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A PREDICTIVE MODELING FOR WATER CONSUMPTION AND WASTEWATER FLOW MANAGEMENT FOR A FOOD PROCESSING MANUFACTURER

Jairo A. de Jesus
University of Nebraska-Lincoln, jairodejesusie@gmail.com

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by

Jairo de Jesus

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A PREDICTIVE MODELING FOR WATER CONSUMPTION AND WASTEWATER FLOW MANAGEMENT FOR A FOOD PROCESSING MANUFACTURER

Jairo de Jesus, M.S.

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Advisor: Erick C. Jones

The City of Cumming, GA, issues special permits for industrial users of sewer services, who meet one or more criteria of discharge regulations. The criteria includes discharge of 25,000 gallons per day or more of processed wastewater, the presence for the potential to inhibit the Advanced Water Reclamation Facility (AWRF) treatment processes, the potential to cause AWRF's bio-solids to be contaminated, and other regulations. The Food Processing Manufacturer in this study is a meat processing facility (processes pork cooked sausage) and its operation and associated wastewater treatment plant meets at least one of the criteria requiring a special sewer service permit from the City of Cumming.

This thesis will describe the steps and processes used by the Food Manufacturer to make certain that it complies with the rules and regulations of the sewer service permit, along with ensuring compliance with all environmental regulations and policies, while introducing innovative ways to continually improve and reduce water consumption and the production of material waste.

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I would like to express gratitude to my employer, Farmland Foods, Inc., whose tuition reimbursement program motivated me to return to school for a second Master's degree and ignited my inner fire for the unquenchable desire for further learning and education. I would like to thank all of my friends and colleagues (Todd Gerken and Jim Sbarro) whose support and motivation allowed me to engage through this program with no hesitation or regrets.

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I wish to thank my parents and sister, Jair, Olinda, and Paula, for all of their love, efforts, and support raising me and building my character of who I am today. I wish to thank my wife and friend Tammy for her support, patience, and motivation to guide me through the completion of my studies and degree program.

I dedicate this thesis to my son Jarrison, whose smile, laughter, and overall persona provide me with the will power to continue to drive for greater achievements in every aspect of human endeavor and make me a better man, husband, and father.

"Dubito ergo cogito; Cogito ergo sum." René Descartes

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INTRODUCTION

1.1 Scope of the Facility

Constructed in 1990, the Food Processor Manufacturer's facility in this study is a meat processing plant (processes pork cooked sausage) that occupies a total of 84,000 ft^2 (64,000 ft^2 production floor, 8,000 ft^2 warehouse space, and 12,000 ft^2 office and employee welfare area). The facility produces an average of 65,000,000 lb annually of partial and fully cooked sausage patties for the leading fast food restaurant chain, along with various other fast food chains and food service channels serving various diners, restaurants, hotels, etc.

The sausage cooking process has an average cook yield of 95%, thus the finished average tonnage of 65,000,000 lb per annum, creates about 3,420,000 lb of material waste that is either in a solid or liquid (grease) state. This facility operates its lines following two basic production patterns: 67 hours and 17 hours (Figure 1).

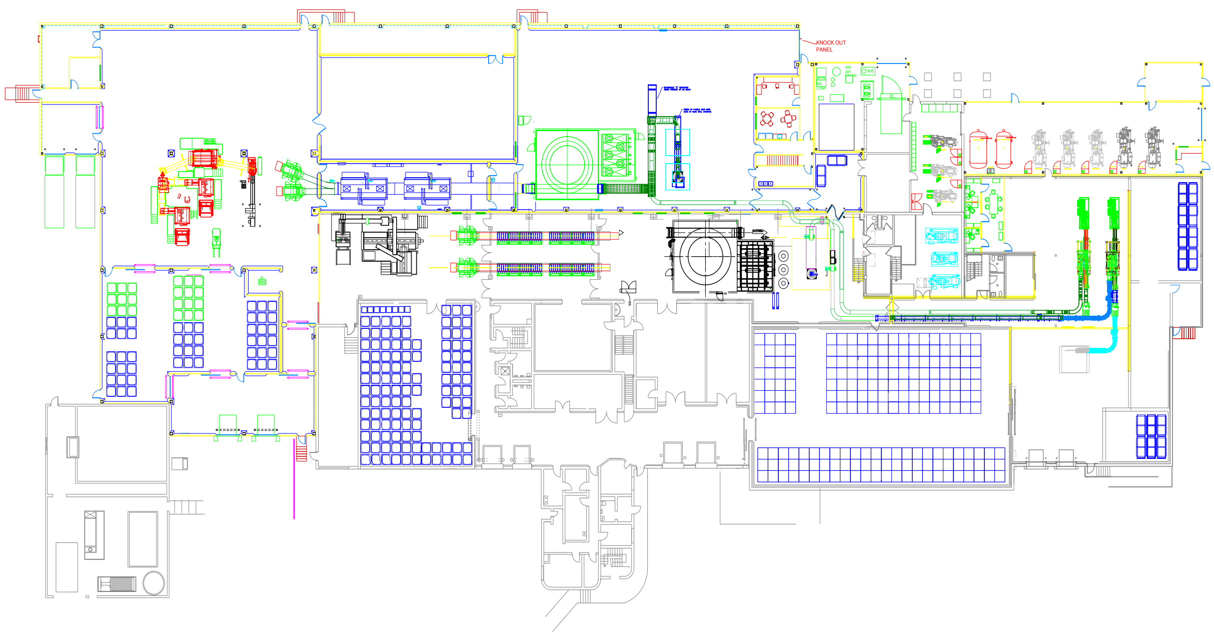

Figure 1: Facility Layout

The 67 hours production pattern entails running the production line for two full days (48 hours) and a partial day (19 hours) allowing five hours of sanitation cycle for the beginning of another cook cycle. The 17 hours production pattern entails running the production line for two shifts of eight hours and a sanitation cycle of seven hours prior to beginning another cook cycle. The facility has a daily average of 75,000 gallons of water usage for its cooking, operational, and sanitation needs. The overall waste water discharge for the current 2011 Fiscal Period (the company's Fiscal year is from May to May) is represented graphically in Figure 2.

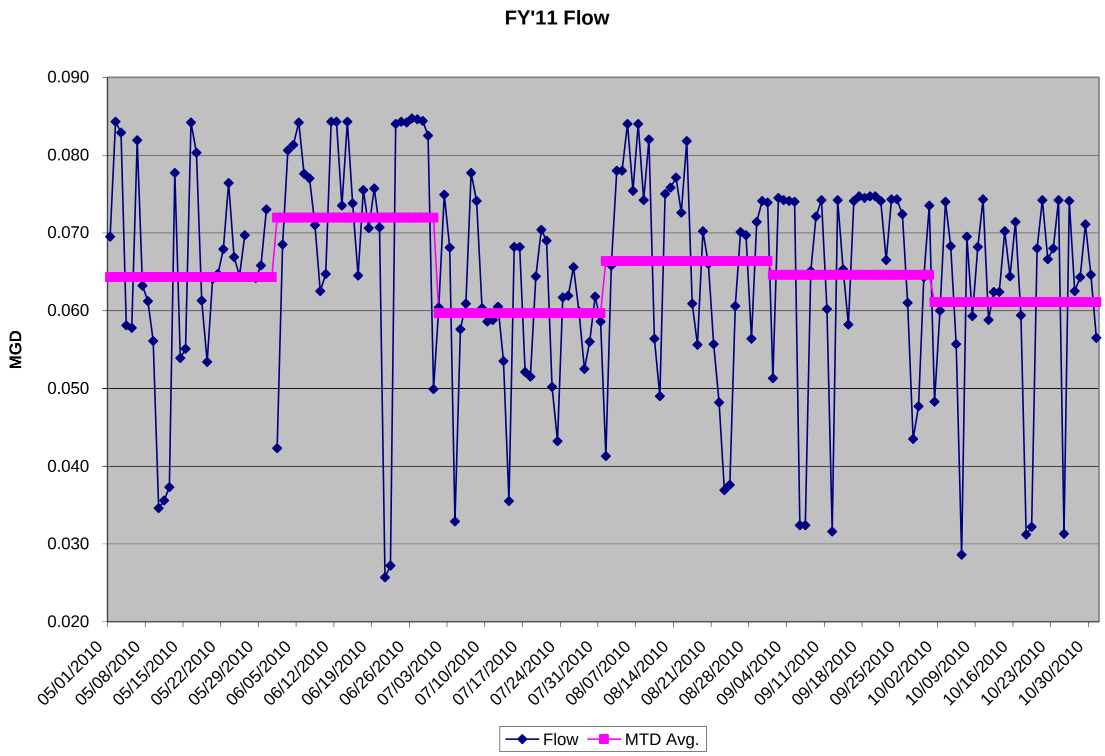

Figure 2: Wastewater Flow (May – October, 2010)

1.2 Problem Description

The purpose of this research is to identify solutions to assist the Food Processing Manufacturer in reducing its water consumption and waste water discharge rates due to the fact that upcoming City Permit regulations could result in significant increase in financial implications. Water usage reduction is an objective of most companies when it comes to natural resources consumption and energy conservation. Sustainability is the responsibility of any organization that is committed with a solid Corporate Social Responsibility Program that is interested in conducting its business while caring and preserving the environment. “Providing good food responsibly means going above and beyond to be good stewards of the environment.” Smithfield Foods (2009).

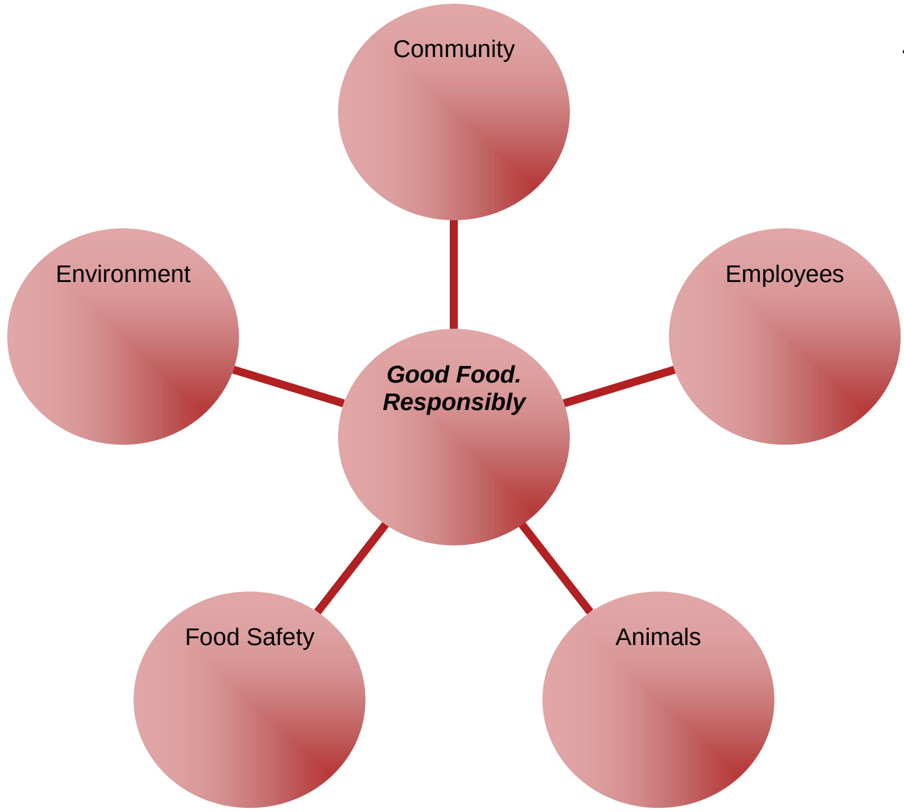

Figure 3: Smithfield Foods' Sustainability Focus

This research will focus on applying regression analysis to validate and predict water consumption reduction alternatives and measure their effectiveness for the specific task. The most effective system will be determined by considering several factors such as waste water flow reduction, results feasibility and sustainability, and cost.

In summary, the plant leadership is faced with the difficult decision of whether or not their current water consumption practice is satisfactory and what can be done to improve it. The intent of this research is to alleviate the difficulty in selecting costly long term solutions with regards to the water management system by meeting two specific objectives.

1.3 Objectives

The first objective of this research is to identify and introduce a set of best practices for water consumption in a Food Processing Plant. A literature review has provided some insight into best operating practices for utilization in the Food Industry. Information was collected from the literature and experts in the industry to establish a set of alternatives to greatly reduce water usage consumption.

The second objective is to conduct a regression analysis based on the results attained from the applied technique in order to validate the achieved results. The regression analysis and a fit test were used to demonstrate the model's effectiveness.

1.4 Thesis Outline

The remainder of this thesis is structured as follows. Chapter 2 details the summary of the background research that was performed during the scope of work. This section focus on previous research that could be utilized to address the first objective, while Chapter 3 describes the background of the methodology used to address the second objective. Chapter 4 describes the data and results concerning the function of the model. The proposed model goes through a fit test to validate its functionality and finally, Chapter 5 discusses the conclusions that were reached, along with any limitations and financial impact, and some enhancements that could be made for further research in this area.

