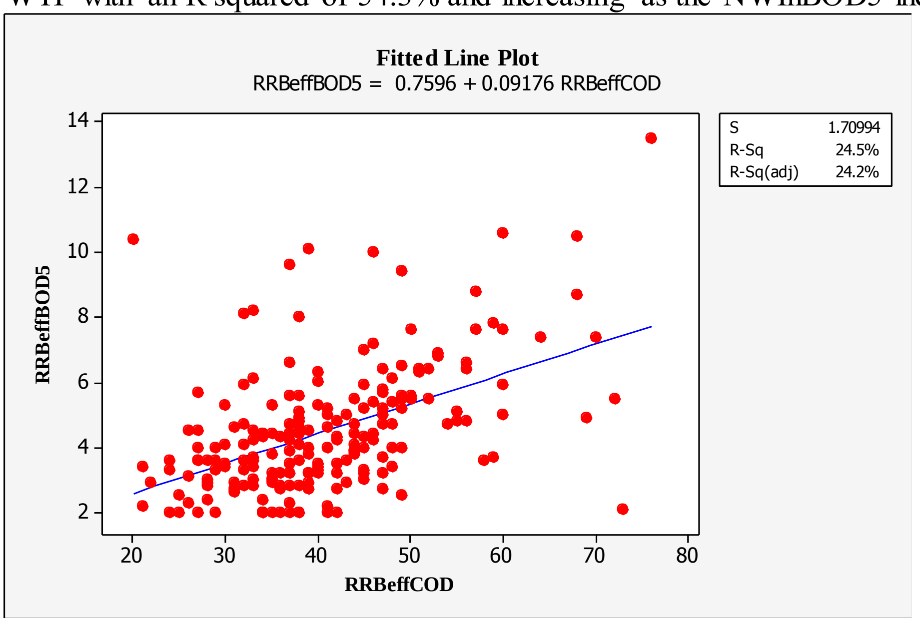

Figure AAA Fitted Line Plot for RRBEffBOD5 as a function of RRBEffCOD.

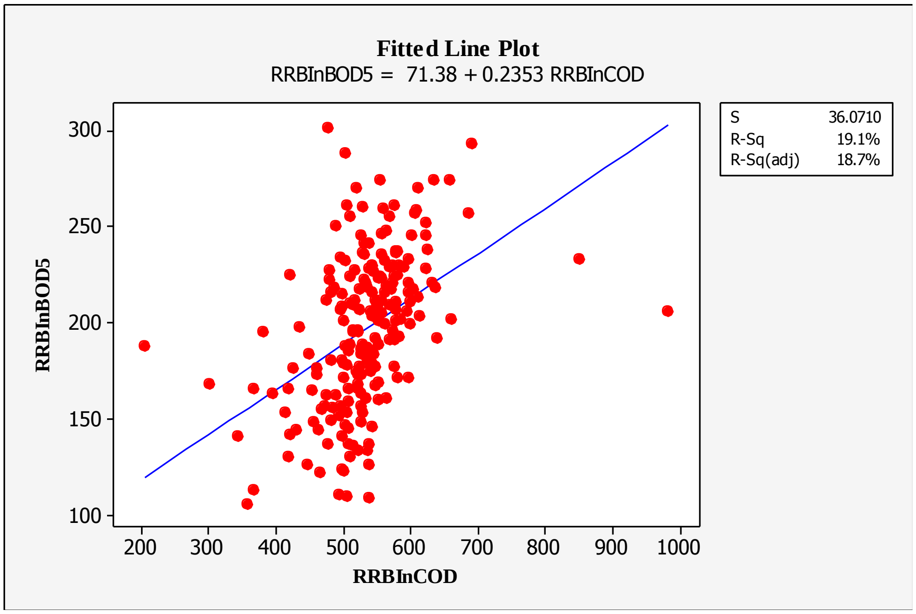

Figure BBB Fitted Line Plot of RRBInBOD5 as a function of RRBInCOD.

Figure BBB shows linear relationship with an R squared of 19.1%.

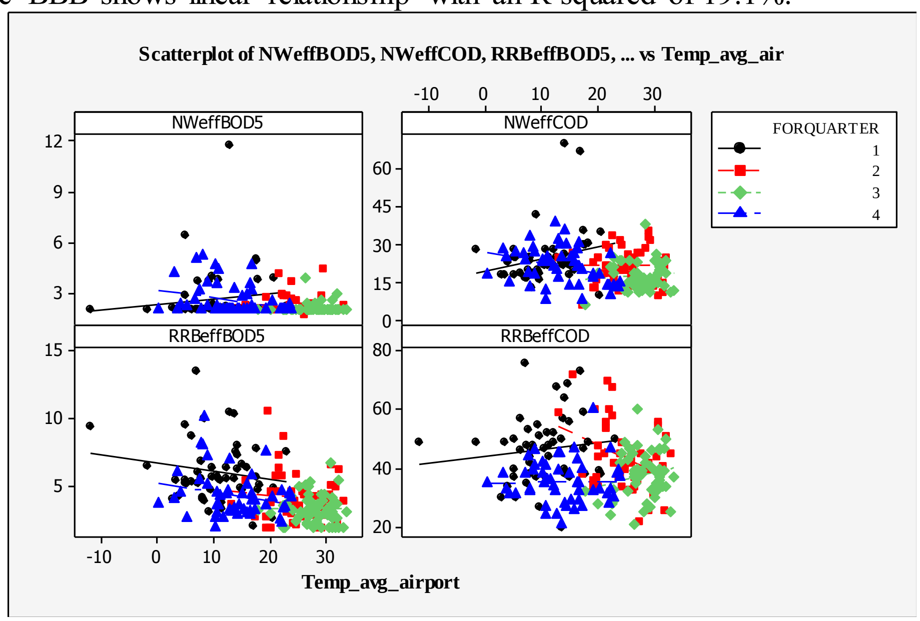

Figure CCC Scatter Plot of NWEffBOD5, NWEffCOD, RREffBOD5, RRBEffCOD vs. Temperature.

Figure CCC shows considerable relationship of Temperature and BOD5 in the Third Quarter of the year. According to records form the weather channel the average temperatures from June to August are from mid-thirties to lower Twenties (°C).

In regards to the use of a C_{pk} study is that, require normality from the data used and there is an assumption that the process is in statistical control. In the event that one uses the C_{pk} study without fulfilling that assumption, the capability cannot be assessed.

If a process is in control, there is approximately a 0.2% probability of a point exceeding three sigma control limits. So, even an in control process graph on a control chart will eventually signal the possible presence of a special cause, even though one may not have actually occurred.

In the case of the Shewhart Charts they detect deviations of cases from the mean of the process. Those deviations have to be large to set off the alarm. The particular case of the I-MR chart serves the purpose of verifying if the process is in statistical control. Moreover, the I-MR chart is for detection of the presence of special causes, and comparison of the process before and after changes in the process.

This will become a limiting factor in using the control charts since some parameters are not normal and according to the I-MR, charts there are some processes out of control.

In addition, keep in mind that the outliers were not removed from the data set since there were no records to justify such action. These points are going to show as special causes.

Revisiting initial conditions, the process is continuous and the data collection is using a 24-hour time weighted average. Collection of data through the above-named average prevented us to describe how the load arrives to the Wastewater Treatment Plant. Furthermore, from the Statistical point of view, this approach is equivalent to gathering twelve unlike samples to create one that provides general aspects is a limiting factor.

In the charts, data from several universes appear on the charts as sets of different sets of data with their respective means of the set. This is apparent in the levels of charts. At least two universes are apparent. Now the assessment and help from Mr. Rip Stauffer, Manager, Quantitative Analyst, and Improvement from WBB (with a website http://wbbinc.com/) was

requested. Mr. Stauffer's professional opinion of the occurrence of several mean values from the same parameter in an I-MR chart served as guide and validation of for the interpretation of data.

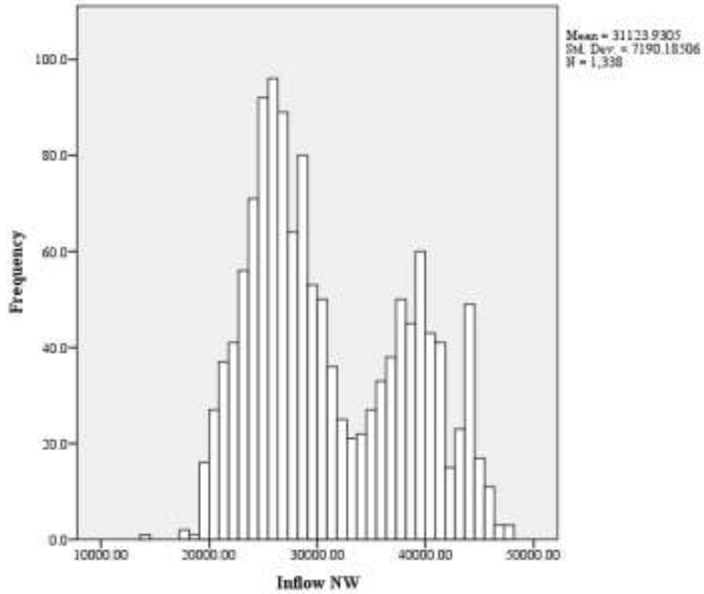

Figure DDD Depiction of bimodal behavior of the incoming flow from the Northwest WWTP.

As per Figure DDD, incoming flow from the Northwest plant is bimodal.

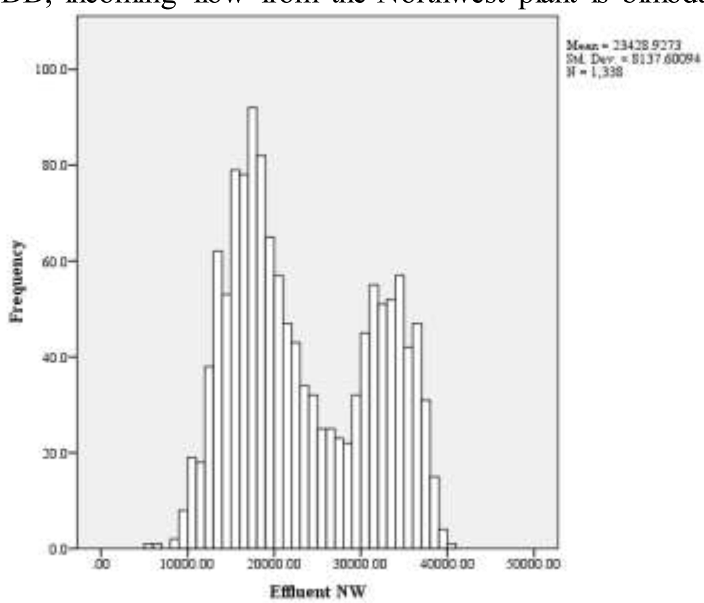

Figure EEE Histogram showing bimodal behavior from the effluent from the Northwest WWTP.

Figure EEE depicts bimodal behavior in the effluent from the Northwest WWTP.

Mr. Rip Stauffer from the company WBB reviewed the data and provided his professional opinion. Among his credentials is American Society for Quality Certified Six Sigma Black Belt, Certified Manager of Quality, and Organizational Excellence.

He used the Anderson-Darling normality test and found several cases as non-normal. His major objection after reviewing data was the lack of "reasonable degree of statistical control" to perform C_{pk} studies.

Moreover, after reviewing and I-MR chart made the comment, "it appears that you have at least two (probably three) separate processes represented in these charts (not really three processes, but one process running at three levels)…From observation 1 to 40-something, there's one level; something happened at that point in time, causing more variation and a higher mean. Somewhere around 110-115, the process reverted to a lower-variation, lower-mean state…In process work, change happens over time. You would not test your entire data set for normality (or try to fit any distribution to it), because the data don't all come from the same universe (same process). There are two or maybe three universes represented in that plot. A stable process is evidence of homogeneity."

Mr. Stauffer is making reference of an I-MR made using the NWEffBOD5 provided as an example of a graph showing some problems. Minitab 16 was flagging 40% of the data used for the analysis when trying to calculate the process mean a screen flagged: "The process mean may not be stable." There is a limitation to Mr. Stauffer's declaration, that he did not had all the background information, just the data provided.

When trying to get the I-MR graph for the RRBEffBOD5 we get the following text "* ERROR * Graph cannot be created because there are no valid data." That means that the software is considering RRBEffBOD5 non-normal. This is despite that the same software evaluated all the parameters, also SPSS, and we got all as normal under the Shapiro-Wilk tests.

There are four rules or reference cases to interpret the R chart and find out if the process is out of control or not stable. Case one states that if a point fall out of the upper or lower limits (outside the three-sigma area) is due to a special cause and not to chance. Probability of this happening is very small. Case 2 mentions that if at least two out of three consecutive values fall in the same side of the mean (center line) and more than two-sigma distant from center line (Zone A and beyond) is a behavior indicating lack of control. Case 3 depicts the case when at least four consecutive out of five data points fall on the same side of the centerline (mean) with one-sigma distant from the reference line, then it is out of control.

Case 4 is when at least eight successive values fall on the same side of the centerline, the process is out of control. These criteria are part of the Software Minitab 16. Whenever a data point is colored red, mean that the process is out of control.

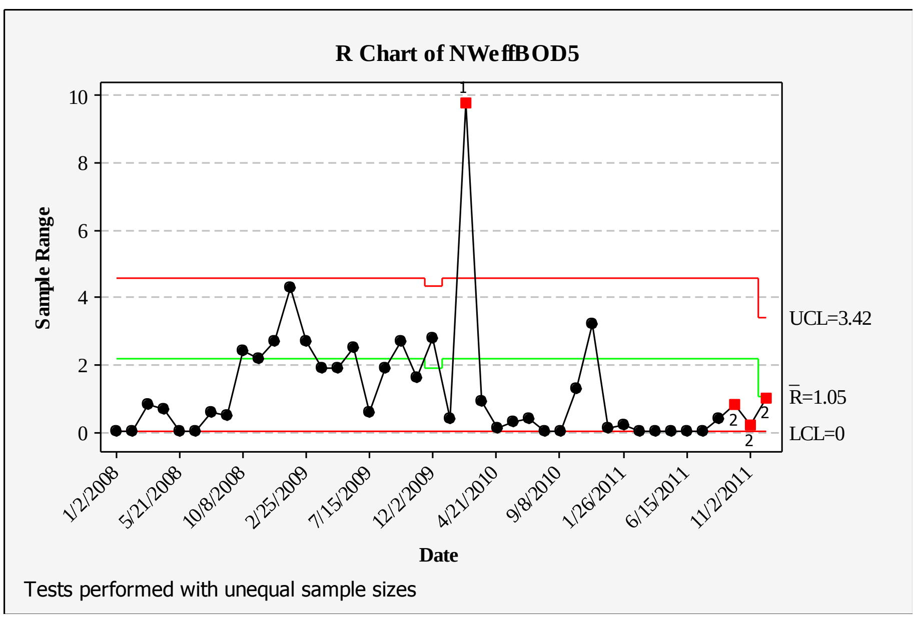

Figure FFF Graph depicts unstable process for the effluent for BOD5 of the Northwest WWTP.

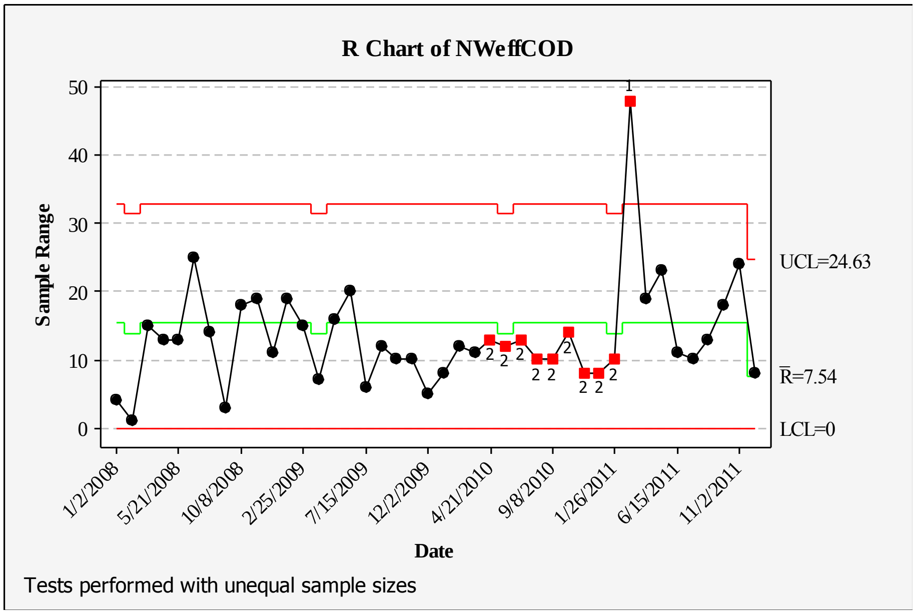

Figure GGG Range Graph showing sequence of points in red indicating process out of control for COD Northwest Wastewater Treatment Plant.

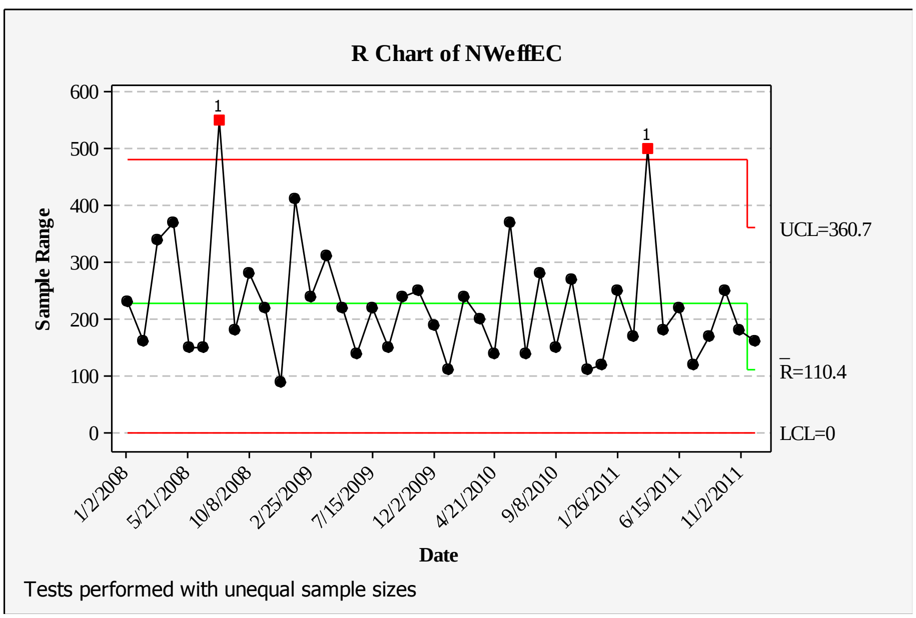

Figure HHH Range chart shows process out of control for the Electrical Conductivity of the Northwest WWTP.

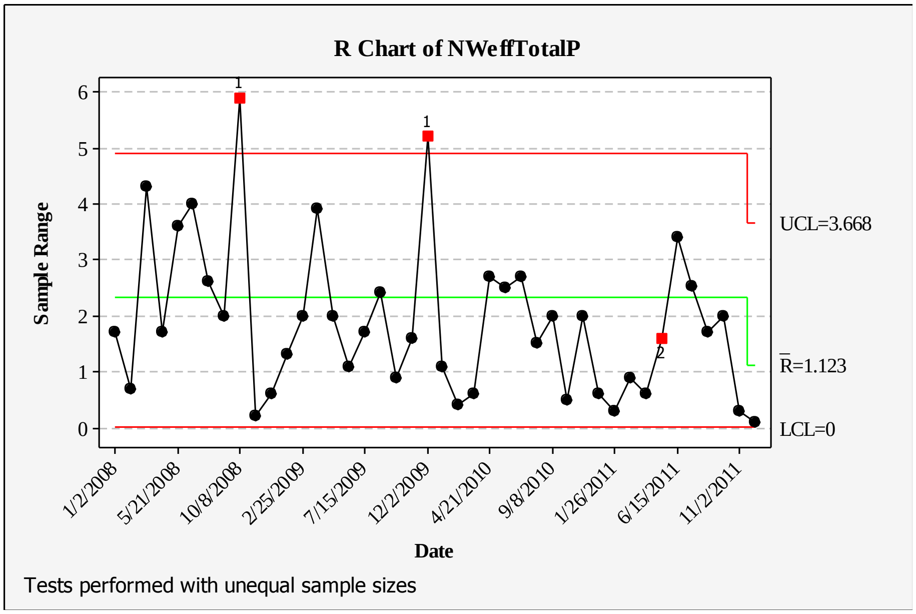

Figure III Chart describing the out of control process for the Total Phosphorus for effluent of the Northwest Wastewater Treatment Plant.

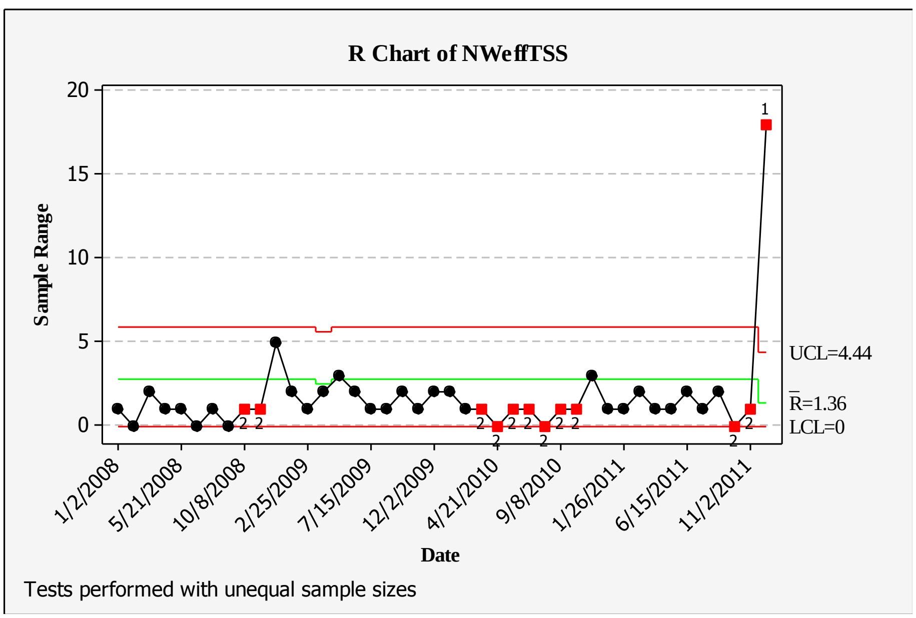

Figure JJJ Chart of out of control process for the Total Suspended Solids for effluent of the Northwest Wastewater Treatment Plant.

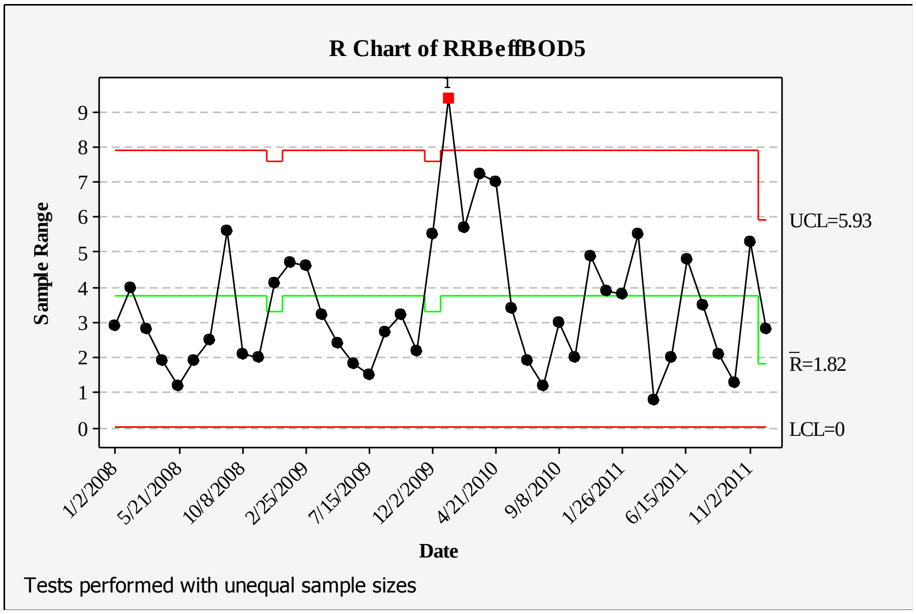

Figure KKK Range chart for the Robert R. Bustamante WWTP describing out of control process for the BOD5 parameter.

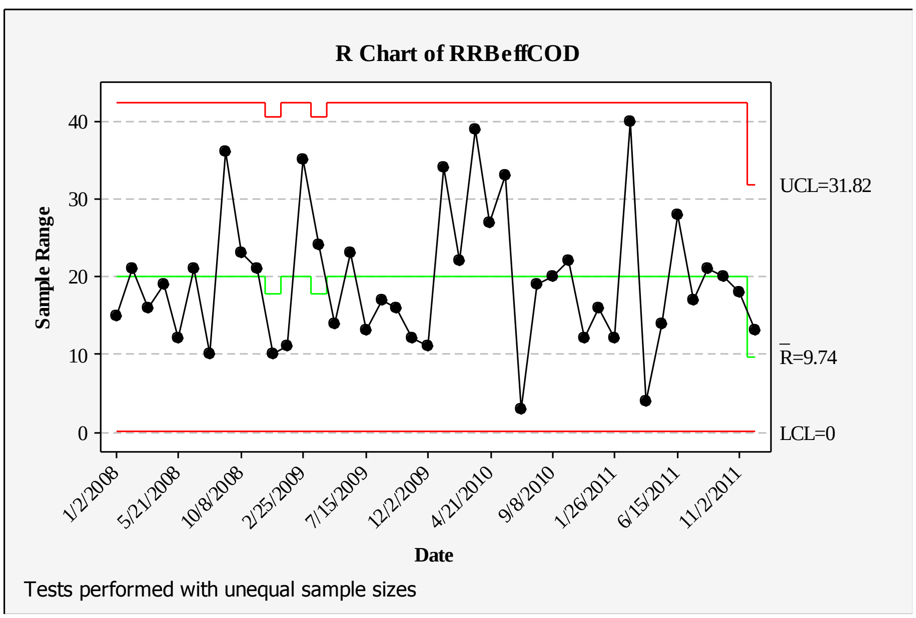

Figure LLL Range Graph describing COD parameter of the Robert R. Bustamante WWTP showing process for the parameter under control.

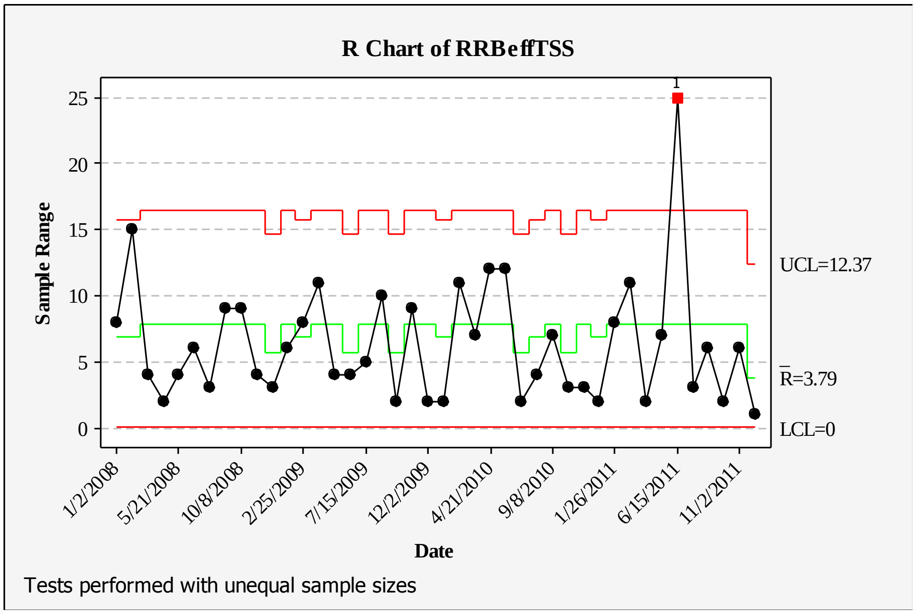

Figure MMM Graph portraying process for Total Suspended Solids as out of control for the Robert R. Bustamante Wastewater Treatment Plant.

