REDUCTION OF THE ENVIRONMENTAL IMPACT OF A SOFT DRINK MANUFACTURING PLANT

By

Yaseer Ally

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ABSTRACT

South Africa is a water stressed country with an increasing demand for water. Pressure is being exerted by greater pollution loads and reduced flows in the rivers. Environmental legislation is therefore, becoming more stringent, in order to reduce environmental degradation and promote sustainable development. The soft drink industry in South Africa is a major water user and polluter. The primary objective of this thesis is to reduce the environmental impact of a soft drink factory.

The study was conducted at a soft drink company located in the South African province of KwaZulu-Natal. This company had been experiencing trade effluent charges in excess of R 70 000 per month as well as additional fines being levied by the local municipality, due to the effluent being consistently out of specification with respect to Chemical Oxygen Demand (COD) and sugar concentration. The scope of the study has therefore, been defined to focus on the reduction of effluent strength and sugar content, hence reducing the environmental impact.

The various concepts or tools to achieve sustainable development were investigated and the Resource Efficient and Cleaner Production (RECP) assessment methodology combined with the methodology to achieve materials efficiency were utilised in order to provide recommendations to solve the effluent issue at the soft drink plant. The RECP procedure follows a five phase approach of planning and organisation, pre-assessment, assessment, feasibility analysis and implementation and continuation. The methodology to achieve materials efficiency uses a 3 step approach of drawing a material flowchart, creating a material balance and generating options.

The sources of the effluent were identified and quantified and the factors influencing the quantity and quality of the effluent from these sources investigated. It was found that the primary COD causing component is sucrose. Approximately 11.4% of the identified losses occurred as a result of staff negligence or a lack of staff training, while other losses were due to easily rectifiable technological shortcomings, or were unavoidable. Solutions were developed in the categories of source elimination or reduction and end-of-pipe treatment. End-of-pipe treatment options were only considered if source elimination and reduction techniques could not be implemented. A feasibility analysis from an environmental aspect yielded the optimum solution to be a combination of source elimination and reduction techniques and one of the end-of-pipe treatments. The

end-of-pipe treatment entails the transporting of high strength effluent to a nearby co-digestion facility, where energy will be produced in the form of methane. The implementation of this optimum solution has the potential to reduce the COD load of the effluent by 10 583 kg COD/month which is 85% of the identified losses. Various other recommendations were developed to reduce the water consumption and hence decrease the volume of effluent to drain.

DECLARATION

I, Yaseer Haroon Tar Ally, declare that

- The research reported in this thesis, except where otherwise indicated, is my original work.
- This thesis has not been submitted for any degree or examination at any other university.
- This thesis does not contain other people's data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
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Name: Yaseer Haroon Tar Ally Signature: ……………………

As the candidate's supervisors, we have approved this thesis for submission

Supervisor: Prof. CA Buckley: Signature: ……………………

Co-Supervisor: Susan Mercer: Signature: ……………………

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ABBREVIATIONS

CSD	Carbonated soft drinks
CIP	Clean in place
COD	Chemical Oxygen Demand
CO_2	Carbon dioxide
DNA	Deoxyribonucleic acid
DWAF	Department of Water Affairs and Forestry in South Africa
EWS	eThekwini Water and Sanitation department
NCPS-SA	National Cleaner Production Centre South Africa
NO_2	Nitrogen dioxide
PET	Polyethylene terephthalate
QA	Quality Assurance
QC	Quality Control
RECP	Resource efficient and cleaner production
SWI	Specific water intake
UN	United Nations
UV	Ultraviolet
TSS	Total Suspended Solids

GLOSSARY

Activated carbon	A form of carbon pre-treated to enhance its adsorption properties. It is used in the pre-treatment of water to remove undesirable substances
Aerobic	Indicates that atmospheric oxygen is required for the growth of microorganisms
Anaerobic	Indicates that atmospheric oxygen is not essential for the growth of microorganisms
Backwashing	The flow of water in the reverse direction to its normal operation through filtration equipment
Brix	The measurement scale on a mass basis, used to describe the percentage of sucrose dissolved in an aqueous solution; it is expressed as (^{o}Brix)
CIP (Clean-in-place)	The system of sanitising or cleaning equipment without dismantling it. It is done by the circulation of either sanitising agents or detergents and water
Coagulation/flocculation	The process where suspended solids are removed from water
Density	The mass of a certain volume of liquid
Disinfection	The complete removal of pathogenic microorganisms and the reduction of non-pathogenic substances to adequate limits, in raw water
Enhanced filtration	A filtration process designed for the removal of matter at molecular level
Final Syrup	A syrup that contains all the base ingredients used in the production of soft drinks

Ion exchange	A water treatment system where unwanted ions are removed from the water by exchanging them with other ions
Membrane filtration	A separation process where materials are forced through a membrane due to a pressure differential
Microorganisms	A wide variety of living organisms that are of a microscopic size
Multiple barrier water treatment	An ordered series of processes that reliably removes unwanted substances in raw water to a satisfactory level
Osmosis	The process where the driving force for molecules to move through a permeable membrane is a concentration differential
Pathogen	A disease causing microorganism
PET (Polyethylene terephthalate)	The chemical compound used to produce PET bottles
Polishing filter	Filtration equipment that is designed to remove particulate matter which was carried over from the previous filtration processes
Potable water	Water that is safe to drink and has specifications according to the local health authorities
QA (Quality assurance)	The authority responsible to ensure a desired level of quality in the product
QC (Quality control)	The authority that maintains the required standards in manufactured products by performing tests on the product and comparing it against the established quality standards
Raw water	Water supplied to a soft drink production facility
RTD (Ready to drink)	The beverage that can be consumed without further dilution with water

Sanitizing	The elimination of pathogens and reduction of microorganisms to an acceptable level on processing equipment
Simple Syrup	The solution of a sweetener and treated water
Sucrose	A crystalline disaccharide consisting of glucose and fructose, which is extracted as sugar from either sugar cane or sugar beet
Syrup proportioning	The process in which final syrup in mixed with treated water in the required ratio
Treated water	Raw water that has underwent treatment and is of acceptable standards
Ultraviolet irradiation	The non-visible part of sunlight that has wavelengths shorter than those of ordinary; commonly known as UV light

Chapter 1: INTRODUCTION

***Water is essential to life, to social development and to economic progress* (Department of Water and Sanitation, 2012).**

***Water is life, respect it, conserve it, and enjoy it* (Department of Water and Sanitation, 2012).**

The Constitution of South Africa guarantees the people of South Africa the right to access to sufficient water, and the right to an environment that is not harmful to their health or well-being (South African Government, 1996).

The amount of water on earth is constant and hence cannot be decreased or increased. South Africa is a semi-arid, water stressed country which receives an average annual rainfall of 492 mm while the rest of the world receives an average annual rainfall of 985 mm. South Africa is regarded as the 30th most water scarce country in the world (National Water Research Strategy, 2012), where about 65% of the country receives less than 500 mm per year, while approximately 35% of the country receives less than 200 mm per year (South African Government, 2012). A total of 80% of the rainfall occurs during summer. South Africa's rainfall is unevenly distributed as well as unreliable and unpredictable and is mainly influenced by moist air moving from the Indian Ocean (east) to the South East. Large fluctuations in the average rainfall are recorded but usually remain well below the global average. The three major challenges that affect water availability are (Department of Water and Sanitation, 2014b):

- Uneven spatial distribution and seasonality of rainfall. In other words 43% of the total rain falls on just 13% of land in the country.
- Relatively low stream flows in the rivers majority of the time.
- Major urban and industrial developments being located far from the large water courses, causing transfers of large quantities of water across catchments.

Surface water resources are the primary source of water in South Africa where its availability is about 49 200 m^3 per annum (Department of Water Affairs, 2014). Groundwater only provides 10% of this volume but is only extensively used in rural and arid regions. Return flows which are flows returned to streams by industries also contribute. The six main water use sectors are irrigation, urban use, environmental reserve, rural use, mining and bulk industrial, power generation and afforestation. The total water requirement for all these sectors is 280 million m^3. In South Africa as a whole a surplus of water exists, however locally, many areas constantly experience water shortages as a shortfall exists in specific water management areas (Department of Water Affairs, 2014).

The increasing demand for water in South Africa arises from the rapid growth of the population, the nature of the economy, standards of living, urbanisation and economic growth and has to be met from limited resources (Department of Water and Sanitation, 2014b). Additional pressures on the limited water resources are also being exerted by greater pollution loads and reduced flows in the countries rivers (Department of Water and Sanitation, 2014b). Industrial water usage results in large amounts of water being used resulting in the resource being more scarce and costly. Water intensive industrial processes are textile, cooling water processes and the beverage or soft drink industry (where water is used in the product itself). South Africa uses more than 50% of its available water while other neighbouring countries, namely Namibia and Botswana only use about 5-10 % of their available water (Pandey, 2003).

South Africa's policy and regulation regards water as a public commodity and promotes sustainable development. The Water Act (Act 36 of 1998) emphasizes the conservation of this asset as well as the most efficient usage of it in public interest. Many environmental Acts have been written with the intention of protecting the people of South Africa and its environment. These laws also assist government in advocating pollution prevention.

The quality of raw water continues to deteriorate due to illegal discharges and inadequate effluent treatment resulting in eutrophication and organic pollution (CSIR, 2010). The soft drink industry in South Africa is a major water user and polluter and is being motivated to reduce both water consumption and organic loads.

"Soft Drink" is a common name given to a non-alcoholic beverage which is consumed chilled. There are many categories of soft drinks such as carbonates, juices, still drinks, dilutables and bottled waters. Carbonates are also commonly called carbonated soft drinks (CSD) which is a drink containing gaseous carbon dioxide also commonly called "Cold Drinks" in South Africa.

Noncarbonated soft drinks do not contain carbon dioxide and consist of drinks such as fruit drinks, health beverages and sports and energy drinks. In the last few decades the popularity of bottled waters (still, flavoured, unflavoured, carbonated and with or without natural sugars) increased drastically. These products are commonly made from natural spring waters or water sources that have high mineral content, or where these minerals are added during the manufacturing process. Dilutables are products that are concentrated like cordials or squashes, that are normally reconstituted by the consumer (by dilution) to make the beverage into a ready to drink (RTD) form (Shachman, 2004).

Juices and nectars are primarily made using natural fruit juices. Juices contain 100 % pure fruit juice and can be sweetened while nectars contain 50% natural juice content and are always sweetened to make up for the non-juice fraction of the drink (Shachman, 2004).

There is a global soft drink consumption of 608 billion L per annum, indicating the huge impact that this industry has on the world economy. Another statistic indicates that every person on earth drinks 70 L of soft drink per year. For a family of 5 this implies the consumption or purchase of approximately 1 L of soft drink per day (Shachman, 2004).

Carbonated soft drinks make up approximately half of the soft drinks consumed in the world and therefore this project primarily focusses upon this category of soft drinks.

The Natsurv 3 guide (1987) was developed as a guideline to reduce water intake and to promote better management of industrial waste in the soft drink industry. The Natsurv 3 guide also contains norms and targets for certain aspects of the soft drink industry including; water intake and waste water disposal. The guide also describes best practices that could be used to achieve the targets set. One of the targets set is for the Specific Water Intake (SWI) which is 2.3 L water/L product.

To complete the practical component of this dissertation, a study was conducted at a soft drink factory (Company A). This company had been experiencing trade effluent charges in excess of R 70 000 per month resulting in fines being levied by the local municipality (eThekwini Municipality). This was due to the company being consistently out of specification with respect to COD and sugar concentration of the effluent. The company was also pressured by the eThekwini municipality to make significant improvements with regards to the effluent COD else their annual trade effluent permit will not be renewed. Company A has a Specific Water Intake (SWI) of 1.54 L water/L product which is which is well below the target set in the Natsurv 3 guide.

Sustainable development is defined as *Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (International Institute for Sustainable Developement (IISD), 2010)*. In order to assist in the achievement of sustainable development, many diverse concepts have been developed, such as; pollution prevention, waste minimisation, eco efficiency or green productivity. The Resource Efficient and Cleaner Production (RECP) concept is a broad term that is based on the concept of cleaner production and incorporates all of the aforementioned concepts.

A local consulting firm that specialises in wastewater management was hired in order to mitigate the effluent problem at Company A. Two end-of-pipe treatment options were recommended by this firm as the only treatment options to reduce the COD of the effluent to an acceptable standard. The first treatment option entailed the design and installation of an anaerobic treatment plant with a capital cost of R 7.8 million. The alternate recommended option was the design and installation of an aerobic plant with a capital cost of R 4.6 million and operational costs of more than R 600 000 per annum. Besides these capital and operating costs required for these treatment options, no space is available on the site at Company A to implement these recommendations.

Therefore senior management initiated a study into identifying the source of the high COD effluent streams and options for reducing this at source.

1.1 OBJECTIVES

This research project is bipartite, with a theoretical and practical component. The theoretical part of this project includes the following:

- Overview of the soft drink industry and the processes involved in the manufacturing of soft drinks
- Overview of effluent characteristics and sources in the soft drink industry
- Environmental legislation pertaining to the disposal of trade effluent
- The concept of sustainable development and the relevant internationally recognised methodologies that can be used to achieve this
- Resource Efficient and Cleaner Production (RECP) concept and methodology
- Materials efficiency concept and methodology.

The practical component of this study involved selecting a soft drink factory (Company A) as a case study to reduce its environmental impact by applying the RECP and materials efficiency techniques.

The goals of this project include:

The assessment of a soft drink plant to reduce its environmental impact by:

- Identification and quantification of effluent sources
- Investigating the factors that influence volume and composition of the effluent discharged
- Identifying opportunities to reduce the effluent discharge
- Producing a conceptual design to minimize effluent charges.

Prove that the application of the RECP and materials efficiency assessment procedures in the soft drink industry result in environmental and economic advantages.

1.2 THESIS STRUCTURE:

Chapter 1: Introduction, scope of the project and list of objectives

Chapter 2: An overview of the manufacturing processes involved in the production of soft drinks

Chapter 3: The prevention and control of water pollution, permitting system and requirements and trade effluent tariff charges

Chapter 4: Sustainable development and internationally recognised concepts promoting sustainable development. The concepts of resource efficiency and cleaner production and materials efficiency and their assessment methodologies.

Chapter 5: Case study

Chapter 6: Conclusions and Recommendations

The link between the different chapters can be seen in **Figure 1**. The introduction provides an insight into; the water situation in South Africa, the concept of sustainable development, the soft drink industry and the project background. Chapters 2, 3 and 4 provide the necessary information to facilitate an understanding of the soft drink process, the legislative requirements and the concepts utilized, which will in turn allow for an enhanced appreciation for the case study and the solution strategies developed within. The conclusions and recommendations link the various chapters.