CHAPTER 2

BACKGROUND

2.1 Definition of Permit Regulation and Change of Terms

The Food Processing Manufacturer entered into an agreement with the City of Cumming, which states that wastewater discharges are allowed under the terms of Industrial Wastewater Discharge Permit No. CMG-WQ-IP-195 . The permit is valid for 18 months and has some defined guidelines regarding its longevity and allowable limits of discharge:

- The permit should be renewed 90 days prior to its expiration date;
- Daily Wastewater flow discharge is regulated by the Permit as follows (in Million Gallons Per day or MGD):

  – Daily Maximum: 0.085 MGD

  – 30 days average: 0.075 MGD

However, the facility has been informed that the City of Cumming will be changing the terms of the permit once it expires. The new permit will lower the Daily Maximum Flow allowed to 0.075 MGD, as the permit will no longer allow a 30-day average flow as flow measurement.

2.2 Definition of Wastewater Treatment Process

Wastewater Treatment Plants (WWTP) are designed to treat wastewater via a multi-stage treatment process prior to the water being discharged into the environment or further use. Such process is accomplished via a three-fold system involving primary, secondary, and tertiary treatment.

Metcalf & Eddy (1991), defines the Primary treatment as the initial stage of the treatment process, where physical unit operations remove solid materials. The wastewater is screened to remove large, inorganic material, such as, paper and plastics, and then further screened for finer grit and silt particles. Once the preliminary treatment is completed, wastewater is then transferred to primary sedimentation tanks where solid particles of organic material are removed from suspension through flocculation. Primary sludge is allowed to settle out from wastewater through gravity. Even though a large amount of solids is removed in this stage, the treated effluent remains high in biological oxygen demand (BOD), suspended solids, and nutrients (Metcalf & Eddy, 1991).

The next step if for treated wastewater to undergo a secondary treatment, a process that entails the biological break down of dissolved and suspended organic solids facilitated by naturally occurring micro-organisms. At this stage, settled wastewater enters aeration tanks or lagoons and is mechanically aerated (Metcalf & Eddy, 1991). The injection of oxygen promotes the growth of micro-organisms and helps to maintain their suspension in the wastewater. During growth and multiplication phases, the active biomass consumes oxygen and organic pollutants and some nutrient constituents of the wastewater.

During this stage, the microbial biomass settles under gravity to the bottom of the tank as secondary sludge. A portion of the settled sludge is retained in the secondary aeration tanks to maintain a healthy microbial population while the remainder is pumped to anaerobic digesters for further treatment through the solids waste stream (Metcalf & Eddy, 1991). The wastewater and the microbial suspension are then processed into clarification units that remove any remaining microbial biomass and suspended solids.

Once wastewater has passed clarification, it will then undergo tertiary treatment where disinfectants are used to reduce pathogen (microbial counts) levels that may otherwise pose a health risk (Metcalf & Eddy, 1991).

Nemade, Kadam, & Shankar (2009) describes that the common methods of disinfection include ozone, chlorine, ultraviolet light (UV), or sodium hypochlorite Chlorine is commonly dosed into the treated wastewater stream for disinfection purposes.

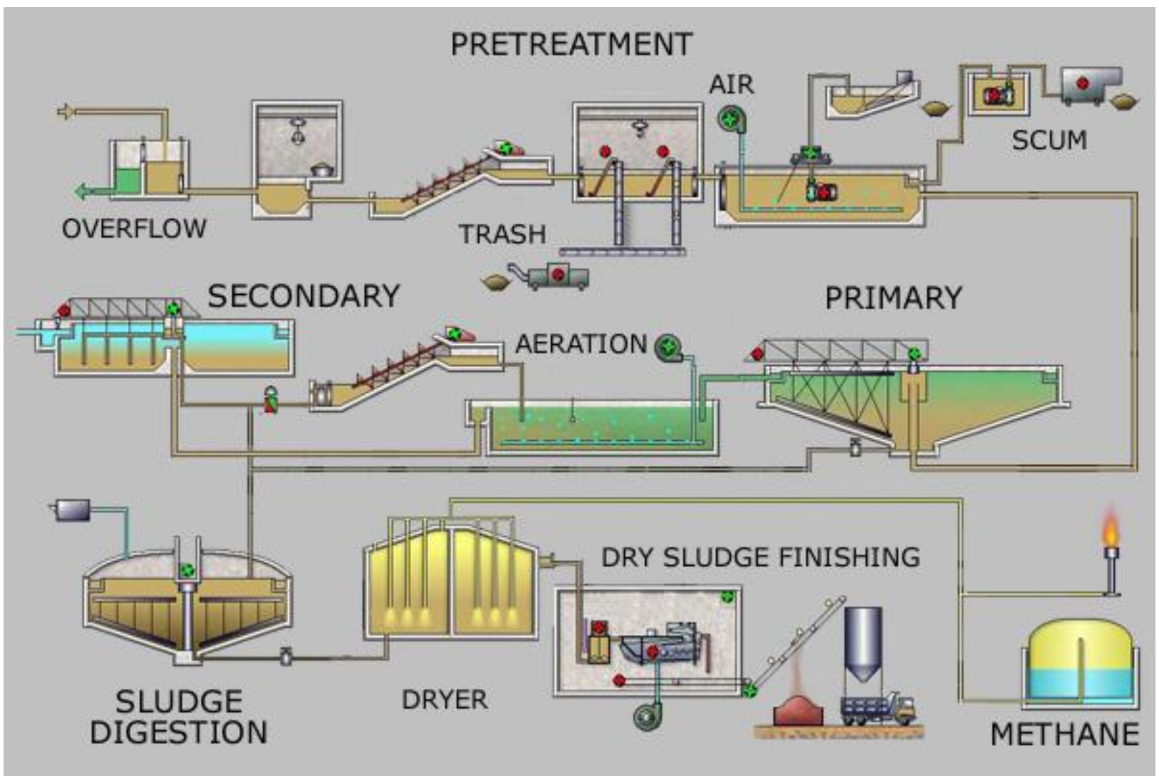

Figure 4: Wastewater Treatment Plant Process Flow (Source: Metcalf & Eddy, 1991)

2.3 Definition of Best Practices

Shipp, Chang, & Wisniewski (2005) categorize Best Practice as a methodology or concept of ideas, methods, or practices that when used wisely and elaborately they will result in a more efficient system. The life cycle loop to develop and achieve Best Practice is defined in four distinctive steps: design/development, implementation, assessment/enforcement, and learning feedback.

The concept of Best Practice can be utilized in any given industry and application while aiming for an end mean of increase productivity, efficiency, revenue , and/or any given metric that can be quantified.

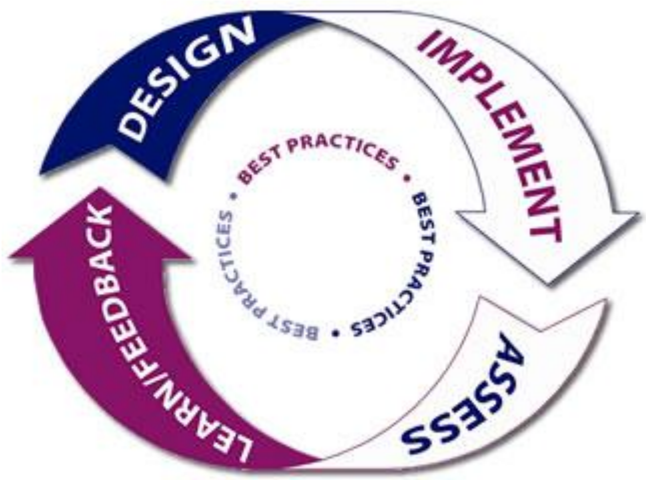

Figure 5: Life Cycle of a Best Practice (Source: Shipp, Chang, & Wisniewski, 2005)

One of the objectives of this thesis was to conduct am industry research to review and identify best practices associated with the efficient use and practices of water conservation. Those set of Best Practices were used to develop some possible solutions for the Food Processing Manufacturer to effectively reduce water consumption.

2.4 Risk Analysis

Based on the new terms of the City's Permit, an eminent and immediate waste water flow reduction and water conservation must be implemented in order to avoid any additional financial burden or liability to the plant.

The current one-time fee for additional sewage capacity is $20 per gallon per day. It will cost the plant $200,000 to purchase the additional flow capacity to elevate the additional flow discharge capacity to allow the 85,000 GPD (0.085 MGD) daily discharge.

Failure to comply with the discharge limits specified in the permit will result in a Notice of Violation (NOV) from the City of Cumming, additional environmental screening and reporting scrutiny, and the assessment of an administrative fee (not to exceed $1,000). As indicated by Heard (2008), if the user of sewer services has abused and/or continues to abuse the permit limitation, provides any false information or withhold information, the user will face civil penalties of $1,000 per day/per incident, criminal prosecution, which if found guilty of the misdemeanor offence, the person could be punished by receiving a $1,000 fine, up to one year in prison, and/or both.

2.5 Influential Factors in Water Conservation

Water Conservation has a different connotation when it comes to a global perspective as opposed to an industry related perspective. Various factors should be considered when reviewing the efficient use of water consumption as it relates to global impact. Factors such as: geography, economy, and social conditions. The importance of efficiency in water use clearly varies across regions and nations, as well as through time.

Tate (1991) categorizes the geographical impact of water conservation as the influence of water availability and the condition that arid and semi-arid regions require a greater efficiency of water use than humid regions and the importance of the geographical patterns. Furthermore he states that the economical conditions may be the most influential factor while dealing with water efficiency as the funding or financing of water development and water conservation programs have strong links to the economy and the benefits derived from those activities will impact the overall efficiency. He also debates how social conditions impact the efficient use of water resources as public education has a significant influence on water conservation efforts. Baumann (1980) defines that water conservation is a social beneficial reduction in water use or water loss.

2.6 Water Demand and Availability

One of the most important aspect of the survival and prosperity of the human civilization has been related to the availability of water supply (Schofer & Hironaka, 2005). Teclaff (1967) highlights the importance of water supply and how much it impacted civilizations throughout history. Interesting enough, 70% of the earth's surface is covered with water, most of that is saltwater. Duddin (1989) pointed that by volume, only 3% of all water on earth is fresh-water, and most of it is largely unavailable due to the fact that such water exists in the form of ice and it’s located in remote areas far away from most human habitation; only about 1% of all available water is easily accessible, surface freshwater. This is mainly the water found in lakes and rivers. Only 0.007% of the world's total supply of water is considered easily accessible for human use Lefort (1996).

Bower (1968) exemplified the complex factors influencing industrial water demand with the following conceptual model:

$Q_{It}•U_t•Q_{Et}•W_{Dt}•W_{Et}$ = f(C_I•PP-PM,RM,OR,R,MR,BI',C_E)

where: Q_{It},U_t•Q_{Et}•W_{Dt}•W_{Et}

= the time pattern of water intake, consumptive use, final effluent, waste load generated, and waste load in the final effluent, respectively.

C_I = the cost of intake water, which is a function of the time pattern of quantity and quality of water available and the cost of water acquisition and treatment.

PP-PM = a combination of production process and product mix.

RM = the nature of raw materials used.

OR = operating rate

R = the degree of recirculation, which is a function of the cost of recirculation, which, in turn is a function of the physical layout of the plant and PP-PM, the cost of waste water treatment, the cost of intake water treatment, and the quality specifications for the final output.

MR = the possibilities for materials recovery.

BP = the possibilities for by-product production.

C_E = the cost of handling and disposing of the final effluent, which, in turn, is a function of the controls imposed on liquid and gaseous waste discharge, the availability of places for disposal of waste and PP-PM.

Bower's conceptualization of industrial water demand implies that water use efficiency is the product of many varied forces and that any idea that water is a fixed constraint is not accurate.

Industrialized nations need to increase their efforts and measures to reuse water efficiently and conserve as much fresh water as possible in order to reduce the significant financial expenditure on water delivery systems and wastewater treatment facilities, and to avoid an impending water crisis and potential environmental damage and issues (Schofer & Hironaka, 2005). Total water-energy analysis should also include the effects of power plant generation, building cooling, water transport and deliveries, household end use and water heating, water and wastewater treatment, desalination, groundwater pumping, and similar energy uses for urban water deliveries. Cohen et al. (2004), motivated by environmental concerns, focus these water-energy relationships on the need to improve overall efficiency through additional water conservation and more-careful planning for the full life-cycle costs of water and energy resource development.

2.7 Industry Best Practices

In order to create a functional, feasible, and effective Best Practices guide for the Food Processing Manufacturer, a research was conducted to evaluate other industries where best practices were already in place. The majority of such practices are interchangeable between industries, as well as in the private sector. However, Food Safety and Parasite free water were considerations that were used while identifying the practical ability and use ability of such practices in a Food Processing environment. Furthermore, the Best Practices identified were not deemed confidential or intellectual property as their use, knowledge, and practices are known world-wide. Tate (1991) indicated practices such as law enforcing regulations affecting the discharge of wastewater into the water streams and the quality of the recycled water for reuse and recycling. Williams (1982) also discussed the encouragement for industries to reuse or recycle their process water whenever possible, or economic to do so and the substitution of potable water with non-potable water (such as treated sewage effluent, so called industrial water, rain water, sea water, etc) for non-potable use in industrial and commercial premises. Nemerow (1998) listed simple but effective solutions such as the use of water saving devices (such as spring-loaded nozzles, constant flow regulators, self-closing delayed-action taps, thimbles, etc), water usage audit and trend line tracking, advice to customers. Maynard (2001) revealed other practices such as water recycling system to reuse water for cooling purposes, the development of system for the collecting of rain water for non-potable usages, the development of water pre-treatment plant for boiler usage to reduce boiler blow-down, and the development of water recovery system for boilers, wherever possible, to recover condensate as make-up water.