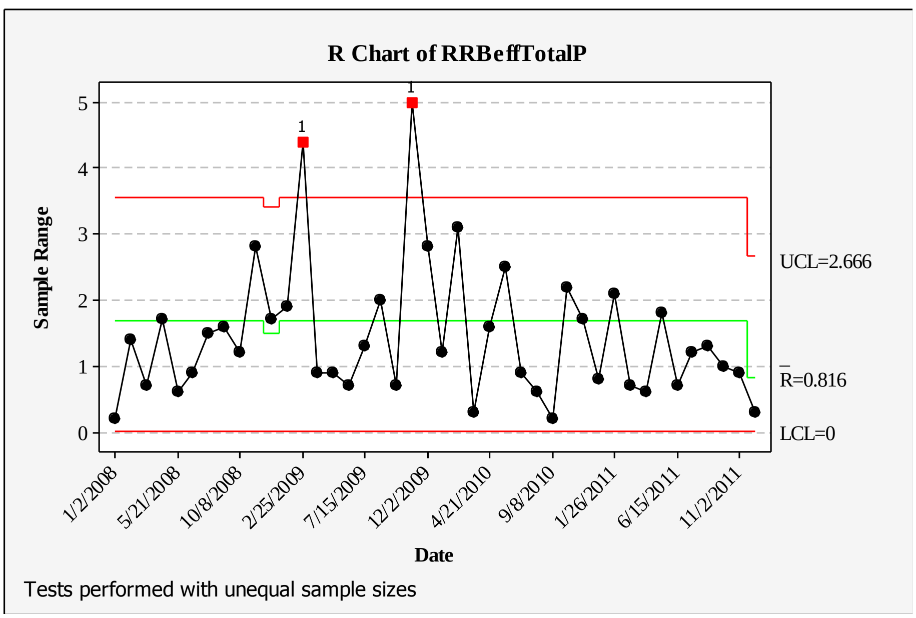

Figure NNN Process out of control for Total Phosphorus of the Robert R. Bustamante Wastewater Treatment Plant as per Range graph.

In previous graphs Figure FFF to Figure NNN, show mostly process out of control. A word of caution, when stating that those above-named processes are out of control means that statistically did not fulfilled the mathematical criteria established, indicating that special causes foreign to the processes involved are the root cause of those outliers outside the Upper Limit.

Given those circumstances, the C_{pk} study did not take place for all the parameters since the process was not under statistical control. Mr. Rip Stauffer Quantitative Analyst and Manager from WBB (Office: 703.448.6081 ext. 237) suggested an approach to this situation.

The identification of the levels of statistical control in a process that overall is not in control, will allow to understand under what index of Capability the process for a given parameter.

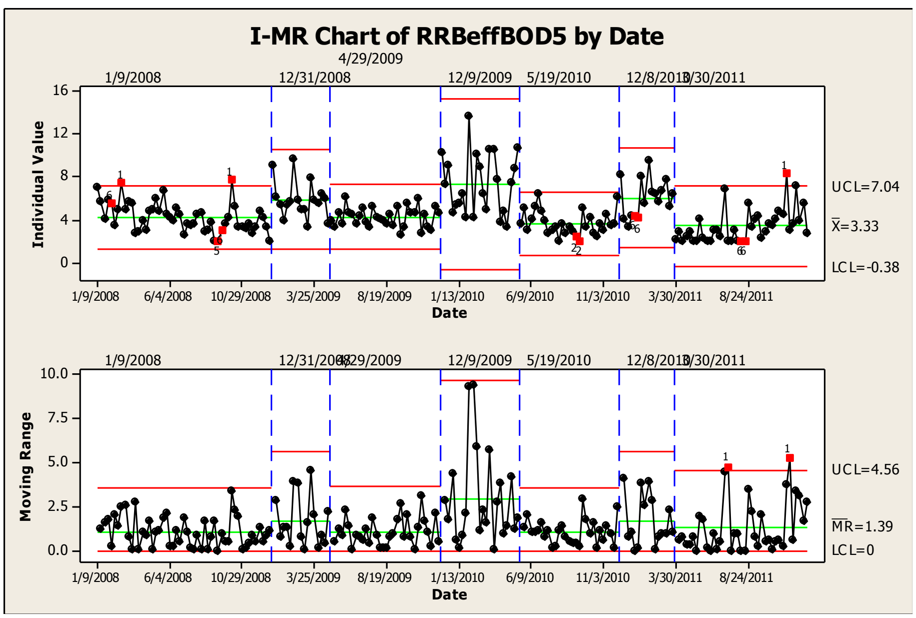

Figure OOO Chart for the BOD5 Effluent of the RRB for the four years of data available.

Mr. Stauffer comments, “So, this first chart looks at RRBeffBOD5 for the entire time period. Note that I have used Minitab signals 1, 2, 5, and 6. This set of four signals is recommended by Wheeler as being the best trade-off between sensitivity and low false-signal rate. I cut the data into roughly in-control (homogeneous) chunks. With more process

knowledge, we could maybe cut them slightly differently; however, it seems clear that there are three unambiguously homogeneous timeframes. I ran individual analyses for each of the timeframes."

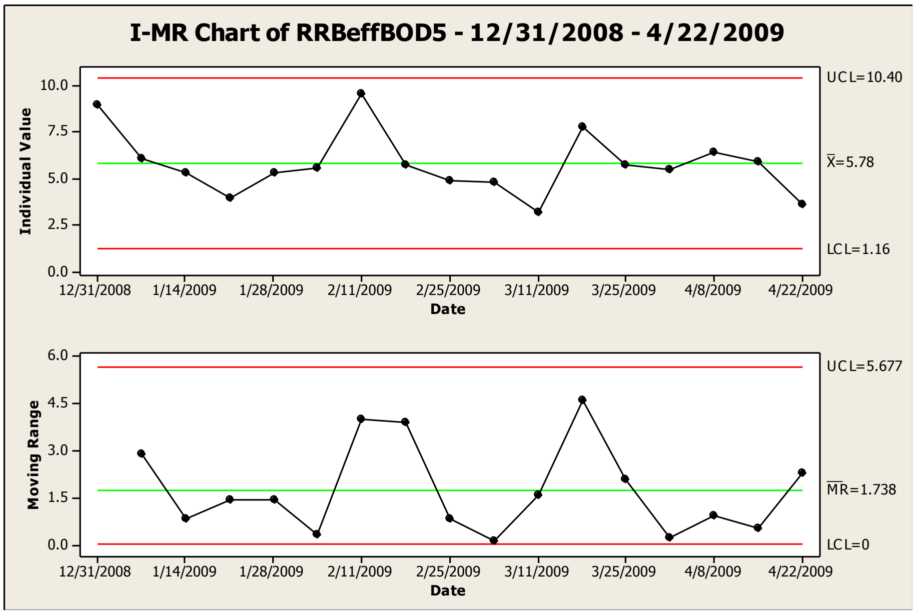

Figure PPP Graph describing period from December 2008 to April 2009 within statistical control.

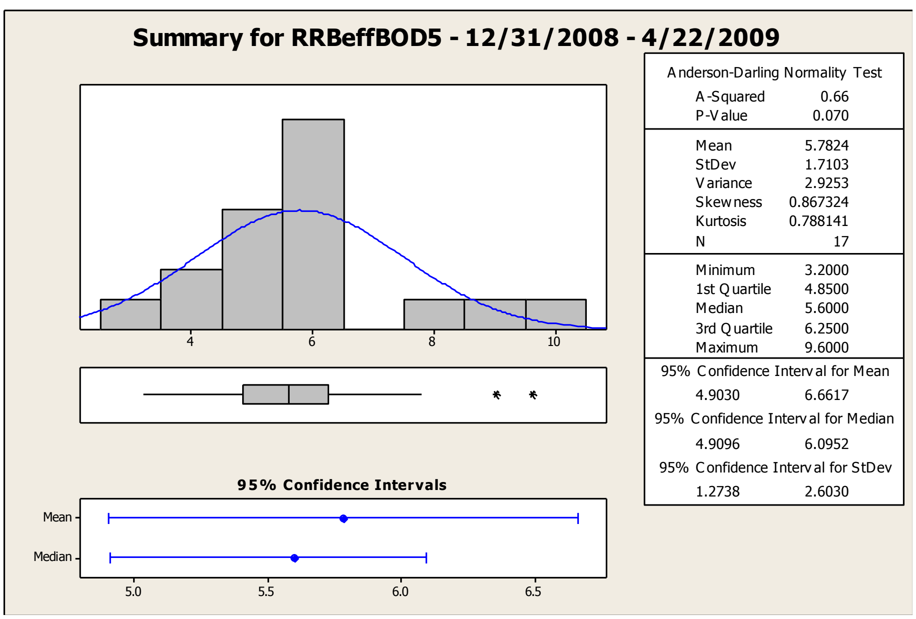

Figure QQQ Descriptive analysis from the same period above-mentioned.

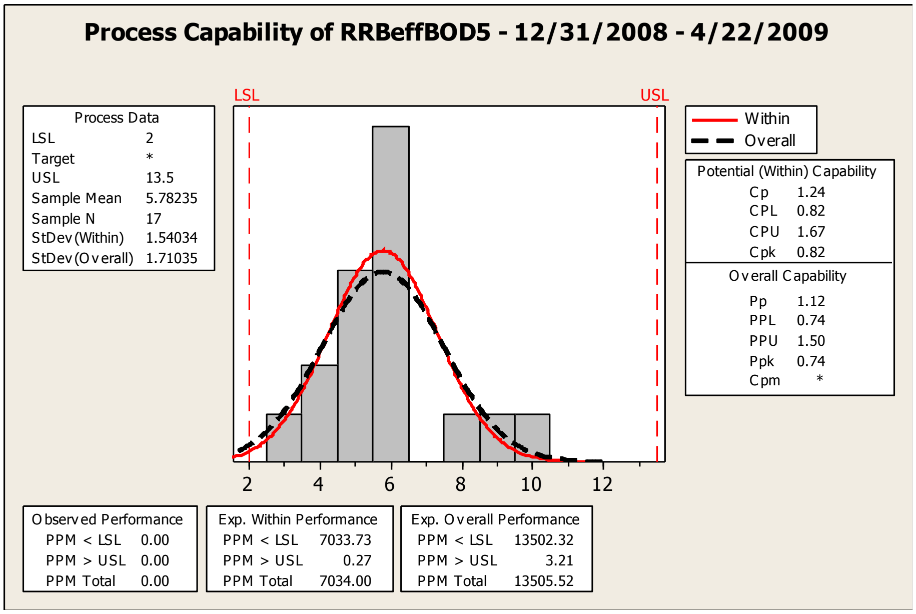

Figure RRR Capability study for BOD5 for RRB with an index of 0.82 for December 2008 to April 2009.

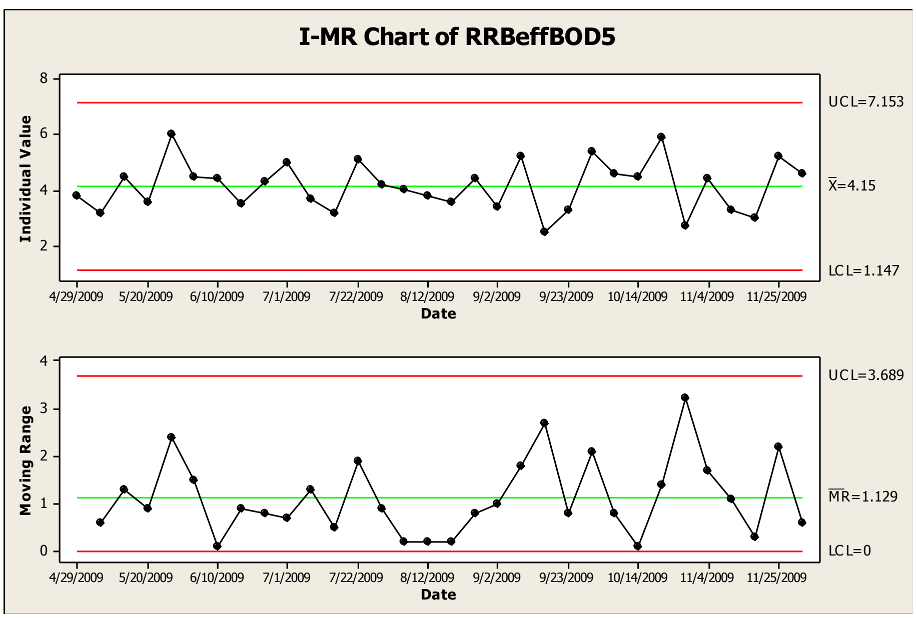

Figure SSS Chart for the BOD5 of the RRB Effluent from April 2009 to November 2009.

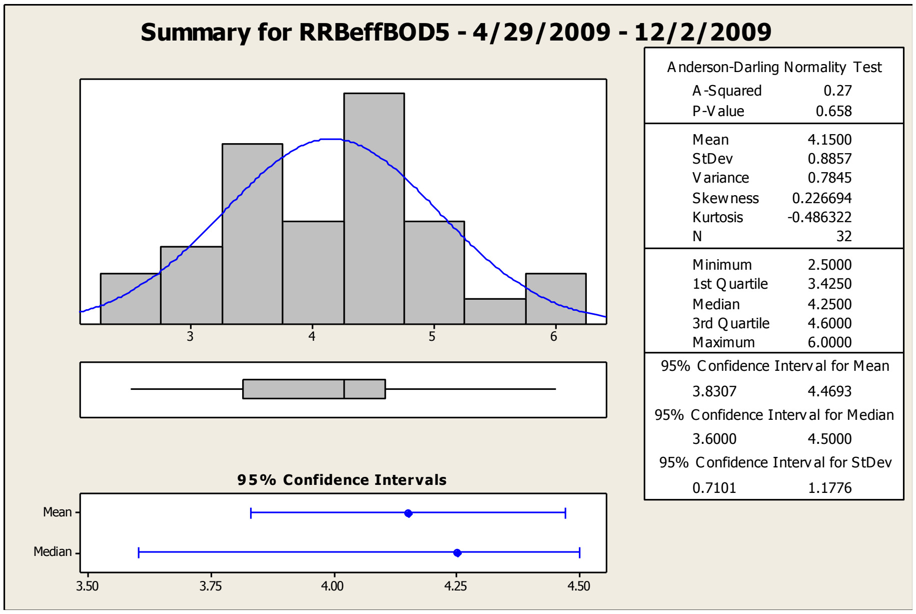

Figure TTT Descriptive analysis for the BOD5 of the RRB from April 2009 to December 2009.

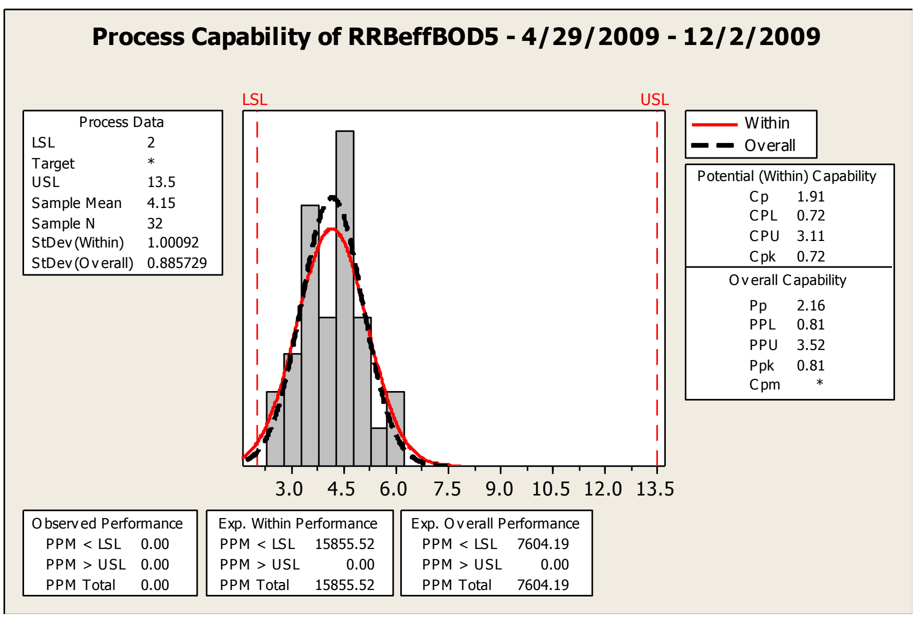

Figure UUU Capability study for BOD5 of RRB from April 2009 to December 2009.

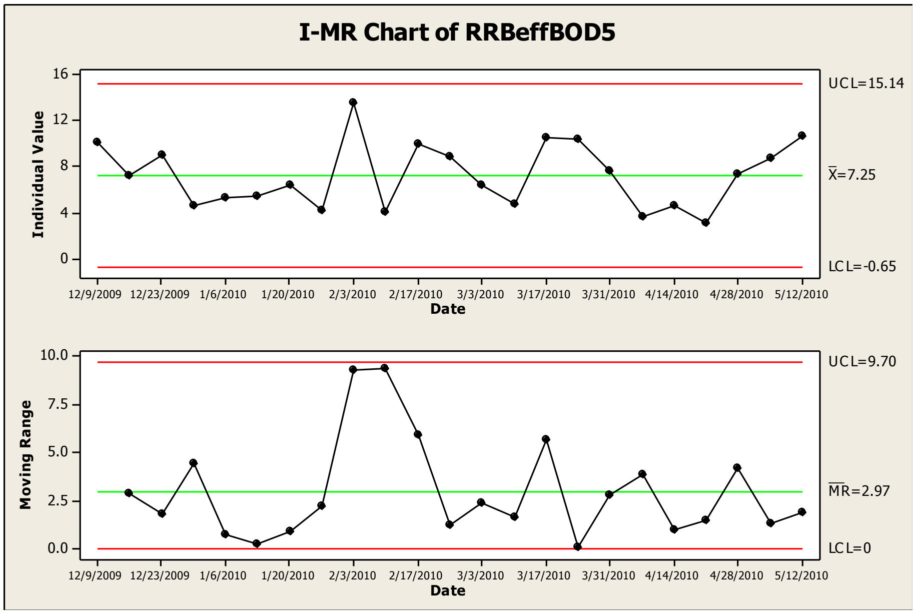

Figure VVV Graph describing BOD5 fluctuations from December 2009 to May 2010.

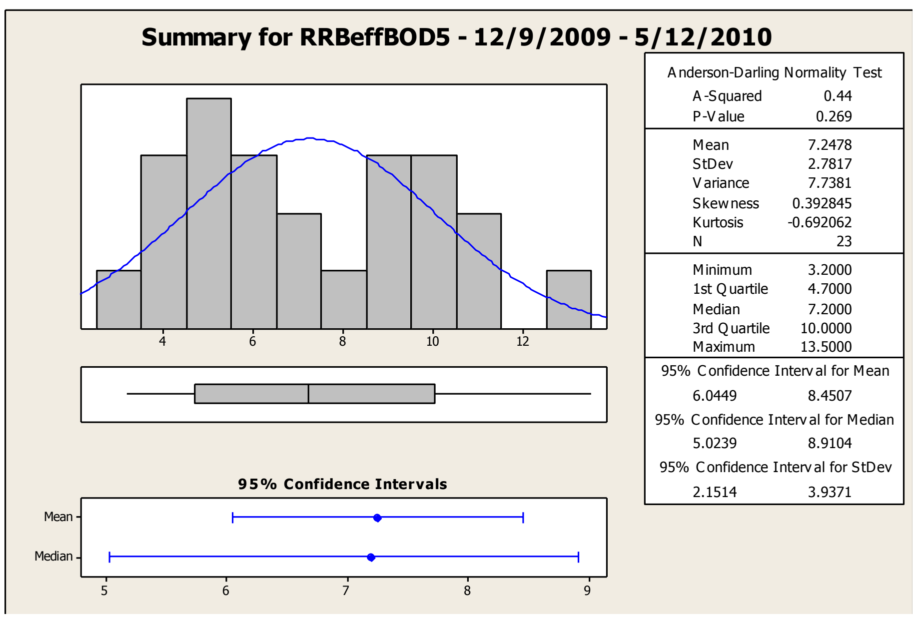

Figure WWW Descriptive statistics for BOD5 of RRB from December 2009 to May 2010.

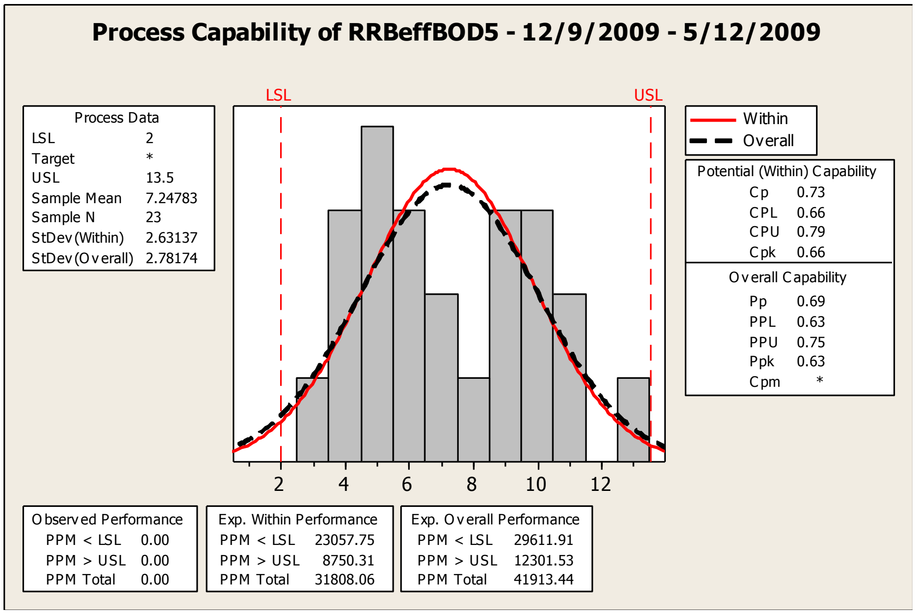

Figure XXX Capability study for BOD5 RRB WWTP from December 2009 to May 2010 with an index of 0.66.

Explaining the procedure followed to have segments of the timeline Mr. Stauffer explained, "What I used to cut the series into stages was the record itself. You look for signals, and for where the signal started. For instance, a rule 2 signals (9 or more above the mean) suggests that the process shifted 8 observations before the signal. You put a stage in at that point, and check the record again. If there are no signals before the shift, and none immediately following the shift, you have found a homogeneous timeframe."

C_{pk} estimates what a given process is capable of producing; assuming the centerline (process mean) is not symmetrically located between the upper and lower limits. The minimum recommended textbook value for two-sided specifications in an existing process is 1.33. Keep in mind that the cost to achieve the recommended limits or even exceeding is high. The setting of a target that allows some room to fluctuate within the statistical and legal limits at reasonable cost is difficult.

Before we continue there are some comments from Paul R. Rivas, Laboratory Services Manager, from International Water Quality Laboratory. Mr. Rivas works for the El Paso Water

Utilities, and he supervises calibration of laboratory equipment and collection of data. "For example for TSS and TDS the balances are calibrated daily. We have a maintenance agreement with the manufacturer to clean, service and certify the balances twice a year. The temperature of the ovens that are used to dry the samples are monitored using thermometers that are calibrated twice a year against an NIST certified thermometer. The thermometers are calibrated at two calibration points that bracket the set point of the oven. The lab NIST is sent out yearly to an NIST certified calibration laboratory for certification. Calibration, precision, and accuracy are checked on a 10% basis utilizing standards, matrix spikes, and matrix spike duplicates. Ammonia is analyzed using a flow injection analyzer. Calibration is done daily using 5 standards that span the range of expected values of the samples. Calibration, precision, and accuracy are checked on a 10% basis utilizing standards, matrix spikes, and matrix spike duplicates. The instrument is under a service contract from the manufacturer which includes two preventative maintenance visits and emergency service," Mr. Rivas wrote.

In regards to the type of data and control charts Mr. Rivas stated, "We use a program called Northwest Analytical Quality Analyst to control chart all of our data. Each test has required calibration, precision, and accuracy standards that are controlled using the control charts. Yes, they do have upper and lower control limits that are derived utilizing the previous 31 points of data. There are upper and lower control limits (UCL and LCL) and upper and lower warning limits (UWL and LWL) that are 3 standard deviations and 2 standard deviations from the mean, respectively. We also utilize upper specified limits (USL) and lower specified limits (LSL) that are hard limits that are specified in the method and we are required to meet. Typically our UCL and LCL are more stringent than the USL and LSL. In the event that our UCL/LCL begins to expand, they cannot increase to the point of being outside the USL/LSL. In that event, the method must be investigated to determine the cause of the widening limits. Our laboratory has over 500 control charts that are used to control the data.

All of the major instrument has service contracts that are purchased from the instrument manufacturer. The service contracts include preventative maintenance visit(s) and emergency service and parts."

Figure PPP to Figure XXX show the Capability study in three parts for the Robert R. Bustamante WWTP focusing in BOD5 we see that C_{pk} fluctuated from an index of 0.82 to 0.66.

Note the comments on the applicability of Statistical Process Control from Mr. Rip Stauffer, "You'll note that I assessed capability for the timeframes in which the process was clearly in control. Note also the implication for monitoring and decision support…imagine you were managing this plant in November and December of 2009. Your process would have been in control for six months or more, averaging 4.15 with an upper natural process limit (control limit) of 7.15. On 12/9, the observation jumps to 10.1. You would immediately know something had changed, and would be able to take action to restore the process to its former (better) levels."

The following graphs will review the Electrical Conductivity and seasonal relationship.

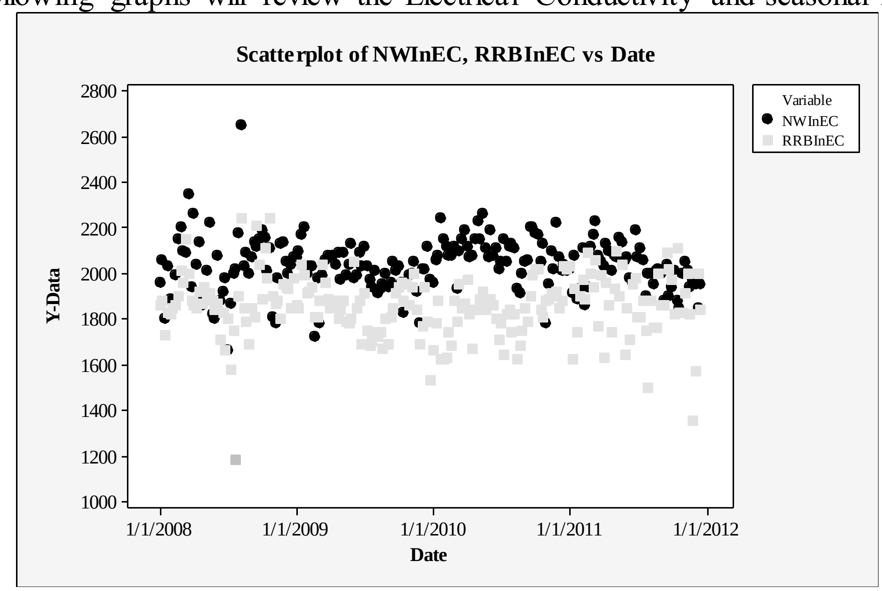

Figure YYY. Chart describing Electrical Conductivity for the NW and RRB WWTP by season.

Figure YYY describes Electrical Conductivity for both NW and RRB WWTP. The black points belong to NW and are above the RRB points.