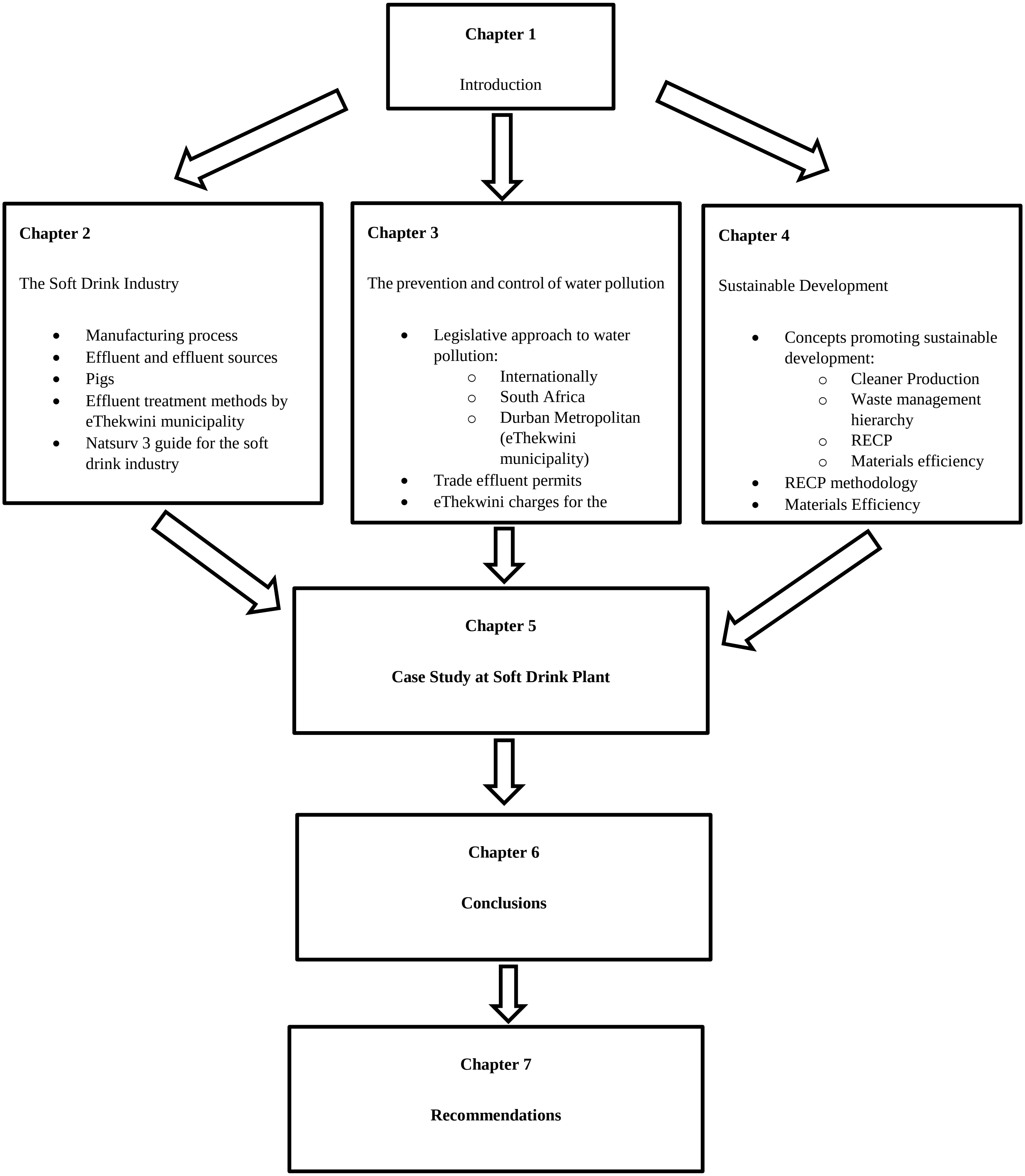


FIGURE 1: THESIS STRUCTURE SHOWING THE RELATIONSHIP BETWEEN THE CHAPTERS.

Chapter 2: THE SOFT DRINK INDUSTRY

A soft drink is described as a non-alcoholic beverage usually carbonated (but not necessarily) that typically contains carbonated water, sweetener, edible acids and natural or artificial flavours. The production principally consists of the blending of a concentrate and additives with water (Shachman, 2004).

2.1 THE PRODUCTION PROCESS OF CARBONATED SOFT DRINKS

A typical process flowchart for the manufacture of carbonated soft drinks is shown in **Figure 2**. There is a slight variation in the processes from plant to plant but the major process steps are basically the same, and are discussed in this section.

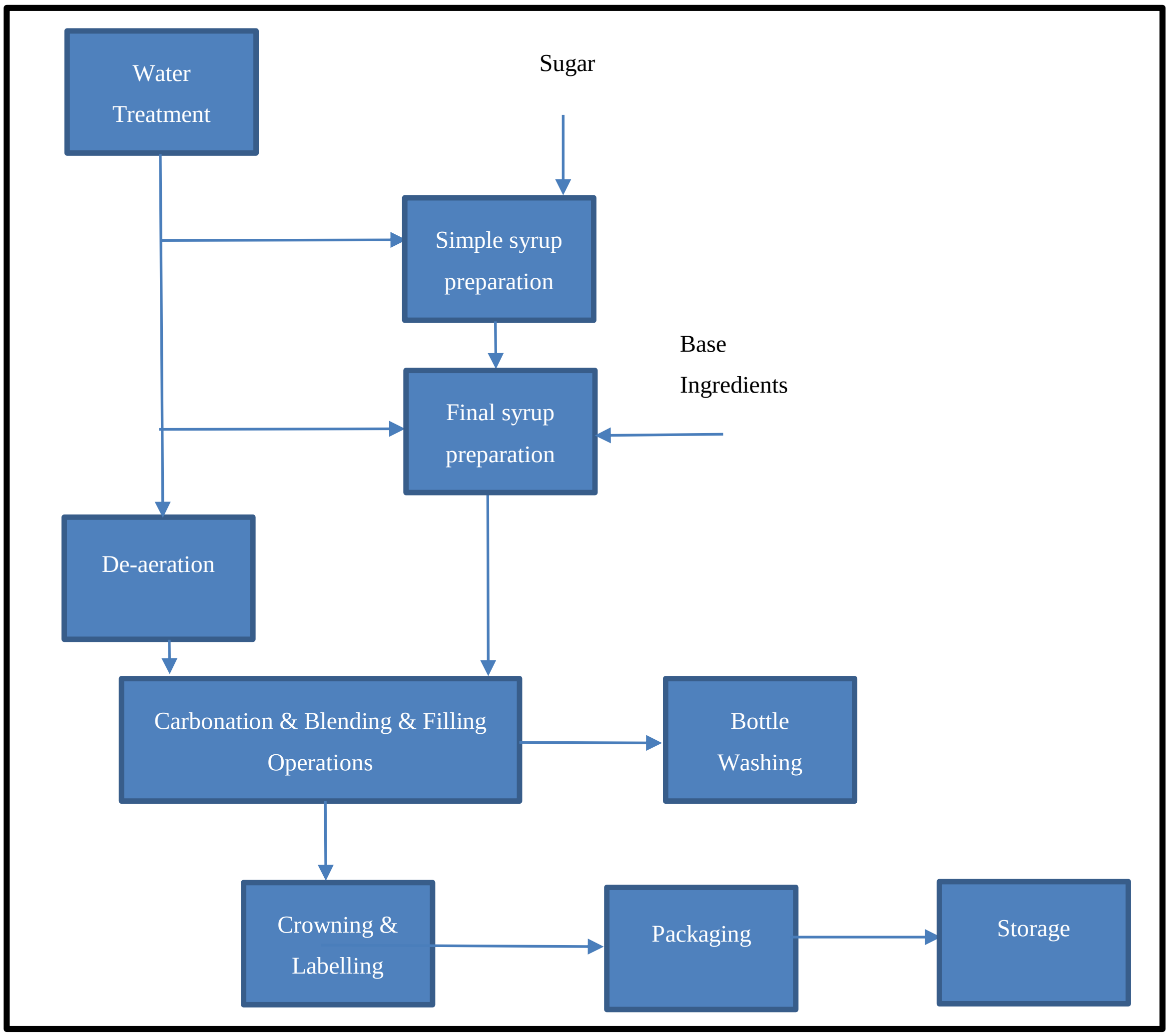


FIGURE 2: TYPICAL PROCESS FLOW DIAGRAM ILLUSTRATING THE MANUFACTURE OF CARBONATED SOFT DRINKS (WATER RESEARCH COMMISSION, 1987).

2.1.1 WATER TREATMENT

Water treatment is the key process in the manufacturing of soft drinks as water is the primary component of soft drinks, contributing from 87% to 92% in a typical soft drink (Shachman, 2004). Therefore the quality of the water used must meet very stringent standards as it has a serious impact on the taste and appearance of the drink as well as its physical and microbiological stability on the shelves in stores. These standards ensure consistent taste and quality of the soft drink and eliminate the risk to the consumer and the manufacturer (Hui, 2006, Steen and Ashurst, 2008).

Raw water is usually obtained from two main sources, namely the municipality or a private well owner, who render the water potable and fit for human consumption. This water may, however, have components or characteristics that could negatively affect the quality of the beverage, and therefore it is essential to either remove or neutralize their effect. Possible adverse factors of raw water include but are not limited to suspended matter, chemical composition, microorganism content and source water quality variations. In addition municipal water treatment plants can encounter operation problems and contamination could occur before reaching the end user. The manufacturer cannot afford to use water of a substandard quality even in a single batch produced. Therefore, raw water must always be treated to meet the specification established by the soft drink manufacturer (Shachman, 2004, Steen and Ashurst, 2008).

2.1.1.1 WATER TREATMENT TECHNOLOGY

In designing a water treatment plant and selecting the grade of technology required, the following factors regarding the raw water supplied to the soft drink manufacturer are essential to consider (Shachman, 2004):

- Consistency of the quality
- Standard levels of the adverse factors of raw water
- Whether contamination can occur
- Seasonal changes in the composition and characteristics
- The type of final product to be produced

2.1.1.1 a) The Multiple Barrier System Concept

The concept of multiple barriers is the core of the production OF treated water for the use in soft drinks. A Multiple Barrier System is an integrated system of procedures, processes and tools that reduce or eliminate adverse factors by providing a high level of performance such that it meets the required specification even if the single most effective unit operation fails. The barriers are usually selected such that the removal capabilities of the different unit in the treatment process are duplicated. This allows for sufficient assistance for continuous operation and when fluctuations in performance occur. The multiple barrier principle is applied in the soft drink water treatment to combine different processes of which the end result is the highest quality water at the minimal cost (Shachman, 2004).

The basic processes required in a multi barrier water treatment system are discussed in this section. Only the full combined effect of each process results in the highest quality water (Shachman, 2004).

(i) Enhanced filtration:

Enhanced filtration is the most crucial process of the Multiple Barrier Water Treatment System. It is filtration at a molecular level capable of removing minute matter and a variety of suspended matter and dissolved chemicals. There are two main types of enhanced filtration processes, namely; coagulation/flocculation and membrane filtration (reverse osmosis, microfiltration and nanofiltration) (Hui, 2006, Shachman, 2004).

(ii) Alkalinity reduction:

Raw water commonly contains bicarbonates, carbonates of calcium, carbonates of magnesium and sodium that are soluble in water and contribute to the alkalinity. Alkalinity reduction is only necessary if the raw water has an alkalinity of above 100 mg/L expressed as calcium carbonate (Steen and Ashurst, 2008). Hydrated lime treatment is the most commonly used process for alkalinity reduction. Hydrated lime or "slaked lime" is added to raw water to chemically react with substances that cause the high alkalinity (calcium and magnesium bicarbonates), which then precipitate forming an insoluble sludge which can be removed from the water (Mitchell, 1990, Steen and Ashurst, 2008).

(iii) Disinfection:

Disinfection is aimed at the removal, deactivation or killing of pathogenic microorganisms present in the raw water and the reduction or preferably elimination of non-pathogenic microorganisms. Disinfection can be accomplished via means of physical or chemical disinfectants. These agents also remove organic contaminants which are nutrients for the microorganisms. A range of disinfectants are available for soft drink water treatment applications, the three most common disinfectants being: chlorination, ozone treatment and ultraviolet radiation (Hui, 2006, Shachman, 2004, Steen and Ashurst, 2008).

Ultraviolet Irradiation

Ultraviolet irradiation also known as UV light is the non-visible portion of the sunlight. UV radiation energy waves have a length in the range of 100-400 nm long and exist between X-ray and visible light in the electromagnetic spectrum. UV light can be produced commercially by custom built lamps which either utilize mercury or xenon sources for disinfection purposes. For the inactivation of microorganisms, the microorganisms must be exposed to a particular intensity of UV irradiation, for a particular period of time, known as the exposure time. The microorganism's genetic material absorbs the UV radiation which causes the chemical disruption of the deoxyribonucleic acid's (DNA) chemical bases. This leaves the microorganism unable to replicate its DNA and hence unable to reproduce and multiply.

The germicidal effect provided by UV light is rapid and happens within seconds and this makes the disinfection process applicable as the water flows through the piping in a multiple barrier water treatment system. The UV light disinfection unit in the form of a reaction chamber is, therefore, positioned in the piping system of flowing water.

The effectiveness of UV Light for disinfection:

UV light has the potential to destroy a wide range of microorganisms provided that the feed water into the UV unit is suitably treated. UV disinfection systems are primarily used to their full potential in two different situations:

- for the disinfection of any stored treated water that is to be used in the succeeding step of a multiple barrier water treatment system
- as the last step in the system (before the water is transported to the filling operation) as a precautionary measure to disinfect fully treated water after the polishing filter.

(iv) Activated carbon purification

Activated carbon is a common support technology. Support technology is described as ancillary unit operations that are not part of primary treatment but serve rather to supplement the primary treatment, transforming it into a durable treatment chain that provides the required quality of water for the food and beverage industries (Parker and Litchfield, 1962). Activated carbon is formed from a range of various carbon rich starting materials such as; coal, coconut shells, wood and peaches pits. The carbon purifier commonly known as a carbon filter is a one of pieces of equipment in a multiple barrier water treatment system. Its structure is very similar to a pressure sand filter.

(v) Polishing filtration

Polishing filters are regarded as imperative in multiple water treatment systems. It acts as a microfilter with the primary function being to remove any carbon granules (from carbon filter), sand particles, flakes, scale or rust that may exist in the water (Shachman, 2004, Steen and Ashurst, 2008).

The objective of polishing filtration is to achieve clear clean treated water for the manufacture of soft drinks and it is therefore placed subsequent to the carbon filter and preceding the final product filing line (Shachman, 2004, Steen and Ashurst, 2008).

2.1.2 SIMPLE SYRUP PREPARATION

The syrup room is dubbed 'the heart' of the beverage plant. This is due to the enormous influence of the efficiency of syrup room operations in the profitability of the plant, and the importance of the simple syrup. The syrup room operations are responsible for the preparation of the high strength simple syrup, to which additives will be added, whereafter proportioning will occur to produce the final product. The simple syrup is prepared by the dissolution of sugar or sweetener in an agitated tank. Modern agitated tanks are fully enclosed, wholly stainless steel tanks, fitted with manholes, sight glasses, spray balls, high level and low level probes and mechanical agitators. A coarse screen is also present to prevent the addition of agglomerated sugar lumps and other coarse matter. A micro-filter (50 μm pore size) is employed at the exit of the agitated tank to remove any particulate impurities (carbonized particles, undissolved sugar, foreign particles etc.). Newer syrup rooms generally employ a large buffer tank to maintain economies of scale in the syrup making process. Considerations for the optimal design of a syrup room are dominated by hygiene-related concerns, but include ease of dissolution of sugar and corrosive conditions (Mitchell, 1990, Shachman, 2004, Steen and Ashurst, 2008). Pertinent aspects of the syrup room include (Mitchell, 1990):

- Construction - Wall finishes, tiling and ceilings must be corrosion resistant, to be able to withstand corrosive conditions due to the use of detergents during cleaning procedures.
- Air conditioning – Adequate ventilation is necessary to reduce airborne contamination. Air-conditioning is recommended to allow for filtering of the ambient air, and to decrease the prevalent relative humidity to aid in dissolution.
- Syrup aeration- To prevent the aeration of the simple syrup, water is first added to the tank to fully submerge the agitator prior to the commencement of mixing. The location of the agitator (at the bottom of the tank) thus serves to allow for the preparation of smaller batches of simple syrup in times of low demand. Ingredient pipework is also generally constructed to run down the sides of the tank to prevent excessive aeration.
- Pipework design – Pipelines are designed to exclude the possibility of the formation of fluid pockets and stagnant zones, which in turn prevents microbial spoilage and syrup contamination by the detergent. The fluid flow velocity should not be excessively high, to prevent mechanical bruising of the syrup.