CHAPTER 3

METHODOLOGY

The proposed solution to wastewater flow management is to develop a framework that can be used by management to determine if the wastewater discharge follows the guidelines as per specified in the permit.

3.1 Methodology for Developing Water Conservation Best Practices

The research background of Industry Best Practices yielded several opportunities that were deemed feasible and applicable for the Food Processing Manufacturer. The next phase of this process is to evaluate which one of the practices could be introduced in a short period of time and also required low cost investments. The program utilized data collection and trend analysis to identify the water usage and the usage of spring-loaded devices to monitor the decrease of water usage in the form of water consumption and wastewater discharge. Spring loaded devices (nozzles) operate under various constraints in regards to pressure for high pressure water application. The desired pressure usage must be determined in order to attain the respective usage flow measured via gallons per minute (GPM).

Other Industry solutions were also considered for a more “robust” reduction of water consumption but those solutions required significant capital investment and lead time for solution implementation. Water conservation involves trade-offs between the benefits and costs of water-management options (Esty & Winston, 2009). More recently, academics and water professionals have made a major effort to ensure that the term "water conservation" refers to reducing water use by improving the efficiency of various uses of water, without decreasing services (Porter & van der Linde, 1995).

3.1.1 USDA Regulation

One of the most important steps in developing a best practice document is to identify the requirements and regulations that pertain to the operating practices. When implementing the operating practices detailed in a best practice document, all efforts must be made to follow and oblige all regulations and requirements. For most Food Manufacturers, the United States Department of Agriculture (USDA) governs the regulations of food manufacturing operating practices and procedures and the same is holds true in regards to water recycling programs. The USDA has the following regulations sanctioned by its Food Safety and Inspection Service (FSIS) USDA (1862):

USDA FSIS 9 CFR 416.2(g)

1) Reuse water to be used to wash livestock pens, trucks, poultry cages, and similar areas.
   - Water to be used for washing be kept free of visible solids
   - Free chlorine concentration of 1-5 ppm maintained in reuse water
   - Water should be collected and handled in a sanitary manner
   - Human waste should be kept separate from plant waste
   - An ongoing microbiological monitoring plan should be established

2) Reuse water to be used to wash inedible product areas.

Washing offal sump screens, flushing feather flow-away troughs, flushing eviscerating troughs)

   - Should be used in a manner that prevents cross-contamination
   - Should not violate any OSHA requirements.
   - The reuse water to be used in inedible areas under USDA jurisdiction, such as pet food areas, must also meet USDA requirements.
   - Should be kept free of visible solids
   - Should be collected and handled in a sanitary manner

3.1.2 Breakdown of Industrial Water Conservation Best Practices

Several opportunities were deemed feasible and applicable for the Food Processing Manufacturer with regards to water conservation and recycling practices. A review of literature, on-site knowledge exchange, and trial of techniques in a Food Processing Manufacture facility led to the development of a Water Conservation Best Practices guide shown in Appendix A. Two types of conservation measures: improving water-use efficiency and substituting reclaimed water for some end uses.

Improving water-use efficiency includes behavioral and managerial improvements, such as adjusting a watering schedule, and technological improvements. Technological improvements usually involve replacing water-using equipment with newer technology that serves the same purpose utilizing lesser water (Tate, 1991). Thus water usage efficiency improvement means reducing the amount of water needed for any goal while still accomplishing that goal.

Data was collected daily via established data sheets, through observations of site operation, and by informal interviews with wastewater personnel and management. Trend lines of water usage consumption were developed and used to review the results of introduced concepts and technology to reduce water consumption. The best practice guide was developed by combining the collected information with good engineering practices in order to attain a feasible and effective water conservation program. These best practices consist of recirculation and conservation systems that will allow the Food Manufacturer to effectively reduce water consumption.

A complete Water Conservation system will incorporate one or more options from three main categories listed below (refer to Appendix A for complete description).

A) Wastewater Recycling for Evaporator Usage Purpose

B) Condensate Water Recycling for Non-Contact Usage Purpose

C) Wastewater Recycling for Plant Operation Usage Purpose

Along with at least one of the water conservation alternatives from these categories, a complete system should include all considerations in Section D (Other Process Considerations and Tools (spring-loaded devices – nozzles), Appendix A).

The complete system also must include operational best practice considerations, tools and equipment along with their standard operating procedures, optimal condition for water usage, and strategies for achieving water usage reductions. This best practice framework provided the basis of the proposed method for selecting the best water conservation system for a given Food Processing Manufacturer.

3.2 Methodology for Monitoring Wastewater Discharge

In order to ensure that the facility complies with the terms and regulations stated in the city permit, it is necessary for the plant to utilize a statistical process control (SPC) to monitor water discharges on a daily, per shift, and per hour basis. SPC is a process of statistical methods to monitor and control a process to ensure that it operates to its full potential and produce conforming product. When applied, SPC allows a process to behave predictably to produce as much conforming product minimizing waste and variability. SPC is frequently applied to controlling manufacturing lines but it is applicable to any process with a measurable output.The SPC tool serves as a gage, allowing the wastewater treament personnel to react to the various situations that arise due to the water consumption and discharge of the facility, along with allowing management time to make pertinent business decisions on the wastewater system.

The information used for the SPC charts is generated from meters located in the incoming water line into the treatment tank, as well as, the discharged end of the pit (this meter is the one that actually measures the flow of water been discharged to the city).

The data was collected by developing a systematic approach where the waste water operator would record the discharges levels of the wastewater treatment plant (WWTP) in order to determine system performance, trends, anomalies, and/or any other situation, which would place the system out of control or compliance. The daily and monthly discharges from the WWTP are represented graphically in Figures 2 and 3.

Table 1: Wastewater Flow (August – November, 2010)

	Wasterwater Flow
Mean	0.06468
Standard Deviation	0.01412
N	177

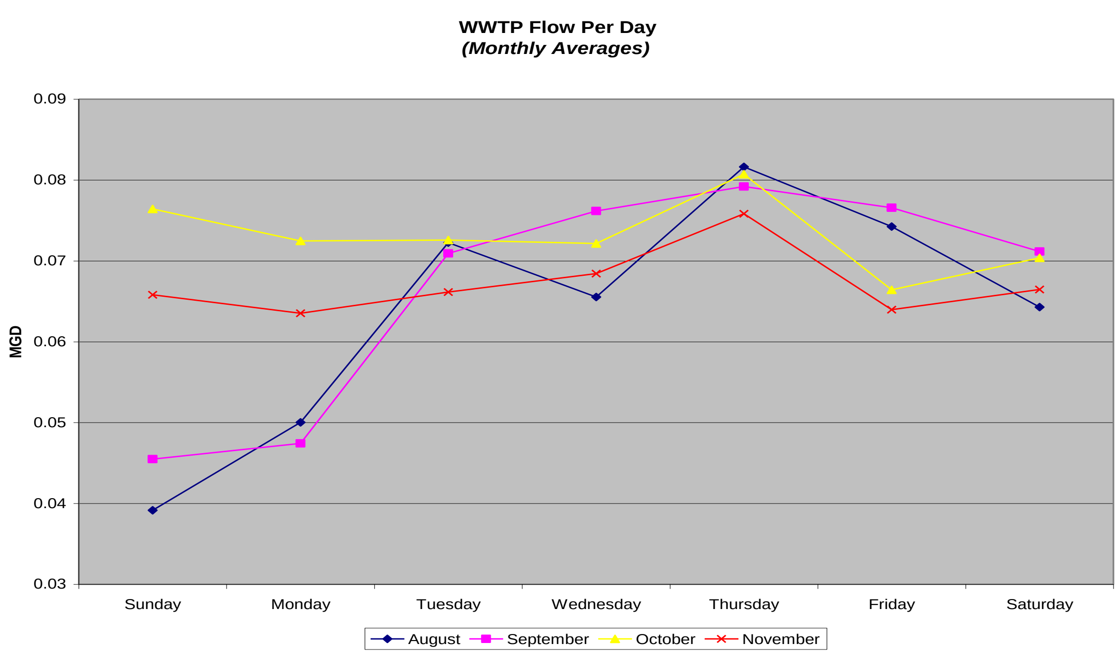

Figure 6: Wastewater Flow Per Day

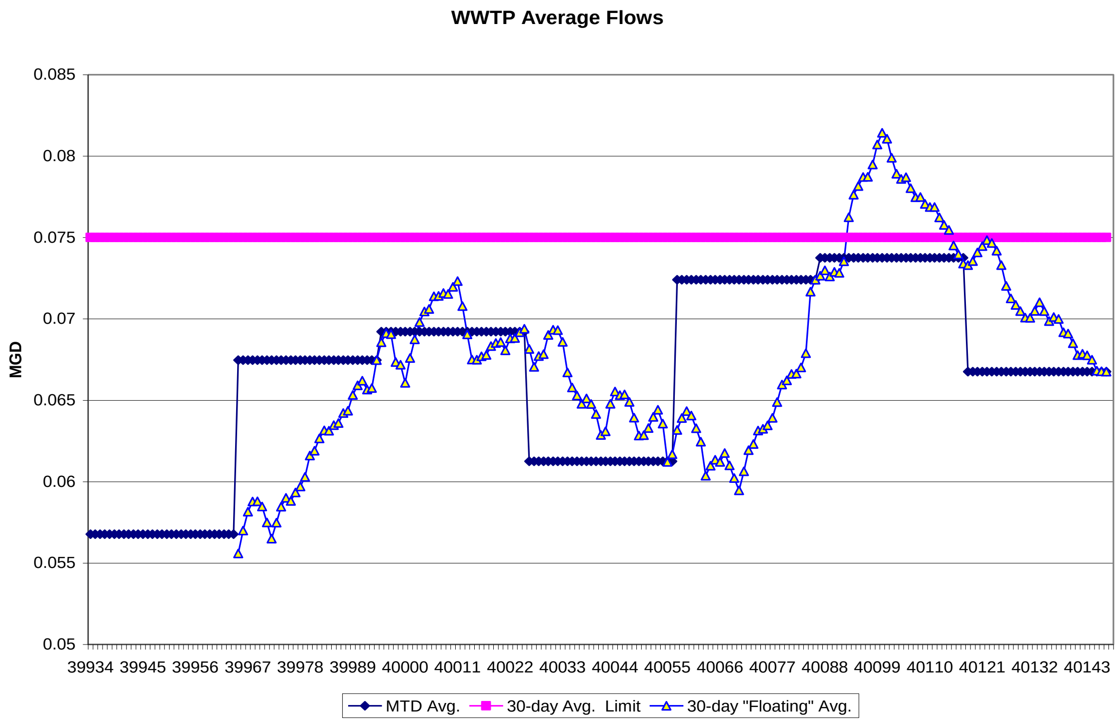

Figure 7: Wastewater Average Flow

Along with the development of SPC tools to monitor the wastewater discharges, it was pertinent to develop a tracking mechanism for water consumption in the facility. The water consumption was even more important than the wastewater discharge as the control and more efficient use of water would have a direct and proactive impact of the wastewater discharge flow (Tate, 1991). In order to accomplish such task, members of the Operations Team (Cook Leaders), were given the task of taking hourly reading from the main water meter in order to review the hourly and daily (by shift) water consumption.