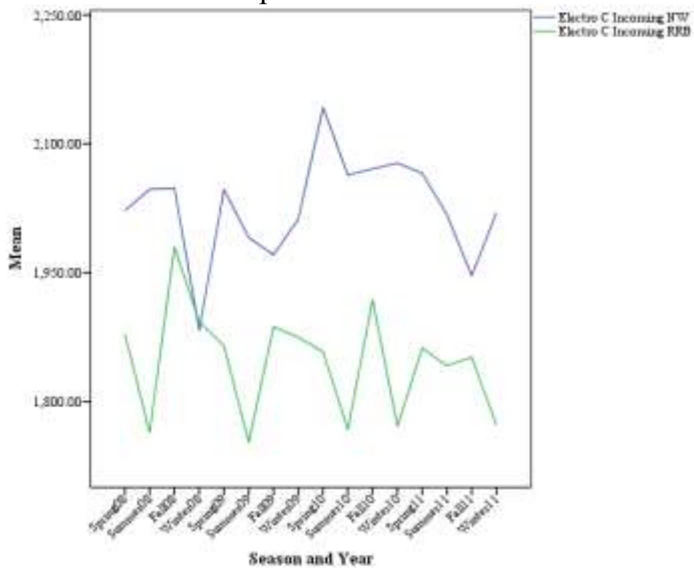

Figure ZZZ Chart comparing the mean values of EC from both WWTP by season-year.

Figure ZZZ compare means in a graph where the green (RRB) shows peaks in the fall to decrease to a minimum during the summer.

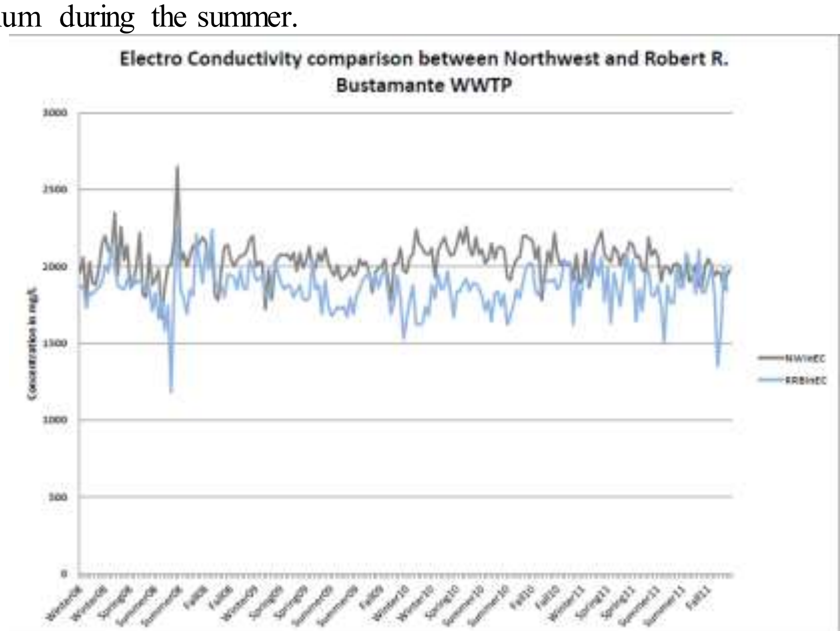

Figure AAAA Graph representing the Electrical Conductivity for both WWTP with all data values.

Electrical Conductivity from Northwest WWTP is numerically greater than the Electrical Conductivity from Robert R. Bustamante WWTP (Figure YYY), that the Robert R. Bustamante shows peaks (increasing tendency) on fall from every year using the mean values (Figure ZZZ), and that the same behavior is less apparent with the weekly values with a lot of noise (Figure AAAA). A similar behavior but less noticeable applies to the Northwest Wastewater Treatment Plant.

According to Mr. William Quinn from the EPWU, Electrical Conductivity should vary by certain dates. "We typically rely on groundwater for our drinking water supply from about October through April each year," he said. Part of autumn (September 21 is the first day of autumn) to beginning of spring (April 21/22 is the first day of spring) El Paso relies on ground water.

The use of Statistical Process Control is to predict behavior of certain processes such as peaks or valleys and to take action to control the process. The following graphs consider the parameter versus day of the week to review load patterns to the Wastewater Treatment Plants.

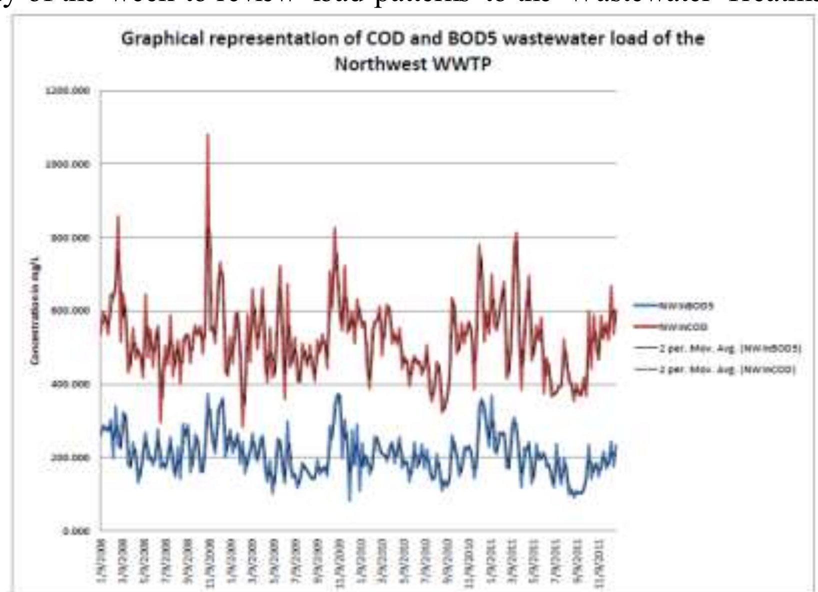

Figure BBBB Presentation of the COD and BOD5 load received by the Northwest Wastewater Treatment Plant.

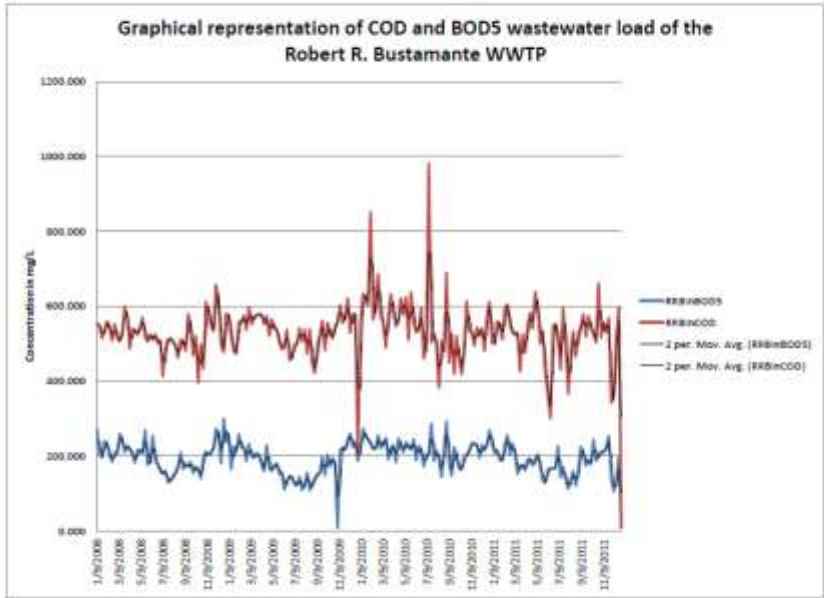

Figure CCCC Presentation of the COD and BOD5 load received by the Robert R. Bustamante Wastewater Treatment Plant.

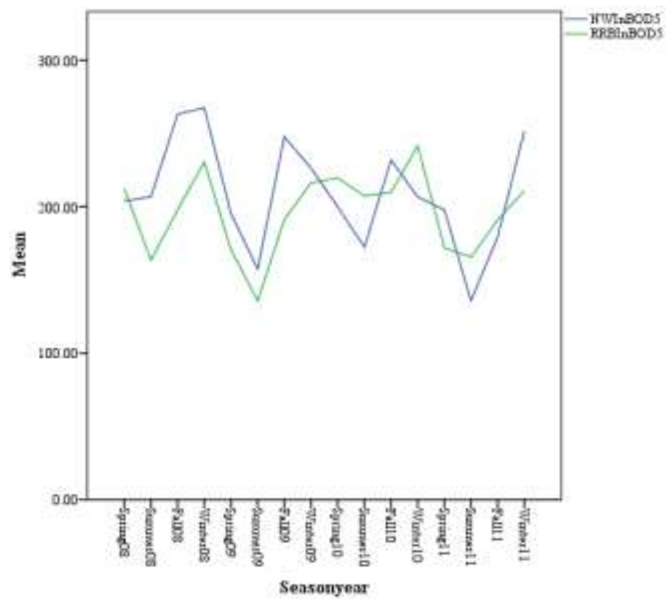

Figure DDDD Description of the mean values of BOD5 of both Northwest and Robert R. Bustamante plants with peak values on fall of the four years of data.

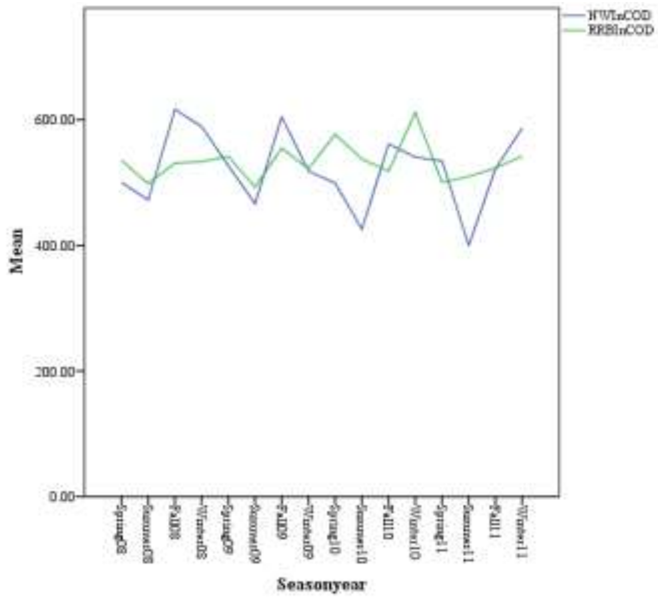

Figure EEEE Depiction of the COD mean values for both Northwest and Robert R. Bustamante WWTP, with NW periodic peaks in the summer-fall transition, while RRB shows a randomized fluctuation.

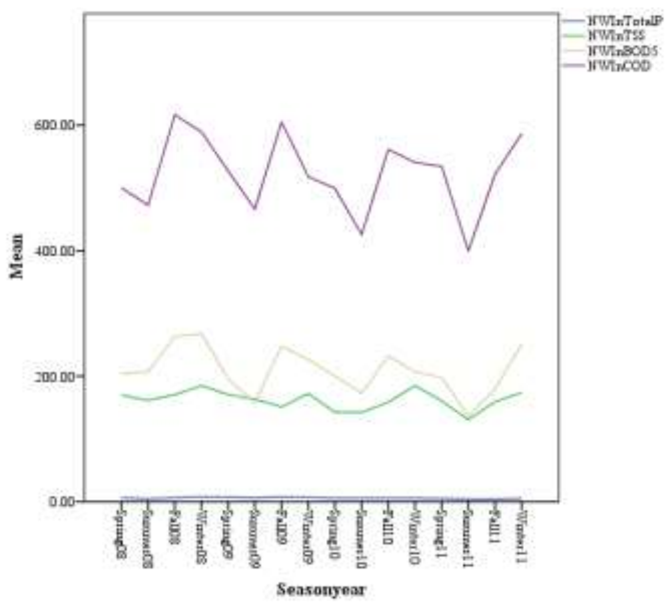

Figure FFFF Graph using mean values describes the peaks for Total P, TSS, BOD5, and COD for the Northwest WWTP by season-year.

Figure BBBB shows peaks during fall season using the mean values for COD, BOD5, and Total Suspended Solids. This is for the Northwest Wastewater Treatment Plant.

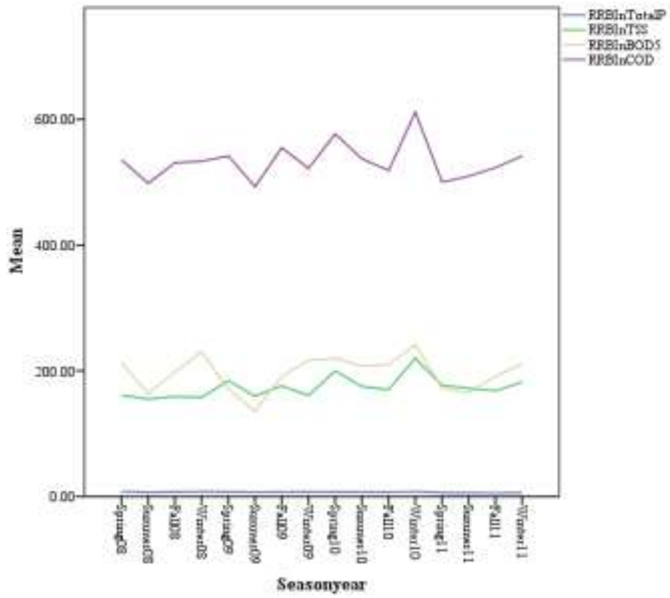

Figure GGGG Graph using mean values with peaks for Total P, TSS, BOD5, and COD for RRB season-year.

Figure CCCC portrays peaks using mean values after beginning of fall of each year. The parameters Total Suspended Solids, BOD5 and COD. In comparison they show a drift or lagging behind the NW values.

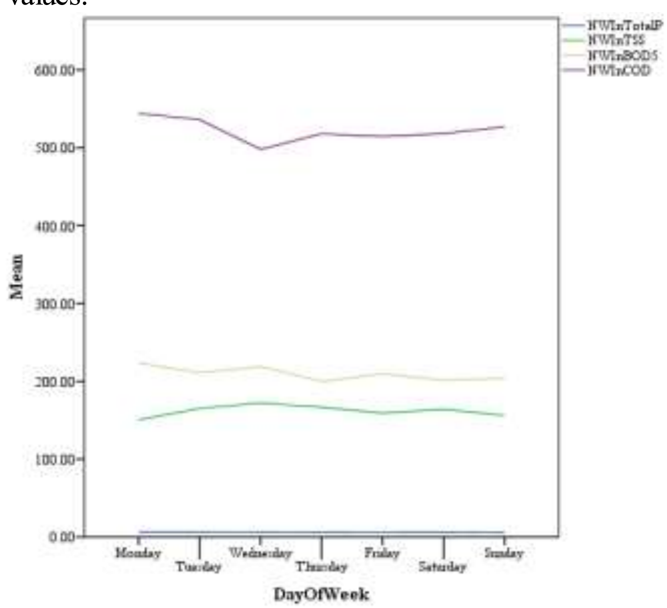

Figure HHHH Chart describing COD, BOD5, TSS, and TotalP for the Northwest WWTP.

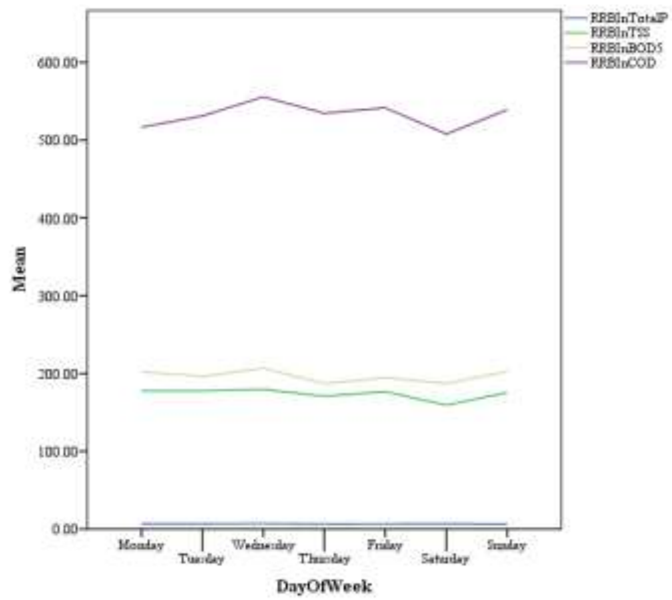

Figure IIII Graph showing peak mean values for the TotalP, TSS, BOD5, and COD for the RRB WWTP.

Figure DDDD shows mean value peaks for COD on Monday decreasing to a minimum in Wednesday. Opposed to that behavior show peak values for BOD5 on Wednesday. Notice that the scales used on these graphs show that difference between max and min values is in the vecinity on 25 units, which is not numerically significant.

Figure EEEE portrays a behavior which coincides mean peak value for COD, BOD5 and TSS on Wednesday and Friday. This for the Robert R. Bustamante Wastewater Treatment Plant.

According to Mr. William Quinn from EPWU, wastewater arrives under hypoxic or low concentration of oxygen. On the other hand, NO_3 concentration in incoming raw water suffers a dramatic increase of NO_3. Nitrogen and Phosphorus Compounds deserve attention due to risk of increasing hypoxic conditions on surface waters that might receive treated waters from both Wastewater Treatment Plants.

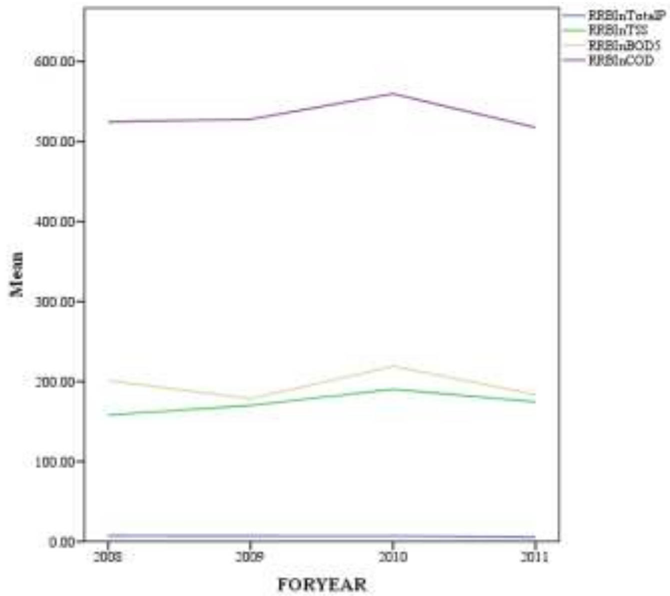

Figure JJJJ Graph showing mean value tendency to decrease in COD, BOD5, and TSS for the RRB plant.

As the final topic for the Results section, the Nitrogen and Phosphorus compounds, and Efficiency of removal of pollutants deserve special consideration.

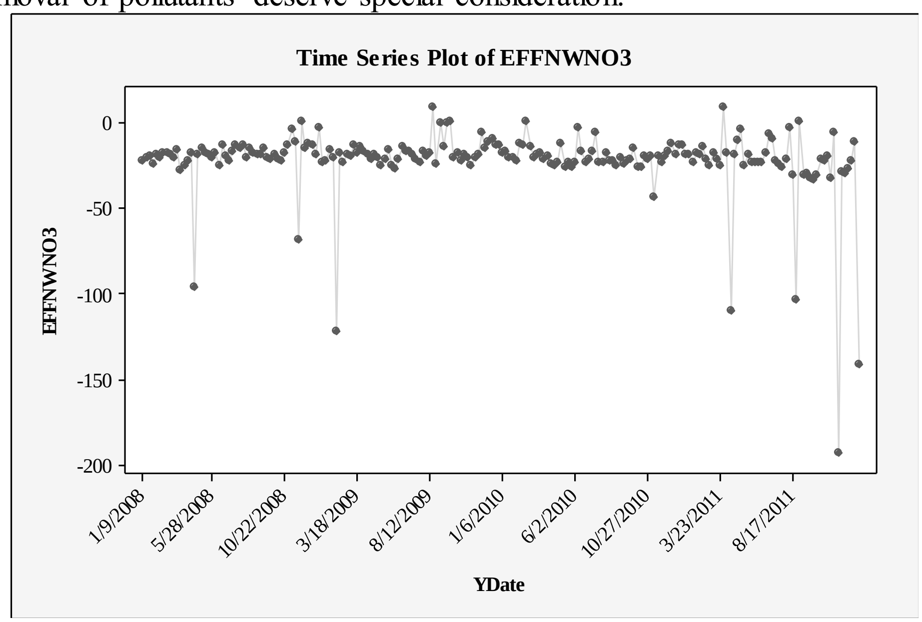

Figure KKKK Efficiency removal of NO3 in the Northwest WWTP is negative most of the year.

Effluent from the Northwest Wastewater Treatment Plant increased the concentration of water soluble nitrogen NO_3.

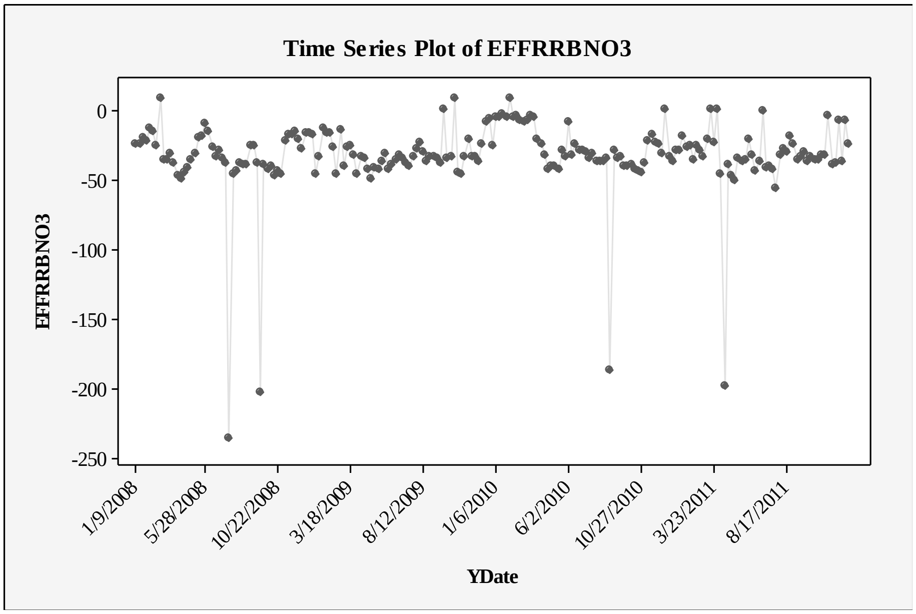

Figure LLLL Efficiency removal of NO3 in the Robert R. Bustamante WWTP is negative most of the year.

Effluent from Robert R. Bustamante WWTP increased the concentration of NO_3 in its effluent.

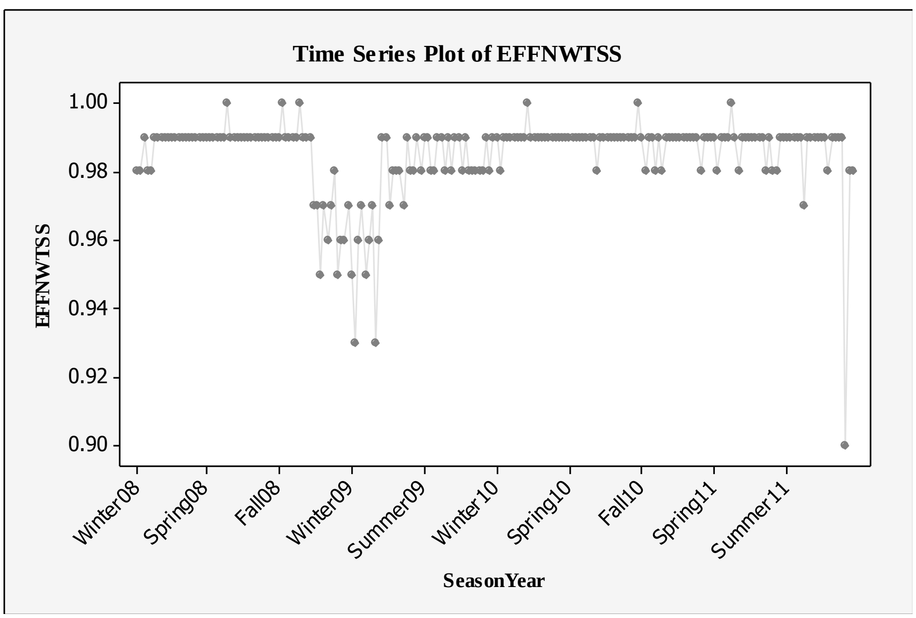

Figure MMMM Efficiency removal of TSS of the Northwest WWTP ranges from 100% to 90% on all seasons of the year.

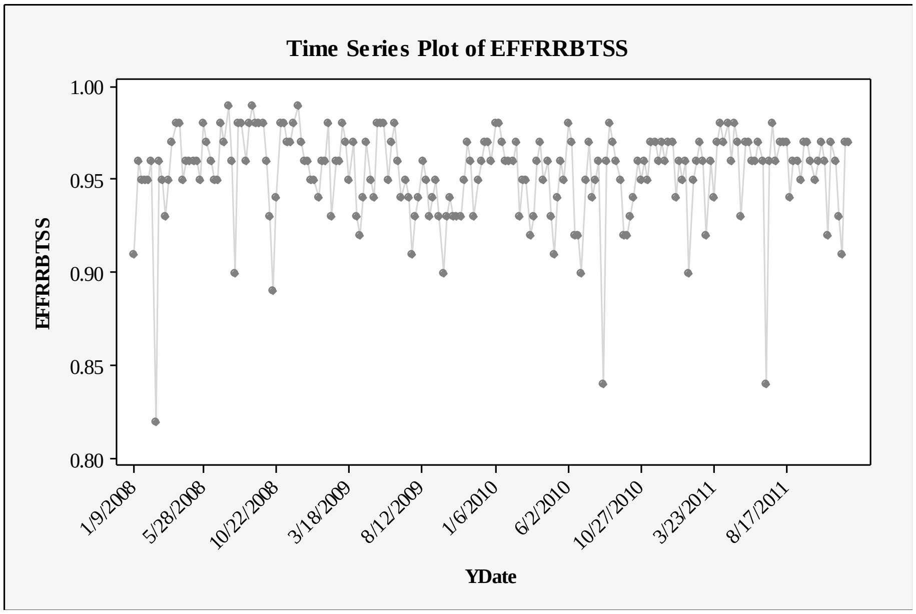

Figure NNNN Efficiency removal of TSS of the Robert R. Bustamante WWTP ranging from 99% to 82%.

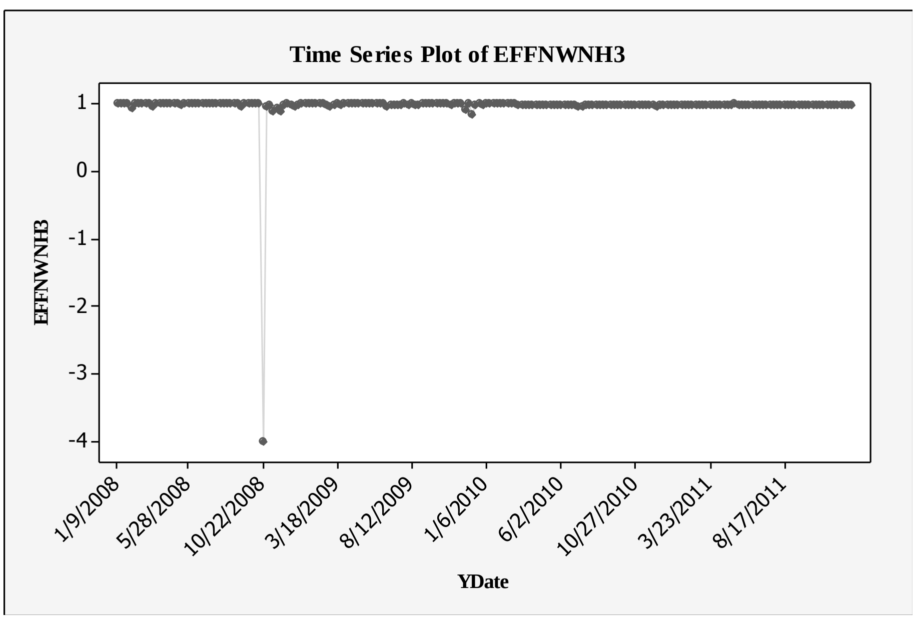

Figure OOOO Efficiency removal of NH3 of the northwest WWTP 100% most of the year and special case of October 2008 effluent that day is 1.8 mg/L.