2.1.3 FINAL SYRUP PREPARATION

The final syrup is prepared by the addition of the base ingredients (preservatives, flavourants etc.) to the simple syrup mixture. This is usually achieved through the use of a separate agitated tank on each production line. The order of addition of the ingredients is of critical importance in the attainment of a clear, uniform final syrup. The first addition should is the requisite quantity of sodium benzoate, the sodium salt of benzoic acid, which is a preserving agent. Sodium benzoate is only sparingly soluble in water, and it converts to its undissociated, antimicrobial, preservative state at pH values lower than 4.5. It is thus desirable that the undissociated state be induced separately for each dispersed molecule, to avoid the possibility of a gelatinous cloud forming. The general sequence of the addition of base ingredients is sodium benzoate, citric acid anhydrous and thereafter flavourants. The solution is then filtered (250 μm) is then to remove any caked material, which can be ground and re-mixed into the solution (Hui, 2006, Mitchell, 1990).

2.1.4 BLENDING

Blending (proportioning) involves diluting the final syrup with water, in order to obtain a solution suitable for packaging after subsequent de-aeration and carbonation steps. The most common proportioning system (Mojonnier proportioner) uses a control system, comprising of a fixed and variable orifice for the syrup and water feed lines respectively. Float valves are also incorporated in order to provide a constant head in the supply lines. Such systems are however susceptible to the production of off-spec portions, particularly at the start and end of the batch. Modern systems employ dosing pumps or metering systems which are capable of mitigating such issues through highly complex control systems (Mitchell, 1990, Steen and Ashurst, 2008).

2.1.5 DEAERATION AND CARBONATION

De-aeration and Carbonation are the subsequent requisite steps to produce the final product. The addition of carbon dioxide increases the palatability and aesthetic appeal of the product, imparting a fizzy, sparkly appearance to the drink. De-aeration is required to remove dissolved oxygen to decrease potential spoilage problems (to increase shelf-life) and to increase the volume available for carbonation, thereby decreasing filling issues. De-aeration is typically geared toward reducing dissolved air to below 0.5 ppm, through the use of either vacuum or reflux de-aeration, or a combination of the two methods. Vacuum de-aeration involves the removal of air through the atomization of the water in a vacuum tank, followed by the use of a stripping gas (CO_2 or N_2) to remove most residual oxygen. Reflux de-aeration involves applying a positive pressure of CO_2 in a sealed vessel to induce nucleation, where the CO_2 binds to the dissolved air and is then liberated. Carbonation is generally achieved through the use of plate carbonators, which allow the solution to be spread over chilled plates in a constant pressure carbon dioxide atmosphere. The cooling of the solution allows for increased gas absorption, while the thin plates allow for increased surface area for both cooling and gas (CO_2) contact. Any dissolved air that may bind to the carbon dioxide is simply bled off. Other carbonator designs include the atomization of the water into a positive pressure carbon dioxide atmosphere, or injection of carbon dioxide, and subsequent dispersion thereof, into the water (Hui, 2006, Mitchell, 1990, Steen and Ashurst, 2008).

2.1.6 FILLING

Filling of the carbonated final product is achieved through the use of a filler, which may utilize gravity filling, or counter pressure filling. Modern counter pressure fillers have found wide industrial usage, although older systems are still used in many cases. The counter-pressure filler initially creates a seal at the container opening, whereafter the atmospheric air in the container is displaced by pressurized gas from the filler bowl. In newer systems, the container air is vented to the atmosphere, while in older systems, the air enters the headspace to be vented. Upon equalization of the pressure of the filler bowl headspace and the container, the gas valve is closed, and the liquid valve is opened to commence filling. Filling is stopped when the pressures are equal, whereafter a settling period, and then 'snifting' occurs prior to capping. Snifting is the process whereby excess headspace gas within the container is vented in a controlled manner by the filler, in order to prevent fobbing/excessive frothing upon the release of the container from the filler bowl seal (Mitchell, 1990, Steen and Ashurst, 2008).

2.1.7 CAPPING, LABELLING AND PACKAGING

The bottles filled with carbonated product are sealed with caps then labelled. Canning plants make use of seamer machines to seal the cans. The final product is then thoroughly inspected before being shrink wrapped and placed on pellets. The product is then distributed to the retailer (Mitchell, 1990, Water Research Commission, 1987).

2.2 EFFLUENT GENERATION IN THE SOFT DRINK INDUSTRY

The effluent from a soft drink bottling plant consists of highly concentrated syrup, wasted soft drinks, water from the rinsing of cans and bottles, detergents and lubricants that are sparingly used in some unit operations (Wang et al., 2005). The primary contaminant in the effluent is sucrose. Such contaminants give rise to high organic contents and other significant wastewater pollutants (Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), sodium, nitrates and phosphates) (Wang et al., 2005, Klemes et al., 2008).

2.2.1 EFFLUENT SOURCES

Effluent is generated from processes areas, such as; washing and rinsing of syrup preparation equipment, washing and rinsing of returnable bottles, washing and rinsing filling and blending unit operations. The preparation of concentrated syrups is the most polluting process as it generates effluent that is rich in sucrose. This effluent typically contains a COD concentration of between 3 110 and 6 000 mg O_2/L, with an average of 4 500 mg/L (Ait Hsine et al., 2005). **Table 1** lists the sources of effluent in the soft drink industry categorized by production activity and the impact of each of these production activities on various quality parameters of the effluent. Other sources of effluent are those that occur due to spillage and housekeeping operations (Porges and Struzeski, 1961).

TABLE 1: EFFLUENT SOURCES AND THEIR IMPACT ON SPECIFIC QUALITY PARAMETERS.

Production activity	Impact on the raw wastewater		
	Flow	COD	pH
Washing and rinsing of final syrup equipment	+	++	++
Washing and rinsing of filling equipment	+	+	+
Washing and rinsing of syrup filtration equipment	+	++	-
Washing of activated carbon filter	+	-	-
Washing of sand filter	+	-	-
Regeneration of softener	+	-	-
Regeneration of the de-carbonator	+	-	-
Washing of simple syrup equipment	+	-	++
Washing of syrup storage tank	-	++	-
Bottles washing	-	++	-
Floors washing	++	++	-

(+ + Very strong impact, + strong impact, - weak impact) (AIT HSINE ET AL., 2005)

2.2.2 PIGS

A ‘pig’ is a device, fabricated from food-grade silicone or a suitable non-newtonian material that serves to clean the pipes (displacement of residual liquid and cleaning of pipe surfaces) and/or provide information about the condition of the pipe (Ashurst, 2008). This is achieved by driving the pig through the length of the pipeline, from the docking station to the destination pigging station (and back), by means of a conveying medium. The design of the pig allows for a seal to be created at the pipe wall, allowing for enhance cleaning ability of the pig. The conveying medium could be either water or product. The pig is generally designed to navigate through bends and other pipeline complexities, although the exact complexities of the pipeline system are a consideration in the selection of a suitable pig (Davidson, 2002). Advantages of pigging include faster product changeovers and decreased wastage leading to decreased effluent discharge (Ashurst, 2008). Various designs (mandrel, single bolt, solid cast, foam etc.) have emerged since the 1960s discovery of pigging, and additions such as brushes, bidirectional seals and scrapers greatly enhance the cleaning effect of the pig. Proper selection of pigs should be done on the basis of experience within the industry, and the use of pigs. Manufacturers will, therefore, provide support regarding factors such as line type and complexities, length, material, condition, propelling medium and the nature of the cleaning required (Davidson, 2002). The ‘clean ice pig’, developed by Bristol University, uses a non-Newtonian material to allow the pig to imitate a liquid flow pattern within the pipeline, thereby scraping the surface clean, and displacing any remaining fluid from the pipes (Ashurst, 2008). Table 2 lists the PIG usage criterion.

TABLE 2: PIG USAGE CRITERION (DAVIDSON, 2002, TIRATSOO, 1992, ASHURST, 2008).

Condition	Applicability
Product suitability	The fluidity (liquid flow profile) of both the product and CIP water enables the usage of pigs as a viable supplement to the CIP cleaning process. Furthermore, valuable product is currently wasted by the CIP process, causing a loss of potential income and a large increase in effluent strength and COD loading.
Current cleaning procedure	Significant quantities of water are used in the CIP procedure. Pigging has the potential to drastically decrease the requisite quantity of water used during the cleaning procedure. This can be attributed to a lower quantity of remaining product in the pipelines after the suggested pigging procedure. The result of the implementation under this condition is that lower water consumption (costs) and effluent discharge rates will be resultant.
Losses of product	As stated above (Product suitability), valuable product can be recovered from pipeline, instead of being flushed as effluent, resulting in multi-fold savings in terms of product losses, water consumption and effluent bills.
Production downtime	In peak production periods, cleaning related downtime proves problematic. Pigging systems clear pipework much quicker than the current CIP procedure.
Pipework Suitability	Current pipework may be altered on the advice of pig suppliers. Addition of straight runs and replacement of valves are potential changes to the system.

2.2.3 MUNICIPAL WASTEWATER TREATMENT OPTIONS

The majority of soft drink plants in South Africa discharge effluent to sewer, further burdening an overworked municipal wastewater treatment works. Municipal wastewater treatment options include aerobic, anaerobic and prospective co-digestion wastewater treatment facilities. Aerobic treatment involves the use of aerobic microorganisms, which utilize dissolved oxygen in order to break down organic contaminants and nutrients within the influent water. The organic content of the water is thus measured as the oxygen demand, or the amount of oxygen required to breakdown the contaminants. The oxygen concentration is replenished, in order to maintain the process rate, through the use of (energy intensive) mechanical aerators. Products from the aerobic process are harmless and non-toxic. Anaerobic treatment involves the breakdown of organic contaminants through the use of anaerobic microorganisms. These microorganisms are able to survive and thrive in the absence of dissolved oxygen, using oxygen that is bound within dissolved salts ($SO4^{2-}$, $NO3^{-}$ etc.) (United States Environmental Protection Agency, 2014, Environmental Business Specialists, 2015, Loughborough University, 2013, United States Environmental Protection Agency, 2013).

Aerobic treatment provides fast ‘breakdown’ rates and is capable of removing dissolved nutrients and other less ‘simple’ wastes, in addition to organic wastes. Aerobic treatment however, is difficult to control, due to the large amount of sludge produced, and is quite costly to operate due to the required energy input. Anaerobic treatment is capable of removing only organic contaminants, at slow rates, but is easy to control and is capable of producing methane (an energy source) (Environmental Business Specialists, 2015, Loughborough University, 2013, United States Environmental Protection Agency, 2013).

The University of KwaZulu-Natal (UKZN) has embarked on a joint project with the eThekwini municipality, in order to fully utilize the current anaerobic digester capacity at one of the municipal wastewater treatment works, through the use of codigestion. Codigestion involves the co-disposal and co-digestion of multiple high strength effluent streams, to create a positive synergistic effect in terms of an increased production of methane and detoxification of toxic compounds and inhibitory components via cometabolic degradation pathways. High strength effluent streams possess a three-fold methane production potential, and can create process upsets in municipal digesters. Other considerable benefits of co-digestion include the usage of existing infrastructure and reduction in greenhouse gas emissions (University of KwaZulu-Natal, 2014).

2.3 SURVEY OF THE SOUTH AFRICAN SOFT DRINK INDUSTRY

The Water Research Commission (WRC) commissioned a series of National Surveys (Natsurv) into water and wastewater practices in various industrial sectors in the 1980's, one of which has the soft drink sector (Water Research Commission, 1987). This document was developed as a guideline to reduce water intake and to promote better management of industrial waste in the soft drink industry. The Natsurv 3 guide also contains norms for the soft drink industry, including; water intake and waste water disposal, which were established by undertaking surveys at various soft drink plants. Targets for some of these norms have also been set within the document. The guide is targeted at soft drink industries, municipalities, researchers, legislators and consultants.

The information contained in the 1987 Natsurv 3 guide was obtained from 25 different soft drink plants and focussed primarily on water intake and effluent generation.

2.3.1 WATER INTAKE

The specific water intake (SWI) was calculated for each of the plants by dividing the volume of water used in production by the volume of soft drink produced. This SWI provides an indication of the water efficiency of the plant. The results obtained from the surveys of the 25 plants show that the SWI typically falls within the range of 1.3 and 5.3 litres of water per litre of product with an average SWI of 2.7 (litre/litre). This wide range is explained by differences in the processes, products and packaging. The major water intensive sectors of the factory were also identified and include:

- Process water
- Bottle washing
- Wash-down water
- Utilities

2.3.2 EFFLUENT GENERATION:

Chemical analysis of the effluent at the various soft drink plants was also performed. The results showed large variances in the volume and pollution loads of the effluent. The range of these variances are summarised in **Table 3**. These variances were attributed to the differences in the processes, product, bottle washing and management practices. The quality of the effluent is affected by a reduced water intake as this led to an increase in concentration. The sources of contaminants in a typical soft drink plant were identified as:

- Water treatment plant
- Syrup room
- Bottle-washer
- Bottling/canning

TABLE 3: SUMMARY OF VARIOUS PARAMETERS IN THE NATSURV 3 GUIDE.

Parameter	Standard Effluent Volume (SEV)	Specific Water Index (SWI)	Specific Pollution Load (SPL) (kg COD/m^3)	Suspended Solids (SS) (kg/m^3)	Total Dissolved Solids (TDS) (kg/m^3)
Range	0.41 – 2.44	2.7- 5.3	0.36 – 8.45	0.01 – 0.95	0.39 – 6.45
Average	1.40	2.7	3.41	0.39	3.70
Target value	-	2.3	3.5	-	-

2.3.3 BEST PRACTICES

The following recommendations to reduce effluent load were identified:

- **Minimise product losses by:**
    - The collection and storage of remnant syrup which should be used at a later stage
    - Reducing the number of product changes by planning in advance
    - Adjustment of bottle and can handling equipment to reduce product loss
    - Monitoring of the filling heights of the plants to reduce beverage spilling

- **Minimise the usage of chemicals by:**
    - Using caustic at lower concentrations and higher temperature combinations
    - Using cleaning agents at lower dilution and if possible recycle and reclamation of these chemicals is recommended
- **Solids reduction**
- **Solids removal:**

  The effluent from a soft drink plant should undergo solids removal before being discharged. This can be done using screens.
- **Balancing or segregation:**

  Balancing refers to the storage and mixing of effluent over a specific period of time to average out the variances that occur as a result of sudden high strength effluent being discharged.