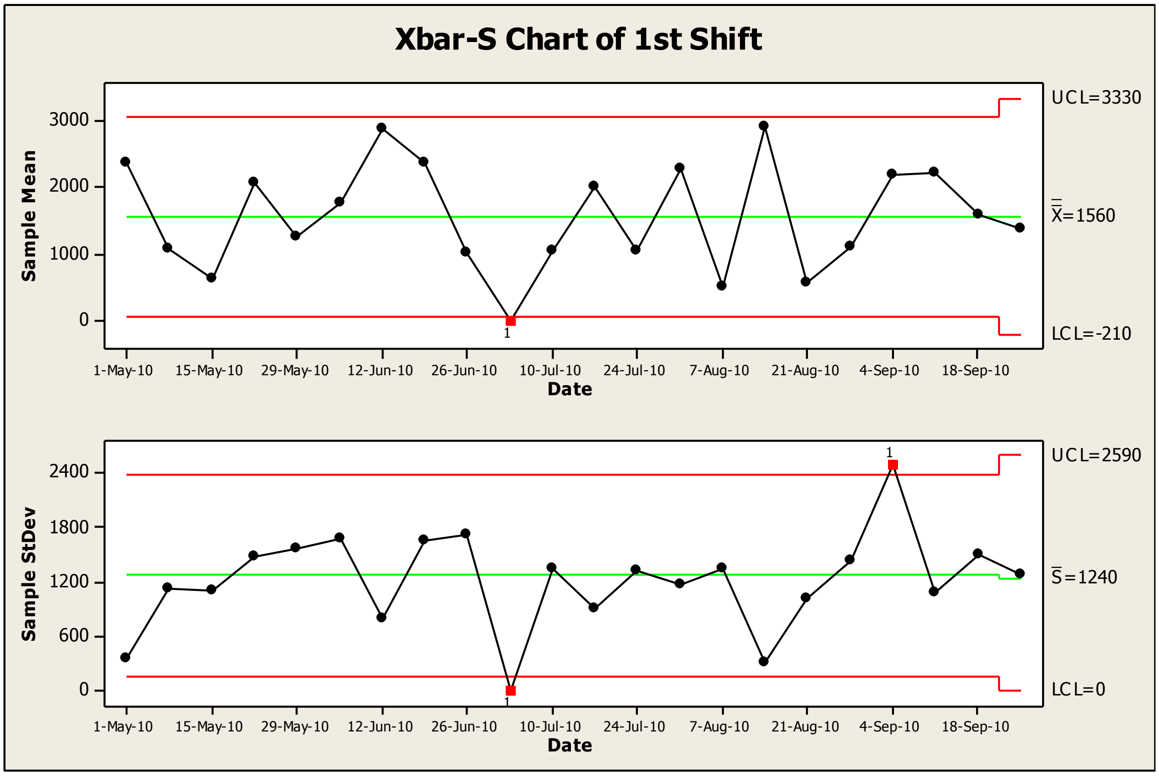

Figure 8: Water Consumption Average Flow First Shift (Hundred Gallons)

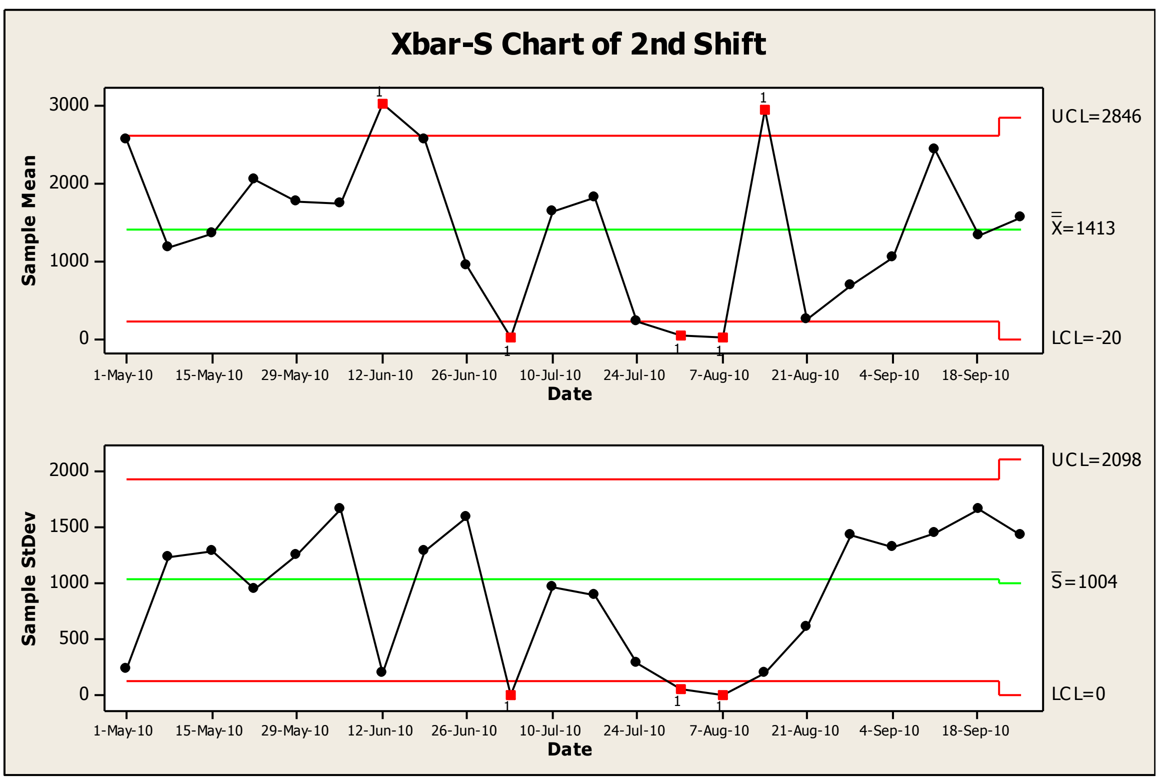

Figure 9: Water Consumption Average Flow Second Shift (Hundred Gallons)

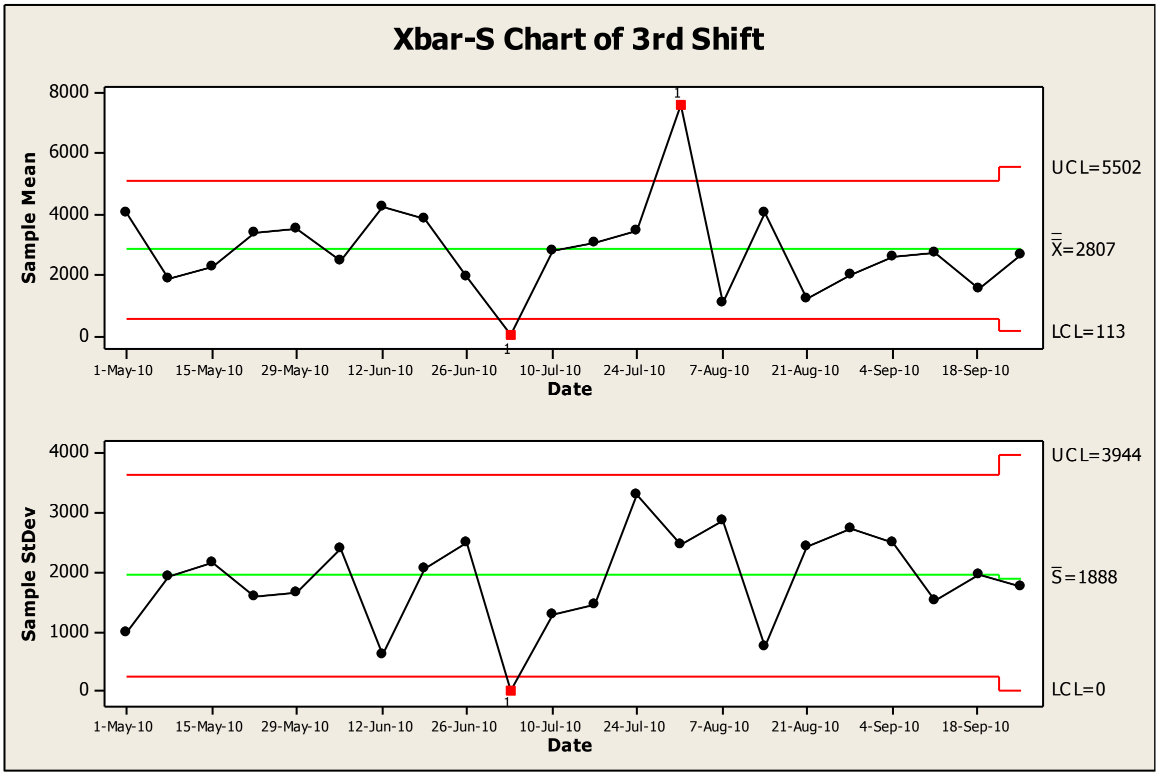

Figure 10: Water Consumption Average Flow Third Shift (Hundred Gallons)

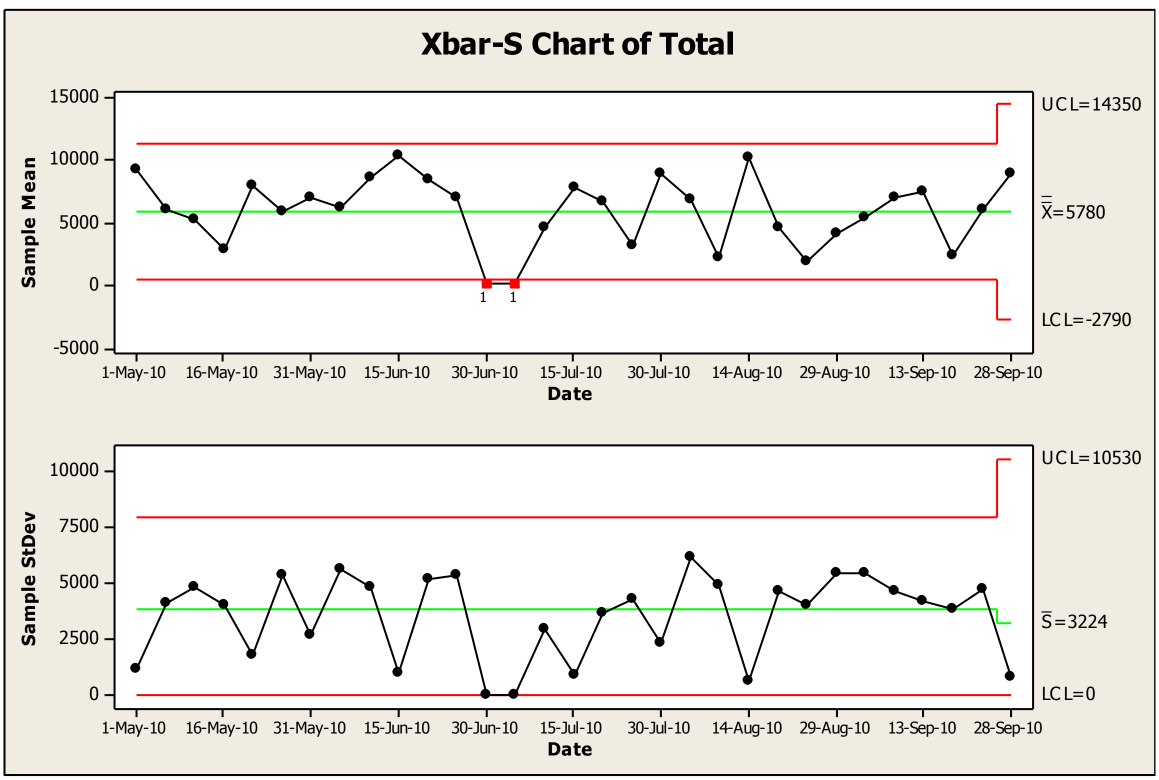

Figure 11: Water Consumption Average Flow Total (Hundred Gallons)

3.3 Forecasting Models and Performance Measures

There is a wide variety of predictive models that can be utilized dependant of the forecasting situation. As per definition, forecasting methods are both qualitative and quantitative (Makridakis, 1985). Quantitative methods can be grouped into deterministic models and probabilistic or stochastic models. In the deterministic models, the relationship between the variable being predicted and the variable used to make the prediction is exact and known with certainty (Makridakis, 1985). In the probabilistic or stochastic models, the relationship between the variable being predicted and the variable used to make the prediction is not exact and is not known with certainty but is inferred from the past data (Makridakis, 1985).

This section of the thesis describes the stochastic models available for forecasting and the statistical measures that can be used to measure the performance of these models.

3.3.1. Simple Time-Series Models

Simple time-series models are considered unsophisticated because they use the basic assumptions of how future values of time series can be predicted with past values.

Table 2. Simple Time-Series Models

Model	Formulation of Forecast
Basic Model	Forecast = actual value for last period
Basic Seasonal Model	Forecast for 1st period=actual value for last period Forecast for 2nd period= actual value for 2nd period Forecast for 3rd period= actual value for 3rd period, etc., “Period” is the forecast period and the number of periods depends on the seasonality
Change Models	Forecast for next period = actual value for last period plus average change where; Average change= average of changes,

Average change = average percentage change times last
value,
Average change= weighted average of changes

3.3.2. Smoothing Models

The smoothing models assume that the time series consists of a leveled pattern plus some fluctuations caused by randomness. The models in this category attempt to smooth out the fluctuations by smoothing or averaging them. The three main models in this category are moving averages, weighted moving averages, and single exponential smoothing (Makridakis, 1985).

3.3.2.a. Moving Averages

Moving averages for a chosen period of length *L* consist of a series of arithmetic means computed over time as each mean is calculated for a sequence of observed values during the particular length (Makridakis, 1985). This methodology tends to smooth out the short-term irregularities in the data series. The methodology is mathematically expressed as follows:

$$\textit{Moving Average} = \frac{\sum \textit{ demand in previous n periods}}{n} \qquad (1)$$

where:

n = the number of period in the moving average

3.3.2.b. Weighted Moving Averages

One of the shortfalls of the moving average technique is that all the past data used in calculating the average is weighted equally. However, one can obtain a more accurate forecast by assigning different weights to data, known as weighted moving averages

(WMA) (Makridakis, 1985). Such concept involves selecting different weights for each data value and then computing a weighted mean as the forecast. Generally the most recent observation receives the most weight, and the weight decreases for older data values.

The methodology is mathematically expressed as follows:

$$\text{WMA}_M = \frac{np_M + (n-1)p_{M-1} + \cdots + 2p_{(M-n+2)} + p_{(M-n+1)}}{n + (n-1) + \cdots + 2 + 1} \qquad (2)$$

3.3.2.c. Single-Exponential Smoothing (SES)

Exponential smoothing is a statistical method of forecasting the future based on the concept that as data becomes older it becomes less relevant and should be given less weight (Makridakis, 1985). SES uses actual data and deviations of previous forecasts to establish a projection of demand for the future. The number of previous periods selected and weight applied to each period in terms of an exponential relationship is set by the planner by selecting a constant α . The basic exponential smoothing formula can be mathematically expressed as follows:

New Forecast $(F_t) = (F_{t-1}) + \alpha\,[\,(A_{t-1}) - (F_{t-1})]$ (3)

where:

α is a weight (or smoothing constant) that has a value between 0 and 1,

F_{t-1}= last period’s forecast, and

A_{t-1}= last period’s actual demand.