Efficiency of 100% in removing NH_3 in the Northwest Wastewater Treatment Plant.

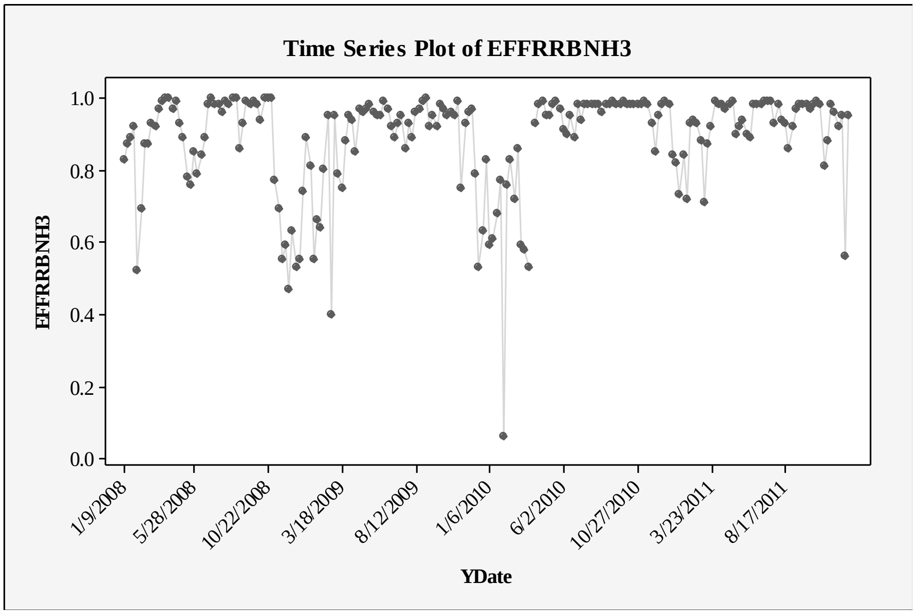

Figure PPPP Efficiency removal of the NH3 of the Robert R. Bustamante WWTP with efficiencies ranging from 100% to 6% removal (2/3/2010, Winter).

Removal efficiency for the Robert R. Bustamante for NH_3 is unstable.

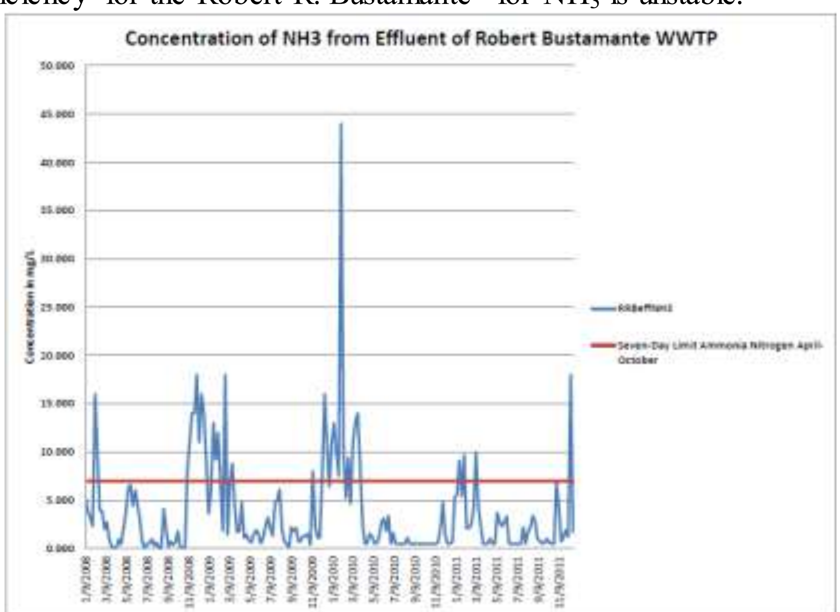

Figure QQQQ Graph showing fluctuation of effluent concentration of NH3 from Robert R. Bustamante plant.

In the above graph we added a reference line of the Seven-Day limit for the Ammonia Nitrogen from the TPDES.

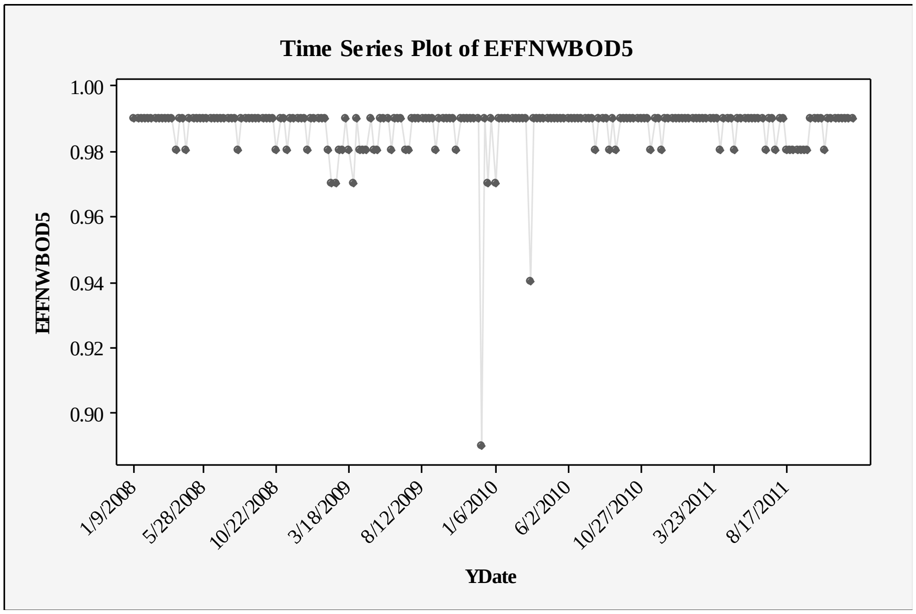

Figure RRRR Efficiency removal for BOD5 of the Northwest WWTP rages from 89% to 100%.

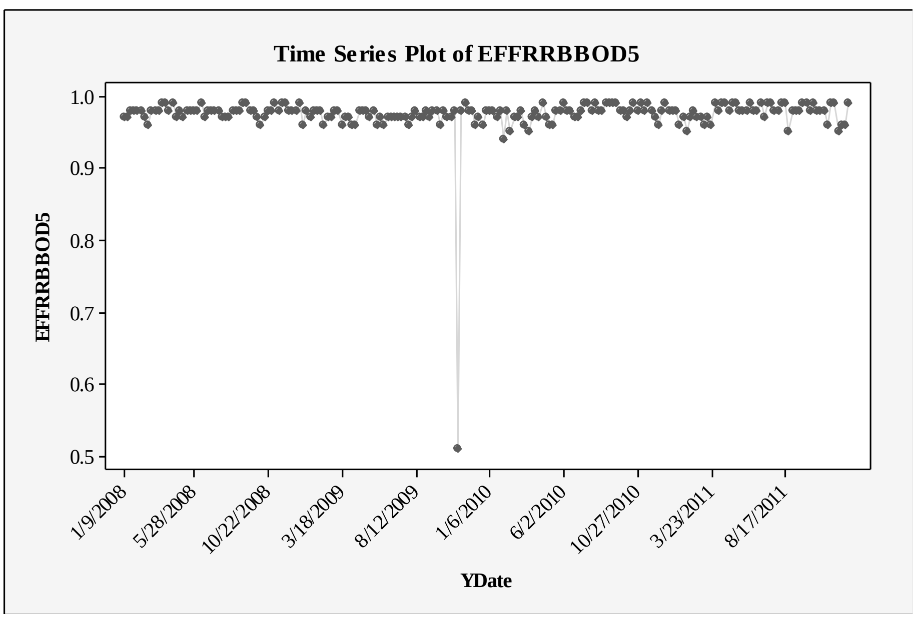

Figure SSSS Efficiency removal of BOD5 from the Robert R. Bustamante WWTP with efficiencies ranging from 100% to 51% (11/04/2009, Fall).

The 51% efficiency removal of BOD5 is a special cause to address in Discussion Section.

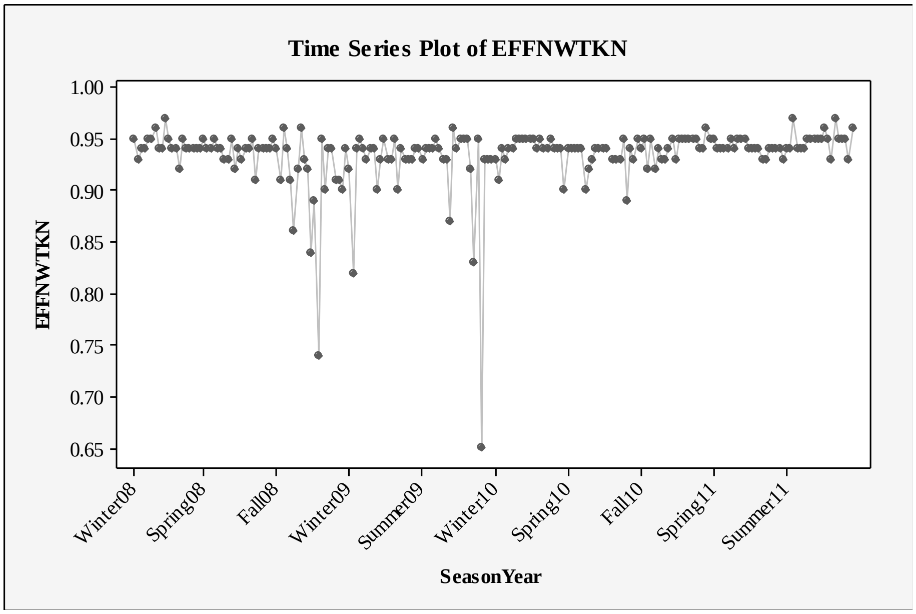

Figure TTTT Efficiency removal of TKN from the Northwest WWTP ranging from 97% to 65%.

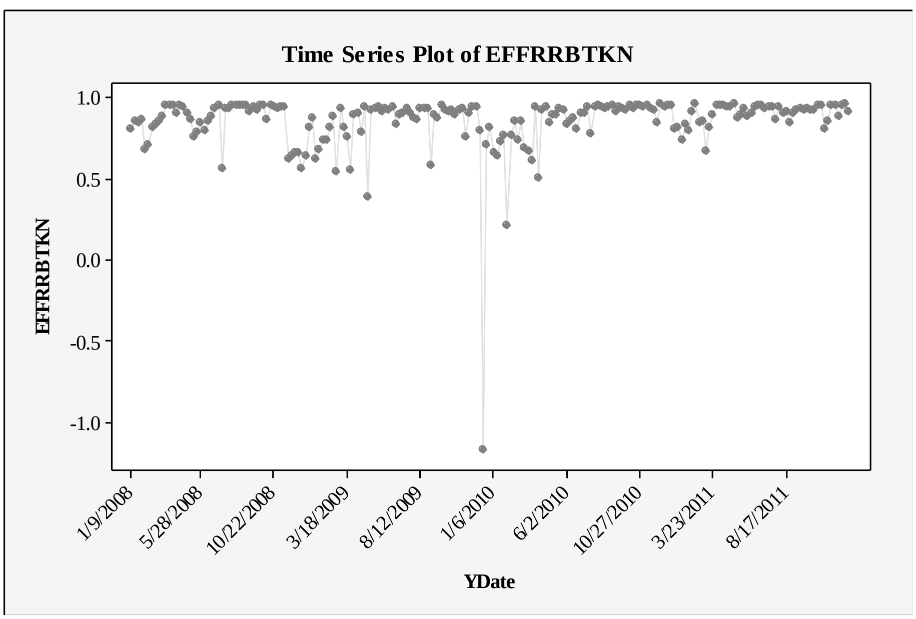

Figure UUUU Efficiency removal of TKN from the Robert R. Bustamante WWTP with removal efficiencies ranging from -117% to 100% (12/16/2009, Fall).

Efficiency of removal for the TKN from the Robert R. Bustamante with high fluctuation. RRB treats higher volume of water compared to the NW plant.

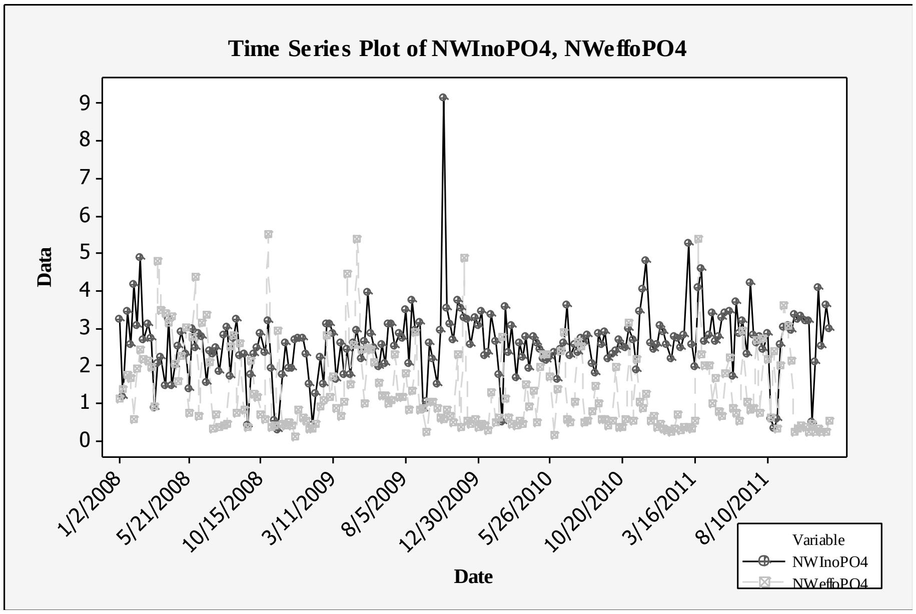

Figure VVVV Graph comparing Ortho-Phosphate of incoming and effluent from the Northwest WWTP.

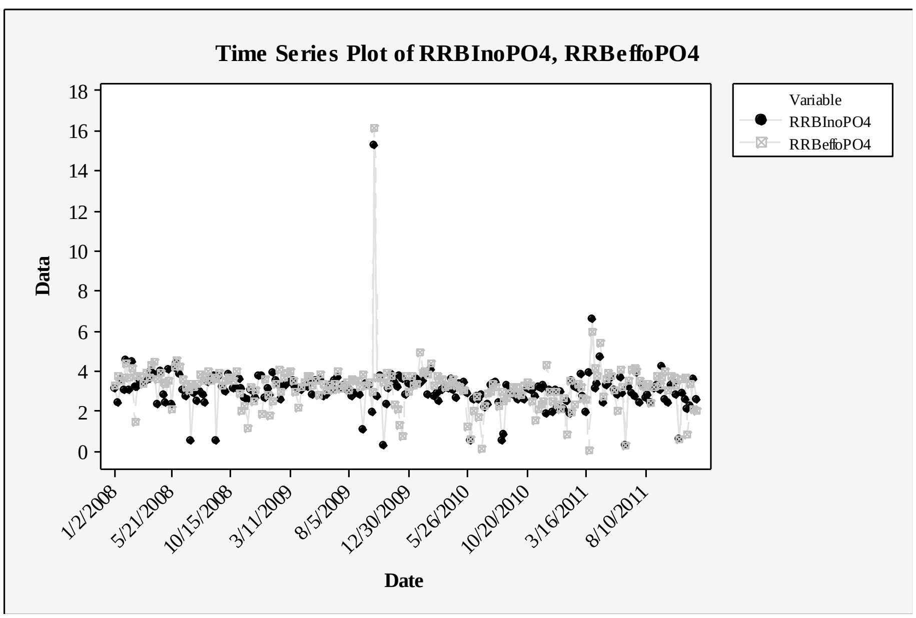

Figure WWWW Chart with incoming and effluent concentration of the Ortho-Phosphate for the Robert R. Bustamante Wastewater Treatment Plant.

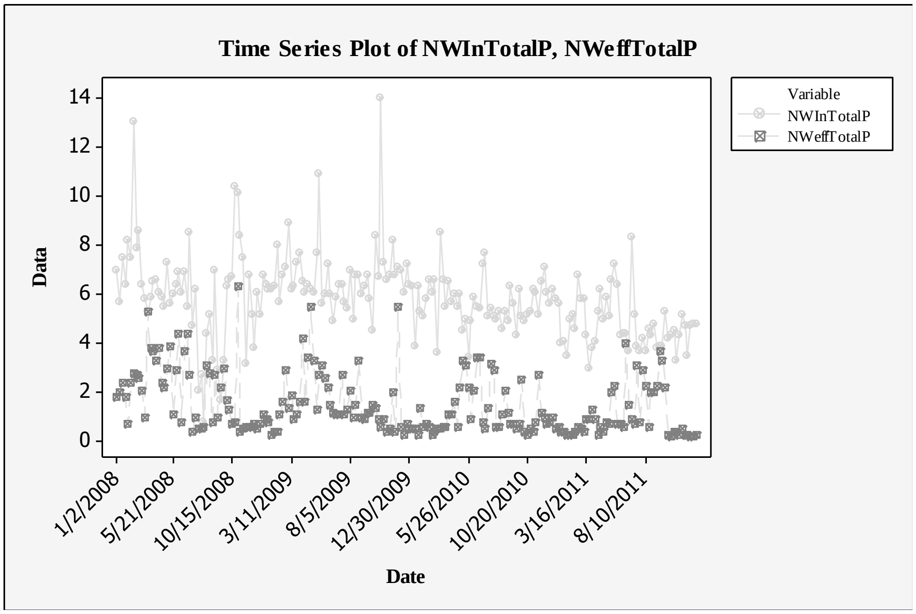

Figure XXXX Total Phosphorus portrayed for the Incoming and Effluent for the Northwest WWTP.

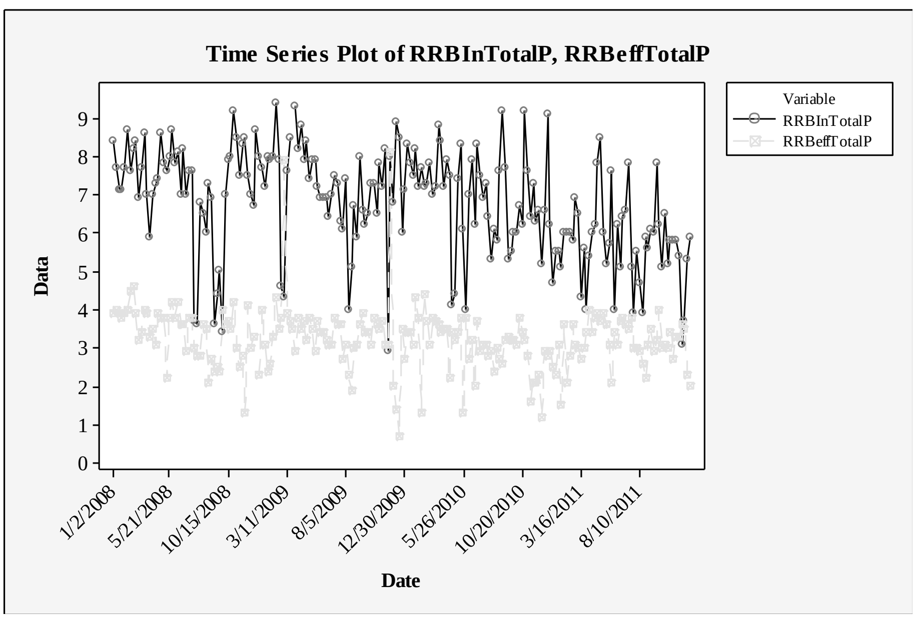

Figure YYYY Graph comparing incoming and effluent TotalP for the Robert R. Bustamante WWTP.

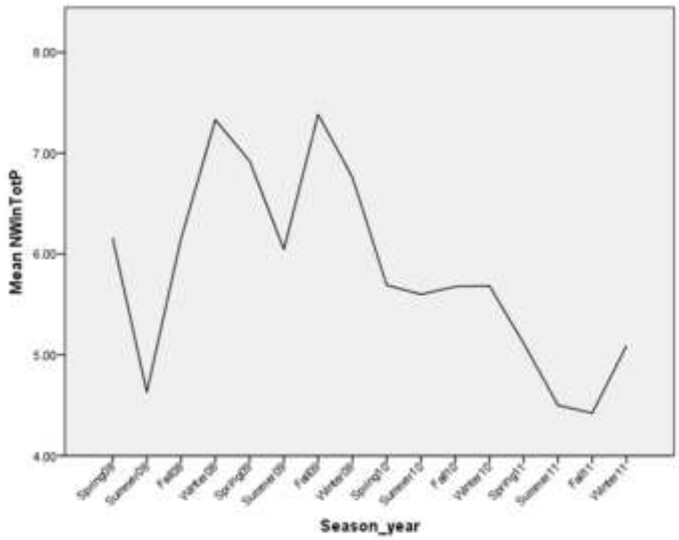

Figure ZZZZ Seasonal fluctuation of the mean values Total Phosphorus incoming flow for the NW WWTP.

The Total Phosphorus of Incoming wastewater from the NW plant has peaks on winter for the last four years.

The Total Phosphorus of Incoming wastewater from the RRB plant has peaks on winter for the last three years in a milder manner than the NW plant.

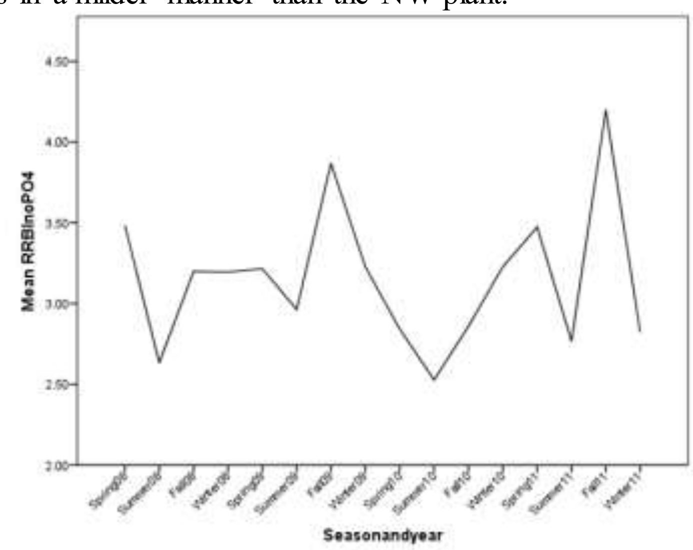

Figure AAAAA. Seasonal fluctuation of the mean values of Total Phosphorus incoming flow for RRB WWTP.

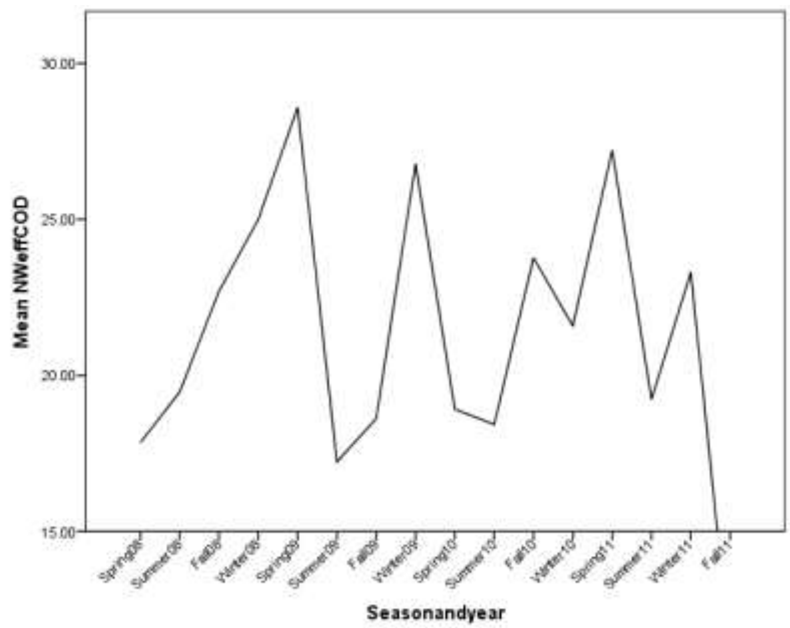

Figure BBBBB. Seasonal fluctuation of the COD for the effluent for the NW WWTP.

The COD for the NW Effluent has peaks on winters for the last four years.

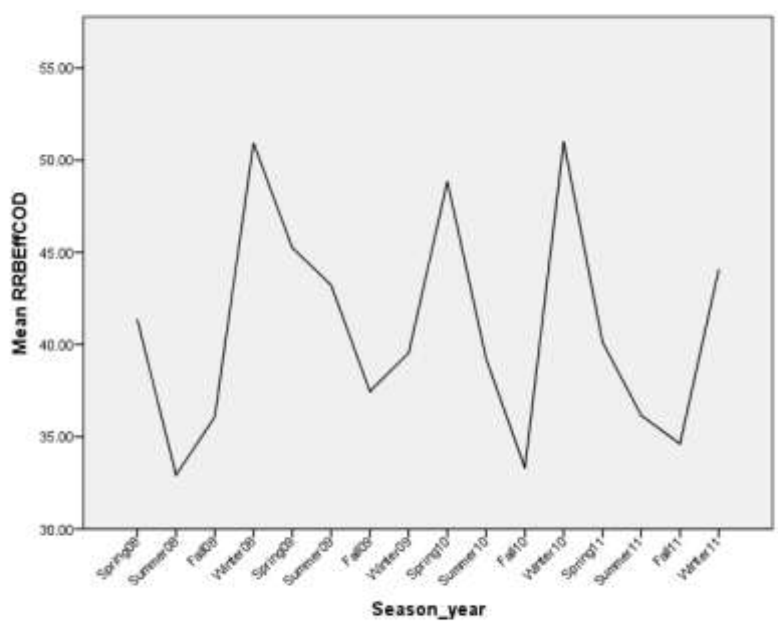

Figure CCCCC. Seasonal fluctuation of the COD for the effluent for the RRB WWTP.

4.2 DISCUSSION

From Descriptive Statistics, the major patterns in the observations are that there are very few linear relationships with an R-squared of 90% or more in the variables considered in this thesis. The Northwest and Robert R. Bustamante are predominantly non-linear systems. In addition, that in a control chart we observed the grouping of data points with different standard deviations for most parameters, suggesting that the samples came from different universes (processes), house hold use, industrial and may be agricultural processes (Figure OOO). In Figure DDD shows a histogram that it is bimodal. A bimodal distribution is a distribution that has two peaks. It occurs when the output of two process are mixed. The basic assumption is that an individual process stream adjusts to any form of an accepted distribution. In our case a normal distribution, but each has a different mean and standard deviation. In our case two different processes generate wastewater with a set of characteristics for each process, then wastewater from different sources are mixed in their way to the Wastewater Treatment Plant.

On Pearson's correlation coefficients, there were very few linear relationships (Table 7) there were ten linear relationships with an r-value of 0.7 to 0.971 using the combination of parameters considered. Using all the parameters provided by the EPWU, there were more linear relationships with high r-value. However, the majority had either low or no linear relationship.

The Robert R. Bustamante serves a refinery that it is the major contributor of wastewater treated by that facility. An almost perfect linear relationship is RRBInVSS and RRBINTSS with an equation RRBInVSS = 5.305 + 0.8665 RRBInTSS with an R squared of 94.2% (Figure U). This type of relationship requires careful consideration.