  An alternative to balancing is segregation, which is the separation of effluent streams that require treatment from those that do not.
- **PH Control**

  Effluent that is of an extremely high pH should be neutralized to bring it to acceptable limits before being discharged.
- **Biological Treatment:**

  This option includes the installation of on-site effluent treatment facilities that are intended to treat effluent that is out of specification in order to comply with acceptable effluent discharge limits.

2.4 SUMMARY:

The main points from Chapter 2 include:

- The major steps in the production of carbonated soft drinks include:
  - Water treatment
  - Simple syrup preparation
  - Final syrup preparation
  - Blending
  - De-aeration
  - Carbonation
  - Filling
  - Capping, labelling and packaging
- Effluent in a soft drink plant typically consists of high concentrate syrup, wasted soft drinks, water from the rinsing of cans and bottles, detergents and lubricants.
- The primary contaminant in the effluent in sucrose.
- The source of effluent are from process areas including:
  - Washing and rinsing of the simple syrup equipment, final syrup equipment and filling equipment
  - Washing of activated carbon and sand filters
  - Bottle washing
  - Floor washing
- Pigs are devices that move through the pipeline and create a seal at the pipe wall. The implementation of pigs results in faster product changeovers and decreased product wastage.
- Municipalities treat water using aerobic or anaerobic digestion.
- The University of KwaZulu-Natal (UKZN) has embarked on a joint project with the eThekwini municipality in order to fully utilize the current anaerobic digester capacity through the use of codigestion. High strength effluent streams will be treated using codigestion which will ultimately result in the production of energy in the form of methane.
- The Natsurv 3 guide outlines norms for the soft drink industry, targets for these established norms and proven methods (best practices) to improve a soft drink plant.

Chapter 3: THE PREVENTION AND CONTROL OF WATER POLLUTION:

Pollution can be defined as the release of any substance into the environment which has a harmful or poisonous effect on the environment or damages it in any way (The Foundation for Water Research, 2010, Pepper et al., 2011). The pollution of water can originate from either a point source or a non-point source. Point source pollution can be traced to specific sources, such as any pipes, industrial outfalls, municipal sewers, domestic drains etc. This can be regulated with the purpose of controlling the quantity of waste discharged. Non-point sources have sources that are not clearly defined and difficult to determine and require adequate land use management to be controlled (U.S. Environmental Protection Agency, 2012, Environmental Protection Agency Victoria, 2012, Water Encyclopedia, 2014, Utah State University, 2014).

The prevention and control of water pollution is a function of government as the decrease in the quality of water has major social, economic and environmental implications (Burchi and D'Andrea, 2003).

3.1 LEGISLATIVE APPROACH TO THE PREVENTION OF WATER POLLUTION

To achieve water pollution control the implementation of legislation which is built on a range of approaches has to be applied. These approaches lie within the following categories (Burchi and D'Andrea, 2003):

- Prohibiting the discharge of waste into bodies of freshwater whether they exist on the ground or underground.
- Restrict the discharge of wastes by implementing licences, permits, authorizations granted by government.
- Charging for the discharge of wastes. This charge should take into account the external costs of pollution.
- Advocate precautionary measures with regards to selected land-based activities.

The aforementioned water pollution control measures work in conjunction with other mechanisms to counter water pollution, namely: quality standards for waste and treated effluent, retaining the type, extent and source of pollution, sampling and testing of the qualities of waste and waters and water quality management planning (Burchi and D'Andrea, 2003).

3.2 THE MANAGEMENT OF WATER RESOURCES IN SOUTH AFRICA

The constitution of South Africa states that the management of water resources is a national responsibility and that water is a public commodity (South African Government, 1996). The National Water Act (Act No. 36 of 1998) is born out of the South African Constitution and contains ideologies regarding water resources and its conservation. This Act accommodates for the manner in which water resources are to be developed, managed and allocated and makes use of incentives and disincentives to encourage water conservation and waste reduction. This Act also commissions the Minister of Water Affairs and Forestry (now the Department of Water and Sanitation) to ensure that water resources are conserved, protected, used and managed equally for the benefit of the people. The Department of Water and Sanitation (DWAS) is the custodian of the water resources of South Africa and is primarily responsible for the formulation and implementation of policies governing water (Department of Water and Sanitation, 2014a). These policies are then carried out by municipalities which ensure the effective and sustainable use of the nation’s water.

3.3 WATER RESOURCE MANAGEMENT BY MUNICIPALITIES

Municipalities deal with water pollution by the collection and treatment of this water in wastewater treatment works. The Water Services Act states clearly that the water authority that either provides water for industrial use, or controls the system through which effluent is disposed, is obliged to create bylaws. These bylaws also help to regulate water pollution where non-compliance is an offence. Wastewater discharge permit are one of the ways of controlling water pollution (Burchi and D'Andrea, 2003).

3.3.1 GRANTING OF WASTE DISCHARGE PERMITS

Generally if the local authority or government grants or refuses a waste discharge permit it is a result of a process that is put together in the legislation as a series of steps as follows (Burchi and D'Andrea, 2003):

- Fulfilling prerequisites to the filling of applications
- Filing of applications
- Review of applications
- Deciding on applications
- Formatting of waste discharge permits
- Appealing from adverse decision
- Recording of decisions and permits

3.3.2 WASTEWATER DISCHARGE CHARGES

Charging mechanisms are used to supplement the use of waste discharge permits. These charges are payable periodically as long as the permit is valid, and could be calculated based on the characteristics of the waste discharged, which accounts for external effects generated by the waste discharged. Another method of achieving pollution control goals is via a financial mechanism where charging is done independently of waste discharge permits (Burchi and D'Andrea, 2003).

3.4 ETHEKWINI INDUSTRIAL EFFLUENT PERMITTING SYSTEM

eThekwini Municipality is found in the province of KwaZulu-Natal where it is the local authority of the largest city in this province and the third largest in South Africa. It is home to one of Africa’s busiest and best managed harbours, which is the port of Durban. eThekwini is a Category A municipality and has been at the forefront of change for the betterment of the environment. It has legislative authority to control the operations of industries within the region (eThekwini Municipality, 2011a). The Pollution and Environment department within the Water and Sanitation Unit of the eThekwini Water and Sanitation is duty bound to ensure that industries within its jurisdiction operate in accordance with the guidelines and bylaws established by the municipality.

The core purpose of the Pollution and Environment Department is to protect the sewage infrastructure, health of staff and public and water receiving environment by regulating industrial effluent pollution to sewer, storm water and receiving water courses through permitting and auditing of industries, attending to complaints and legal enforcement (eThekwini Municipality, 2011c). In order to fulfil these duties the eThekwini municipality with the aid of the Norwegian pollution control authority developed a five year permitting system for sewer discharge in December 2004 (Braum et al., 2003). This permitting system called for industries to implement components of an environmental management system. Hence they are obliged to identify and prioritise risks to the environment and compose a five year improvement programme which asses these risks. This improvement programme is then assessed using recognised international benchmarks and integrated into the permit. To ensure continuous improvement the performance of the company then evaluated by using reporting mechanisms, compliance auditing and annual audits. This regulatory approach consequently makes environmental objectives understandable for industries resulting in concepts such as sustainable environmental planning, environmental management system, receiving environment objectives, resource efficient and cleaner production, continual improvement, and best available technology being understood and implemented (Braum et al., 2003, Mzulwini et al., 2004).

3.4.1 DUTY TO APPLY FOR A TRADE EFFLUENT PERMIT.

The duty to apply for a trade effluent discharge permit is in accordance with the Sewage Disposal Bylaws which clearly states that no person shall discharge or cause or permit to be discharged any trade effluent except with and in terms of written permission of an authorised officer and within the provisions of the sewage disposal bylaws (eThekwini Municipality, 2004).

3.4.2 APPLICATION OF A TRADE EFFLUENT PERMIT:

The information mandatory for the application of a permit includes general information regarding the enterprise (date which the enterprise started operating, land use classification, a map showing the location of the site with respect to its external environment); Process details (process block diagram, colour coded site drainage plan and production details) and details of the releases of pollutants to the air, sewer, storm water and ground water. The application also requires the applicant to list all possible sources of pollutants released to the environment and a plan of action to minimise and manage the impact. The application also calls for information on waste preventative measures and contingency plans that attend to acute pollution, occupational health and safety, major hazard installations present and environmental management systems (eThekwini Municipality, 2004).

3.4.3 PROCESSING OF APPLICATION FOR A TRADE EFFLUENT PERMIT:

The processing of applications for trade effluent permits is performed by the pollution and environment department of the eThekwini water and sanitation. The Pollution and Environment department is the authority delegated to make decisions regarding discharge permits for industrial activities in agreement with the sewage disposal bylaws. The eThekwini Water and Sanitation charges a fee for processing applications pursuant to the Sewage Disposal Bylaws. The average time required to process an application and issue a trade effluent permit is 3 – 4 months. In order to ensure fair administrative procedures the permit applicant has the right to appeal and to make representation before a Tribunal (eThekwini Municipality, 2004).

It is the responsibility of the management of the enterprise to ensure that the conditions stipulated in the discharge permit and regulations are complied with. To ensure that the industries comply the eThekwini Wastewater management Authority and eThekwini Health Service Authority control and inspect the releases of pollutants (eThekwini Municipality, 2004).

3.4.4 PAYMENT FOR THE USE OF THE SEWAGE DISPOSAL SYSTEM:

The payment for the use of the sewage disposal system shall be payable on the due date prescribed by the Municipality which is stipulated on the account and be made by the enterprise based on either of the following (eThekwini Municipality, 2011b):

- A sewerage rate levied in terms of section 150 of the Local Authorities Ordinance 25 of 1974
- The prescribed tariff rates for the disposal of sewage
- Special agreement between the council and the enterprise
- Some other method prescribed by the council

The most common of the aforementioned methods is the payment that is based on the prescribed tariff rates for the disposal of sewage.

3.4.5 TRADE EFFLUENT CHARGES WHEN SEWAGE RATES ARE APPLIED:

The Trade effluent charge when sewage rates are applied for the usage of the sewage disposal system is implemented when a person or enterprise holds a permit for the discharge of trade effluent and releases effluent in excess of 100 kL a month. In this case the permit holder will be charged by means of the sewerage rates as determined by equation 1 (eThekwini Municipality, 2011b):

Equation 1:

$$X + V\left(\frac{COD}{360}\right) + Z\left(\frac{TSS}{9}\right)$$

Where:

a) "X" is the volume base charge established by an authorised officer.
b) "V" is the established rate for the treatment of the effluent in the treatment works of standard domestic effluent having a prescribed COD value
c) "Z" is the established rate which is for the treatment of domestic effluent with a certain settleable solids value in the treatment works of the council. It incorporates all operational, maintenance, repair and annual capital expenses.
d) "COD" is the chemical oxygen demand
e) "TSS" is the settleable solids

3.4.6 SEWAGE DISPOSAL CHARGE WHEN A TARIFF RATE IS APPLIED:

If the charge for the usage of the sewage disposal system is done using the prescribed tariff rates, the charges for standard domestic effluent will be payable by the consumer when a premises (eThekwini Municipality, 2011b):

- is connected or capable of being connected to the sewage disposal system
- receives a supply of water from the council

3.4.7 TRADE EFFLUENT CHARGE WHEN TARIFF RATE IS APPLIED:

The trade effluent charge is applicable to any person or enterprise that possesses a permit for the discharge of trade effluent that is in surplus of the minimum volume 100 kL. The permit holder will be charged per kilolitre of trade effluent disposed according to charges for the disposal of standard domestic effluent. However if the permit holder discharges effluent with a strength of quality exceeding that of standard domestic effluent, an additional charge with respect to high strength sewage will be calculated as shown in Section 3.6.6 (eThekwini Municipality, 2011b).

3.4.8 CALCULATION FOR ADDITIONAL CHARGE FOR HIGH STRENGTH EFFLUENT TO THE SEWAGE DISPOSAL SYSTEM:

The rate for the additional charge for trade effluent in cents per kL is determined using the formula below (eThekwini Municipality, 2011b):

$$V\left(\frac{C}{R}-1\right)+Z\left(\frac{B}{S}-1\right)$$

Where V, C, R, B, Z and S are defined in Section 3.6.6

The values for C and B are to be determined by an authorised office from the eThekwini pollution and environment department by using chemical analysis methods appropriate to the nature of the sewage to be analysed. The details of the methods used for analysis and results will be recorded for a period of one year (eThekwini Municipality, 2011b).

3.4.9 VOLUME OF TRADE EFFLUENT DETERMINED:

The volume of trade effluent discharged to the sewer is determined in one of the following ways:

- If there exists direct measurements (effluent meter) of the volume of trade effluent discharged from the operating premises this will be used
- If no direct measurement of the volume of trade effluent discharged from the operating premises exists then the volume will be determined as a percentage of the water supplied by the council
- Where the operating premises utilize other sources of water the volume will be determined by an authorised officer based on the criteria they regard relevant

If a portion of the water supplied to the permit holder is lost by reaction or evaporation or forms part of the end product of the manufacturing process or for other reasons, the permit holder can apply for a reduction in the assessed volume of trade effluent and this will be granted by the authorised officer at his or her discretion.

EThekwini Municipality Equation to calculate the total cost of high strength effluent (including the fixed charge)

$$c/_{kl} = X + V\left(\frac{C}{R} - 1\right) + Z\left(\frac{B}{S} - 1\right)$$

Where X is a fixed cost for the treatment and V, C, R, Z, B, S are as defined in Section 3.4.5.

3.5 METRO TRADE EFFLUENT TARIFFS 2013/2014:

The Metro trade effluent tariffs are shown as regulatory and monitoring charges (**Table 4)** and tariff charges for the established rates X, V and Z (**Table 5)**.

TABLE 4: REGULATORY AND MONITORING CHARGES.

Range of effluent disposed (kL per month)	Charges excluding VAT (Rand)
<100	149.12
100 – 999	719.30
1000 – 9999	1337.72
>10000	2078.95

TABLE 5: TARIFF CHARGES FOR ESTABLISHED RATES X, V AND Z.

Local Authority area	X (Including VAT)	V (Including VAT)	Z (Including Vat)
Metro Areas	6.07	R 0.65	R 0.52
Other Metro Unicity areas	6.07	R 0.59	R 0.59

3.6 SUMMARY

- The prevention and control of water pollution is a function of government as a decline in the water quality could have major social, economic and environmental implications
- The Department of Water Affairs and Forestry (DWAF) is the custodian of the water resources of South Africa and is primarily responsible for the formulation and implementation of policies governing water. These policies are then carried out by municipalities which ensure the effective and sustainable use of the nation's water.
- Municipalities control the system through which effluent is disposed and have therefore created bylaws to help regulate water pollution.
- EThekwini Municipality has implemented a 5 year permitting system for sewer discharge, where industries will be obliged to implement components of an environmental management system.
- EThekwini also charge for the disposal of effluent via the sewage disposal system. This charge is based on the quantity and characteristics (including COD and TSS) of the effluent discharged.

Chapter 4: PROMOTING SUSTAINABLE DEVELOPMENT

In this Section of the literature review the concept of sustainable development will be briefly explained as well as the manner in which this concept was developed. Section 4.2 explains the relevant internationally recognised concepts that can be used to achieve sustainable development. The concept of Resource Efficient and Cleaner Production (RECP) and its assessment methodology is discussed in Section 4.3. RECP is a concept which encompasses various other concepts. The methodology to improve materials efficiency (and hence reduce effluent production at source) is described in Section 4.4.