3.3.3. Linear Trend Models

The linear trend models assume that the time-series consist of an upward or downward trend pattern plus fluctuations from randomness (Render, 2000). The two models in this category, which are more complex than the simple or smoothing models, are described as follows.

3.3.3.a. Linear Regression

Linear regression assumes a dependent variable is linearly related to an independent variable. It then finds the equation of the line-of-best fit through the data. Mathematically, it is expressed as follows:

$$Y(t) = \alpha + \beta\, t, \tag{4}$$

where :

t = time index.

The parameters alpha and beta (the "intercept" and "slope" of the trend line) are usually estimated via a simple regression in which Y is the dependent variable and the time index t is the independent variable. Such model will be further discussed in a later session of this research.

3.3.3.b. Double Exponential Smoothing (Holt's Method)

Single exponential smoothing is often referred to as first-order smoothing, and trend adjusted smoothing is called "second-order," or "double smoothing." As with any moving average technique, simple exponential smoothing fails to respond to trends (Render, 2000).

A more complex exponential smoothing model that adjusts for trends can be considered. The idea is to compute a single exponential smoothing forecast and then to adjust for positive or negative lag in trend (Render, 2000). To smooth out the trend, the equation for the trend correction uses a smoothing constant, β, in the same way the simple exponential model uses α. Mathematically, it is expressed as follows:

$$T_t = (1-\beta)T_t\text{-}1+\beta (F_t-F_{t-1}) \quad (5)$$

where:

T_t = smoothed trend for period t,

T_{t-1} = smoothed trend for preceding period,

β = selected trend smoothing constant,

F_t = simple exponential smoothed forecast for period t, and

F_{t-1} = forecast for previous period.

The value of the trend smoothing constant, β , resembles the α constant in that a high β is more responsive to recent changes in trend. A low β value gives less weight to the most recent trends to smooth out the trend present. Values of β can be found by the trial-and-error approach, with the Mean Absolute Deviation (MAD) used as a measure of comparison.

3.3.4. Nonlinear Trend Models

The linear trend models attempt to fit data to a straight line that is a graph of a linear trend. The nonlinear trend models attempt to fit the data to other curves, which are not linear trends (Render, 2000). If F represents the forecast, t the time period, and a, b, and c the parameters, we have the following curves and their associated forecasting models:

• Inverse Linear $F = a/t + b$ (6)

• Exponential Curve $F = b \exp(at)$ (7)

• Compound Growth $F = b\ at + c$ (8)

• Modified Exponential F = b ta + c (9)

• Logistic F = 1 / (b at + c) (10)

3.3.5. Decomposition Method

The underlying assumption in the decomposition method is that the data pattern comprises four components: a trend component (T), a seasonal component (S), a cyclical component (C), and a random component (R). The decomposition method attempts to isolate these components in the historical time series and then recombines them into a forecast for the future (Makridakis, 1985).

The most common time series model used is the multiplicative model, which assumes that demand is the product of the four components:

Demand = T * S * C * R. (11)

An additive model adds the components to provide an estimate:

Demand = T + S + C + R. (12)

3.3.6 Box-Jenkins Method

The Box-Jenkins Method is not an actual model but is an approach to forecasting complex situations whereas the data pattern is not evident. The steps followed in this method decide the types of models to consider, identifying which models will fit the data, estimating the necessary coefficients (of the models), and diagnosing the model (Box & Jenkins, 1970).

Developing the Box-Jenkins method is complex and a thorough knowledge of its use requires higher-order mathematics likely beyond that of forecasting specialists (Pankratz, 1983). Even though this method is complicated, the growth in computer power has made it feasible. Three types of forecasting models use the Box-Jenkins techniques.

3.3.6.a. Auto-Regressive Model (AR)

The AR model postulates that the current value of a variable is the weighted linear sum of past values plus some error term (Box & Jenkins, 1970). The model can be represented as follows:

$$Y_t = b_0 + b_1 + Y_{t-1} + e_t \tag{13}$$

where:

Y_t = dependent variable,

Y_{t-1} = one period lagged dependent variable,

b_0 = constant term,

b_1 = regression coefficient, and

e_t = error term that represents random events not explained by the model.

3.3.6.b. Moving Average (MA)

The MA model postulates that the current value of a variable is a weighted linear relationship of past error terms and the current random term (Box & Jenkins, 1970). The model can be represented as follows:

$$Y_t = e_t - W_1 e_{t-1} + b_0 \tag{14}$$

where :

Y_t = dependent variable,

W_1 = weight,

e_t = error term that represents random events not explained by the model,

e_{t-1} = one period lagged error term, and

b_0 = constant term.

3.3.6.c. Integrated Auto-Regressive Moving Average (ARIMA)

The ARIMA model entails that the current value of the variable is the combination of the AR and MA models (Box & Jenkins, 1970). The model can be represented as follows:

$$Y_t = b_0 + b_1 + Y_{t-1} - W_1 e_{t-1} + e_t \tag{15}$$

3.3.7. Combined Forecasts

Data patterns often exhibit both trend and randomness or two or more other attributes. Since different models work better with different data patterns, limiting a forecast to a single model in this case may not produce a good forecast. Using an average of two or more forecasting techniques may be better than using a “wrong” model or a single poor forecasting model (Makridakis, 1985). Unless strong evidence indicates a particular forecasting model is better than other models for a given data pattern, combining the output from several models might be desirable. A combined forecast is less sensitive to the specific choice of models, and it uses more information about the data pattern than a single model. The potential for large errors is reduced because the forecast is not built on a single set of assumptions (Makridakis, 1985).

3.3.8. Forecast Performance Error

In order to rank or validate forecasting methods, there are error calculation models to estimate the error associated with the forecasted model such as, the mean-squared error, or mean-absolute deviation (Makridakis, 1985). Ideally, one will want the model that will provide the least error in the forecast (Render, 2000). The model can be measured at the differences over time, meaning that the model will be measured via the bias of the model or if it is over forecasting (negative sum) or under forecasting (positive sum) (Makridakis, 1985). However, the model will be measuring accuracy if it is measured by the size of the differences disregarding whether they are negative or positive (Makridakis, 1985).

The Mean Error (ME) and Mean Percentage Error (MPE) Models measure forecast bias, while the Mean-Square Error (MSE), Mean-Absolute Deviation or Mean-Absolute Error (MAD or MAE), Mean-Absolute Percentage Error (MAPE) Models measure forecast accuracy (Render, 2000).

3.3.8.a. Mean Error (ME)

ME of the Standard Error of the Mean (SEM) is simply the average of the total differences between the actual demands and forecasted demands. Mathematically it is expressed as:

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}} \tag{16}$$

3.3.8.b. Mean-Percentage Error (MPE)

MPE is the average of all of the percentage errors between the actual demands and the forecasted demands. Mathematically it is expressed as:

$$\mathrm{MPE} = \frac{1}{n}\sum_{t=1}^{n}\frac{f_t - a_t}{a_t} \tag{17}$$

3.3.8.c. Mean-Square Error (MSE)

MSE is the average of the square of the differences between the actual demands and the forecasted demands. Mathematically it is expressed as:

$$\mathrm{MSE}(\hat{\theta}) = \mathrm{Var}(\hat{\theta}) + \left(\mathrm{Bias}(\hat{\theta}, \theta)\right)^2 . \tag{18}$$

3.3.8.d. Mean-Absolute Deviation or Mean-Absolute Error (MAD or MAE)

MAD is the sum of the absolute values of the differences between the actual demands and the forecasted demands, divided by the number of periods of data *n*. Mathematically it is expressed as:

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n} |f_i - y_i| = \frac{1}{n}\sum_{i=1}^{n} |e_i| . \tag{19}$$

3.3.8.e. Mean-Absolute Percentage Error (MAPE)

MAPE is the average of the sum of all absolute values of the percentage errors between the actual demands and the forecasted demands. Mathematically it is expressed as:

$$\mathrm{M} = \frac{1}{n}\sum_{t=1}^{n} \left| \frac{A_t - F_t}{A_t} \right| \tag{20}$$

3.4 Methodology for Implementing Water Conservation Best Practices

With several Water Conservation systems available, the second objective is to determine which system is the most effective for a specific application. The systems can easily be compared by cost, however, one of the objectives of this study was to evaluate and implement a solution that was economic feasible, due to the capital constraints of the Food Processing Manufacturer, and the time constraint associated with the sought solution since immediate impact towards water conservation was a reality. In order to validate the effectiveness of the solution and water conservation system, a linear regression modeling was conducted in order to forecast the water consumption rate of the Food Processing Manufacturer, which would predict the wastewater permit compliance.

Linear regression modeling evaluates the linear relationship between two continuous variables: one response (y) and one predictor (x). When the two variables are related, it is possible to accurately predict a response value from a predictor value (El-Korashey, 2009). Regression provides the line that "best" fits the data for the purpose of identifying how the response variable changes as the predictor variable changes, as well as, predicting the value of a response variable (y) for any predictor variable (x). The method used to draw this best line is called the least-squares criterion. Helsel (1995) describes how the least-squares criterion requires that the best-fitting regression line is the one with the smallest sum of the squared error terms (the distance of the points from the line), along with categorizing the computations for regression estimation and identify measures commonly used to evaluate regression equations, including mean square error, standard deviation, and coefficient of multiple determination R^2. $R^2$is used in the context of statistical models as prediction of future outcomes on the basis of other related information. It is the proportion of variability in a data set in a statistical model and it provides a measure of how well future outcomes are likely to be predicted by the model Helsel (1995).

In order to statistically evaluate all of the collected data, the Minitab software tool was used as the means for output generation. Minitab is a comprehensive statistical and graphical analysis software tool package used in the Industry and Academia for data analysis. This software application is commonly utilized for Continuous Improvement and Quality Improvement projects and applications and due to its comprehensive statistical modeling capabilities, accuracy and reliability of results, and user friendliness.

Regression analysis of the water usage data collected from May to September was used to estimate the water usage consumption demand for the Food Processing Manufacturer at any given time. To test the developed regression equations for a specific period, the modeling equations were applied to a specific month (September) in order to estimate the water consumption rate and errors.

The regression model is of the form:

$$y_i = \beta_1 x_{i1} + \cdots + \beta_p x_{ip} + \varepsilon_i = x_i'\beta + \varepsilon_i, \qquad i = 1, \ldots, n, \tag{21}$$

Where:

β_0 = *y*-intercept

β_1 = slope of the line

ε_i = error term.

Often these *n* equations are stacked together and written in vector form as

$$y = X\beta + \varepsilon, \tag{22}$$

where:

$$y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{pmatrix}, \quad X = \begin{pmatrix} x_1' \\ x_2' \\ \vdots \\ x_n' \end{pmatrix} = \begin{pmatrix} x_{11} & \cdots & x_{1p} \\ x_{21} & \cdots & x_{2p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{np} \end{pmatrix}, \quad \beta = \begin{pmatrix} \beta_1 \\ \vdots \\ \beta_p \end{pmatrix}, \quad \varepsilon = \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{pmatrix}.$$

In a regression model we make four assumptions (Helsel, 1995):

1. The given value of the independent variable, the population of potential error term has a mean equal to zero.

2. The given value of the independent variable, the population of potential error term has a variance not dependent on the independent variable. That is the different populations of potential error terms corresponding to different values of the independent variables have equal variances. This is the constant variance assumption.

3. The given value of the independent variable, the population of potential error term is normally distributed. This is the normality assumption.

4. The independence assumption states the independent variable is independent of one another in regards to the population of potential error term. As an indicator of the ability of the regression relations to estimate water consumption, the measured water rate consumption were compared to the water consumption estimated by the regression relations by calculating its relative percentage difference (RPDs) using the following equation:

$$RPD = \left| \frac{E - M}{M} \times 100 \right| . \tag{23}$$

Where; **E:** is the water consumption estimated from the regression equation **M:** is the measured water consumption concentration.

CHAPTER 4

RESULTS

4.1 Problem Statement

The model proposed in this thesis aims to provide management with a methodology that can be used to make more accurate decisions regarding the historical performance of the WWTP rather than just monitor its discharge levels. The regression analysis is used to predict the system's performance and its control level as the basis for further technique and control processes. Using the results from Objective 1, we seek to 1) validate the effectiveness of the methodology selected as the most effective manner to manage the daily operation water consumption and subsequent wastewater discharge WWTP 2) institute aggressive ways to re-gain control of the system when out of compliance.

4.2 Model Definition

Regression analysis of the water usage data collected from May to September was used to estimate the water usage consumption demand for the Food Processing Manufacturer at any given time and the manner in which the management team should behave in regards to making decisions to quickly re-gain control of the system in case of non-compliance and implement the best solution for the particular application. It does not signify merely a solution to the problem but rather represents a methodology for allowing better management of the complexities of the system.