A behavior that deserves special considerations are the ones from COD and BOD5 for both WWTP. For both plants, the concentration of COD is statistically significant superior to the BOD5 (Figure BBBB and Figure CCCC).

BOD5 concentration from Northwest is numerically greater than Robert R. Bustamante WWTP (Figure DDDD). On the same graph we appreciate that the mean values describe peaks on fall for the four years of data for both plants.

Figure EEEE describes a similar behavior for the NW shown in relation to COD, which peaks in fall. This graph also used mean values for the depiction of this relationship.

El Paso Water Utilities uses surface water and ground water to provide to customers after processing the water. As explained earlier, from October to April EPWU relies on ground water, and May through September from the Rio Grande. In Figure ZZZ, the graph show peaks (using mean values) for every fall season of the four years covered by the data for the Robert R. Bustamante, while the Northwest WWTP received raw water with showed no pattern. Since both plants receive water with different Electrical Conductivity concentrations, we can infer that sectors being served by both WWTPs get their ground water from different wells.

Figure CCC shows considerable relationship of Temperature and BOD5 in the Third Quarter of the year. According to records form the weather channel the average temperatures from June to August are from mid-thirties to lower Twenties (°C).

In regards to the Robert R. Bustamante WWTP, some behaviors show in few graphs that optimization of treatment of effluent from that plant should be considered. Figure LLLL portrays the Efficiency removal of NO_3 with negative numbers, meaning that Nitrification of effluent is successful. In Figure PPPP removal efficiency of NH_3 is shown, describing fluctuation during the last four years in the removal, fluctuating less in 2011. The concentration of NH_3 shown in Figure QQQQ with concentration peaks less severe, supporting the notion of gradual control of the removal process of NH_3. Additionally, Figure UUUU depicts the removal efficiency of TKN achieving stability after a period of struggle to maintain removal efficiency high. Finally, Total Phosphorus in Figure YYYY with effluent values fluctuating around 3 mg/L. The concentration of NO_2 data points are fewer in number and are very low that barely

show in graphs. The quantitative contribution is low that only has the upper limit. The majority of each event above described is a red flag signaling the delicate balance in the biological process. The additive effect of having all the above-named nutrients available for algal blooms, some of them soluble in water, might create favorable chemical conditions for eutrophication, and subsequently hypoxia.

Another behavior that deserves attention is the highly fluctuation of COD in the effluent from the Robert R. Bustamante wastewater plant. The lowest efficiency is around 85%, which is acceptable, but stability of the output is a desirable goal.

The condition of homogeneity for data set is not met by this data since the samples gathered are every two hours for a twenty four hour period and the taken the time weighted average. We have behaviors that are time dependent, like the generation of BOD5 in a sector of the city. For statistical purposes, manipulation of data using the time-weighted average disrupts relationships that characterize a process. This is a requirement of Meta-analysis that gathers different studies with different datasets and tries to arrive to a valid conclusion.

Academically there is a Capability index as recommended as ideal for a process, but there is no Capability index for unit operations or overall process of a Wastewater Treatment Plant, if the removal of pollutant process is a statistically controllable process.

The likely causes behind the non-linear part of the process are that wastewater treatment is a modular treatment, with different unit operations, which includes biological treatment. There are linear relationships in aerobic digesters like flows, mean residence time and some chemical reactions rates, while temperature relationships are exponential. The overall system behavior has to reflect both types of behaviors.

Furthermore, random variables and covariates (like temperature) do not follow normal distribution, adding complexity that affects the type relationships that defines the wastewater system. The best to determine the overall behavior of the system is by means of design of

experiments, where controlled conditions of few factors will help to produce a mathematical model.

Also, keep in mind that we have initial and final conditions of the overall process, and do not have unit operation data and evaluation. Additionally, the mixing of samples from different universes or processes, manipulation of the data calculating the time weighted average, and measuring errors of equipment will introduce noise, and will create other types of interactions that add to the complexity of the situation.

Now, wastewater treatment is a complex process. If the type of process is household water, the expectation is that such process will generate an outcome that fits any type of statistical distribution, usually a normal distribution. When other process like industrial and the petrochemical processes come into play, at least three distributions are involved in the analysis. This is evident in the analysis process when using the whole dataset and Minitab for any parameter. When using Minitab's I-MR chart analysis, a dialog box show up flagging that there were several means and standard deviations. This indicates the coexistence of several universes (processes) or stages. From Figure OOO to Figure XXX there is a description of such analysis. In Figure OOO, the reader will find segments of dataset grouped by mean as confirmation of that multiple universe claim. This shift of mean was present on the parameters tested.

Due to the above-named development, the description of the process using I-MR and C_{pk} for the whole timeline of each parameter was not possible. A statistically control process as a prerequisite to analyze the C_{pk} did not take place. The capability indexes processed above by segments is not standard practice. The existence of several C_{pk} indexes for the same parameter process becomes a function of time.

The application of Shewhart charts is standard procedure in the application of Process Control. The definition of upper and lower limit and the legal limit deserve attention since the

model yielded out of control while the practical results showed compliance from both the Northwest and Robert R. Bustamante Wastewater Treatment Plant.

The capability of prediction of the behavior of the Statistical tools used in this thesis is limited because of the method collecting the dataset and the diversity of samples coming from different processes. However, descriptive statistics provided useful information related to the collection and treatment of wastewater for the Northwest and Robert R. Bustamante WWTP.

The need of calibrating the Shewhart Control Charts to the special circumstances to a process such as the generation of wastewater and treatment of the same is an endeavor worth trying.

The significance of having specialized Statistical Control Process tools for the wastewater treatment process that helps predict events that affect efficiency of removal of pollutants, and proper functioning of the overall process, especially when water becomes a scarce commodity and increases in price in the market.

In retrospect, this thesis has enabled us to understand the power of statistical control process, the complexity of wastewater treatment process, and that there is no universal tool for all processes. That any process output has a distribution and the absence of that condition becomes in mathematical terms as out of control process.

CHAPTER 5: CONCLUSIONS

In the previous chapters, we presented graphs, tables, and statistical models to process and analyze a dataset of four years from the Northwest and Robert R. Bustamante Wastewater Treatment Plants. The application of Statistical Control Process and descriptive Statistics explored with reasonable results for the dataset from the Northwest and Robert R. Bustamante Wastewater Plants with Secondary Treatment (biological).

Homogeneity of the subsets of the dataset for each parameter failed to have the same statistical characteristics. That is, mean and standard deviation varied for the timeline. Four years of data from two renowned facilities produced the same results, statistically non-controlled processes. Data deviated in most of the cases from the blue line in the Normality Test but had a p-value smaller than our alpha of 0.05. At any rate, the process of most parameters is statistically out of control for the whole timeline.

On the other hand, Descriptive Analysis yielded more results. From the Normal parameters correlation matrices, correlation graphs scatter dot plots, and linear regression results indicated that most of the variables analyzed had weak or no linear relationships amongst them.

Methodology of collection of data, for statistical analysis purposes, produced a sample without specific characteristics that prevented understanding the load of pollutants of the incoming flow. The dataset had subsets with no statistical relationship among them.

Descriptive Statistics detected interesting behaviors such as seasonal and day of the week peaks, strong linear relationships, and special behaviors of some parameters.

This thesis was successful in accomplishing the detection of trends, peaks and valleys, but in the predictive part was very limited.

General statistical models require calibration to specific conditions of a process like wastewater treatment with secondary treatment. Adaptation of Shewhart charts need to this set

of dynamic conditions. The determination of the upper and lower limits of the control chart should be address considering moving means and different standard deviations.

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APPENDIX

NORTHWEST WASTEWATER TREATMENT PLANT SCHEMATICS

(EXHIBIT A)

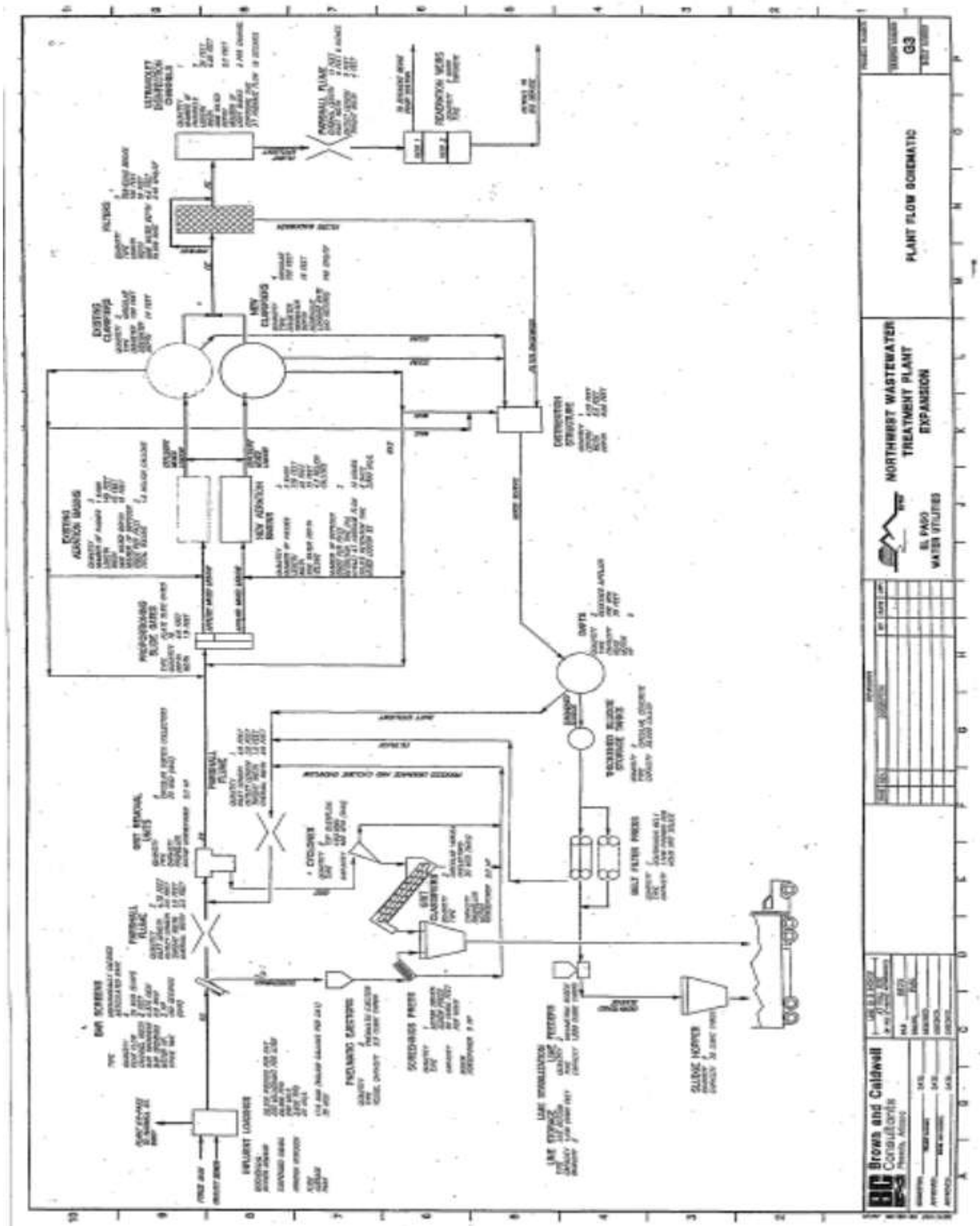

Figure DDDDD. Schematics of the Northwest showing the operations of the WWTP. Configuration of operations might change before publication of the present thesis. Provided by EPWU.

ROBERT R. BUSTAMANTE WASTEWATER TREATMENT PLANT SCHEMATICS (EXHIBIT B)

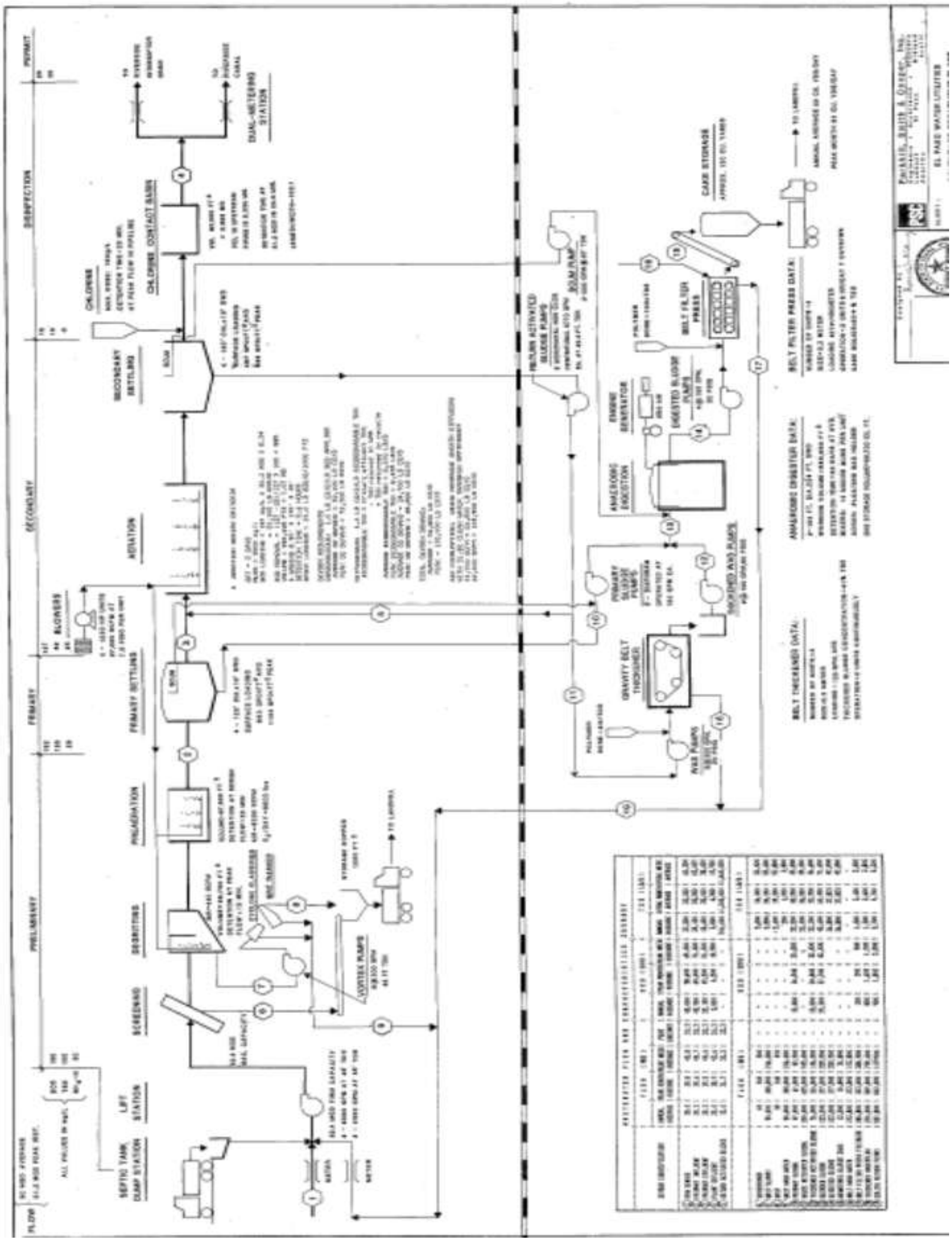

Figure EEEEE. Schematics of the Robert R. Bustamante showing the operations of the WWTP. Configuration of operations might change before publication of the present thesis. Provided by EPWU.

LIST OF CUSTOMERS AND WWTP TREATING THEIR EFFLUENTS
(EXHIBIT C)

INDUSTRIAL CONTRIBUTION				
Industry Name	Permit Number	Mailing Address	Receiving WWTP	Discharge (sanitary + process) gpd
AMERI-TECH DIST., INC.	010-5405.300	5227 Montview	BUSTAMANTE	2,920
CHAMPLAIN CABLE	20-5493.301	9560 Plaza Circle	BUSTAMANTE	6,043
COCA-COLA REFRESHMENTS USA, INC.	180-4227.300	11001 Gateway West	BUSTAMANTE	123,615
DEL SOL MEDICAL CENTER	230-7830.300	10301 Gateway West Blvd	BUSTAMANTE	48,179
DYNAMIC TOOL CO., INC.	270-0515.300	1421 Vanderbilt	BUSTAMANTE	509
ELECTROPLATING OF EL PASO	010-7176.301	1040 Hawkins	BUSTAMANTE	11,467
FARMERS SELECT	180-4271.400	7237 N. Loop	BUSTAMANTE	43,589
FEDERAL MOGUL	20-9700.302	1277 Joe Battle Boulevard	BUSTAMANTE	8,879
FLEXAUST APPLIANCE, INC.	270-6012.301	12134 Esther Lama	BUSTAMANTE	9,565
GH DAIRY EL PASO	20-9405.301	9747 Pan American Dr	BUSTAMANTE	92,951
INTERNATIONAL LAUNDRY SERVICES	2601-5538.300	12651 Montana Ave	BUSTAMANTE	2,452
INTERNATIONAL PAPER COMPANY	020-7864.300	9301Billy The Kid	BUSTAMANTE	18,403
LAS PALMAS-DEL SOL REGIONAL HEALTHCARE SYSTEM	231-0022.301	10125 Gateway West Boulevard	BUSTAMANTE	25,307
PHELPS DODGE EL PASO OPERATIONS	010-7145.300	P.O. Box 20001	BUSTAMANTE	26,933
PRODUCTOS REAL	20-6167.308	1100 Pendale Road	BUSTAMANTE	7,065
STAMPCOAT	270-0573.303	10863 Pellicano	BUSTAMANTE	8,879
STAMPCOAT	270-5857.300	10863 Pellicano	BUSTAMANTE	3,286
STERIS ISOMEDIX SERVICES	270-4456.300	1435 Isomedix Place	BUSTAMANTE	6,540
STERIS ISOMEDIX SERVICES	271-0824.400	1441 Don Haskins	BUSTAMANTE	2,679
THERMOLINK OF TEXAS	270-4783.300	1295 Henry Brennan	BUSTAMANTE	70,958
UNIFIRST HOLDINGS, LPD.	010-7026.300	P.O. Box 26159	BUSTAMANTE	130,162
WESTERN REFINING COMPANY	180-4277.300	6501 Trowbridge	BUSTAMANTE	1,366,430
AZAR NUT COMPANY	080-4418.300	1800 Northwestern	NORTHWEST	5,407
CAREFUSION 213, LLC	080-9271.300	1550 Northwestern	NORTHWEST	12,617
COLEMAN CABLE	080-9595.302	7811 Hoover Ave	NORTHWEST	57,692
EAGLE FAMILY FOODS	060-4879.301	255 Montoya	NORTHWEST	282,937
GLOBAL ALTERNATIVE FUELS	180-4747.300	3500 Doniphan Dr., Ste. A	NORTHWEST	8,579
GLOBAL ENTERPRISES	060-6327.300	6056 Luckett	NORTHWEST	8,390
THE HOOVER COMPANY, INC	080-4231.300	7850 Hoover Ave	NORTHWEST	16,179
INTERNATIONAL WIRE COMPANY	080-8093.300	12 Masonic Ave	NORTHWEST	27,891
LEVITON MANUFACTURING	080-5405.300	7800 Trade Center	NORTHWEST	7,925
SUMITOMO ELECTRIC WIRING SYSTEMS	080-9286.300	6500 N. Desert Blvd.	NORTHWEST	134,072

Estimate based on annual average water consumption
Obtained based on flow meter readings

WWT Plant	Design Capacity MGD	Actual MGD (Average)	dustrial Flo MGD (Average)	Approximate Industrial Flow %
NORTHWEST	17.5	7.72	0.561769	7.28
BUSTAMANTE	39.0	27.84	2.016811	7.24

Figure FFFFF. List of Industrial Customers using the services of NW or RRB WWTP. Provided by EPWU.

WASTEWATER AND STATISTICS GLOSSARIES (EXHIBIT D)

Glossary for Wastewater

Partially provided by EPWU

˚C: Degrees Celsius

μg/L: Micrograms per Liter

ALKALINITYTO: Total Alkalinity

AMMONIA: NH_4

Bio solids: Nutrient-rich, organic material removed during the treatment process. After digested and dewatered.

BOD: Biochemical Oxygen Demand

BOD5: 5-day Biochemical Oxygen Demand

Br: Bromide

Ca: Calcium

Cl: Chloride

COD: Chemical Oxygen Demand

C_{pk}: Is the measure of closeness to a target value or the consistency of performance around an average value.

CWA: Clean Water Act

Digestion: Process under which organisms break down sludge.

Disinfection: Final step in the tertiary wastewater treatment process to kill disease-

causing microorganisms.

E. Coli: Escherichia coli

EC: Electrical Conductivity

Effluent: Treated wastewater flowing out from a treatment plant.

EPA: U.S. Environmental Protection Agency

F: Fluoride

GPD: Gallons per Day

Grit Chamber: Tank in which the flow of wastewater slows down, allowing heavy solid materials to sink to the bottom.

Groundwater: Water beneath the surface of the earth recovered in wells or springs.

H_2S: Hydrogen Sulfide

HARDNESS: Total Hardness

Headworks: Area of treatment plant where influent begins treatment.

Influent: Untreated wastewater flowing into a treatment plant.

K: Potassium

Mg: Magnesium

mg/L: Milligrams Per Liter, unit of measure that equates to parts per million

MGD: Million Gallons Per Day

MLSS: Mixed Liquor Suspended Solids

Na: Sodium

NH_4: Ammonium as Nitrogen

NO_2: Nitrate

NO_3: Nitrate-N

Nonpoint Source Pollution: Water pollution caused by sources of runoff such as farm fields, urban areas and other sources.

o-PO_4: Orthophosphate

Potable Water: Water that meets the U.S. Environmental Protection Agency drinking water standards.

Raw sewage: Untreated wastewater from the sewage pipes.

Reclaimed water: Product produced by tertiary treatment of wastewater used for turf irrigation and certain industrial uses.

Run off: Rainfall or other type of water that drains off the street or land.

Secondary Treatment: Second stage of wastewater treatment that uses biological digestion to degrade organic matter.

Sewage: Home or industrial wastewater discharged to a sewer system.

SiO_2: Silica

Sludge: The waste material that deposits out in the wastewater treatment process.

SO_4: Sulfate

TDS: Total Dissolved Solids

TKN: Total Kjeldahl Nitrogen

Total Dissolved Solids (TDS): Quantity of dissolved material in water measured in (mg/L).

Total P: Total Phosphorus

TS: Total Solids

TSA: Total Suspended Ash

TSS: Total Suspended Solids

TSS (Total Suspended Solids): Solids in water that trapped by a filter.

Turb: Turbidity

UV: Ultra-Violet

VOC: Volatile Organic Carbon

VSS: Volatile Suspended Solids

WWTP: Wastewater Treatment Plant

GLOSSARY FOR STATISTICS

ANOVA: Analysis of Variance

ARIMA: Autoregressive Integrated Moving Average Model (aka Box-Jenkins model). It is a model of random processes in time series.

Average: The arithmetic mean, but it can also mean the median, the mode, among other things.

Categorical Variable: A variable whose value ranges over categories, such as Gender, Days of week, Season of the year.

Covariate: An independent variable not manipulated by the experimenter but still affecting the response.

Database: A structured collection of data.

Dependent Variable: Response variable. Variable of interest in investigation.

Descriptive statistics: Methods of graphing, tabulating, and presenting characteristics of data (i.e. mean standard deviation, etc.).

Effect: Change in a response variable produced by a change in one or more independent variables.

Factor: Categorical variable with small number of levels.

Forecast: Is the projection of most likely value to provide an accurate prediction of future values in a process. It is related to Time series.

Homogeneity: Assumption that the statistical characteristics of any subset of the whole dataset are the same as any other part.

Independent Variable: The variable usually plotted on the horizontal axis.

Levene test: A test used for detecting heterogeneity of variance

MANOVA Analysis of Variance for more than one factor

MANOVA: Multivariate analysis of variance.

Meta-analysis: Methods that contrast and combine results from different studies (datasets), aimed to find and identify patterns among study results,

MINITAB: A general-purpose statistical software package widely used in Manufacturing.

Model: A description of the structure of a set of observations by the use of a mathematical expression originated from a set of data.

Monte Carlo methods: Methods for finding solutions to mathematical and statistical problems by simulation.

Noise: A process of irregular fluctuations.

Outlier: An observation that deviates notoriously from the set of members of the sample.

P-value: The probability of the observed data when the null hypothesis is true.

Q-Q plot: Quantile–quantile plot used to compare two probability plots. One distribution is Normal while the other is the distribution of the data points of the study.

Reliability: The extent to which repeated measurements on units (for instance people) yield similar results.

Repeatability: The closeness of the results obtained in the same test material by the same observer or tech person using same resources like apparatus and equipment.

Reproducibility: The closeness of results obtained on the same test material under changes of Technicians, equipment, and apparatus.

Type I error: The error that results when the null hypothesis is falsely rejected.

Type II error: The error that results when the null hypothesis is falsely accepted.

RESULTS SUPPORTING DATA, GRAPHS AND DOCUMENTS

(EXHIBIT E)

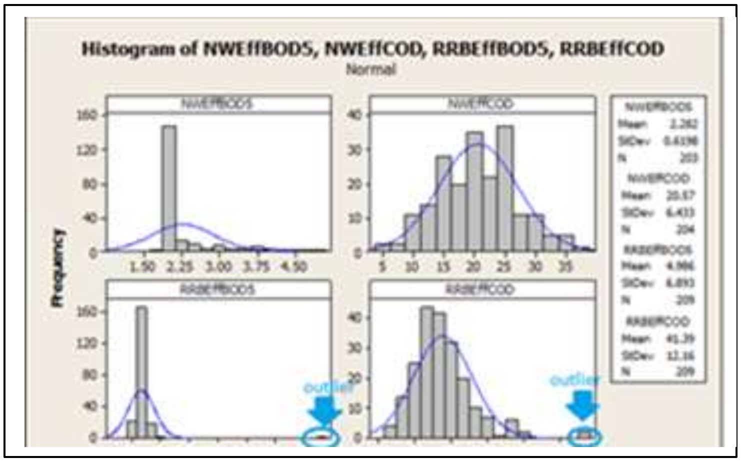

Figure GGGGG. Panel view of histograms and outliers for the four variables.

In order to graph the X-r and the C_{pk} using data with outliers the software require to follow the sequence of steps described in Figure G.2.

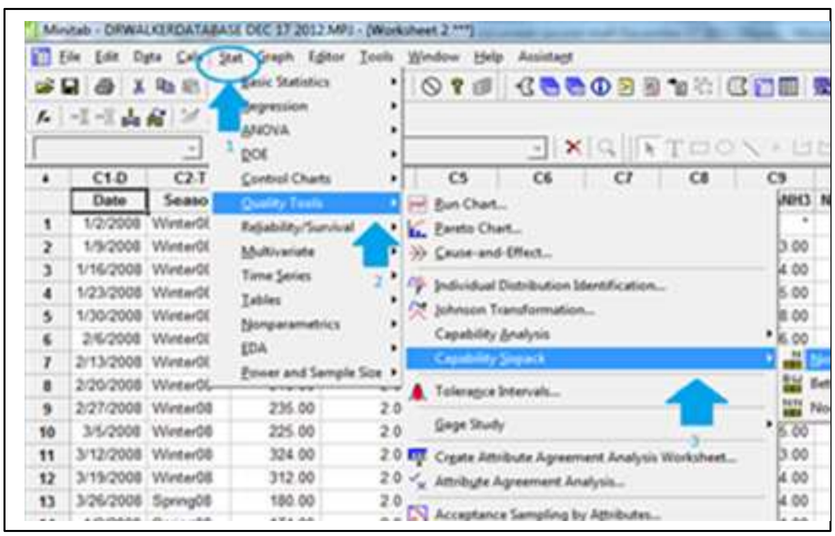

Figure HHHHH. Front view of the Edit Window for Minitab 16 showing the sequence of steps to get the Cpk.[6][5]

[5] Reprint Courtesy of International Business Machines Corporation, © International Business Machines Corporation.