4.1 SUSTAINABLE DEVELOPMENT

The United Nations (UN) sponsored conferences that dealt with global issues. Among these issues was the concern about pollution caused by industries and agriculture. In response to this issue the UN set up a Conference on the Human Environment which was held in Stockholm in 1972. At the end of the conference the meeting agreed upon a declaration which placed pollution due to passive strategies (dilute and disperse) at the top of the environmental agenda (Green Industry Virtual Centre Malaysia, 2011).

In 1983 the UN set up the World Commission on Environment and Development to address the accelerating deterioration of natural resources due to economic development. The commission proposed the concept of sustainable development as an alternative method to one based solely on economic growth. Sustainable development has various definitions and is understood differently, but the most widely used definition is from the Brundtland report published by the World Commission on Environment and Development. It defines sustainable development as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (International Institute for Sustainable Developement (IISD), 2010) Sustainable development aims at achieving social and economic progress without the exhaustion of the earth's natural resources (Sustainable Development Information, 2012, United Nations, 2014b, United Nations Environment Programme, 2014b).

The UN Earth Summit that took place in 2002 was a major UN summit that was aimed at addressing the destruction of irreplaceable natural resources due to economic development. Three major agreements, namely; Agenda 21, The Rio Declaration on Environment and Development and The Statement of Forest Principles, were adopted by more than 178 governments (United Nations, 2014b).

Agenda 21, a programme developed by the UN, consists of a comprehensive plan of action to achieve sustainable development. Cleaner Production (CP) is a core component for achieving sustainable development for business and industry and is set as one of the objectives in the Agenda 21 document (Council on Foreign Relations, 2014, Sustainable Development Information, 2012, United Nations, 2014b, United Nations, 2014a, United Nations Environment Programme, 2014b, International Institute for Sustainable Developement (IISD), 2010).

4.2 CONCEPTS TO ACHIEVE SUSTAINABLE DEVELOPMENT

Many tools or concepts have been developed to promote sustainable development. Some of the cornerstones for sustainable development are cleaner production, pollution prevention, waste minimisation, waste management hierarchy, eco efficiency and green productivity. Only concepts pertinent to this study will be discussed in this section.

4.2.1 CLEANER PRODUCTION:

Cleaner production is a practical approach of moving towards sustainable development, by allowing industry to produce more goods with less environmental impact and greater sustainability. The term cleaner production has been defined by the United Nations Environment Programme as “The continuous application of an integrated environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment” (United Nations Environment Programme, 2014c). Cleaner production has many benefits such as increasing economic benefits, improving the environmental situation, gaining a competitive advantage, recovery of valuable by-products, increased efficiency, lower energy consumption and increasing productivity (Green Industry Virtual Centre Malaysia, 2011).

4.2.2 WASTE MANAGEMENT HIERARCHY

The waste management hierarchy is an internationally recognized tool which helps understand waste management options in order of their environmental desirability (Waste Authority, 2014). The waste management hierarchy is not a standalone tool for decision making but rather should be used alongside other tools to analyse the environmental, social and economic impacts of the waste management options (Waste Authority, 2014). As shown in the Waste Management Hierarchy (**Figure 3**), the lowest priority is placed on the straight disposal of waste which offers no incentives and the highest priority is placed on the cleaner production option which is source reduction or reuse techniques (U.S. Environmental Protection Agency, 2014b). The elimination of pollutants at source is commonly less expensive than the other waste management options like collecting treating and disposing of waste (U.S. Environmental Protection Agency, 2013).

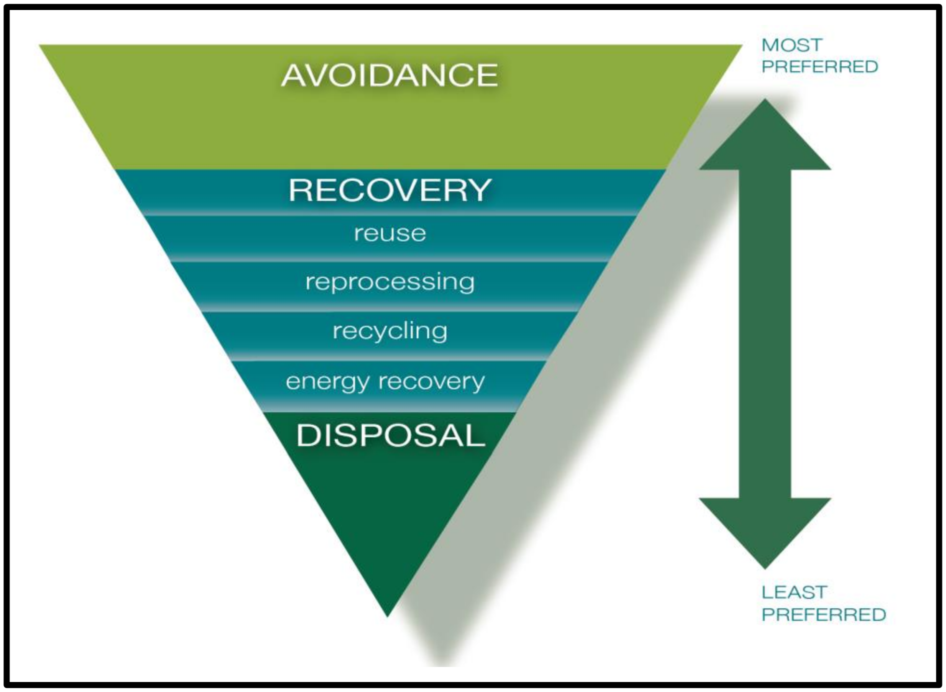


FIGURE 3: WASTE MANAGEMENT HIERARCHY (WASTE AUTHORITY, 2014).

4.2.2.1 SOURCE AVOIDANCE OR REDUCTION:

Avoidance is the highest and most preferred option on the Waste Management Hierarchy and is also known as waste prevention. It refers to the prevention or reduction of waste generation at its source. It is the most effective way to reduce waste which saves natural resources, protects the environment and saves money (U.S. Environmental Protection Agency, 2013). If it is not possible to avoid the generation of waste then waste generation should be minimized as much as possible (Environmental Protection Department, 2005). This can include the following (Waste Authority, 2014):

- Improving the efficiency of production processes
- The substitution of raw materials with more environmentally products.

4.2.2.2 RECOVERY

Recovery involves activities (such as; chemical, mechanical, thermal or biological processes) that occur with the purpose of recovering all or a portion of materials that would have alternately been disposed of as waste (Waste Authority, 2014). There are 4 recovery options as described as follows.

4.2.2.2 a) Reuse

Reuse is the most preferable form of recovery and pertains to the usage of an item instead of it being disposed of. Reuse requires no or minimal resources and hence has no or minimal impact on the environment. By reusing these materials, resources such as energy, virgin materials, landfill space are conserved (U.S. Environmental Protection Agency, 2014b). Reuse includes the following (Waste Authority, 2014).

- The reuse of an item in its original form for its initially intended purpose
- The reuse of an item in its original form for a new purpose
- The substitution of disposal items with items that can be reused

4.2.2.2 b) Recycling

Recycling is the process of collecting or processing raw materials that would have alternately been thrown away with the intention of substituting recovered waste materials for extracted raw materials (U.S. Environmental Protection Agency, 2014a, Waste Authority, 2014).

4.2.2.2 c) Energy recovery

Energy recovery involves the conversion of waste materials that cannot be recycled into some form of energy (electricity, useable heat, fuel) using various processes which include combustion, gasification, pyrolization, landfill gas recovery and anaerobic digestion. This process of energy recovery is commonly called waste-to-energy (WTE) (U.S. Environmental Protection Agency, 2013).

4.2.2.3 DISPOSAL

Disposal involves the disposal of waste into the environment. The most common form of waste disposal is landfills. Disposal is the least desirable option in the waste management hierarchy (U.S. Environmental Protection Agency, 2013, Waste Authority, 2014).

4.3 RESOURCE EFFICIENT AND CLEANER PRODUCTION

The Resource Efficient and Cleaner Production (RECP) research methodology is based on the concept of cleaner production and is the continuous application of integrated and preventive strategies to processes, products and services. It has the purpose of increasing efficiency and reducing risks to humans and the environment. It specifically works to advance product efficiency, environmental management and human development.

RECP illustrates a preventative outlook to environmental management. It is not a scientific definition but a broad term that incorporates concepts such as pollution prevention, waste minimisation, eco efficiency or green productivity. It also includes addition ideologies:

- RECP refers to the manner in which goods are produced and services delivered with the minimum environmental impact but considering the present economic and technological constraints.
- RECP emphasizes that growth be ecologically sustainable and considered as an environmental and economic strategy.

- RECP protects the environment, the worker and the customer as well as improves the profitability, competitiveness and efficiency of the business.
- The fundamental difference between RECP and Pollution Prevention (PP) is that CP focuses on optimizing the process to ensure better efficiency and reduced waste output while PP employs a conventional end-of-pipe pollution control strategy.

4.3.1 RESOURCE EFFICIENT AND CLEANER PRODUCTION ASSESSMENT METHODOLOGY

The RECP assessment methodology is aimed at identifying and evaluating RECP opportunities and the implementation of them in industry. The main RECP steps are discussed in this section.

RECP is both a systematic and comprehensive method for identifying options that reduce or eliminate the generation of waste. This assessment methodology can be applied to all fields encompassing RECP and consists of 5 phases, as shown in **Figure 4** (United Nations Industrial Development Organization, 2014).

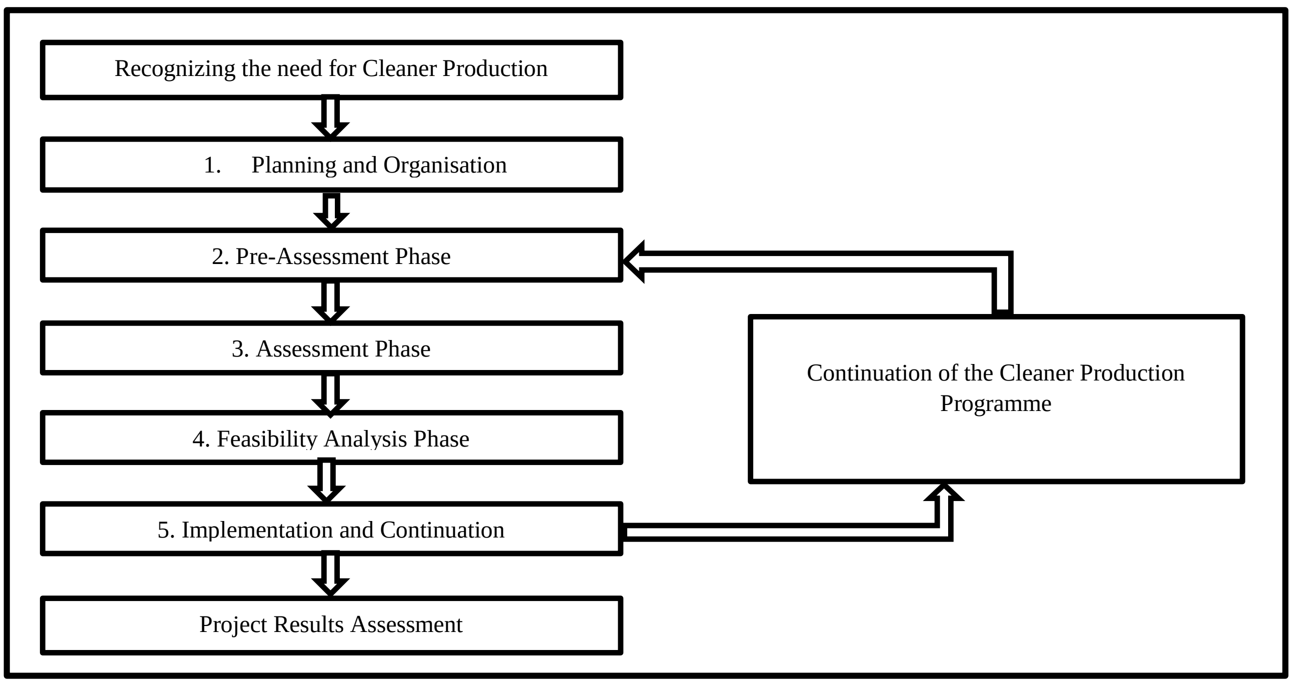


FIGURE 4: DIAGRAM SHOWING THE PHASES OF THE RESOURCE EFFICIENT AND CLEANER PRODUCTION ASSESSMENT METHODOLOGY (UNITED NATIONS ENVIRONMENT PROGRAMME, 2014C).

4.3.1.1 PLANNING AND ORGANISATION:

The Planning and Organisation phase starts with people in the company being interested in the implementation of RECP.

The following elements are proven to be essential in a successful start of a RECP programme:

- **Management commitment:**
  This is of great importance as the commitment of senior management can ensure the collaboration and participation of employees at all levels.
- **Employee involvement:**
  The level of participation of employees plays a vital role in finding RECP opportunities and solutions. Those employees that are involved in the daily operations or maintenance often have the knowledge, insight and understanding of the sources of waste generation and hence are often able to assist in finding solutions.
- **Cost awareness:**
  Cost awareness is essential in convincing management and employees that producing cleaner is a way of generating profits. Companies often do not know the amount of money wasted and generally only costs incurred for the treatment of waste is considered. The generation of waste generally costs significantly more than the treatment of the waste. A small saving in the minimisation of waste can result in a considerable increase in profits.
- **Organise a project team:**
  Members of the project team should be selected such that the team has sufficient knowledge of the process, to be able to review and analyse current production practices. Enough creativity is also necessary to develop changes for the current production practices and adequate authority is requisite to enable implementation of proposed changes in production practices.

- **Identify barriers and solutions:**
  This entails identifying barriers and challenges to RECP implementation, with the aim of developing solutions to overcome these issues.
- **Set plant wide goals:**
  Set plant-wide RECP goals with the aim of establishing a framework for the assessment, as well as challenging the project team. The goals set should be challenging and realistic without undervaluing the potential of RECP.

4.3.1.2 ASSESSMENT PROCEDURE:

During this phase of the assessment a material balance should be drafted and studied. The material balance will indicate the sources of waste generation and therefore appropriate measures to prevent or reduce waste can be proposed.

The project team can make use of a wide variety of sources such as literature searches, personal knowledge, discussions with suppliers, specialised databases and further research and development, to generate appropriate waste reduction measures. Brainstorming coupled with personal knowledge is a vital tool in exhaustively generating creative intellectual ideas. Before beginning to brainstorm a thorough understanding of the plant should be obtained. A site inspection should also occur in order to make the brainstorming process more efficient and productive.

It is recommended that the brainstorming process should be conducted in co-ordination with staff members from all parts of the factory.

During this assessment procedure different possible options for immediate improvement may be identified. The process should be conceptually separated into the following three essential elements:

- **Source identification:**
  A process flow diagram should be drawn whereafter a material balance should be developed in order to identify all sources of waste and emission generation.

- **Cause diagnosis:**

  This process in an investigation of the various factors that influence the volume and composition of the waste and emissions produced. At this stage a material and energy balance is necessary in order to objectively the causes of waste generation.