Table 3: Regression Equation for Estimate of Water Consumption

Constituent	Equation	S	R-Sq	R-Sq (adj)
1st Shift	Total = 4648 + 1.693 1st Shift	1210.24	51.80%	51.10%

Table 4: Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	119426918	119426918	81.54	0
Error	76	111315008	1464671		
Total	77	230741926			

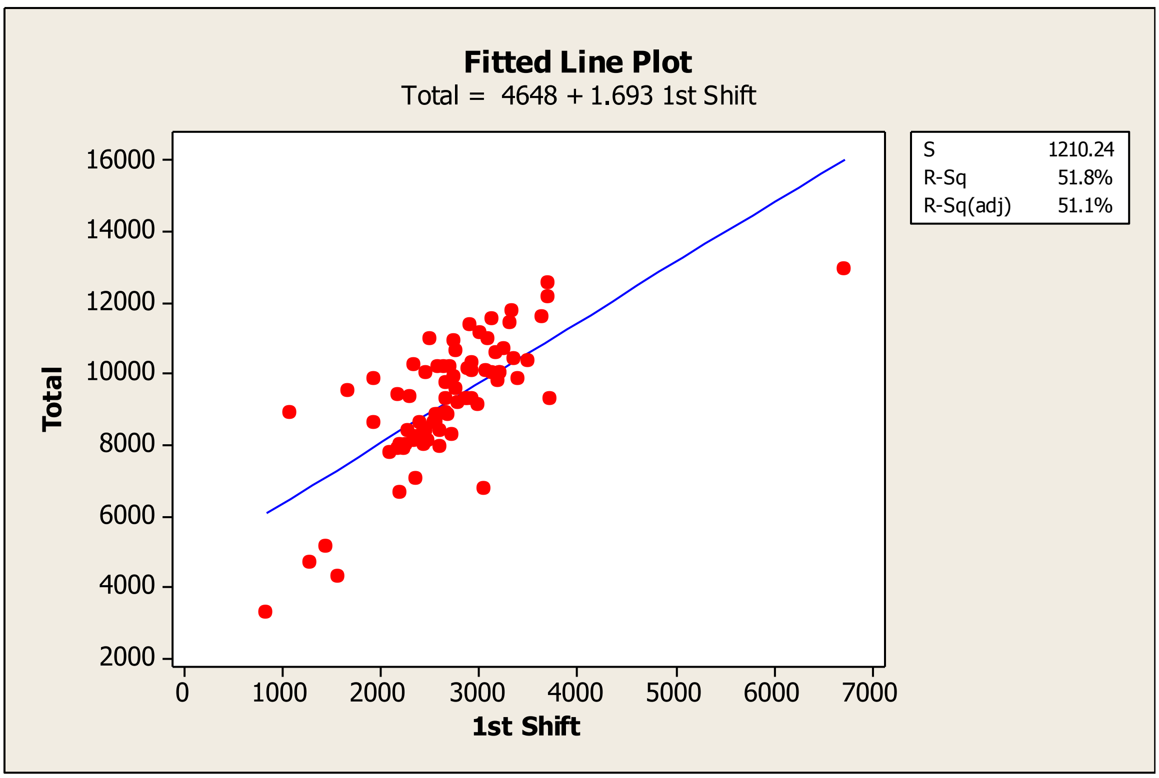

Figure 12: Fitted Line Plot for Water Consumption Prediction

Table 5: Unusual Observations

Obs	1st Shift	Total	Fit	SE Fit	Residual	St Residual
6	844	3285	6076	374	-2791	-2.43RX
8	1575	4255	7314	252	-3059	-2.58R
18	3056	6749	9820	152	-3071	-2.56R
18	6724	12940	16029	766	-3089	-3.30RX
43	1076	8883	6469	334	2414	2.08R

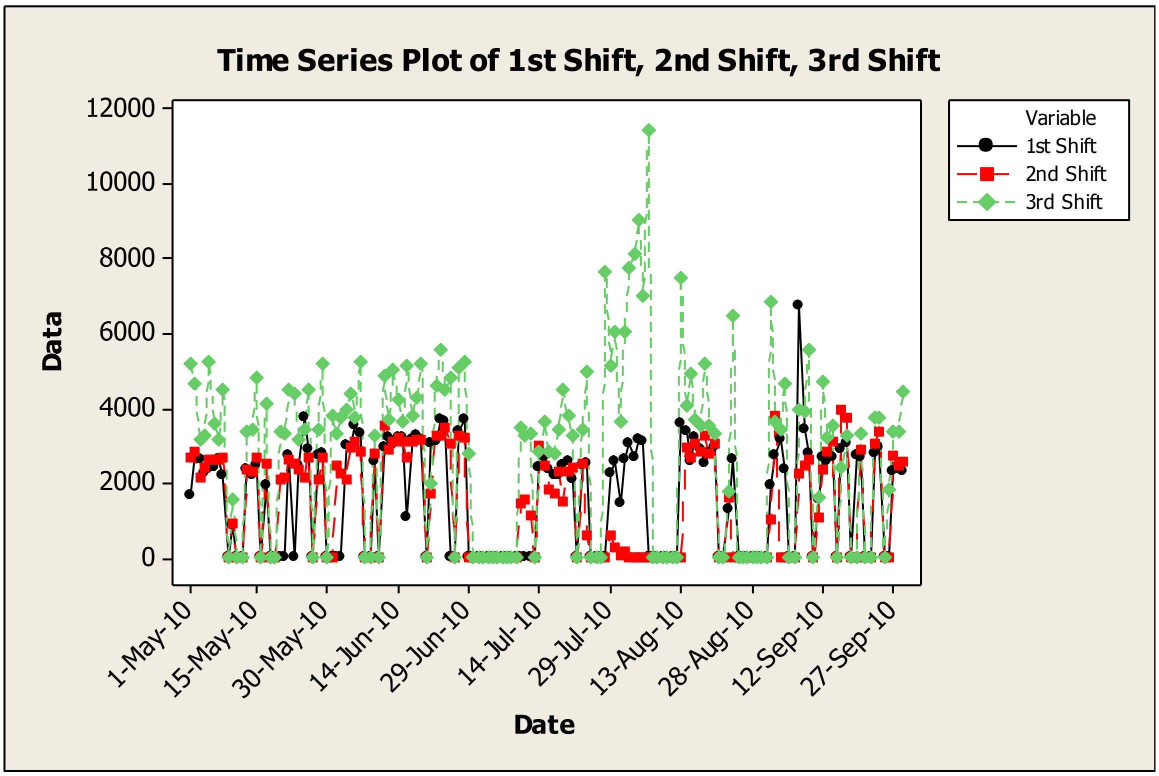

Figure 13: Time Series Plot for Water Consumption by Shift

4.2.1 Specification of Attributes

The problem is comprised of four alternatives that were identified in the suggested best practice guide: Wastewater Recycling for Evaporator Usage Purpose, Condensate Water Recycling for Non-Contact Usage Purpose, Wastewater Recycling for Plant Operation Usage Purpose, and Other Process Considerations and Tools (spring-loaded devices – nozzles), which were compared will be compared upon four attributes: complexity, efficiency, ease of implementation, and cost. A brief description of each alternative is given below. The full description is detailed in Appendix A.

A. Wastewater Recycling for Evaporator Usage Purpose.

Introduction of a system to recycle treated wastewater for make-up to evaporative cooling systems via a wastewater recycle using Submerged Ultra Filtration.

B. Condensate Water Recycling for Non-Contact Usage Purpose

Recycling of condensate water (COW) from evaporator units utilizing a combination of oxidation, filtration, and Ultra Violet (UV) light to clean / disinfect the COW water to acceptable microbial levels based on receiving process.

C. Wastewater Recycling for Plant Operation Usage Purpose Recycling, filtering, and re-introducing the processed wastewater back in to the plant operation to be used back into the plant operations utilizing biological and other filtration system to replace the original evaporation process for the treatment of the wastewater.

D. Other Process Considerations and Tools (spring-loaded devices – nozzles)

This alternative restricts and conserves water consumption at its source by minimizing the water flow discharge required by any given task.

For the purpose of this task, alternative D was chosen and implemented during the month of September. Fifteen spray gun nozzles were introduced during the sanitation cycle and the benefits from water consumption reduction were observed immediately, which were also supported by statistical data.

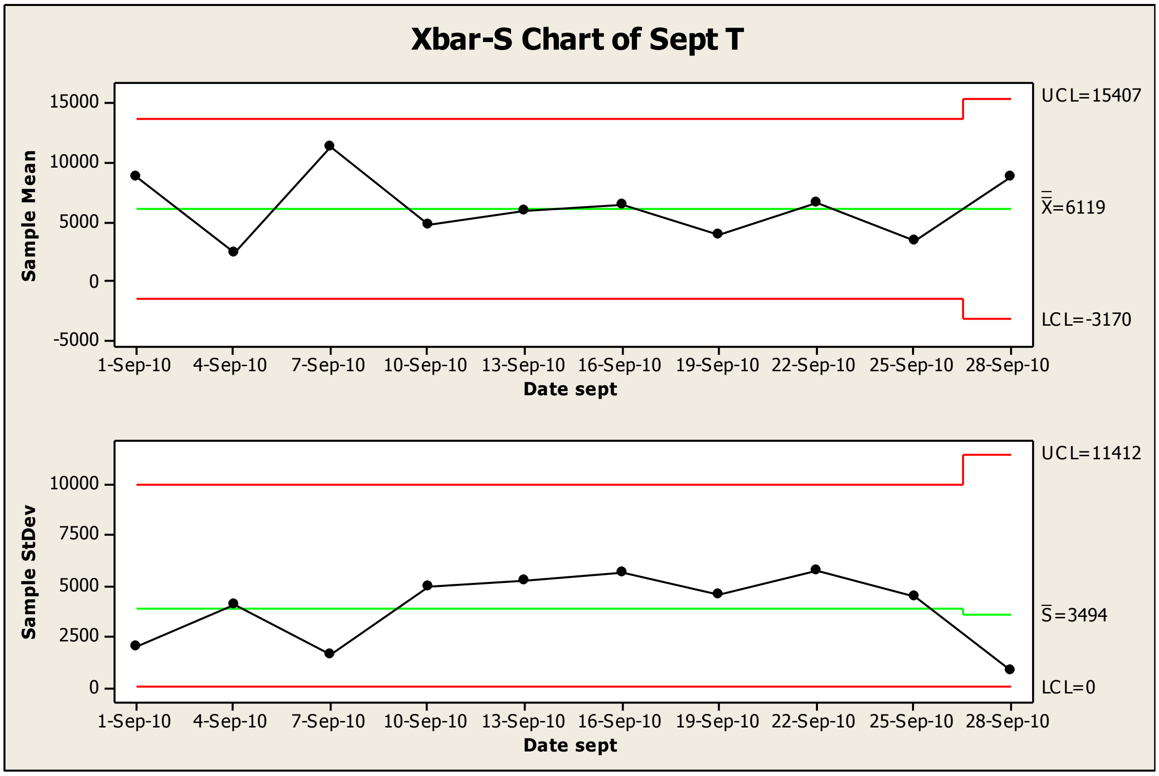

Figure 14: September Water Flow Analysis

4.3 Cost Benefit Analysis

The use of low-flow nozzles and auto-shut off valves has savings potentials of 50 percent and can be simultaneously implemented at the same facilities (Esty & Winston, 2009). Clearly, the savings are not additive because if we implement both water use does not decrease by 100 percent. We describe technologies as complementary if they can be simultaneously implemented at one facility.

If the technologies have savings of S_i and penetration rates of P_i, respectively, the savings possible for each technology is:

$$C_{Nozzles} = \frac{(1-P_{Nozzles}) * S_{Nozzles}}{(1 - S_{Nozzles} * P_{Nozzles})}$$

The total savings from implementing both technologies is:

Total Conservation Potential % = 1 - (*1* - $C_{Nozzles}$) * (*1* - $C_{Auto\text{-}shutoff}$)

Generalizing for complementary technologies

Total Conservation Potential % = 1-Π(1- Cj)

Table 6: Water Flow Savings

Low -Flow Nozzle	Rate (Gal Per Minute)	Hourly Usage Rate (Gal)	Water Consumption Savings Per Hour (Gal)
0	10	600	
1	5	300	300

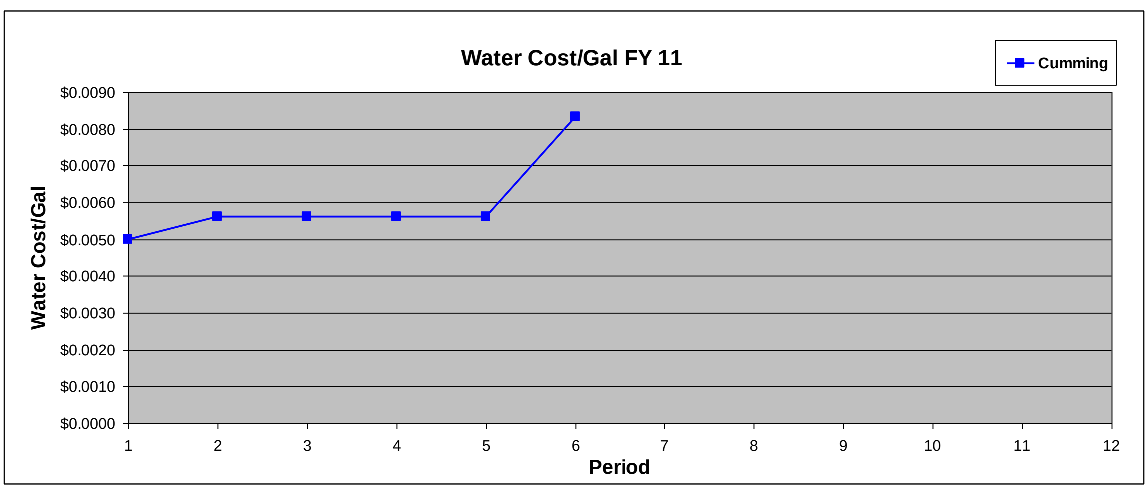

Figure 15: Water Cost per Gallon

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

The goal of this thesis was to meet two specific objectives. The first objective was accomplished through an extensive literature search along with data collection through on-site observations and interviews. This information was utilized to develop a water consumption reduction best practice guide to effectively manage wastewater discharge flow. (Refer to Appendix A for the best practice guide). The second objective was fulfilled by applying a simple regression analysis technique known to one of the best practices identified in the first objective. This research utilized a linear regression analysis in order to predict the system behavior with regards to water consumption and the impact on the wastewater plant as it relates to its current levels of discharge. The results of the analysis indicated that the system is in-control. However, the system is currently operating at its limit and any major change to the system or significant event will easily make the system to be out of control.