Table 11 Normality Test Results for all Parameters both plants.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Temp_avg_airport	.084	207	.001	.958	207	.000
NWIn	.110	207	.000	.953	207	.000
RRBIn	.063	207	.045	.973	207	.001
NWEff	.126	207	.000	.938	207	.000
RRBEff	.095	207	.000	.959	207	.000
NWInBOD5	.069	207	.019	.974	207	.001
NWInCOD	.064	207	.037	.954	207	.000
NWInNH3	.093	207	.000	.859	207	.000
NWInNO2	.476	207	.000	.264	207	.000
NWInNO3	.471	207	.000	.183	207	.000
NWInTDS	.071	207	.014	.953	207	.000
NWInTKN	.090	207	.000	.893	207	.000
NWInTSS	.162	207	.000	.785	207	.000
NWInVSS	.144	207	.000	.796	207	.000
NWInEC	.067	207	.024	.964	207	.000
NWInoPO4	.094	207	.000	.881	207	.000
NWInTotalP	.094	207	.000	.937	207	.000
NWInTOTHARD	.084	207	.001	.822	207	.000
NWeffBOD5	.344	207	.000	.469	207	.000
NWeffCOD	.111	207	.000	.892	207	.000
NWeffNH3	.335	207	.000	.539	207	.000
NWeffNO2	.392	207	.000	.427	207	.000
NWeffNO3	.112	207	.000	.948	207	.000
NWeffTDS	.058	207	.092	.965	207	.000
NWeffEC	.052	207	.200*	.981	207	.006
NWeffTKN	.363	207	.000	.378	207	.000
NWeffTSS	.287	207	.000	.564	207	.000
NWeffVSS	.306	207	.000	.666	207	.000
NWeffoPO4	.167	207	.000	.842	207	.000
NWeffSO4	.195	207	.000	.724	207	.000
NWeffTotalP	.190	207	.000	.850	207	.000

NWeffTHard	.042	207	.200*	.938	207	.000
RRBInBOD5	.051	207	.200*	.981	207	.007
RRBInCOD	.114	207	.000	.879	207	.000
RRBInNH3	.155	207	.000	.750	207	.000
RRBInNO2	.498	207	.000	.147	207	.000
RRBInNO3	.491	207	.000	.119	207	.000
RRBInTDS	.145	207	.000	.731	207	.000
RRBInTKN	.166	207	.000	.744	207	.000
RRBInTSS	.108	207	.000	.848	207	.000
RRBInVSS	.118	207	.000	.832	207	.000
RRBInEC	.089	207	.000	.957	207	.000
RRBInoPO4	.176	207	.000	.596	207	.000
RRBInSO4	.078	207	.004	.971	207	.000
RRBInTotalP	.095	207	.000	.954	207	.000
RRBInTHard	.118	207	.000	.971	207	.000
RRBeffBOD5	.103	207	.000	.917	207	.000
RRBeffCOD	.079	207	.003	.965	207	.000
RRBeffNH3	.236	207	.000	.656	207	.000
RRBeffNO2	.314	207	.000	.462	207	.000
RRBeffNO3	.124	207	.000	.935	207	.000
RRBeffoPO4	.177	207	.000	.649	207	.000
RRBeffSO4	.063	207	.044	.955	207	.000
RRBeffTDS	.185	207	.000	.695	207	.000
RRBeffTKN	.214	207	.000	.743	207	.000
RRBeffTotalP	.129	207	.000	.856	207	.000
RRBeffTHard	.100	207	.000	.943	207	.000
RRBeffTSS	.190	207	.000	.906	207	.000
RRBeffVSS	.154	207	.000	.900	207	.000

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Table 12 Descriptive Statistics for the all Parameters of both Wastewater Treatment Plants.

Descriptives

			Statistic	Std. Error
Temp _avg_airport	Mean		19.3444	.62081
	95% Confidence Interval for Mean	Lower Bound	18.1205	
		Upper Bound	20.5684	
	5% Trimmed Mean		19.6190	
	Median		20.3000	
	Variance		79.779	
	Std. Deviation		8.93190	
	Minimum		-11.90	
	Maximum		33.65	
	Range		45.55	
	Interquartile Range		14.75	
	Skewness		-.403	.169
	Kurtosis		-.541	.337
NWIn	Mean		31205.7708	505.70609
	95% Confidence Interval for Mean	Lower Bound	30208.7476	
		Upper Bound	32202.7939	
	5% Trimmed Mean		31112.1007	
	Median		29295.9000	
	Variance		52937900.821	
	Std. Deviation		7275.84365	
	Minimum		14307.30	

	Maximum		46063.45	
	Range		31756.15	
	Interquartile Range		12528.35	
	Skew ness		.268	.169
	Kurtosis		-1.030	.337
RRBIn	Mean		102384.6157	533.02032
	95% Confidence Interval for Mean	Low er Bound	101333.7413	
		Upper Bound	103435.4901	
	5% Trimmed Mean		102155.1894	
	Median		102157.1500	
	Variance		58810906.019	
	Std. Deviation		7668.82690	
	Minimum		78122.40	
	Maximum		128387.20	
	Range		50264.80	
	Interquartile Range		9651.75	
	Skew ness		.417	.169
	Kurtosis		1.451	.337
NWEff	Mean		23325.1769	587.35559
	95% Confidence Interval for Mean	Low er Bound	22167.1780	
		Upper Bound	24483.1759	
	5% Trimmed Mean		23280.0895	
	Median		22064.9400	

Variable	Statistic	Bound	Value	Std. Error
	Variance		71412222.763	
	Std. Deviation		8450.57529	
	Minimum		5565.90	
	Maximum		40234.55	
	Range		34668.65	
	Interquartile Range		16063.72	
	Skewness		.176	.169
	Kurtosis		-1.283	.337
RRBEff	Mean		104131.3841	477.38689
	95% Confidence Interval for Mean	Lower Bound	103190.1935	
		Upper Bound	105072.5746	
	5% Trimmed Mean		103935.8765	
	Median		103141.2500	
	Variance		47174935.760	
	Std. Deviation		6868.40125	
	Minimum		79674.25	
	Maximum		128387.20	
	Range		48712.95	
	Interquartile Range		7267.20	
	Skewness		.510	.169
	Kurtosis		1.938	.337
NWIn BOD5	Mean		208.4068	4.35241
	95% Confidence Interval for	Lower Bound	199.8258	

	Mean		Upper Bound	216.9877	
		5% Trimmed Mean		205.9914	
		Median		199.0000	
		Variance		3921.295	
		Std. Deviation		62.62024	
		Minimum		82.70	
		Maximum		374.00	
		Range		291.30	
		Interquartile Range		83.00	
		Skewness		.540	.169
		Kurtosis		-.031	.337
COD	NWIn	Mean		521.5217	7.58808
		95% Confidence Interval for Mean	Lower Bound	506.5615	
			Upper Bound	536.4820	
		5% Trimmed Mean		516.1731	
		Median		518.0000	
		Variance		11918.843	
		Std. Deviation		109.17345	
		Minimum		284.00	
		Maximum		1080.00	
		Range		796.00	
		Interquartile Range		133.00	
		Skewness		1.008	.169
		Kurtosis		2.990	.337
NH3	NWIn	Mean		24.2385	.31421
		95% Confidence Interval for	Lower Bound	23.6190	

	Mean		Upper Bound	24.8579	
		5% Trimmed Mean		24.1288	
		Median		24.0000	
		Variance		20.437	
		Std. Deviation		4.52076	
		Minimum		.36	
		Maximum		56.00	
		Range		55.64	
		Interquartile Range		5.00	
		Skewness		1.115	.169
		Kurtosis		14.268	.337
NO2	NWIn	Mean		.2478	.00435
		95% Confidence Interval for Mean	Lower Bound	.2392	
			Upper Bound	.2564	
		5% Trimmed Mean		.2500	
		Median		.2500	
		Variance		.004	
		Std. Deviation		.06260	
		Minimum		.00	
		Maximum		.86	
		Range		.86	
		Interquartile Range		.00	
		Skewness		3.709	.169
		Kurtosis		48.786	.337
NO3	NWIn	Mean		.7384	.10436
		95% Confidence Interval for	Lower Bound	.5326	

	Mean		Upper Bound	.9441	
		5% Trimmed Mean		.5087	
		Median		.5000	
		Variance		2.254	
		Std. Deviation		1.50148	
		Minimum		.00	
		Maximum		13.00	
		Range		13.00	
		Interquartile Range		.00	
		Skewness		6.729	.169
		Kurtosis		45.996	.337
TDS	NWIn	Mean		1224.6860	5.31004
	Mean	95% Confidence Interval for	Lower Bound	1214.2170	
			Upper Bound	1235.1550	
		5% Trimmed Mean		1222.4316	
		Median		1220.0000	
		Variance		5836.673	
		Std. Deviation		76.39812	
		Minimum		1030.00	
		Maximum		1640.00	
		Range		610.00	
		Interquartile Range		90.00	
		Skewness		.923	.169
		Kurtosis		4.047	.337
TKN	NWIn	Mean		36.3019	.41324
		95% Confidence Interval for	Lower Bound	35.4872	

	Mean		Upper Bound	37.1166	
		5% Trimmed Mean		36.2637	
		Median		36.3000	
		Variance		35.348	
		Std. Deviation		5.94542	
		Minimum		2.00	
		Maximum		68.90	
		Range		66.90	
		Interquartile Range		6.40	
		Skewness		-.137	.169
		Kurtosis		9.286	.337
TSS	NWIn	Mean		161.8986	3.27252
		95% Confidence Interval for Mean	Lower Bound	155.4466	
			Upper Bound	168.3505	
		5% Trimmed Mean		156.4557	
		Median		152.0000	
		Variance		2216.849	
		Std. Deviation		47.08342	
		Minimum		75.00	
		Maximum		430.00	
		Range		355.00	
		Interquartile Range		42.00	
		Skewness		2.532	.169
		Kurtosis		9.422	.337
VSS	NWIn	Mean		140.1353	2.78773

Mean	95% Confidence Interval for	Lower Bound	134.6391	
		Upper Bound	145.6314	
	5% Trimmed Mean		135.7343	
	Median		134.0000	
	Variance		1608.690	
	Std. Deviation		40.10848	
	Minimum		67.00	
	Maximum		374.00	
	Range		307.00	
	Interquartile Range		35.00	
	Skewness		2.515	.169
	Kurtosis		9.960	.337
NWInEC	Mean		2035.5556	8.18263
Mean	95% Confidence Interval for	Lower Bound	2019.4231	
		Upper Bound	2051.6880	
	5% Trimmed Mean		2036.2829	
	Median		2040.0000	
	Variance		13859.763	
	Std. Deviation		117.72749	
	Minimum		1660.00	
	Maximum		2650.00	
	Range		990.00	
	Interquartile Range		140.00	
	Skewness		.326	.169
	Kurtosis		3.366	.337
NWIno	Mean		2.5978	.06534

PO4	Mean	95% Confidence Interval for	Low er Bound	2.4690	
			Upper Bound	2.7266	
		5% Trimmed Mean		2.5872	
		Median		2.6200	
		Variance		.884	
		Std. Deviation		.94006	
		Minimum		.27	
		Maximum		9.14	
		Range		8.87	
		Interquartile Range		.85	
		Skew ness		1.398	.169
		Kurtosis		11.276	.337
TotalP	NWIn	Mean		5.8275	.11470
	Mean	95% Confidence Interval for	Low er Bound	5.6014	
			Upper Bound	6.0537	
		5% Trimmed Mean		5.7680	
		Median		5.9000	
		Variance		2.723	
		Std. Deviation		1.65029	
		Minimum		.80	
		Maximum		14.00	
		Range		13.20	
		Interquartile Range		1.70	
		Skew ness		.954	.169
		Kurtosis		4.416	.337
TOTHARD	NWIn	Mean		211.3527	1.8541 1

	Mean	95% Confidence Interval for	Lower Bound	207.6972	
			Upper Bound	215.0081	
		5% Trimmed Mean		209.8148	
		Median		211.0000	
		Variance		711.608	
		Std. Deviation		26.67598	
		Minimum		168.00	
		Maximum		434.00	
		Range		266.00	
		Interquartile Range		33.00	
		Skewness		2.935	.169
		Kurtosis		22.302	.337
BOD5	NWeff	Mean		2.3797	.07043
	Mean	95% Confidence Interval for	Lower Bound	2.2409	
			Upper Bound	2.5186	
		5% Trimmed Mean		2.2331	
		Median		2.0000	
		Variance		1.027	
		Std. Deviation		1.01330	
		Minimum		.00	
		Maximum		11.80	
		Range		11.80	
		Interquartile Range		.20	
		Skewness		4.902	.169
		Kurtosis		37.388	.337
	NWeff	Mean		20.9662	.59363

COD	Mean	95% Confidence Interval for	Lower Bound	19.7958	
			Upper Bound	22.1365	
		5% Trimmed Mean		20.6331	
		Median		20.0000	
		Variance		72.945	
		Std. Deviation		8.54081	
		Minimum		.00	
		Maximum		70.00	
		Range		70.00	
		Interquartile Range		9.00	
		Skewness		1.565	.169
		Kurtosis		8.422	.337
NH3	NWeff	Mean		.4729	.03670
	Mean	95% Confidence Interval for	Lower Bound	.4005	
			Upper Bound	.5453	
		5% Trimmed Mean		.3967	
		Median		.5000	
		Variance		.279	
		Std. Deviation		.52806	
		Minimum		.02	
		Maximum		5.00	
		Range		4.98	
		Interquartile Range		.32	
		Skewness		4.871	.169
		Kurtosis		32.560	.337
	NWeff	Mean		.3113	.01473

NO2	Mean	95% Confidence Interval for	Lower Bound	.2823	
			Upper Bound	.3404	
		5% Trimmed Mean		.2797	
		Median		.2500	
		Variance		.045	
		Std. Deviation		.21196	
		Minimum		.00	
		Maximum		1.86	
		Range		1.86	
		Interquartile Range		.00	
		Skewness		4.741	.169
		Kurtosis		28.565	.337
NO3	NWeff	Mean		10.1289	.23204
	Mean	95% Confidence Interval for	Lower Bound	9.6714	
			Upper Bound	10.5864	
		5% Trimmed Mean		10.2283	
		Median		10.4000	
		Variance		11.145	
		Std. Deviation		3.33848	
		Minimum		.00	
		Maximum		22.40	
		Range		22.40	
		Interquartile Range		3.25	
		Skewness		-.476	.169
		Kurtosis		1.898	.337
TDS	NWeff	Mean		1213.6812	5.3134 0

	Mean	95% Confidence Interval for	Lower Bound	1203.2055	
			Upper Bound	1224.1568	
		5% Trimmed Mean		1212.8288	
		Median		1220.0000	
		Variance		5844.073	
		Std. Deviation		76.44653	
		Minimum		982.00	
		Maximum		1590.00	
		Range		608.00	
		Interquartile Range		90.00	
		Skewness		.508	.169
		Kurtosis		3.003	.337
EC	NWeff	Mean		1918.5024	8.1587 0
	Mean	95% Confidence Interval for	Lower Bound	1902.4172	
			Upper Bound	1934.5877	
		5% Trimmed Mean		1919.3237	
		Median		1910.0000	
		Variance		13778.814	
		Std. Deviation		117.38319	
		Minimum		1580.00	
		Maximum		2450.00	
		Range		870.00	
		Interquartile Range		150.00	
		Skewness		.155	.169
		Kurtosis		1.511	.337
	NWeff	Mean		2.3981	.08491

TKN	Mean	95% Confidence Interval for Mean	Lower Bound	2.2307	
			Upper Bound	2.5655	
		5% Trimmed Mean		2.2090	
		Median		2.0000	
		Variance		1.492	
		Std. Deviation		1.22161	
		Minimum		1.10	
		Maximum		14.00	
		Range		12.90	
		Interquartile Range		.30	
		Skewness		6.111	.169
		Kurtosis		47.348	.337
TSS	NWeff	Mean		2.1932	.14104
		95% Confidence Interval for Mean	Lower Bound	1.9152	
			Upper Bound	2.4713	
		5% Trimmed Mean		1.9300	
		Median		2.0000	
		Variance		4.118	
		Std. Deviation		2.02924	
		Minimum		.00	
		Maximum		22.00	
		Range		22.00	
		Interquartile Range		2.00	
		Skewness		5.183	.169
		Kurtosis		43.914	.337
	NWeff	Mean		1.7826	.08625

VSS	Mean	95% Confidence Interval for	Lower Bound	1.6126	
			Upper Bound	1.9527	
		5% Trimmed Mean		1.6151	
		Median		1.0000	
		Variance		1.540	
		Std. Deviation		1.24092	
		Minimum		1.00	
		Maximum		7.00	
		Range		6.00	
		Interquartile Range		1.00	
		Skewness		2.006	.169
		Kurtosis		3.718	.337
NWeff oPO4		Mean		1.3487	.07818
	Mean	95% Confidence Interval for	Lower Bound	1.1946	
			Upper Bound	1.5029	
		5% Trimmed Mean		1.2367	
		Median		.8900	
		Variance		1.265	
		Std. Deviation		1.12486	
		Minimum		.11	
		Maximum		5.49	
		Range		5.38	
		Interquartile Range		1.62	
		Skewness		1.409	.169
		Kurtosis		1.901	.337
NWeff SO4		Mean		322.7440	3.6466 9

	Mean	95% Confidence Interval for	Lower Bound	315.5543	
			Upper Bound	329.9336	
		5% Trimmed Mean		325.1704	
		Median		326.0000	
		Variance		2752.755	
		Std. Deviation		52.46670	
		Minimum		.00	
		Maximum		637.00	
		Range		637.00	
		Interquartile Range		36.00	
		Skewness		-.297	.169
		Kurtosis		16.361	.337
TotalP	NWeff	Mean		1.4864	.08459
	Mean	95% Confidence Interval for	Lower Bound	1.3196	
			Upper Bound	1.6531	
		5% Trimmed Mean		1.3754	
		Median		1.0000	
		Variance		1.481	
		Std. Deviation		1.21703	
		Minimum		.20	
		Maximum		6.30	
		Range		6.10	
		Interquartile Range		1.60	
		Skewness		1.304	.169
		Kurtosis		1.394	.337
THard	NWeff	Mean		208.3222	1.68165

	Mean	95% Confidence Interval for Mean	Lower Bound	205.0068	
			Upper Bound	211.6377	
		5% Trimmed Mean		208.4683	
		Median		210.0000	
		Variance		585.382	
		Std. Deviation		24.19466	
		Minimum		62.70	
		Maximum		264.00	
		Range		201.30	
		Interquartile Range		34.00	
		Skewness		-.876	.169
		Kurtosis		5.100	.337
BOD5	RRBIn	Mean		195.6473	2.93258
		95% Confidence Interval for Mean	Lower Bound	189.8656	
			Upper Bound	201.4291	
		5% Trimmed Mean		196.2099	
		Median		199.0000	
		Variance		1780.200	
		Std. Deviation		42.19242	
		Minimum		.00	
		Maximum		301.00	
		Range		301.00	
		Interquartile Range		58.00	
		Skewness		-.460	.169
		Kurtosis		1.391	.337

COD	RRBIn	Mean		532.3333	5.16107
		95% Confidence Interval for Mean	Lower Bound	522.1581	
			Upper Bound	542.5086	
		5% Trimmed Mean		532.5153	
		Median		533.0000	
		Variance		5513.777	
		Std. Deviation		74.25481	
		Minimum		205.00	
		Maximum		982.00	
		Range		777.00	
		Interquartile Range		69.00	
		Skewness		.698	.169
		Kurtosis		9.225	.337
NH3	RRBIn	Mean		31.9372	.36645
		95% Confidence Interval for Mean	Lower Bound	31.2147	
			Upper Bound	32.6597	
		5% Trimmed Mean		31.5150	
		Median		31.0000	
		Variance		27.797	
		Std. Deviation		5.27229	
		Minimum		22.00	
		Maximum		74.00	
		Range		52.00	
		Interquartile Range		5.00	
		Skewness		3.464	.169
		Kurtosis		22.725	.337

NO2	RRBIn Mean	Mean		.2582	.00838
		95% Confidence Interval for Mean	Lower Bound	.2416	
			Upper Bound	.2747	
		5% Trimmed Mean		.2500	
		Median		.2500	
		Variance		.015	
		Std. Deviation		.12060	
		Minimum		.05	
		Maximum		1.69	
		Range		1.64	
		Interquartile Range		.00	
		Skewness		9.606	.169
		Kurtosis		106.798	.337
NO3	RRBIn Mean	Mean		.7062	.11631
		95% Confidence Interval for Mean	Lower Bound	.4769	
			Upper Bound	.9355	
		5% Trimmed Mean		.5004	
		Median		.5000	
		Variance		2.800	
		Std. Deviation		1.67338	
		Minimum		.10	
		Maximum		17.70	
		Range		17.60	
		Interquartile Range		.00	
		Skewness		8.497	.169
		Kurtosis		74.129	.337

TDS	RRBIn	Mean		1041.0242	8.44702
		95% Confidence Interval for Mean	Lower Bound	1024.3705	
			Upper Bound	1057.6779	
		5% Trimmed Mean		1043.3419	
		Median		1040.0000	
		Variance		14769.897	
		Std. Deviation		121.53147	
		Minimum		.00	
		Maximum		1740.00	
		Range		1740.00	
		Interquartile Range		84.00	
		Skewness		-2.168	.169
		Kurtosis		30.594	.337
TKN	RRBIn	Mean		43.0681	.45800
		95% Confidence Interval for Mean	Lower Bound	42.1651	
			Upper Bound	43.9711	
		5% Trimmed Mean		43.5312	
		Median		43.3000	
		Variance		43.421	
		Std. Deviation		6.58948	
		Minimum		.00	
		Maximum		57.80	
		Range		57.80	
		Interquartile Range		5.30	
		Skewness		-3.171	.169
		Kurtosis		18.719	.337

TSS	RRBIn Mean	Mean		173.2271	2.94874
		95% Confidence Interval for	Lower Bound	167.4135	
			Upper Bound	179.0406	
		5% Trimmed Mean		170.5904	
		Median		170.0000	
		Variance		1799.875	
		Std. Deviation		42.42494	
		Minimum		62.00	
		Maximum		424.00	
		Range		362.00	
		Interquartile Range		40.00	
		Skewness		2.077	.169
		Kurtosis		10.295	.337
VSS	RRBIn Mean	Mean		144.8019	2.63203
		95% Confidence Interval for	Lower Bound	139.6128	
			Upper Bound	149.9911	
		5% Trimmed Mean		142.5615	
		Median		142.0000	
		Variance		1434.004	
		Std. Deviation		37.86825	
		Minimum		48.00	
		Maximum		400.00	
		Range		352.00	
		Interquartile Range		36.00	
		Skewness		2.316	.169

		Kurtosis		13.076	.337
RRBInEC		Mean		1855.1691	9.59326
	Mean	95% Confidence Interval for	Lower Bound	1836.2555	
			Upper Bound	1874.0826	
		5% Trimmed Mean		1857.9817	
		Median		1860.0000	
		Variance		19050.335	
		Std. Deviation		138.02295	
		Minimum		1180.00	
		Maximum		2240.00	
		Range		1060.00	
		Interquartile Range		150.00	
		Skewness		-.691	.169
		Kurtosis		3.217	.337
RRBInoPO4		Mean		3.0761	.08017
	Mean	95% Confidence Interval for	Lower Bound	2.9180	
			Upper Bound	3.2342	
		5% Trimmed Mean		3.0665	
		Median		3.0900	
		Variance		1.331	
		Std. Deviation		1.15351	
		Minimum		.27	
		Maximum		15.30	
		Range		15.03	
		Interquartile Range		.74	
		Skewness		5.532	.169

		Kurtosis		61.618	.337
SO4	RRBIn	Mean		206.3130	3.60253
	Mean	95% Confidence Interval for	Lower Bound	199.2105	
			Upper Bound	213.4156	
		5% Trimmed Mean		208.1235	
		Median		212.0000	
		Variance		2686.491	
		Std. Deviation		51.83137	
		Minimum		.00	
		Maximum		327.00	
		Range		327.00	
		Interquartile Range		67.00	
		Skewness		-.688	.169
		Kurtosis		1.319	.337
TotalP	RRBIn	Mean		6.7362	.10192
	Mean	95% Confidence Interval for	Lower Bound	6.5353	
			Upper Bound	6.9372	
		5% Trimmed Mean		6.8038	
		Median		7.0000	
		Variance		2.150	
		Std. Deviation		1.46632	
		Minimum		.00	
		Maximum		9.40	
		Range		9.40	
		Interquartile Range		1.90	
		Skewness		-.899	.169

		Kurtosis		1.472	.337
RRBInTHard	Mean	Mean		229.1594	2.76942
		95% Confidence Interval for Mean	Low er Bound	223.6994	
			Upper Bound	234.6195	
		5% Trimmed Mean		229.0322	
		Median		237.0000	
		Variance		1587.630	
		Std. Deviation		39.84507	
		Minimum		124.00	
		Maximum		347.00	
		Range		223.00	
		Interquartile Range		64.00	
		Skew ness		-.025	.169
		Kurtosis		-.594	.337
RRBeffBOD5		Mean		4.4512	.13894
		95% Confidence Interval for Mean	Low er Bound	4.1773	
			Upper Bound	4.7251	
		5% Trimmed Mean		4.2954	
		Median		4.1000	
		Variance		3.996	
		Std. Deviation		1.99895	
		Minimum		.00	
		Maximum		13.50	
		Range		13.50	
		Interquartile Range		2.20	
		Skew ness		1.257	.169

		Kurtosis		2.556	.337
fCOD	RRBef Mean	Mean		40.3333	.78229
		95% Confidence Interval for Mean	Lower Bound	38.7910	
			Upper Bound	41.8757	
		5% Trimmed Mean		40.0335	
		Median		39.0000	
		Variance		126.680	
		Std. Deviation		11.25520	
		Minimum		.00	
		Maximum		76.00	
		Range		76.00	
		Interquartile Range		14.00	
		Skewness		.283	.169
		Kurtosis		1.680	.337
fNH3	RRBef Mean	Mean		3.6210	.34950
		95% Confidence Interval for Mean	Lower Bound	2.9319	
			Upper Bound	4.3100	
		5% Trimmed Mean		2.9845	
		Median		1.7000	
		Variance		25.285	
		Std. Deviation		5.02843	
		Minimum		.00	
		Maximum		44.00	
		Range		44.00	
		Interquartile Range		4.10	
		Skewness		3.454	.169
		Kurtosis		20.162	.337

fNO2	RRBef Mean	Mean		.9759	.12515
		95% Confidence Interval for Mean	Lower Bound	.7291	
			Upper Bound	1.2226	
		5% Trimmed Mean		.6525	
		Median		.2700	
		Variance		3.242	
		Std. Deviation		1.80066	
		Minimum		.00	
		Maximum		11.60	
		Range		11.60	
		Interquartile Range		.58	
		Skewness		3.956	.169
		Kurtosis		17.236	.337
fNO3	RRBef Mean	Mean		15.1453	.45328
		95% Confidence Interval for Mean	Lower Bound	14.2517	
			Upper Bound	16.0390	
		5% Trimmed Mean		15.4103	
		Median		17.0000	
		Variance		42.530	
		Std. Deviation		6.52154	
		Minimum		.00	
		Maximum		28.20	
		Range		28.20	
		Interquartile Range		8.10	
		Skewness		-.725	.169
		Kurtosis		-.287	.337
	RRBef	Mean		3.2090	.08939

foPO4 Mean	95% Confidence Interval for	Lower Bound	3.0328	
		Upper Bound	3.3853	
	5% Trimmed Mean		3.2123	
	Median		3.3200	
	Variance		1.654	
	Std. Deviation		1.28612	
	Minimum		.00	
	Maximum		16.20	
	Range		16.20	
	Interquartile Range		.85	
	Skewness		4.580	.169
	Kurtosis		50.437	.337
RRBef fSO4	Mean		237.1517	4.34085
Mean	95% Confidence Interval for	Lower Bound	228.5935	
		Upper Bound	245.7099	
	5% Trimmed Mean		238.9807	
	Median		242.0000	
	Variance		3900.490	
	Std. Deviation		62.45391	
	Minimum		.00	
	Maximum		512.00	
	Range		512.00	
	Interquartile Range		80.00	
	Skewness		-.395	.169
	Kurtosis		2.893	.337

fTDS	RRBef	Mean		1057.6039	10.08052
		95% Confidence Interval for Mean	Lower Bound	1037.7296	
			Upper Bound	1077.4781	
		5% Trimmed Mean		1069.0488	
		Median		1070.0000	
		Variance		21034.697	
		Std. Deviation		145.03343	
		Minimum		.00	
		Maximum		1380.00	
		Range		1380.00	
		Interquartile Range		90.00	
		Skewness		-3.907	.169
		Kurtosis		26.480	.337
fTKN	RRBef	Mean		5.9435	.36916
		95% Confidence Interval for Mean	Lower Bound	5.2157	
			Upper Bound	6.6713	
		5% Trimmed Mean		5.3178	
		Median		3.9000	
		Variance		28.210	
		Std. Deviation		5.31129	
		Minimum		.00	
		Maximum		39.80	
		Range		39.80	
		Interquartile Range		4.80	
		Skewness		2.404	.169
		Kurtosis		8.503	.337