- **Option generation:**

  This step and has the purpose of identifying possible measures to eliminate or reduce the causes of waste and emission generation. A financial analysis for each option is also required in order to determine the financial viability of the options. The next step in the process calls for the sequential consideration of the following areas for improvement:

  - **Change in raw materials:**

    By changing raw materials (purification or substitution), Cleaner production may be achieved by reducing or eliminating hazardous materials from entering, or being generated in, the process.

  - **Technology change:**

    Technology changes are geared towards modifying existing equipment or processes to achieve a reduction in the amount of waste and emissions being generated. These modifications may range from short-term, low-cost alterations to capital intensive process replacements. These may include, but are not limited to the following:

    - Modifications to the current production process
    - Plant modifications i.e. modifications of the layout, equipment piping etc.
    - Changes in process conditions i.e. flow rates, temperatures, pressures and residence times
    - Process automation

  - **Good operating practices:**

    Good operating practices, commonly known as good housekeeping are usually procedural, administrative or institutional measures used to reduce waste generation and emissions. These Good operating practices can generally be inexpensively executed in most areas of operation.

Good operating practices include but are not limited to the following:

- Management and personnel practices: includes encouraging employees to reduce waste and emissions by employing schemes such as employee training, incentives, bonuses and other programmes.
- Material handling and inventory practices: These are training programmes where loss in input materials are reduced by proper handling of the materials.
- Loss prevention: This avoids leaks and spills from equipment, hence minimizing wastes and emissions
- Waste segregation: this is a process whereby the hazardous and non-hazardous waste are separated.
- Cost accounting practices: Involves assigning waste treatment and disposal costs to the department that generates it.
- Production scheduling: The departments that produce the waste and emissions must be accountable for their treatment and disposal practices. Financial incentives can be introduced to assist in minimizing emissions and wastes. By scheduling batch production runs meticulously, emissions and waste generation can be minimized due to less frequent equipment cleaning.

- **Product Changes:**

  Product changes in terms of quality standards, product composition, durability and product substitution are performed by the manufacturers themselves in order to reduce waste and emissions. The resulting product could possibly have a lower environmental impact throughout the stages of its life cycle.

- **On site reuse and recycling:**

  Recycling or reuse encompasses the usage of a waste material as an input material.

4.3.1.3 FEASIBILITY STUDIES:

The feasibility study evaluates each of the options generated by proving that they are technically, economically and environmentally friendly.

This process is divided into 5 tasks:

- **Preliminary evaluation:**

  All the options developed are sorted in order to identify additional requirements. Managerial options do not always need to be technically evaluated, just as simple options do not always require environmental evaluations and low cost options do not require financial evaluation. Options that are equipment based, complex or expensive do require further evaluations in their respective categories.
- **Technical evaluation:**

  Technical evaluation consists of two parts. Firstly the option should be assessed whether it can be implemented. This requires further investigations into the reliability and availability of the equipment, the utility and maintenance requirements, the required operating and supervising skill and the effect on quality and productivity. Secondly the changes in the technical specifications should be utilized to calculate the savings in raw material efficiency, water and energy requirements after the implementation of the option. The options that are not capital intensive can be implemented faster and those options that require capital expenditure should be technically investigated by an appointed group of experts.
- **Economic evaluation:**

  The economic evaluation consists of three parts:
  - Data collection (regarding the investment costs, operational costs and benefits)
  - Choice between evaluation criteria (payback period by calculating NPV and IRR)
  - Feasibility calculations

- **Environmental evaluation:**

  The purpose of environmental evaluation is to check the impact of the option on the environment. This environmental evaluation must take into account the complete life-cycle of the product or service.

- **Selection of feasible options:**

  The technically unfeasible options and the options that do not benefit the environment are removed. The remaining options can be implemented depending on the funding available.

4.3.1.4 IMPLEMENTATION AND CONTINUATION:

Implementation and continuation is the final phase where the feasible prevention measures are put into practice and provisions to ensure the continuous application of RECP. Monitoring and targeting and evaluation of the results achieved by the implementation of the prevention measures need to occur as part of the continuous programme.

Three types of results can be expected from this phase:

1. The implementation of cleaner production measures that are feasible
2. The monitoring and evaluation of the options implemented
3. Commencement of the implementation of the continuous application of RECP activities.

To achieve these results, three tasks should to be completed as follows:

- Prepare a RECP plan: The measures are sorted by the date of implementation and the department or person responsible for the implementation of the option is identified.
- Implement RECP measures: Simple RECP measures with little or no capital expense can be implemented easily, but measures that require a large capital input need further assessment. These measures may require preparation such as installation, funding and installation of equipment.
- Monitor RECP progress: All interested parties should be informed regarding the progress that is being monitored.
- Sustain RECP: In order to sustain the continuous application of RECP activities structural changes within management and other parts of the organization might need to occur.

4.4 MATERIALS EFFICIENCY

Materials efficiency in industrial production focusses on the amount of a certain material required to produce a certain product. Material efficiency can be improved by either reducing the quantity of material in the final product, also known as light weighting, or reducing the amount of material entering the process and leaving as waste. In more general terms material efficiency refers to the amount of virgin natural resources required to produce a particular amount of product, with the recycling of waste material back into production contributing to material efficiency (United Nations Environment Programme, 2014a).

There are numerous benefits of material efficiency for industry, such as:

- The conservation of natural resources, results in the extended availability of the most accessible and lowest cost resources, a reduction in production costs, and improves standard of living while ensuring that the resource is available for future generations.
- A reduction in the demand for raw materials decreases both the social and environmental impacts of raw material extraction.
- Energy will be conserved and greenhouse gas emissions reduced. The recycling of materials have the potential to save the majority of energy required for refining and processing.
- By increasing material efficiency the waste produced will be reduced decreasing the quantity of waste going to landfills or to be incinerated, reducing land usage, reduction in air and water pollution and other negative impacts of waste handling.
- Improved collection and recycling of waste reduces the quantity of litter on land and in water and all the other impacts associated with it.

4.4.1 METHODOLOGY TO IMPROVE MATERIAL EFFICIENCY:

A material flow analysis is a systematic approach based on principles of physical balance targeted at:

- Providing an overview of the materials used in a company

- Identifying the volumes and points of origin of the waste and the causes of the waste and emissions
- Developing a basis for an evaluation and forecasting of future developments
- Providing strategies to improve the general situation.

The waste and emission issues of a company occur at the points of production where materials are used, processed or treated. In finding a strategic solution to these issues it is essential to record the current material flows which will indicate points of origin, volumes and causes of wastes and emissions. A material flow analysis incorporates the analyses of the substances used to determine its composition and economic value and future developments are also forecasted. The implementation of an information system will allow management to track material flows within the company and direct them in order to ensure their efficient use.

4.4.1.1 STEP 1: DRAW A MATERIAL FLOWCHART

Drawing a Material Flowchart consists of four core elements, namely:

- Define the objective of the material flow analysis and the parameters to be monitored
- Define the scope of the balance
- Define the time period of the balance
- Identify and define process steps

4.4.1.1 a) Defining parameters

One of the primary objective of a material flow analysis is to retrace the flow of either goods, chemical compounds or a single element through the company based on different criteria (volumes, cost, risk, safe disposal, etc.). This criterion needs to be decided upon in the beginning of this process.

If the objective is not already defined it is best to start with the material flow analysis of the company in its entirety (material balance at a company level) by performing a global input/output analysis which should contain the following information:

- The materials used in the company

- Amount of materials processed
- The economic value of the materials
- The quantities of waste and emissions generated by the process and disposed of

A list of all raw materials, processed materials, products, emissions and energy sources is generated using accounting and stock keeping records. In identifying priorities the identified material flows can be ranked according to their value and toxicity. Most commonly a detailed analysis will be conducted on expensive and ecologically problematic materials.

4.4.1.1 b) The scope of the balance

The scope of the balance depends on the objectives of the analysis and can either encompass the company as a whole or be restricted to individual processes. It is standard to perform a material balance at a company level to identify a focus area and thereafter the process is divided into single steps.

4.4.1.1 c) The balance period

It has been proven successful to select a specific time span for the balance which could be a production batch, production week, a month or even a year.

4.4.1.1 d) Identifying and defining production steps

In this phase the processes are divided and into sections and illustrated in the form of a flowchart. The flowchart can be based on equipment or activities, on profit centres, or production units. Production steps are symbolized using rectangles and material flows using arrows. Thereafter all relevant data (such as components, volumes, data sources, values etc.) should be indicated on the flowchart. Other important data (such as temperatures, pressures, batch sizes etc.) should also be documented. This flow diagram is aimed at gaining a clear understanding of the process.

4.4.1.1 e) Preparing the process flowchart:

Prior to preparing the process flowchart the boundaries of the process needs to be decided and this depends on the available information. Thereafter a list of activities in the process are to be generated and arranged in sequence. The sequence of activities should be discussed with the company employees (workers or supervisor) to confirm that it is correct. The process flowchart is then drawn and reviewed by company employees and other relevant stakeholders to ensure that it is accurately drawn.

4.4.1.1 f) Identifying the materials, quantities and the hazards involved in the process:

- Identify the materials involved in each step of the process and indicate them on the flowchart
- Identify the quantities of the materials involved in each step of the process and indicate them on the flowchart

4.4.1.2 STEP 2: CREATE A MATERIAL BALANCE

The core principle applied in a material balance is the conservation of mass, which states that mass can never be created nor destroyed but only transferred from one volume to another (Angelo, 2009). In other words all raw and processes materials have to either leave as product, waste or emissions.

The data required to create a material balance can be acquired from log books, production data acquisitions, individual measurements, routine measurements, documentation of equipment and the production department and also by calculating and estimating. Data regarding raw and processed materials can be obtained from the accounts department while data regarding the process can be obtained from the production planning and control departments. If for any reason the data is not retrievable or available then either measurements have to be carried out or estimates relied upon. A good estimate with the accuracy of 80 – 90 % is generally sufficient and is preferable to having no balance at all.

It is usual for output data to be detailed on control sheets, therefore flows of some materials can be retraced from their point of entry through the process right to the point of output.

4.4.1.3 STEP 3: CONSIDER OPTIONS

The final step entails the interpretation of the flowchart. The material paths are retraced and key efficiency and performance ratios for each production step as well for the company as a whole are calculated. In order to do this, waste generation points have to be determined and the ratio between raw materials and waste calculated. The calculated or real efficiency can be compared to the previously projected efficiency. The weak points in the system can be identified by comparing the real efficiencies to the projected efficiencies. The weak points then ranked and then analysed. Thereafter discuss these weak points should be discussed with the relevant personnel in the company. By updating data, material use and material flows regularly, an instrument for technical control is created.

4.5 SUMMARY

- The concept of sustainable development was proposed by the World Commission on Environment and Development (2014) and is aimed at achieving social and economic progress without the exhaustion of the earth's natural resources
- Concepts such as cleaner production, pollution prevention, waste minimisation, eco efficiency and green productivity promote sustainable development. Resource Efficiency and Cleaner Production is a broad concept that encompasses all of the above mentioned concepts.
- The concepts of cleaner production, waste minimisation hierarchy, RECP and materials efficiency are pertinent to this study.

Chapter 5: CASE STUDY

Company A is a privately owned beverage company which produces non-alcoholic beverages under a number of different brands and has industry experience exceeding 50 years. The company produces a variety of different carbonated soft drinks as well as bottled water. They are located in Durban, but supply the whole of South Africa. This facility has five bottling lines that produce 2 L, 1.5 L, 1.25 L, 500 mL and 300 mL products from Polyethylene terephthalate (PET) bottles which are blown on site, in addition to a 330 mL caning line. A small ice lolly packaging line is also located onsite, all of which are in operation 24 hours daily and 7 days a week due to the increased demand of the products. The factory operates with staff rotation every 8 hours, hence 3 shifts per day.

Senior Management have identified effluent generation and concentration as being the most significant problem at the site. The scope of the study has, therefore, been defined to focus specifically on the reduction of the effluent as the company has been moved to a higher COD tariff, resulting in trade effluent charges exceeding R70 000 per month being levied by the local municipality. This is due to Company A being consistently out of specification with respect to COD, sugar concentration and pH value. The renewal of the yearly effluent discharge permit is contingent upon efforts to decrease the COD concentration and sugar concentration of the effluent.

5.1 OBJECTIVES:

The objectives of this study were to:

1. Characterise the effluent being generated
2. Identify the sources which contribute to the high COD effluent discharged
3. Investigate the factors that influence volume and composition of the effluent discharged
4. Quantify the effluent sources
5. Identify saving opportunities to reduce the effluent discharge
6. To produce a conceptual design to minimize effluent charges
7. Describe regulatory conditions
8. Draft site plans, water pipeline plans, effluent pipeline plans and sugar pipelines.

5.2 METHODOLOGY OF ASSESSMENT

The comprehensive and systematic 5-Phase Resource Efficiency and Cleaner Production assessment (RECP) methodology (Section 4.3) was combined with the Materials Efficiency Assessment procedure (Section 4.4). Materials efficiency aims at reducing raw materials (increasing materials efficiency) which would inevitably result in a decrease in the waste produced.

5.3 ASSESSMENT PROCEDURE

5.3.1 PHASE 1: PLANNING AND ORGANISATION

Senior management had frugally attempted to initiate Phase I of the RECP methodology by briefing staff members, at every level of the organization, about the pressing effluent problem, and a vague common goal was set. The project team selected comprised of the head of each of the following departments; Research and Analysis, Quality Assurance, Quality Control, Operations, Accounting, Engineering and Maintenance as well as staff involved in the daily operations of the plant such as the line operators, and syrup supervisors.

5.3.2 PHASE 2 & 3: ASSESSMENT PROCEDURE

Waste and emissions issues arise at specific points of production within the soft drink industry, usually where materials are used, processed or treated. In order to find solutions to these issues a 3 step procedure was followed as described in this section.

5.3.2.1 STEP 1: DRAWING A MATERIAL FLOWCHART

The material flowchart incorporates four core elements, as listed below:

- Define the objective of the material flow analysis and parameters to be monitored
- Define the scope of the balance
- Define the time period of the balance
- Identify and define process steps.

5.3.2.1 a) Defining the objective and parameters:

The primary objective of the material balance at Company A is to describe the flow of components contributing to the high COD effluent.