A case study was applied to a specific industry problem to exemplify the effectiveness of this model by using the researcher's preferences and knowledge acquired during the observations of the WWTP operation and Food Processing Manufacturing processes. The model was validated by monitoring the consistency of the decision maker's preferences and identifying the comparisons that contributed most to inconsistency in the model. The use of regression equations to estimate water consumption rate provides management with timely performance information feedback that was otherwise not available. The regression relations may be used to continuously estimate constituent concentrations for the Food Processor Manufacturer and these estimates may be used to continuously estimate consumption rate. The regression equations presented in this study are site specific and apply only to the Food Processing Manufacturer.

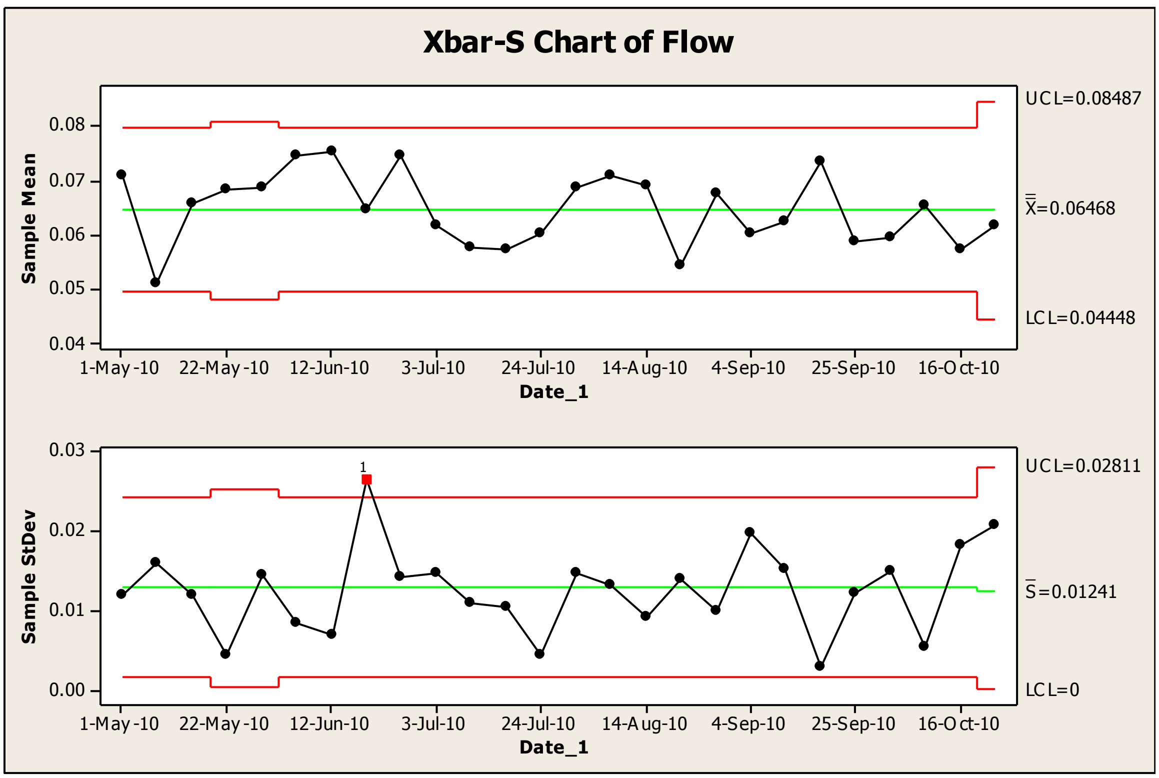

Figure 16: Average Daily Water Usage

5.2 Contribution to the Body of Knowledge

The wastewater operators are responsible for the management of the WWTP facility and the affluent rate discharge generated by the system. They are faced with the task of managing and controlling the amount of solid separation from the system, along with making sure that all discharges are done in compliance with the City Permit’s limitations. This research will provide management with a tool to make informed decisions as to what type of water conservation system is most appropriate for their application. By definition, residuals from a fitted model are the differences between the responses at each combination values of the explanatory variables and the corresponding prediction of the response computed by the regression function. The residuals will approximate the random errors that make the relationship between the explanatory variables and the response variable a statistical relationship if the model fit to the data is appropriate. If the residuals appear to behave randomly, it suggests that the model fits the data. However, a non-random structure evidence it the residuals suggests that the model fits the data poorly. A sample output of the residual plots is shown in Appendix B.

The literature research discovered various solutions aimed to achieve water conservation, which use may or may not be suitable to Food Processing Manufacturers. This led to the development of a suggested best practice guide that can be used by any industry striving to reduce water consumption via usage reduction or water recycling programs. The best practice guide is shown in Appendix A. The methodology presented in this research can be used by similar industries where good operating practices are not publicly available and it is unclear as to which process or equipment would be the most suitable to their operation.

5.3 Limitations

Any issues with the data collected could have influenced the research and results. Although the model calculated the most accurate water use and conservation potential estimates with the information available, increasing the accuracy of future estimates requires water users, suppliers, and managers at all levels to increase the reliability and accessibility of water use and conservation data.

One constraint that may be beneficial to include is the notion that one attribute should not negatively affect another, such as; the selected option should increase water conservation without negatively affecting production or increased cost. This constraint was not specifically incorporated into the model.

5.4 Future Work

The results of the analysis indicated that even though the system is within range/control, the system is operating very closely to its maximum allowable operating levels. In order to prevent the system from being out of compliance, the facility should invest in several measures to ensure that the daily intake or consumption of water does not surpass the maximum allowable discharge levels for the WWTP. Measure such as:

- Routine facility audits to ensure that there are no faucets or water drops leaking water;
- Review of the water temperature during the sanitation process to ensure that temperature is maintained with 120° and 140° at 400 PSI to allow the proper break down of protein levels during sanitation and the lesser usage of water.
- Re-train all employees about water conservation concepts and make sure that they conduct a thorough dry pick-up during sanitation prior to using water to rinse floors and equipment.
- Continue to identify methodologies for water recirculation throughout the process and re-use it for sanitation and/or other purpose. UV filters and screens are industry accepted solutions to sanitize water and filter off any solids.

- Further investigate the use of mechanical, electronic or computerized acoustic instruments to locate water line leaks for repair. Four types of leak detection equipment technology normally used: Stethoscope, Geophone, Electronic Leak Detector, and Leak Noise Correlator.

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APENDIX A

Suggested Water Recycling Systems for Water Consumption and Waste Water Discharge Reduction

This appendix details the alternatives available for implementing additional water recycling systems for the purpose of water consumption and waste water discharge. As with any type of best practice, continuous improvement is needed, since there may be additional alternatives that arise. It should also be noted that implementation of any of the following alternatives should be accompanied with a set of standard operating procedures (SOPs) along with the proper economic model in order to validate a return on investment (ROI) for the given alternatives. Such information can be attained from the original equipment manufacturer (OEM).

For Non Contact Areas for Meat Processors, various alternatives can be identified as potential equipment investment or techniques used to achieve water conservation or water consumption efficiency. Such alternatives can be segregated into three distinct groups:

Conservation Alternatives:

- Efficient scheduling of production
- Eliminate single pass cooling
- Optimize process layout
- Use air cooling

Operations Rationalization Alternatives:

- Reduce leakages
- Eliminate continuous running of water

- Use impaired water sources instead of fresh water

Water Re-Usage Within Plant Alternatives:

- Upgrade waste water
- Recover water from waste
- Reuse rinse water
- Use rinse water for cooling
- Reuse waste water/reuse condensate

An effective system would consist of a single option from sections A through C. The implementation of one of these systems would generate benefits for more efficient water usage, as well as water consumption reduction.

A. Wastewater Recycling for Evaporator Usage Purpose.

One of the primary opportunities for water recirculation for a non-contact area is the introduction of a system to recycle treated wastewater for make-up to evaporative cooling systems in order to reduce the associated with softening and the usage of fresh water. Such effort can be realized via a wastewater recycle using Submerged Ultra Filtration. This type of system normally cost around $450,000.

Figure 17: Ultra Filtration (NalSUF) System (Source: Nalco, 2009)

B. Condensate Water Recycling for Non-Contact Usage Purpose

Another good water recycling opportunity lies with the recycling of condensate water (COW) from evaporator units. Most system discharges the COW directly from the evaporator to the sewage lines. A good system to eliminate such practice should be to recycle COW from the impacted evaporators to either steam generator (boiler make-up), refrigeration (cooling tower make-up), or clean in place (CIP) rinse tanks in the wastewater plant (rinse water). The system utilizes a combination of oxidation, filtration and Ultra Violet (UV) light to clean / disinfect the COW water to acceptable microbial levels based on receiving process. The cost for such system solutions ranges from $50,000 - $500,000.

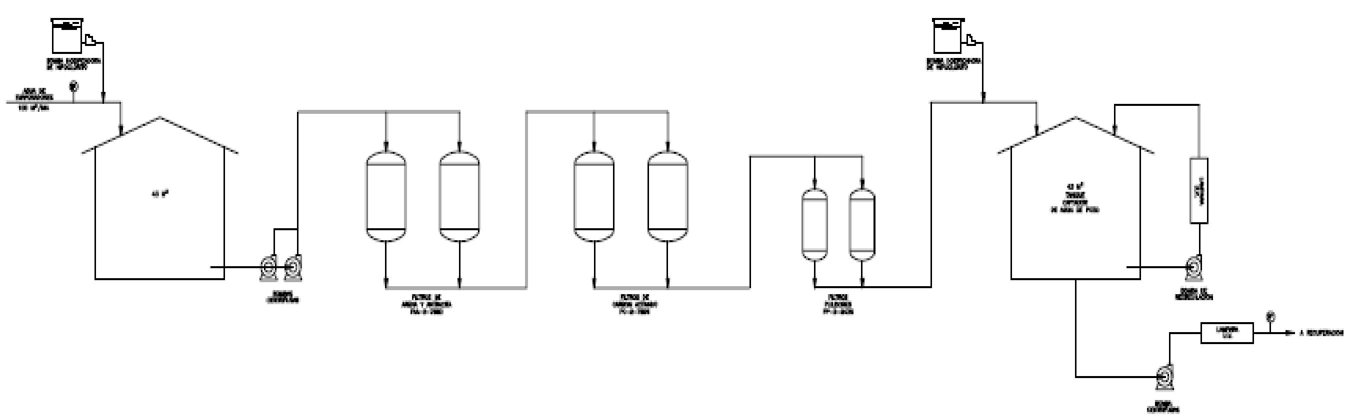

Figure 18: Closed Loop Filtration System for water recirculation (Source: Nalco, 2009)

C. Wastewater Recycling for Plant Operation Usage Purpose

The most challenging and costly water recirculation solution is related to the wastewater treatment plant itself. The objective is to recycle, filter, and re-introduce the processed wastewater back in to the plant operation to be used back into the plant operations. The system entails of biological and other filtration devices to replace the original evaporation process for the treatment of the wastewater to re-introduce it back to the plant operation. Such set up carries a minimum cost of $1,000,000.