RRBef fTotalP	Mean			3.2285	.05912
	95% Confidence Interval for Mean	Lower Bound		3.1119	
		Upper Bound		3.3451	
	5% Trimmed Mean			3.2381	
	Median			3.3000	
	Variance			.724	
	Std. Deviation			.85059	
	Minimum			.00	
	Maximum			8.10	
	Range			8.10	
	Interquartile Range			.80	
	Skewness			.939	.169
	Kurtosis			9.608	.337
RRBef fTHard	Mean			231.3092	2.96726
	95% Confidence Interval for Mean	Lower Bound		225.4591	
		Upper Bound		237.1593	
	5% Trimmed Mean			231.6720	
	Median			239.0000	
	Variance			1822.564	
	Std. Deviation			42.69150	
	Minimum			.00	
	Maximum			353.00	
	Range			353.00	
	Interquartile Range			69.00	
	Skewness			-.639	.169
	Kurtosis			3.018	.337

fTSS	RRBef Mean	Mean		6.9855	.28571
		95% Confidence Interval for Mean	Lower Bound	6.4222	
			Upper Bound	7.5488	
		5% Trimmed Mean		6.7638	
		Median		6.0000	
		Variance		16.898	
		Std. Deviation		4.11070	
		Minimum		.00	
		Maximum		30.00	
		Range		30.00	
		Interquartile Range		3.00	
		Skewness		1.307	.169
		Kurtosis		4.862	.337
fVSS	RRBef Mean	Mean		6.0580	.22617
		95% Confidence Interval for Mean	Lower Bound	5.6121	
			Upper Bound	6.5039	
		5% Trimmed Mean		5.9034	
		Median		6.0000	
		Variance		10.589	
		Std. Deviation		3.25405	
		Minimum		.00	
		Maximum		25.00	
		Range		25.00	
		Interquartile Range		3.00	
		Skewness		1.350	.169

Kurtosis	5.605	.337

Table 13 Correlation Table for the Effluent RRB THard, BOD5, COD,…

	RRBInTotalP	RRBInTHard	RRBeffBOD5	RRBeffCOD
RRBInTHard	-0.044 0.534			
RRBeffBOD5	0.046 0.511	-0.303 0.000		
RRBeffCOD	0.082 0.244	-0.012 0.869	0.495 0.000	
RRBeffNH3	0.240 0.001	-0.485 0.000	0.443 0.000	0.216 0.002
RRBeffNO2	0.214 0.002	-0.379 0.000	0.351 0.000	0.293 0.000
RRBeffNO3	-0.101 0.151	0.453 0.000	-0.302 0.000	-0.125 0.073
RRBeffoPO4	0.025 0.726	0.174 0.012	-0.045 0.518	0.006 0.933
RRBeffSO4	-0.153 0.029	0.640 0.000	-0.290 0.000	-0.052 0.459
RRBeffTDS	-0.050 0.478	0.467 0.000	-0.155 0.027	0.028 0.693
RRBeffTKN	0.290 0.000	-0.425 0.000	0.430 0.000	0.256 0.000
RRBeffTotalP	0.127 0.069	0.028 0.685	-0.026 0.706	0.130 0.064
RRBeffTHard	-0.091 0.194	0.924 0.000	-0.296 0.000	0.013 0.855
RRBeffTSS	-0.044 0.544	-0.021 0.773	0.489 0.000	0.527 0.000
RRBeffVSS	-0.059 0.410	-0.044 0.537	0.515 0.000	0.493 0.000

Table 14 Correlation Table for the Effluent RRB NO2, oPO4, SO4,…

	RRBeffNH3	RRBeffNO2	RRBeffNO3	RRBeffoPO4
RRBeffNO2	0.300 0.000			
RRBeffNO3	-0.598 0.000	-0.448 0.000		
RRBeffoPO4	-0.073 0.298	0.083 0.237	0.138 0.048	
RRBeffSO4	-0.353 0.000	-0.322 0.000	0.352 0.000	0.163 0.019
RRBeffTDS	-0.265 0.000	-0.305 0.000	0.372 0.000	0.199 0.004
RRBeffTKN	0.845 0.000	0.327 0.000	-0.516 0.000	-0.062 0.378
RRBeffTotalP	-0.028 0.691	0.027 0.698	0.162 0.020	0.261 0.000
RRBeffTHard	-0.483 0.000	-0.387 0.000	0.479 0.000	0.207 0.003
RRBeffTSS	-0.026 0.717	0.161 0.027	0.021 0.771	-0.001 0.989
RRBeffVSS	0.017 0.810	0.123 0.086	0.014 0.846	-0.001 0.994

Table 15 Correlation Table for the Effluent of RRB with TDS, TKN, TotalP,…

	RRBeffSO4	RRBeffTDS	RRBeffTKN	RRBeffTotalP
RRBeffTDS	0.548 0.000			
RRBeffTKN	-0.309 0.000	-0.250 0.000		
RRBeffTotalP	0.058 0.412	0.129 0.065	0.002 0.979	
RRBeffTHard	0.679 0.000	0.597 0.000	-0.424 0.000	0.073 0.298
RRBeffTSS	-0.073 0.316	-0.035 0.632	0.035 0.631	0.117 0.107
RRBeffVSS	-0.096 0.183	-0.031 0.670	0.071 0.323	0.064 0.372

	RRBeffTHard	RRBeffTSS
RRBeffTSS	-0.005	

	0.949	
RRBeffVSS	-0.030	0.953
	0.673	0.000

Cell Contents: Pearson correlation
P-Value

Table 16 Correlation Table for the Incoming Flow NW of Effluent, BOD5, COD,...

Correlations: NWIn, NWEff, NWInBOD5, NWInCOD, NWInNH3, NWInNO2, NWInNO3, ...

	NWIn	NWEff	NWInBOD5	NWInCOD	NWInNH3
NWEff	0.900 0.000				
NWInBOD5	0.235 0.001	0.305 0.000			
NWInCOD	0.217 0.002	0.253 0.000	0.737 0.000		
NWInNH3	0.189 0.006	0.266 0.000	0.093 0.182	0.134 0.054	
NWInNO2	0.081 0.250	0.083 0.236	0.041 0.559	0.047 0.500	0.052 0.458
NWInNO3	-0.153 0.028	-0.167 0.017	-0.079 0.258	-0.050 0.472	-0.095 0.173
NWInTDS	-0.120 0.085	-0.169 0.015	0.165 0.018	0.171 0.014	-0.229 0.001
NWInTKN	0.248 0.000	0.335 0.000	0.533 0.000	0.561 0.000	0.195 0.005
NWInTSS	0.015 0.836	0.053 0.446	0.314 0.000	0.321 0.000	0.076 0.275
NWInVSS	0.023 0.746	0.061 0.379	0.310 0.000	0.317 0.000	0.091 0.192
NWInEC	-0.036 0.606	-0.083 0.236	-0.007 0.925	-0.060 0.389	-0.110 0.115
NWInoPO4	0.249 0.000	0.239 0.001	0.207 0.003	0.251 0.000	0.116 0.096
NWInTotalP	-0.010 0.885	-0.015 0.835	0.380 0.000	0.385 0.000	0.028 0.688
NWInTOTHARD	-0.273 0.000	-0.419 0.000	-0.194 0.005	-0.210 0.002	-0.275 0.000

NWeffBOD5	-0.120	-0.031	0.111	0.114	0.043
	0.086	0.655	0.111	0.104	0.536
NWeffCOD	0.152	0.174	0.236	0.294	0.069
	0.031	0.013	0.001	0.000	0.325
NWeffNH3	0.234	0.253	0.012	0.073	0.168
	0.001	0.000	0.861	0.293	0.016
NWeffNO2	0.205	0.248	0.304	0.224	0.135
	0.003	0.000	0.000	0.001	0.053
NWeffNO3	-0.047	-0.068	-0.281	-0.252	0.049
	0.505	0.331	0.000	0.000	0.482
NWeffTDS	-0.175	-0.203	-0.026	-0.093	-0.225
	0.012	0.003	0.706	0.185	0.001
NWeffEC	-0.109	-0.153	-0.081	-0.153	-0.146
	0.118	0.027	0.244	0.028	0.035
NWeffTKN	0.103	0.140	0.011	0.061	0.077
	0.141	0.044	0.879	0.383	0.273
NWeffTSS	0.001	0.058	0.078	0.111	0.042
	0.984	0.409	0.263	0.113	0.547
NWeffVSS	-0.084	-0.054	0.014	0.021	0.012
	0.228	0.444	0.838	0.764	0.859
NWeffoPO4	-0.198	-0.268	-0.206	-0.118	-0.140
	0.004	0.000	0.003	0.089	0.045
NWeffSO4	0.100	0.100	-0.079	0.005	0.021
	0.153	0.152	0.259	0.945	0.765
NWeffTotalP	-0.323	-0.402	-0.222	-0.147	-0.200
	0.000	0.000	0.001	0.035	0.004
NWeffTHard	-0.304	-0.486	-0.251	-0.257	-0.318
	0.000	0.000	0.000	0.000	0.000

Table 17 Correlation Table for the Incoming –Effluent of NW NO2, TDS< TKN,…

	NWInNO2	NWInNO3	NWInTDS	NWInTKN	NWInTSS
NWInNO3	0.060				
	0.391				
NWInTDS	-0.000	-0.027			
	0.996	0.704			
NWInTKN	0.032	0.005	-0.068		
	0.651	0.939	0.328		
NWInTSS	0.038	0.056	0.089	0.368	
	0.591	0.425	0.202	0.000	
NWInVSS	0.020	0.069	0.094	0.375	0.956

	0.771	0.326	0.178	0.000	0.000
NWInEC	0.003	-0.006	0.561	-0.075	-0.049
	0.971	0.934	0.000	0.282	0.483
NWInoPO4	0.290	-0.177	-0.129	0.227	0.040
	0.000	0.011	0.063	0.001	0.563
NWInTotalP	-0.019	0.036	-0.023	0.358	0.323
	0.787	0.603	0.742	0.000	0.000
NWInTOTHARD	-0.047	0.000	0.482	-0.321	-0.060
	0.498	0.997	0.000	0.000	0.392
NWeffBOD5	-0.012	-0.065	-0.042	0.111	0.132
	0.869	0.356	0.553	0.111	0.058
NWeffCOD	0.248	-0.126	0.091	0.147	0.023
	0.000	0.074	0.199	0.036	0.743
NWeffNH3	0.030	-0.041	-0.108	0.143	-0.048
	0.668	0.560	0.121	0.040	0.492
NWeffNO2	0.029	0.007	-0.105	0.201	0.050
	0.684	0.925	0.132	0.004	0.472
NWeffNO3	-0.130	-0.126	-0.068	-0.116	-0.094
	0.063	0.071	0.333	0.097	0.180
NWeffTDS	-0.014	-0.011	0.701	-0.158	-0.046
	0.838	0.871	0.000	0.023	0.506
NWeffEC	0.004	0.032	0.455	-0.148	-0.135
	0.960	0.645	0.000	0.034	0.053
NWeffTKN	0.026	-0.009	-0.003	0.187	-0.003
	0.711	0.893	0.970	0.007	0.971
NWeffTSS	0.073	0.012	-0.083	0.143	0.165
	0.298	0.866	0.235	0.040	0.018
NWeffVSS	0.036	-0.012	-0.037	0.083	0.072
	0.607	0.868	0.598	0.237	0.303
NWeffoPO4	0.264	0.094	0.138	-0.094	-0.073
	0.000	0.179	0.048	0.176	0.299
NWeffSO4	-0.012	0.011	0.161	0.045	-0.001
	0.860	0.879	0.021	0.522	0.994
NWeffTotalP	0.002	0.029	0.171	-0.152	-0.074
	0.975	0.680	0.014	0.029	0.288
NWeffTHard	-0.056	0.001	0.434	-0.414	-0.141
	0.422	0.990	0.000	0.000	0.043

Table 18 Correlation Table for Incoming-Effluent EC, oPO4, TotalP,….

	NWInVSS	NWInEC	NWInoPO4	NWInTotalP	NWInTOTHARD
NWInEC	0.012 0.861				
NWInoPO4	-0.009 0.897	-0.094 0.179			
NWInTotalP	0.298 0.000	-0.194 0.005	0.303 0.000		
NWInTOTHARD	-0.077 0.270	0.415 0.000	-0.129 0.064	-0.001 0.986	
NWeffBOD5	0.176 0.011	-0.094 0.180	-0.013 0.849	0.108 0.124	-0.166 0.017
NWeffCOD	0.059 0.404	0.063 0.370	0.023 0.746	0.034 0.628	-0.162 0.021
NWeffNH3	-0.034 0.627	-0.085 0.221	0.024 0.731	0.101 0.146	-0.093 0.183
NWeffNO2	0.067 0.341	-0.062 0.378	0.124 0.076	0.186 0.007	-0.206 0.003
NWeffNO3	-0.088 0.211	0.016 0.821	0.117 0.094	-0.090 0.199	0.047 0.504
NWeffTDS	-0.028 0.689	0.457 0.000	-0.114 0.103	-0.160 0.021	0.416 0.000
NWeffEC	-0.074 0.292	0.805 0.000	-0.114 0.101	-0.172 0.013	0.413 0.000
NWeffTKN	0.040 0.569	0.029 0.675	0.001 0.986	0.133 0.056	-0.101 0.147
NWeffTSS	0.187 0.007	-0.106 0.130	0.056 0.422	0.162 0.020	-0.177 0.011
NWeffVSS	0.116 0.095	-0.060 0.387	-0.029 0.682	0.248 0.000	-0.175 0.012
NWeffoPO4	-0.077 0.269	0.005 0.946	0.030 0.664	0.105 0.130	0.198 0.004
NWeffSO4	0.035 0.617	0.204 0.003	0.034 0.624	-0.179 0.010	0.091 0.193
NWeffTotalP	-0.085 0.224	0.011 0.870	-0.042 0.547	0.149 0.033	0.277 0.000
NWeffTHard	-0.121 0.081	0.373 0.000	-0.189 0.006	-0.085 0.221	0.687 0.000

Table 19 Correlation Table for Effluent NW with COD, NH3, NO2,…

	NWeffBOD5	NWeffCOD	NWeffNH3	NWeffNO2	NWeffNO3
NWeffCOD	0.160 0.023				
NWeffNH3	0.094 0.180	0.019 0.791			
NWeffNO2	0.109 0.119	0.213 0.002	0.376 0.000		
NWeffNO3	-0.107 0.125	-0.122 0.084	-0.221 0.001	-0.178 0.010	
NWeffTDS	-0.063 0.367	0.048 0.497	-0.141 0.042	-0.204 0.003	0.092 0.190
NWeffEC	-0.103 0.141	0.047 0.510	-0.028 0.693	-0.076 0.280	0.044 0.530
NWeffTKN	0.144 0.038	0.160 0.023	0.571 0.000	0.296 0.000	-0.195 0.005
NWeffTSS	0.304 0.000	0.224 0.001	-0.011 0.874	0.037 0.596	0.005 0.940
NWeffVSS	0.369 0.000	0.347 0.000	-0.017 0.810	0.096 0.170	0.047 0.503
NWeffoPO4	-0.103 0.141	0.088 0.214	0.048 0.488	-0.035 0.617	0.132 0.058
NWeffSO4	-0.075 0.283	0.044 0.534	-0.014 0.841	-0.099 0.159	0.152 0.029
NWeffTotalP	-0.087 0.213	-0.018 0.800	-0.025 0.719	-0.052 0.457	0.189 0.006
NWeffTHard	-0.140 0.045	-0.166 0.018	-0.057 0.412	-0.214 0.002	0.087 0.213

Table 20 Correlation Table for Effluent of NW with EC, TKN, TSS,…

	NWeffTDS	NWeffEC	NWeffTKN	NWeffTSS	NWeffVSS
NWeffEC	0.634 0.000				
NWeffTKN	-0.005 0.938	0.044 0.525			
NWeffTSS	-0.114 0.102	-0.124 0.076	0.239 0.001		
NWeffVSS	-0.041	-0.050	0.348	0.657	

	0.555	0.478	0.000	0.000	
NWeffoPO4	0.134	0.097	0.107	-0.016	0.123
	0.055	0.163	0.126	0.819	0.077
NWeffSO4	0.267	0.264	-0.052	0.204	-0.072
	0.000	0.000	0.460	0.003	0.307
NWeffTotalP	0.164	0.112	0.081	-0.014	0.145
	0.018	0.109	0.247	0.839	0.037
NWeffTHard	0.530	0.495	-0.051	-0.189	-0.113
	0.000	0.000	0.464	0.007	0.106

Table 21 Correlation Tables for Effluent of NW with SO4, Total P, THard,...

	NWeffoPO4	NWeffSO4	NWeffTotalP
NWeffSO4	0.012		
	0.859		
NWeffTotalP	0.874	-0.038	
	0.000	0.588	
NWeffTHard	0.232	0.063	0.308
	0.001	0.371	0.000

Cell Contents: Pearson correlation
P-Value

Table 22Correlation Table for Temperature, Quarter-year, Date, NWin,...

Correlations: Temp_avg_air, yearquart, YDATE, NWIn, RRBIn, NWEff, RRBEff, ...

	Temp_avg_airport	yearquart	YDATE
yearquart	0.025		
	0.721		
YDATE	0.045	0.988	
	0.522	0.000	
NWIn	-0.296	0.399	0.404
	0.000	0.000	0.000
RRBIn	0.393	0.475	0.506
	0.000	0.000	0.000
NWEff	-0.528	0.375	0.373
	0.000	0.000	0.000
RRBEff	0.423	0.189	0.230
	0.000	0.006	0.001
NWInBOD5	-0.443	-0.260	-0.256

	0.000	0.000	0.000
NWInCOD	-0.427 0.000	-0.138 0.048	-0.133 0.056
NWInNO2	-0.052 0.460	0.032 0.648	0.028 0.690
NWInNO3	0.013 0.857	-0.013 0.856	-0.003 0.965
NWInNH3	-0.255 0.000	0.294 0.000	0.296 0.000
NWInTDS	0.085 0.226	-0.281 0.000	-0.308 0.000
NWInTKN	-0.484 0.000	-0.064 0.361	-0.056 0.424
NWInTSS	-0.244 0.000	-0.152 0.029	-0.170 0.014
NWInVSS	-0.228 0.001	-0.144 0.039	-0.158 0.023
NWInEC	0.075 0.281	0.008 0.907	-0.011 0.879
NWInoPO4	-0.087 0.213	0.158 0.023	0.160 0.021
NWInTotalP	-0.183 0.008	-0.345 0.000	-0.353 0.000
NWInTOTHARD	0.472 0.000	-0.203 0.003	-0.213 0.002
NWeffBOD5	-0.199 0.004	-0.128 0.067	-0.125 0.075
NWeffCOD	-0.207 0.003	0.010 0.891	-0.005 0.946
NWeffNH3	-0.139 0.046	0.057 0.412	0.102 0.144
NWeffNO2	-0.249 0.000	-0.040 0.567	0.012 0.861
NWeffNO3	0.149 0.032	0.233 0.001	0.216 0.002
NWeffTDS	0.242 0.000	-0.177 0.011	-0.202 0.004
NWeffEC	0.203 0.003	-0.014 0.842	-0.027 0.695

NWeffTKN	-0.252 0.000	-0.150 0.031	-0.128 0.066
NWeffTSS	-0.240 0.001	-0.093 0.184	-0.108 0.122
NWeffoPO4	0.288 0.000	-0.224 0.001	-0.230 0.001
NWeffSO4	0.078 0.266	0.320 0.000	0.304 0.000
NWeffTotalP	0.354 0.000	-0.328 0.000	-0.331 0.000
NWeffTHard	0.634 0.000	-0.197 0.004	-0.201 0.004

Table 23 Correlation Table for Incoming and Effluent for both WWTP.

	NWIn	RRBIn	NWEff
RRBIn	0.150 0.031		
NWEff	0.900 0.000	0.002 0.980	
RRBEff	0.110 0.113	0.914 0.000	-0.038 0.585
NWInBOD5	0.235 0.001	-0.245 0.000	0.305 0.000
NWInCOD	0.217 0.002	-0.214 0.002	0.253 0.000
NWInNO2	0.081 0.250	0.040 0.564	0.083 0.236
NWInNO3	-0.153 0.028	0.056 0.427	-0.167 0.017
NWInNH3	0.189 0.006	0.063 0.368	0.266 0.000
NWInTDS	-0.120 0.085	-0.116 0.096	-0.169 0.015
NWInTKN	0.248 0.000	-0.262 0.000	0.335 0.000
NWInTSS	0.015 0.836	-0.130 0.062	0.053 0.446
NWInVSS	0.023 0.746	-0.122 0.079	0.061 0.379

NWInEC	-0.036 0.606	0.010 0.882	-0.083 0.236
NWInoPO4	0.249 0.000	0.070 0.314	0.239 0.001
NWInTotalP	-0.010 0.885	-0.232 0.001	-0.015 0.835
NWInTOTHARD	-0.273 0.000	0.120 0.084	-0.419 0.000
NWeffBOD5	-0.120 0.086	-0.184 0.008	-0.031 0.655
NWeffCOD	0.152 0.031	-0.140 0.047	0.174 0.013
NWeffNH3	0.234 0.001	0.036 0.605	0.253 0.000
NWeffNO2	0.205 0.003	-0.121 0.084	0.248 0.000
NWeffNO3	-0.047 0.505	0.106 0.128	-0.068 0.331
NWeffTDS	-0.175 0.012	-0.030 0.672	-0.203 0.003
NWeffEC	-0.109 0.118	0.020 0.771	-0.153 0.027
NWeffTKN	0.103 0.141	-0.144 0.038	0.140 0.044
NWeffTSS	0.001 0.984	-0.028 0.687	0.058 0.409
NWeffoPO4	-0.198 0.004	-0.060 0.394	-0.268 0.000
NWeffSO4	0.100 0.153	0.172 0.013	0.100 0.152
NWeffTotalP	-0.323 0.000	-0.094 0.176	-0.402 0.000
NWeffTHard	-0.304 0.000	0.226 0.001	-0.486 0.000

Table 24 Correlation Table for the Incoming-Effluent of NW with RRBEff, NWInBOD5, NWInCOD,...

	RRBEff	NWInBOD5	NWInCOD
NWInBOD5	-0.158 0.023		
NWInCOD	-0.169 0.015	0.737 0.000	
NWInNO2	0.026 0.709	0.041 0.559	0.047 0.500
NWInNO3	0.025 0.716	-0.079 0.258	-0.050 0.472
NWInNH3	-0.047 0.505	0.093 0.182	0.134 0.054
NWInTDS	-0.014 0.846	0.165 0.018	0.171 0.014
NWInTKN	-0.244 0.000	0.533 0.000	0.561 0.000
NWInTSS	-0.089 0.204	0.314 0.000	0.321 0.000
NWInVSS	-0.089 0.204	0.310 0.000	0.317 0.000
NWInEC	0.005 0.942	-0.007 0.925	-0.060 0.389
NWInoPO4	0.008 0.913	0.207 0.003	0.251 0.000
NWInTotalP	-0.214 0.002	0.380 0.000	0.385 0.000
NWInTOTHARD	0.229 0.001	-0.194 0.005	-0.210 0.002
NWeffBOD5	-0.242 0.000	0.111 0.111	0.114 0.104
NWeffCOD	-0.187 0.007	0.236 0.001	0.294 0.000
NWeffNH3	0.040 0.566	0.012 0.861	0.073 0.293
NWeffNO2	-0.126 0.070	0.304 0.000	0.224 0.001
NWeffNO3	0.043 0.539	-0.281 0.000	-0.252 0.000
NWeffTDS	0.047	-0.026	-0.093

	0.505	0.706	0.185
NWeffEC	0.031 0.663	-0.081 0.244	-0.153 0.028
NWeffTKN	-0.181 0.009	0.011 0.879	0.061 0.383
NWeffTSS	-0.107 0.127	0.078 0.263	0.111 0.113
NWeffoPO4	0.035 0.619	-0.206 0.003	-0.118 0.089
NWeffSO4	0.116 0.095	-0.079 0.259	0.005 0.945
NWeffTotalP	0.024 0.727	-0.222 0.001	-0.147 0.035
NWeffTHard	0.312 0.000	-0.251 0.000	-0.257 0.000

Table 25 Correlation Table for the Incoming-Effluent of NW with NO3, NO@, NH3,…

	NWInNO2	NWInNO3	NWInNH3
NWInNO3	0.060 0.391		
NWInNH3	0.052 0.458	-0.095 0.173	
NWInTDS	-0.000 0.996	-0.027 0.704	-0.229 0.001
NWInTKN	0.032 0.651	0.005 0.939	0.195 0.005
NWInTSS	0.038 0.591	0.056 0.425	0.076 0.275
NWInVSS	0.020 0.771	0.069 0.326	0.091 0.192
NWInEC	0.003 0.971	-0.006 0.934	-0.110 0.115
NWInoPO4	0.290 0.000	-0.177 0.011	0.116 0.096
NWInTotalP	-0.019 0.787	0.036 0.603	0.028 0.688
NWInTOTHARD	-0.047 0.498	0.000 0.997	-0.275 0.000
NWeffBOD5	-0.012	-0.065	0.043

	0.869	0.356	0.536
NWeffCOD	0.248 0.000	-0.126 0.074	0.069 0.325
NWeffNH3	0.030 0.668	-0.041 0.560	0.168 0.016
NWeffNO2	0.029 0.684	0.007 0.925	0.135 0.053
NWeffNO3	-0.130 0.063	-0.126 0.071	0.049 0.482
NWeffTDS	-0.014 0.838	-0.011 0.871	-0.225 0.001
NWeffEC	0.004 0.960	0.032 0.645	-0.146 0.035
NWeffTKN	0.026 0.711	-0.009 0.893	0.077 0.273
NWeffTSS	0.073 0.298	0.012 0.866	0.042 0.547
NWeffoPO4	0.264 0.000	0.094 0.179	-0.140 0.045
NWeffSO4	-0.012 0.860	0.011 0.879	0.021 0.765
NWeffTotalP	0.002 0.975	0.029 0.680	-0.200 0.004
NWeffTHard	-0.056 0.422	0.001 0.990	-0.318 0.000

Table 26 Correlation Table for Incoming-Effluent of NW with TKN, TSS, EC,…

	NWInTDS	NWInTKN	NWInTSS
NWInTKN	-0.068 0.328		
NWInTSS	0.089 0.202	0.368 0.000	
NWInVSS	0.094 0.178	0.375 0.000	0.956 0.000
NWInEC	0.561 0.000	-0.075 0.282	-0.049 0.483
NWInoPO4	-0.129 0.063	0.227 0.001	0.040 0.563
NWInTotalP	-0.023	0.358	0.323

	0.742	0.000	0.000
NWInTOTHARD	0.482	-0.321	-0.060
	0.000	0.000	0.392
NWeffBOD5	-0.042	0.111	0.132
	0.553	0.111	0.058
NWeffCOD	0.091	0.147	0.023
	0.199	0.036	0.743
NWeffNH3	-0.108	0.143	-0.048
	0.121	0.040	0.492
NWeffNO2	-0.105	0.201	0.050
	0.132	0.004	0.472
NWeffNO3	-0.068	-0.116	-0.094
	0.333	0.097	0.180
NWeffTDS	0.701	-0.158	-0.046
	0.000	0.023	0.506
NWeffEC	0.455	-0.148	-0.135
	0.000	0.034	0.053
NWeffTKN	-0.003	0.187	-0.003
	0.970	0.007	0.971
NWeffTSS	-0.083	0.143	0.165
	0.235	0.040	0.018
NWeffoPO4	0.138	-0.094	-0.073
	0.048	0.176	0.299
NWeffSO4	0.161	0.045	-0.001
	0.021	0.522	0.994
NWeffTotalP	0.171	-0.152	-0.074
	0.014	0.029	0.288
NWeffTHard	0.434	-0.414	-0.141
	0.000	0.000	0.043

Table 27 Correlation Table for the Incoming-Effluent NW with VSS, EC, oPO4,....