With the components contributing to the high COD being unknown, a material balance at a factory level was done by performing a global input/output analysis, which contained the following information:

- The materials used in the company in the production of the soft drink products
- Amount of materials processed
- The economic value of the materials
- The quantities of waste and emissions generated by the process and the quantities disposed off-site

5.3.2.1 b) The scope of the balance:

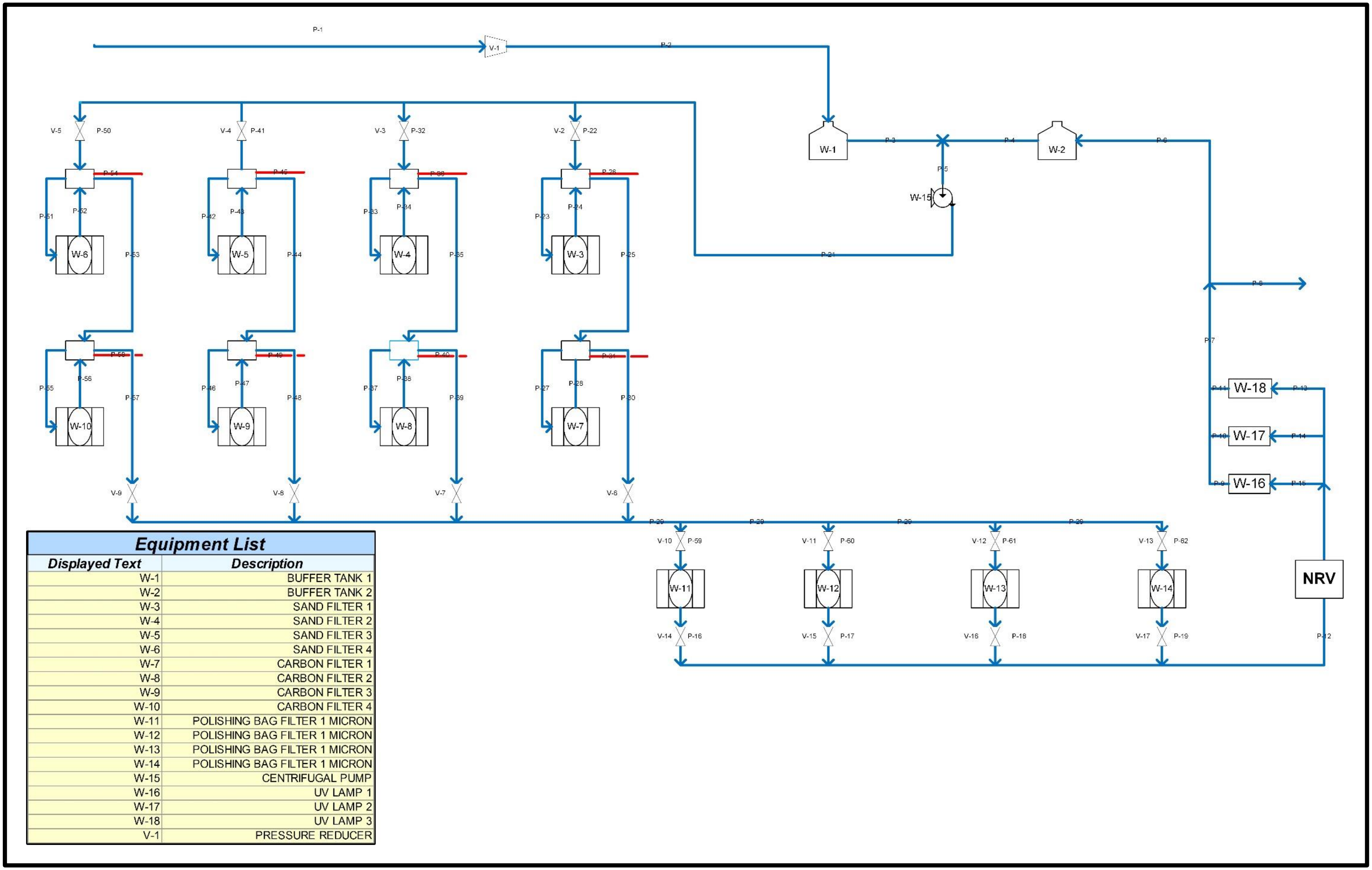
The scope of the balance is dependent on the objective and results from the previous step. It encompasses all the steps of the process where there COD contributing elements are utilised.

5.3.2.1 c) Identifying and defining production steps:

In this step, the flowchart was prepared based on equipment and production units. All the relevant data such as the components involved in each step of the process, are indicated on the water treatment process flow diagram (**Figure 5**) and process flow diagram of the wet section of Factory A (**Figure 6**).

5.3.2.1 d) Preparing the process flowchart:

Prior to preparing the process flowchart the boundaries of the system were decided upon where only the pertinent sections of the plant (wet section and sugar store), where effluent is generated, were considered. Company A did not possess a process flow diagram, therefore a site inspection was conducted, where after the process flowchart (**Figure 5** and **Figure 6**) and a site drainage plan (**Figure 7** and **Figure 8**) was drawn and reviewed by company employees and other relevant stakeholders to verify the accuracy all information presented. The process flowchart is presented in **Figure 6**.



Equipment List

Displayed Text	Description
W-1	BUFFER TANK 1
W-2	BUFFER TANK 2
W-3	SAND FILTER 1
W-4	SAND FILTER 2
W-5	SAND FILTER 3
W-6	SAND FILTER 4
W-7	CARBON FILTER 1
W-8	CARBON FILTER 2
W-9	CARBON FILTER 3
W-10	CARBON FILTER 4
W-11	POLISHING BAG FILTER 1 MICRON
W-12	POLISHING BAG FILTER 1 MICRON
W-13	POLISHING BAG FILTER 1 MICRON
W-14	POLISHING BAG FILTER 1 MICRON
W-15	CENTRIFUGAL PUMP
W-16	UV LAMP 1
W-17	UV LAMP 2
W-18	UV LAMP 3
V-1	PRESSURE REDUCER

FIGURE 5: WATER TREATMENT PROCESS FLOW DIAGRAM OF FACTORY A.

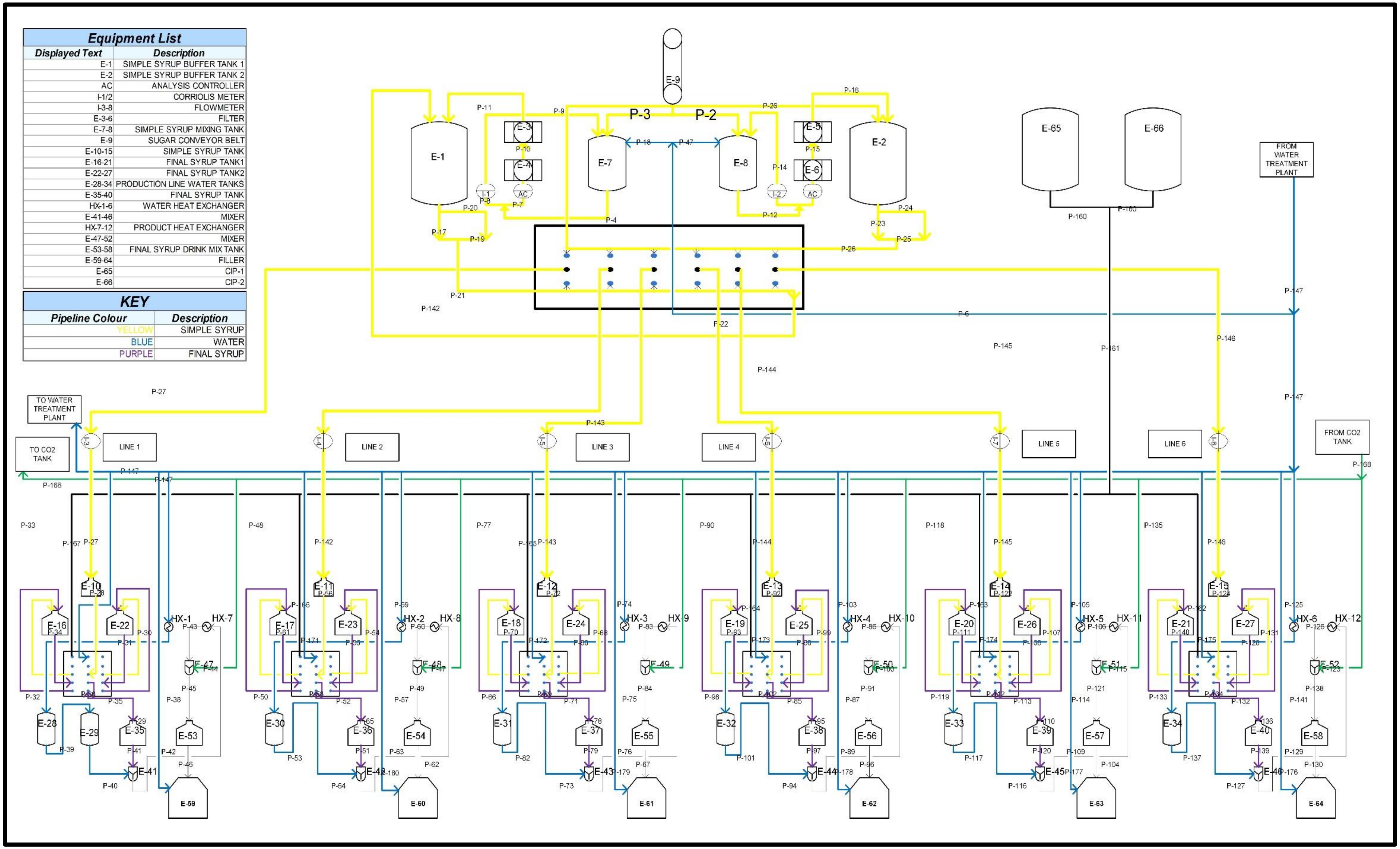


FIGURE 6: PROCESS FLOW DIAGRAM OF SUGAR ROOM AND WET SECTION OF FACTORY A.

5.3.2.1 e) Process Description

Municipal water is used for all production processes in this facility. The incoming water is pumped into a water treatment plant (**Figure 5**) where it passes through sand filtration (W-3 to W-6) and then carbon filtration (W-7 to W-10), thereafter it is sterilised with UV (W-16 to W-18) prior to its utilization. The water treatment plant continuously re-circulates the treated water from batch tanks (W-1 and W-2) through the ring main systems to the water plant to ensure the system is continuously sterile. Water is drawn from the ring main system to multiple unit operations within the production facility (**Figure 6**).

The production facility is shown in **Figure 6**. The first stage in the manufacturing process is the preparation of sugar syrup (simple syrup). The process of dissolving the granular sugar is continuous, where granulated sugar from the sugar storage is fed via an elevated conveyor belt (E-9). It is simultaneously sifted and transported, to the sugar dissolving vessels (E-7 and E-8), by the conveyer system. A parallel system of two sugar dissolving systems is used, each of which comprises of a sugar dissolving vessel (E-7 and E-8), the online density meters that measure the sugar content in (^{o}Brix) of each sugar dissolving system, coriolis meter, (I-1 and I-2), filters (E-3, E-4 and E-5, E-6) and simple syrup buffer tanks (E-1 and E-2). Only one sugar dissolving system is operational at any time while the other remains on standby. The reason for the presence of two sugar dissolving systems, is to increase the reliability of the system by duplication of the critical components of the system. In this way, downtime during filter cleaning, and other unaccounted maintenance procedures, is avoided.

During the sugar dissolving process the conglomerated sugar particles or lumps are removed from the system as solid waste, as they tend to create difficulties in making the simple syrup and delay the dissolving process. This solid waste is not discarded into the drainage system but rather disposed of to landfill, and it therefore does not affect the COD of the effluent.

The granulated sugar and water are fed continuously into the dissolving vessels (E-7 and E-8) where water is fed through a pipe that enters the top of the vessel, and runs down its side to the base of the vessel. This pipe configuration is used to minimize aeration. The sugar dissolving tanks (E-7 and E-8) are fitted with agitators to improve the rate of sugar dissolution. They are in constant operation until the sugar granules are completely dissolved. The water feed into these tanks (E-7 and E-8) is automatically controlled by the coriolis meters. This process is carried out at ambient temperature by simple agitation making it a relatively slow process. A portion of the syrup (which is off specification) is then recycled around each of the sugar dissolving tanks (E-7 and E-8) via lines P-8 and P-14. Present on each of the lines (P-8 and P-14) are coriolis meters (I-1 and I-2). The syrup continues to recirculate, controlled by the coriolis meter, in this manner until it reaches the specified sugar concentration. Once the specification is met, the Automatic Controllers (AC) receive a signal from the coriolis meters, which causes the valves present on lines P-7 and P-13 to open. The simple syrup then flows through two filters (either E-4, E-3 or E-5, E-6) and into the simple syrup buffer tank (E-1 and E-2), where it is again recycled to maintain and ensure homogeneity. The simple syrup is then pumped to the simple syrup tanks present in each line (E-11 to E-15), the volume of which depends on the size of the batch that is to be produced. Powdered ingredients such as preservatives are manually added to each of the simple syrup tanks (E-11 to E-15) which are also fitted with agitators. The simple syrup is then then transferred to either of the production lines final syrup tanks (E-16 to E-27) into which the colourants, flavourants and acidulants are added making it into final syrup.

The factory has a total of six production lines of which four were operational at the time of the study. Production Line 4 was out of order and Production Line 6 was being commissioned as a canning production line. Production Line 5 has been recently installed and is equipped with the most recent generation of technology while Production Lines 1, 2 and 3 are older and comprise of technology of a similar standard. Two final syrup tanks are present (in parallel) in each production line, to allow for the preparation of the next batch of final syrup to be produced while the other tank is in use.

The group of tanks before the filler and after the final syrup tanks (E-16 to E-27) are known as the drink mix section. The final syrup is transferred to the final syrup tank in the drink mix sections (final syrup drink mix tank; E-35 to E-40) where it is diluted with cooled water from the water tanks in the drink mix section (E-28 to E-34). The final syrup tanks in the drink mix section are equipped with level sensors as well as low and high level alarms. The level sensor has the function of controlling the flow of syrup to the proportioners (E-41 to E-46) by toggling the pump (that is placed after the final syrup drink mix tank) on or off. Proportioners are sophisticated unit operations that combine the final syrup and treated water by regulating the flow rates of these liquids. Towards the end of a production batch, the level sensor continuously monitors the quantity of final syrup remaining in the tank and switches the pump off once a certain minimum level is reached. This level is set by the user and can be altered. This dilution must occur in the correct proportions in order to meet the beverage specifications. It is controlled by proportioners (E-41to E-46) which use a fixed orifice to meter the final syrup whilst the water is fed through a variable orifice. Both operate under a constant head of pressure supplied by a tank and a float valve. The float valve has the function of maintaining the liquid level in the tank. Such a system results in the product at the beginning of a batch being out of specification, although once set up, the batch consistency is maintained.

The diluted syrup (product) is then cooled through heat exchangers (HX-7 to HX-12). The product is then pre-carbonated with CO_2 injection shown in units E-47 to E-52 and then exposed to a CO_2 atmosphere directly in the drink mix tanks (E-53 to E-58) where cooling and deaeration take place. The amount of CO_2 gas that can be absorbed is dependent on the temperature of the soft drink and the pressure of the drink mix tank, both of which must therefore be tightly controlled. The freshly prepared and carbonated finished product is then packaged and sealed in the fillers (E-59 - E-64). The filler includes bottle handling components, a filling machine and a capper. The fillers can be inaccurate resulting in a number of under-filled packages.

CIP System:

An important part of the process in a soft drink plant is the clean-in-place (CIP) system. CIP is performed depending on the production schedule as well as a weekly procedure as per the shutdown and start-up operations of Company A. There are two types of CIP procedures performed, namely 3-step and 5-step CIP.

The 5 step CIP system aims at cleaning the connecting pipework and batch tanks and uses both the syrup line and batch tank flow rate. The procedure is outlined below:

1) Quick rinse (approximately 10 min)

2) Chlorine solution (1 000 L)
3) Quick rinse (approximately 10 min)
4) Chlorine solution (1 000 L)
5) Final rinse (approximately 15 min)

The 5 step CIP is conducted on start-up and is scheduled to occur weekly. The 3-step CIP consists of only the first 3 steps of this programme and occurs after every product flavour change.