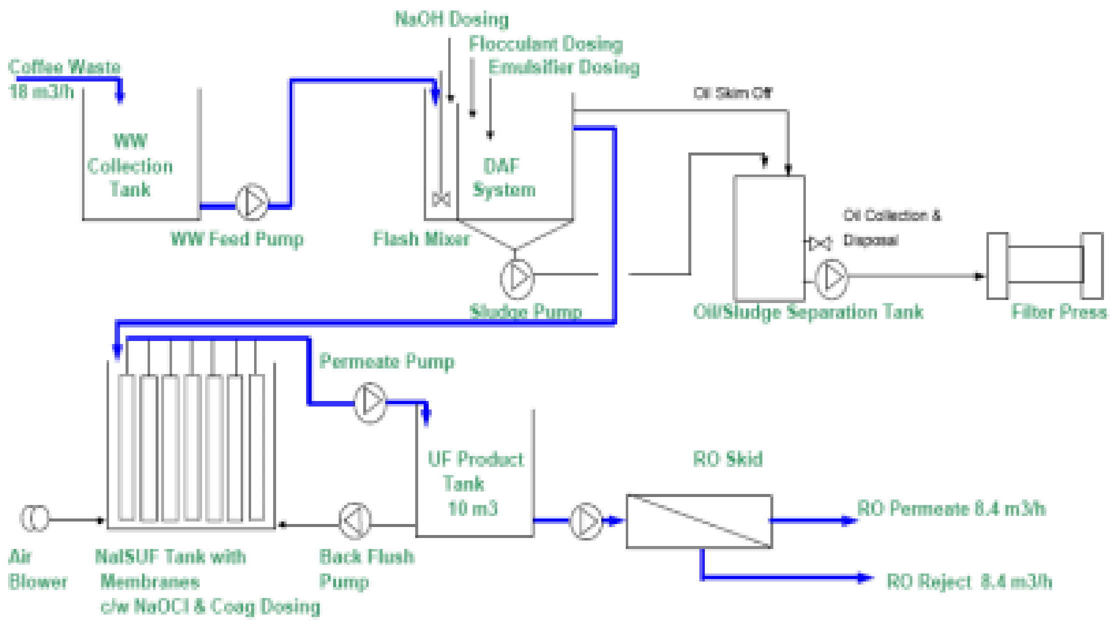

Figure 19: Wastewater recycling and filtration system (Source: Nalco, 2009)

D. Other Process Considerations and Tools (spring-loaded devices – nozzles)

This alternative restricts and conserves water consumption at its source by minimizing the water flow discharge required by any given task. Nozzles prices ranges from $5 - $50 dependent on the application in question to be used, water pressure resistance (PSI), or other consideration.

Figure 20: Pistol Grip Nozzles (Source: Gapco, 2010)

The diagram below simply illustrates the performance of various size nozzle tips and the water pressure in terms of gallons discharge per minute or gallons per minute.

GAPCO NOZZLE SIZING CHART

Capacity Size	300	400	500	600	700	800	1000	1500	2000	2500	3000
	PSI	PSI	PSI	PSI	PSI	PSI	PSI	PSI	PSI	PSI	PSI
01	.28	.32	.36	.39	.42	.45	.50	.60	.70	.80	.85
02	.55	.63	.71	.77	.84	.89	1.0	1.2	1.4	1.6	1.7
03	.82	.95	1.1	1.2	1.3	1.4	1.5	1.8	2.1	2.4	2.6
04	1.1	1.3	1.4	1.6	1.7	1.8	2.0	2.5	2.8	3.2	3.5
05	1.4	1.6	1.8	1.9	2.1	2.2	2.5	3.1	3.5	4.0	4.3
06	1.6	1.9	2.1	2.3	2.5	2.7	3.0	3.7	4.2	4.7	5.2
07	1.9	2.2	2.5	2.7	2.9	3.1	3.5	4.3	4.9	5.5	6.1
08	2.2	2.5	2.8	3.1	3.4	3.6	4.0	4.9	5.7	6.3	6.9
09	2.5	2.9	3.2	3.5	3.8	4.0	4.5	5.5	6.4	7.1	7.8
10	2.7	3.2	3.5	3.9	4.2	4.5	5.0	6.1	7.1	7.9	8.7
12	3.3	3.8	4.2	4.6	5.0	5.4	6.0	7.3	8.5	9.5	10.4
15	4.1	4.7	5.3	5.8	6.3	6.7	7.5	9.2	10.6	11.9	13.0
20	5.5	6.3	7.1	7.7	8.4	8.9	10.0	12.3	14.1	15.8	17.3
25	6.9	7.9	8.9	9.7	10.5	11.2	12.5	15.3	17.7	19.	22.
30	8.2	9.5	10.6	11.6	12.5	13.4	15.0	18.4	21	24	26
40	11.0	12.6	14.1	15.5	16.7	17.9	20	24	28	32	35
50	13.7	15.8	17.7	19.4	21	22	25	31	35	40	43

Figure 21: Nozzle flow rate in gallons per minute (GPM) (Source: Gapco, 2010)

All of the technology concepts for water recirculation and recycling opportunities were developed via identification of a Water Usage Mapping, Water Cost Mapping, and Water / Energy Assessment. Such exercise yield the risk and tolerance for technology improvement dependant on a facility rate of return on investment (ROI) requirement, time constraint, industry acceptability, and capital availability.

The diagram below identifies various Meat Plant non-contact areas and the potential for further water recirculation and recycling systems.

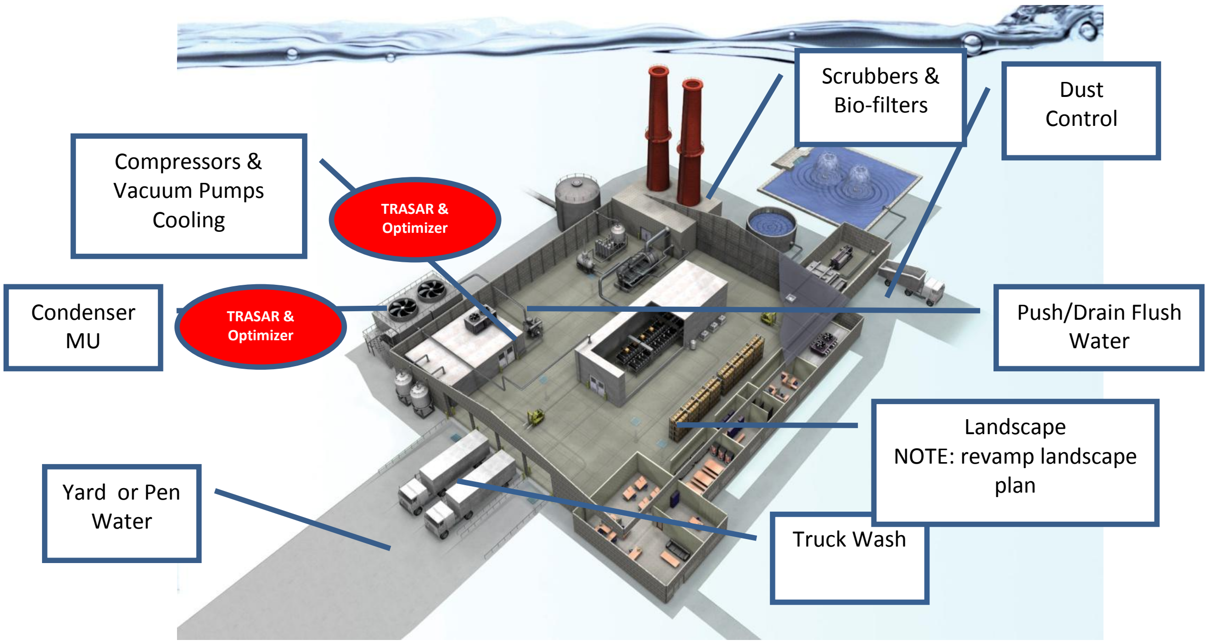

Figure 22: Examples of Meat Plant Non Contact Water Reuse Possibilities (Source: Nalco, 2009)

APPENDIX B

Sample Output of Residual Plot Data

A part of the contribution of this thesis is the evaluation of the residual plot data to review the accuracy of the regression function. The residuals will approximate the random errors that make the relationship between the explanatory variables and the response variable a statistical relationship if the model fit to the data is appropriate. If the residuals appear to behave randomly, it suggests that the model fits the data. However, a non-random structure evidence it the residuals suggests that the model fits the data poorly.

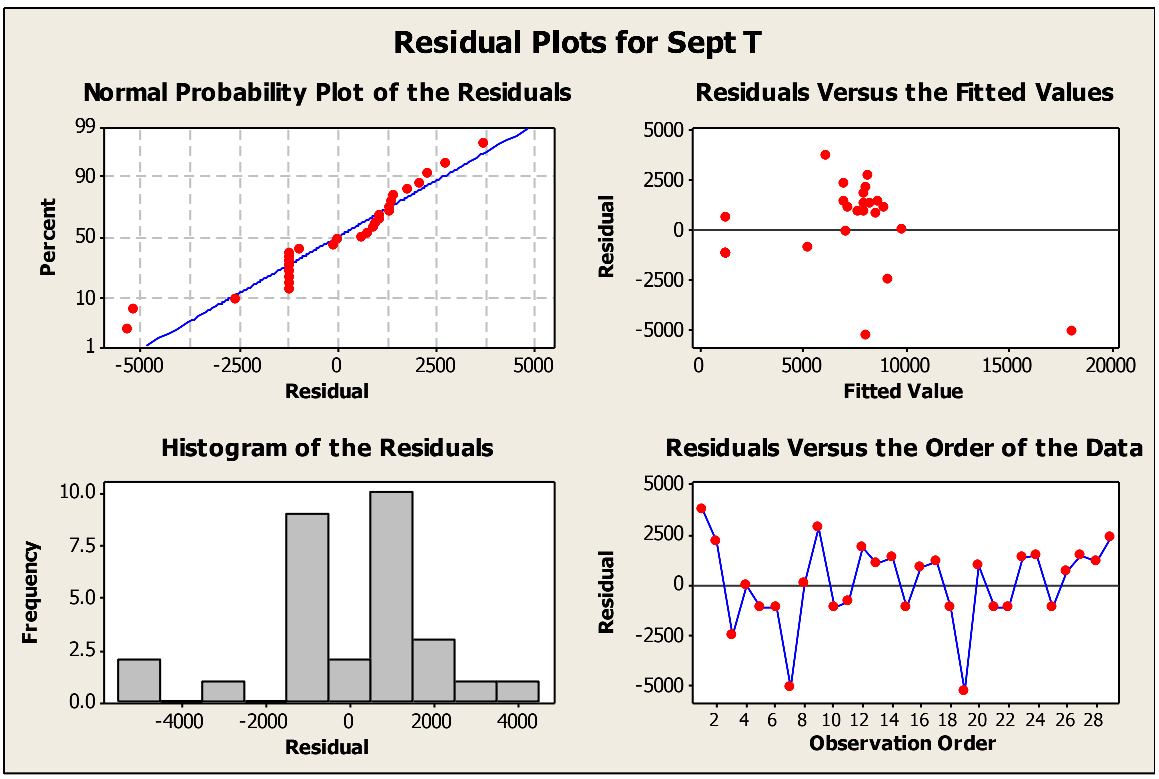

Figure 23: Residual Plot Data for September

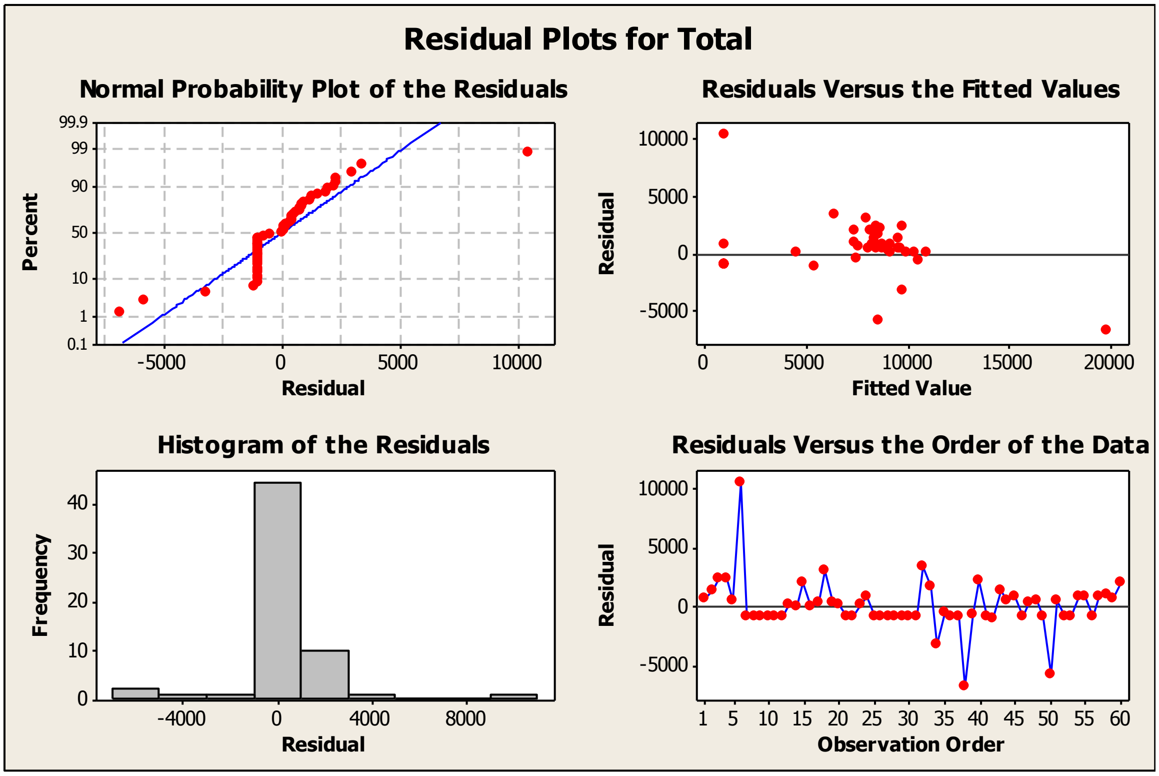

Figure 24: Residual Plot Data for Total