	NWInVSS	NWInEC	NWInoPO4
NWInEC	0.012		
	0.861		
NWInoPO4	-0.009	-0.094	
	0.897	0.179	
NWInTotalP	0.298	-0.194	0.303
	0.000	0.005	0.000
NWInTOTHARD	-0.077	0.415	-0.129

	0.270	0.000	0.064
NWeffBOD5	0.176 0.011	-0.094 0.180	-0.013 0.849
NWeffCOD	0.059 0.404	0.063 0.370	0.023 0.746
NWeffNH3	-0.034 0.627	-0.085 0.221	0.024 0.731
NWeffNO2	0.067 0.341	-0.062 0.378	0.124 0.076
NWeffNO3	-0.088 0.211	0.016 0.821	0.117 0.094
NWeffTDS	-0.028 0.689	0.457 0.000	-0.114 0.103
NWeffEC	-0.074 0.292	0.805 0.000	-0.114 0.101
NWeffTKN	0.040 0.569	0.029 0.675	0.001 0.986
NWeffTSS	0.187 0.007	-0.106 0.130	0.056 0.422
NWeffoPO4	-0.077 0.269	0.005 0.946	0.030 0.664
NWeffSO4	0.035 0.617	0.204 0.003	0.034 0.624
NWeffTotalP	-0.085 0.224	0.011 0.870	-0.042 0.547
NWeffTHard	-0.121 0.081	0.373 0.000	-0.189 0.006

Table 28 Correlation Table for the Effluent of NW with TotHard, TotalP, BOD5,…

	NWInTotalP	NWInTOTHARD	NWeffBOD5
NWInTOTHARD	-0.001 0.986		
NWeffBOD5	0.108 0.124	-0.166 0.017	
NWeffCOD	0.034 0.628	-0.162 0.021	0.160 0.023
NWeffNH3	0.101 0.146	-0.093 0.183	0.094 0.180
NWeffNO2	0.186 0.007	-0.206 0.003	0.109 0.119

NWeffNO3	-0.090 0.199	0.047 0.504	-0.107 0.125
NWeffTDS	-0.160 0.021	0.416 0.000	-0.063 0.367
NWeffEC	-0.172 0.013	0.413 0.000	-0.103 0.141
NWeffTKN	0.133 0.056	-0.101 0.147	0.144 0.038
NWeffTSS	0.162 0.020	-0.177 0.011	0.304 0.000
NWeffoPO4	0.105 0.130	0.198 0.004	-0.103 0.141
NWeffSO4	-0.179 0.010	0.091 0.193	-0.075 0.283
NWeffTotalP	0.149 0.033	0.277 0.000	-0.087 0.213
NWeffTHard	-0.085 0.221	0.687 0.000	-0.140 0.045

Table 29 Correlation Table for Effluent of NW with NH3, NO2, NO3,…

	NWeffCOD	NWeffNH3	NWeffNO2
NWeffNH3	0.019 0.791		
NWeffNO2	0.213 0.002	0.376 0.000	
NWeffNO3	-0.122 0.084	-0.221 0.001	-0.178 0.010
NWeffTDS	0.048 0.497	-0.141 0.042	-0.204 0.003
NWeffEC	0.047 0.510	-0.028 0.693	-0.076 0.280
NWeffTKN	0.160 0.023	0.571 0.000	0.296 0.000
NWeffTSS	0.224 0.001	-0.011 0.874	0.037 0.596
NWeffoPO4	0.088 0.214	0.048 0.488	-0.035 0.617
NWeffSO4	0.044 0.534	-0.014 0.841	-0.099 0.159

NWeffTotalP	-0.018 0.800	-0.025 0.719	-0.052 0.457
NWeffTHard	-0.166 0.018	-0.057 0.412	-0.214 0.002

Table 30 Correlation Table for Effluent of NW TDS, NO3, EC,...

	NWeffNO3	NWeffTDS	NWeffEC
NWeffTDS	0.092 0.190		
NWeffEC	0.044 0.530	0.634 0.000	
NWeffTKN	-0.195 0.005	-0.005 0.938	0.044 0.525
NWeffTSS	0.005 0.940	-0.114 0.102	-0.124 0.076
NWeffoPO4	0.132 0.058	0.134 0.055	0.097 0.163
NWeffSO4	0.152 0.029	0.267 0.000	0.264 0.000
NWeffTotalP	0.189 0.006	0.164 0.018	0.112 0.109
NWeffTHard	0.087 0.213	0.530 0.000	0.495 0.000

Table 31 Correlation Table for Effluent of NW with TSS, oPO4, SO4,...

	NWeffTKN	NWeffTSS	NWeffoPO4
NWeffTSS	0.239 0.001		
NWeffoPO4	0.107 0.126	-0.016 0.819	
NWeffSO4	-0.052 0.460	0.204 0.003	0.012 0.859
NWeffTotalP	0.081 0.247	-0.014 0.839	0.874 0.000
NWeffTHard	-0.051 0.464	-0.189 0.007	0.232 0.001

	NWeffSO4	NWeffTotalP
NWeffTotalP	-0.038	
	0.588	
NWeffTHard	0.063	0.308
	0.371	0.000

Cell Contents: Pearson correlation
P-Value

Table 32 Correlation Table for Temperature, Date, Inflow for the RRB BOD5,...

Correlations: Temp_avg_air, yearquart, YDATE, RRBInBOD5, RRBInCOD, ...

	Temp_avg_airport	yearquart	YDATE
yearquart	0.025		
	0.721		
YDATE	0.045	0.988	
	0.522	0.000	
RRBInBOD5	-0.470	-0.059	-0.077
	0.000	0.403	0.270
RRBInCOD	-0.188	0.001	-0.028
	0.007	0.994	0.687
RRBInNH3	-0.080	0.162	0.163
	0.254	0.019	0.019
RRBInNO2	-0.008	0.133	0.124
	0.906	0.056	0.075
RRBInNO3	-0.016	0.054	0.064
	0.818	0.440	0.357
RRBInTDS	0.093	-0.267	-0.248
	0.184	0.000	0.000
RRBInTKN	-0.315	0.054	0.040
	0.000	0.440	0.566
RRBInTSS	-0.138	0.173	0.156
	0.047	0.013	0.025
RRBInVSS	-0.169	0.204	0.191
	0.015	0.003	0.006
RRBInEC	-0.136	-0.045	-0.037
	0.050	0.521	0.595
RRBInoPO4	-0.022	-0.114	-0.127
	0.756	0.103	0.069
RRBInSO4	0.538	-0.072	-0.060
	0.000	0.304	0.396

RRBInTotalP	-0.124 0.075	-0.389 0.000	-0.406 0.000
RRBInTHard	0.684 0.000	-0.147 0.034	-0.137 0.049
RRBeffBOD5	-0.422 0.000	-0.045 0.522	-0.092 0.189
RRBeffCOD	-0.105 0.136	-0.075 0.287	-0.137 0.050
RRBeffNH3	-0.467 0.000	-0.119 0.087	-0.141 0.043
RRBeffNO2	-0.372 0.000	-0.058 0.410	-0.116 0.098
RRBeffNO3	0.354 0.000	-0.024 0.737	-0.011 0.873
RRBeffoPO4	0.117 0.093	-0.151 0.030	-0.161 0.021
RRBeffSO4	0.531 0.000	-0.045 0.518	-0.021 0.767
RRBeffTDS	0.139 0.047	-0.161 0.021	-0.133 0.057
RRBeffTKN	-0.413 0.000	-0.173 0.013	-0.206 0.003
RRBeffTotalP	-0.004 0.949	-0.194 0.005	-0.224 0.001
RRBeffTHard	0.666 0.000	-0.144 0.039	-0.131 0.061
RRBeffTSS	-0.088 0.224	0.132 0.069	0.109 0.133
RRBeffVSS	-0.121 0.093	0.176 0.014	0.150 0.036

Table 33 Correlation Table for Incoming-Effluent oPO4, SO4, TotalP,…

	RRBInEC	RRBInoPO4	RRBInSO4
RRBInoPO4	0.103 0.142		
RRBInSO4	0.355 0.000	0.107 0.125	
RRBInTotalP	0.199 0.004	0.128 0.067	-0.056 0.426

RRBInTHard	0.288	0.088	0.773
	0.000	0.206	0.000
RRBeffBOD5	-0.019	0.033	-0.268
	0.782	0.635	0.000
RRBeffCOD	-0.027	0.108	-0.006
	0.701	0.122	0.937
RRBeffNH3	-0.051	0.044	-0.397
	0.465	0.527	0.000
RRBeffNO2	-0.118	0.089	-0.358
	0.092	0.204	0.000
RRBeffNO3	0.039	-0.066	0.423
	0.574	0.349	0.000
RRBeffoPO4	0.013	0.718	0.161
	0.858	0.000	0.021
RRBeffSO4	0.188	0.084	0.726
	0.007	0.230	0.000
RRBeffTDS	0.424	0.178	0.505
	0.000	0.010	0.000
RRBeffTKN	-0.031	0.020	-0.351
	0.658	0.776	0.000
RRBeffTotalP	-0.035	0.057	0.073
	0.618	0.419	0.297
RRBeffTHard	0.191	0.102	0.712
	0.006	0.144	0.000
RRBeffTSS	-0.056	-0.013	-0.038
	0.445	0.860	0.601
RRBeffVSS	-0.065	0.006	-0.063
	0.369	0.929	0.382

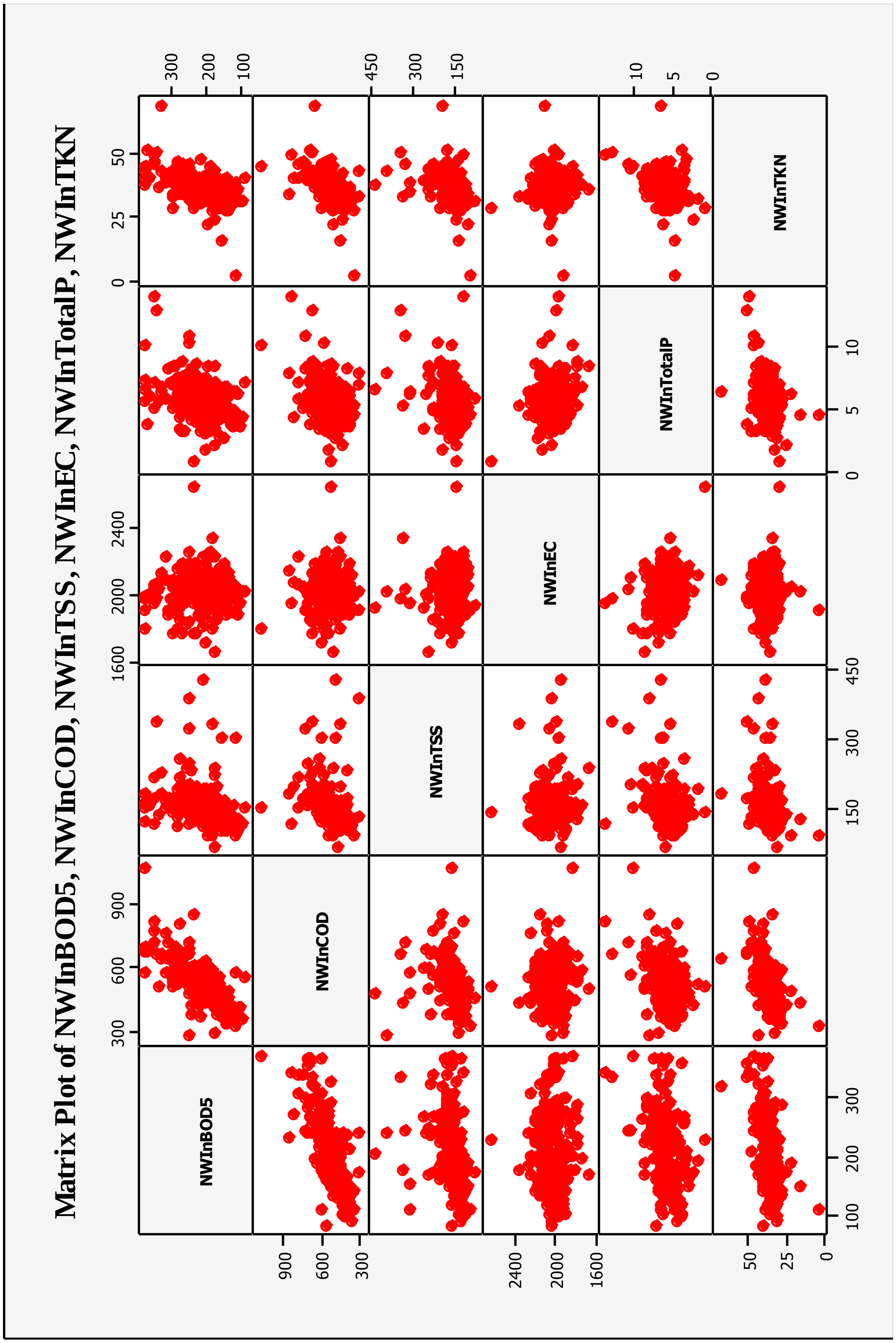

Figure IIIII Matrix plot of NW Incoming WWTP for the BOD5, COD, TSS, EC, Total P, and TKN.

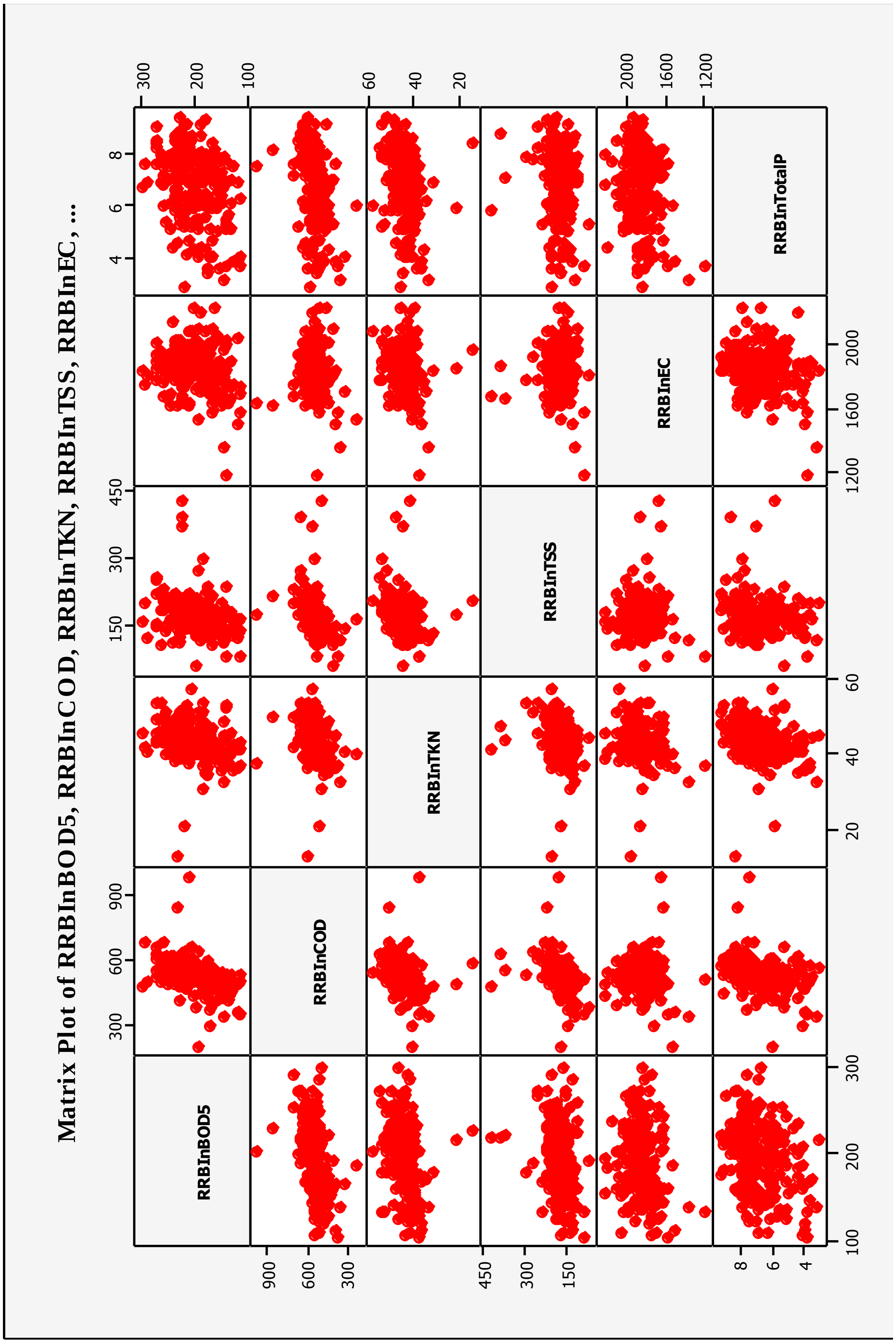

Figure JJJJJ Matrix plot of RRB Incoming WWTP for the BOD5, COD, TSS, EC, Total P, and TKN.

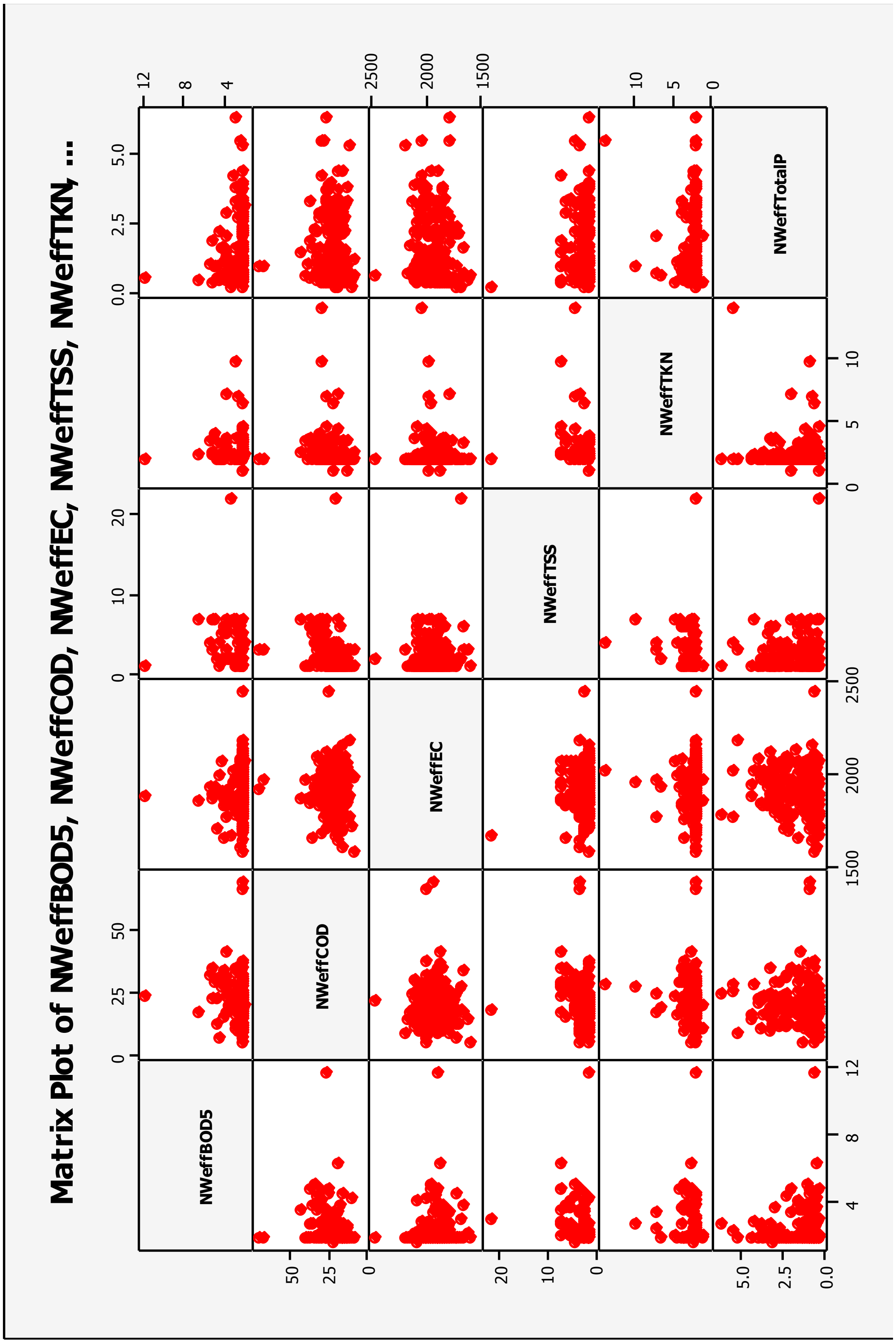

Figure KKKKK Matrix plot of NW Effluent WWTP for the BOD5, COD, TSS, EC, Total P, and TKN.

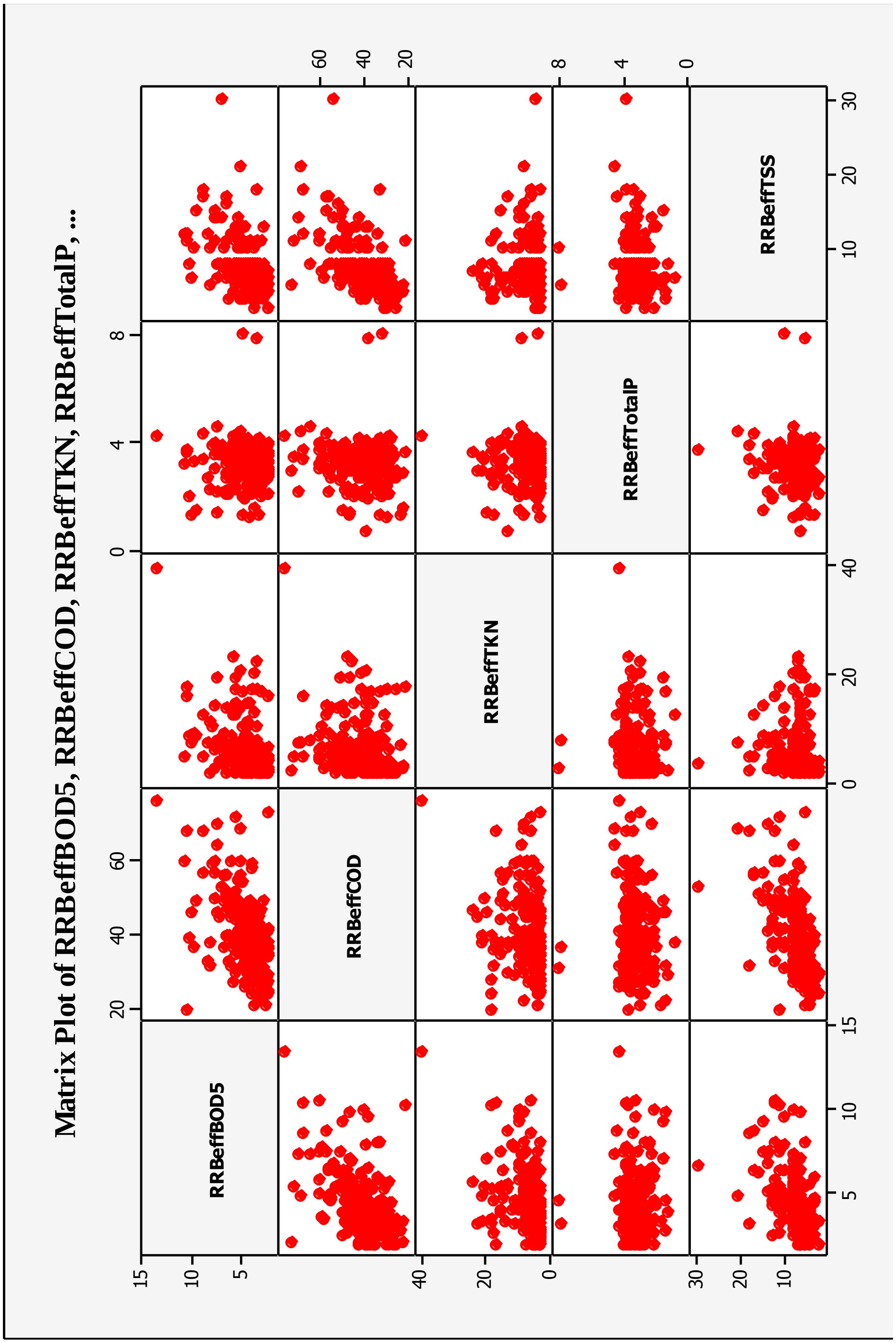

Figure LLLLL Matrix plot of RRB Effluent WWTP for the BOD5, COD, TSS, EC, Total P, and TKN.

CURRICULUM VITA (EXHIBIT F)

CURRICULUM VITA

Juan Carlos Adame was born in Ciudad Juarez, Chihuahua. He is the second child from a family of five siblings. His parents are Oscar Adame and Sara Meléndez.

Juan Carlos Adame graduated from high school in Ciudad Juarez. The name of the school was "Preparatoria Diurna del Chamizal" in summer of 1984 with honors.

When pursuing his Bachelor's degree in Physics, Juan Carlos Adame was recipient the Departmental Physics and the National Science Foundation Scholarships.

Once he graduated from the University of Texas at El Paso, he worked on several Twin Plants over Ciudad Juarez gaining experience as Process, Quality Engineering, and Environmental Engineering.

During 1993, he was awarded full scholarship by USAID to pursue his Master's Degree in Environmental Engineering. He completed his class workload by 1996 but due to new marriage and his newborn child had to postpone the thesis writing.

For several years dedicated his time to raise a family and to gain professional experience in different professional opportunities, among them as a Senior Environmental Engineer, and then as an Environmental Engineer.

In 2001, he participated in a Research and Development Group applied to two stroke internal combustion engines. Juan Carlos Adame held the position of Compliance Engineer certifying engines with EPA, CARB, and European Union.

Nowadays Juan Carlos Adame works in the "Universidad Tecnologica de Ciudad Juarez" as Teacher and Student Support Administrator.