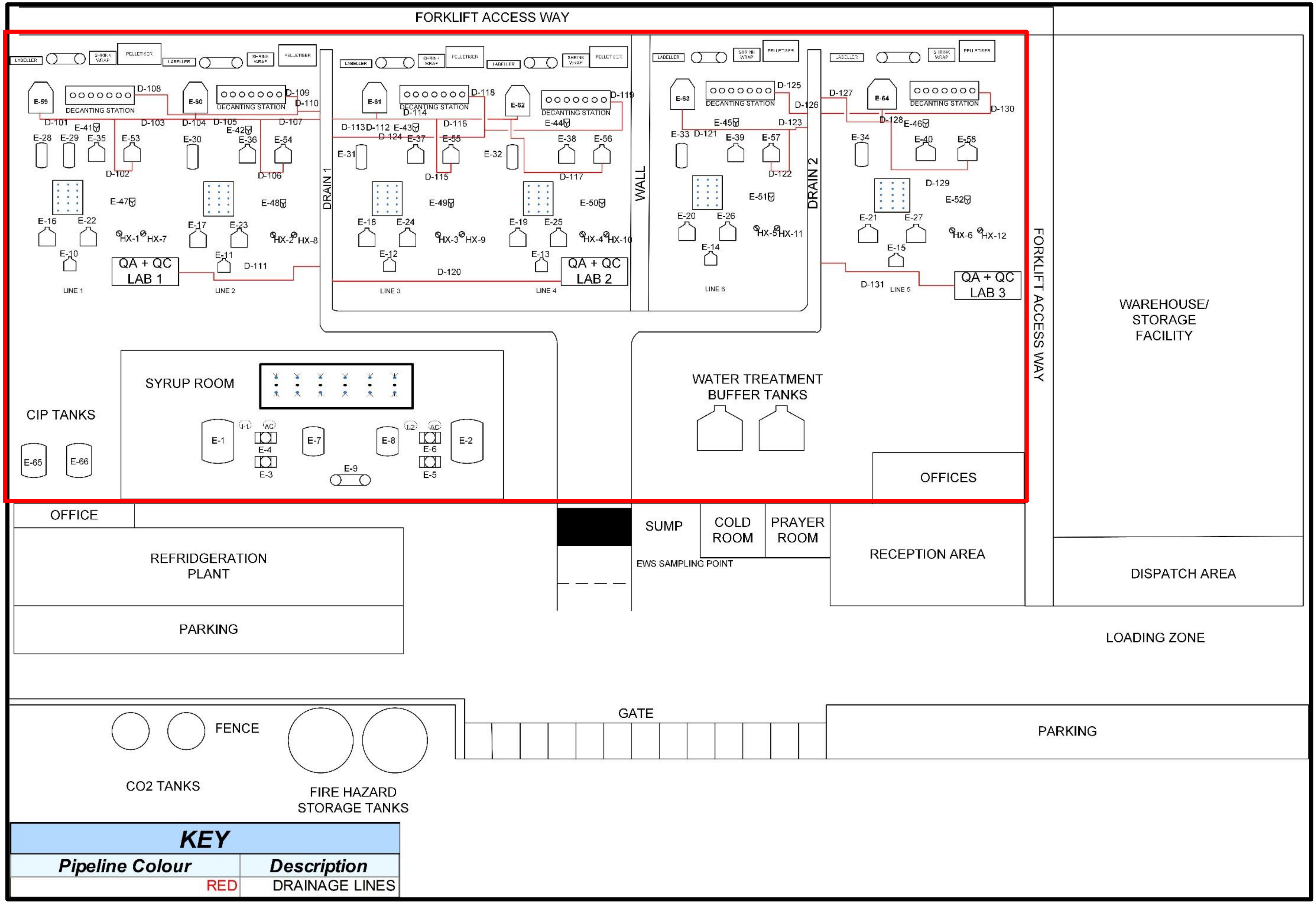


FIGURE 7: SITE DRAINAGE PLAN, COMPANY A.

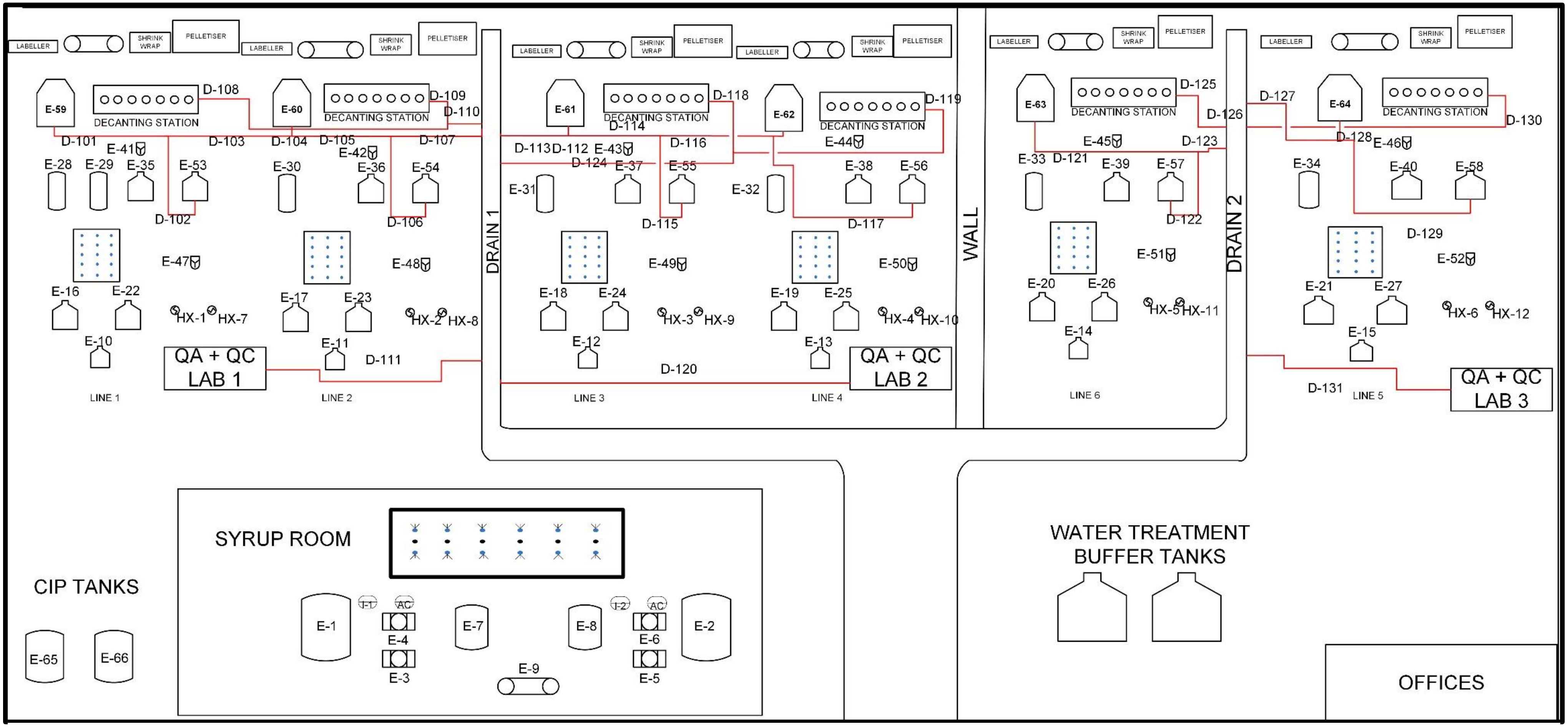


FIGURE 8: CLOSE UP VIEW OF THE SITE DRAINAGE PLAN.

5.3.2.1 f) Water Consumption and Effluent Generation

Raw water is supplied to Company A by the local municipality (eThekwini Municipality). The water charge for the factory is based on readings from a municipal water meter located outside the production area. The analysis of the invoice data (**Table A1**, **Appendix A**) determined the average water usage to be 557 m^3/day or 16 700 m^3/month. A notable reduction in the water usage for the month of June was observed. This can be attributed to the annual maintenance. **Figure 9** provides an overview of the monthly water consumption and effluent charges incurred.

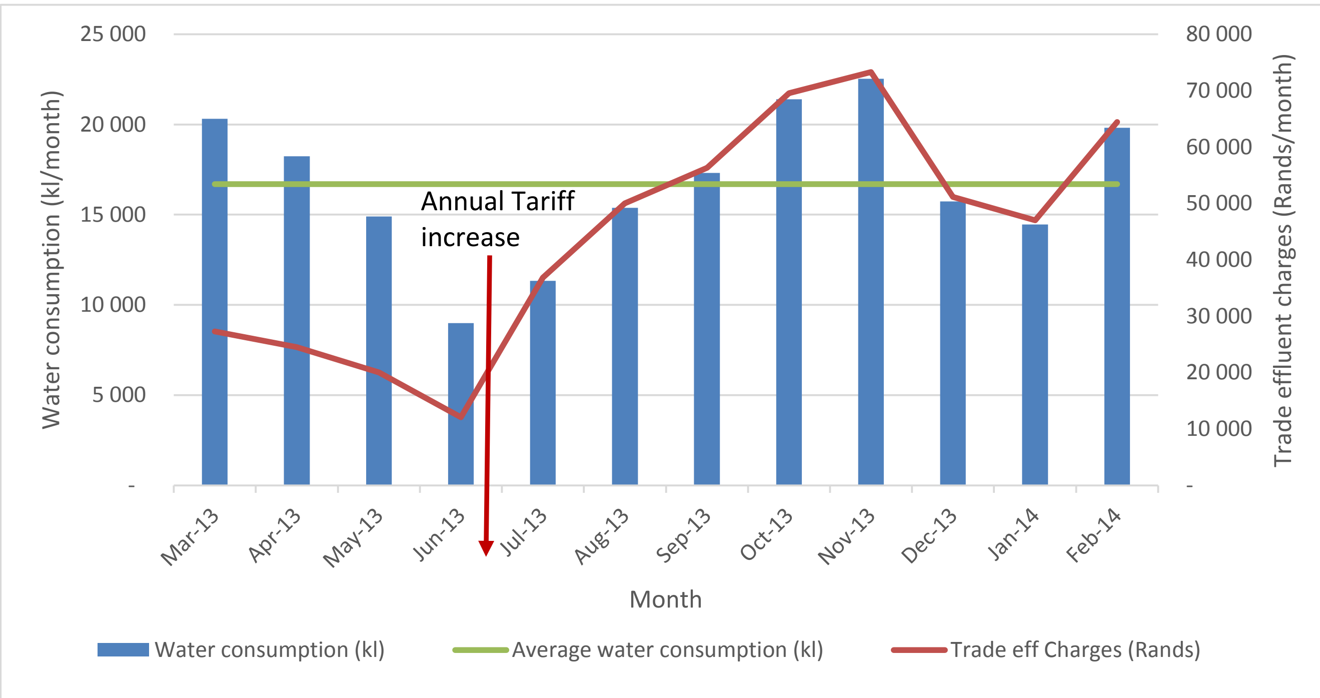


FIGURE 9: MONTHLY WATER CONSUMPTION AND EFFLUENT CHARGES, COMPANY A.

Company A is charged R14.59/kL for potable water (2013/2014 rate). The tariff is increased in June every year with the 2012/2013 charge being R12.97/kL. Based on an average consumption of 16 700 kL of potable water per month (**Figure 9**), the monthly water cost is R 235 221, which includes a fixed charge of R 379.47 per month.

The municipality charges for effluent disposal based on the assumption that 25% of the potable water use is discharged as domestic effluent and that 10.32% is discharged as trade effluent. This tariff formula (Section 3.4) makes the trade effluent charges directly proportional to the water consumption as shown in **Figure 9**. The average calculated monthly effluent discharge volume is therefore 1 700 kl. A trade effluent charge of R32.52/kL and a fixed daily charge of R43.15 is being billed to Company A, which results in an effluent bill of approximately R 44 377/month (**Table A1**).

A comparison of the effluent bills for 2013/2014 and 2014/2015 confirm that Company A experienced an average increase of 59% in effluent charges. In addition, the concentration of COD in the effluent increased during the period of July 2012 – July 2013. The trade effluent charge is based on the results of the COD analysis of the effluent samples taken by the municipality over a period of 12 months. This resulted in an increase in the effluent tariff from R 13.43/kL in 2012/2013 to R 32.52/kL in 2013/2014. Based on an average monthly effluent volume of 1 723 kL/month, the trade effluent charge increased by R 32 892/month during this period.

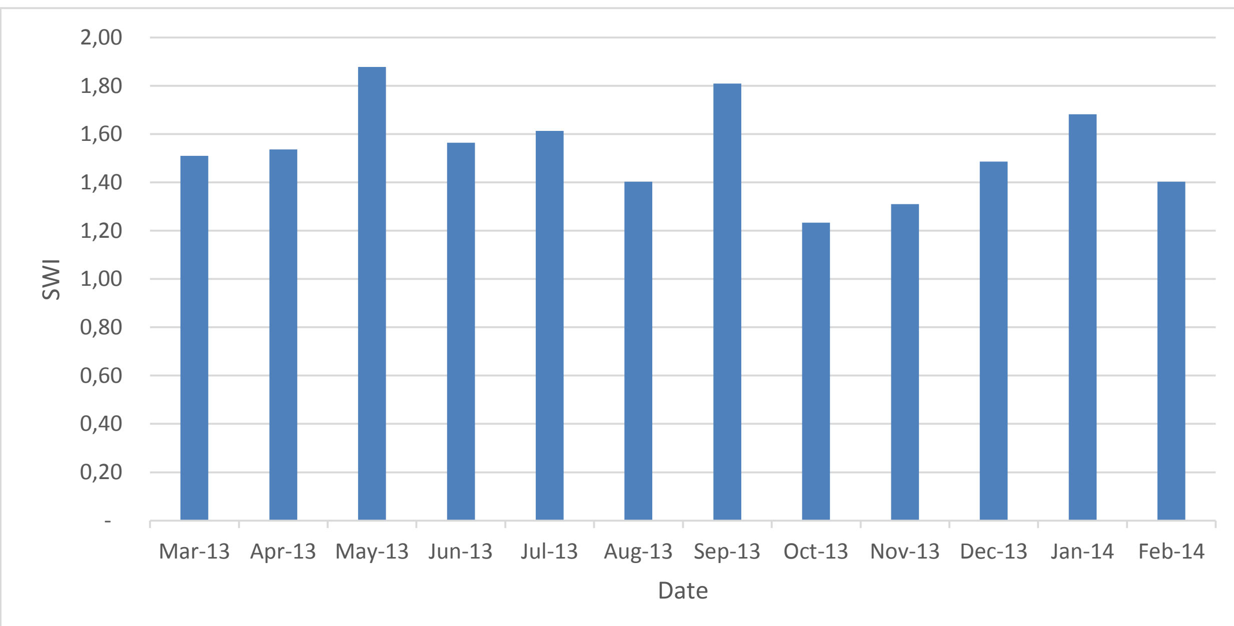


FIGURE 10: MONTHLY SPECIFIC WATER INTAKE, COMPANY A.

A comparison of the site water usage (**Table A1**, **Appendix A**) and production figures (**Table B1**, **Appendix B**) for the period March 2013 – February 2014 is plotted in **Figure 10** and confirms a water ratio or Specific Water Intake (SWI) of 1.54 L water/L product. This water usage is well below the average SWI of 2.3 L/L product (Water Research Commission, 1987) determined in the 1987 survey of the soft drink industry (Natsurv 3).

5.3.2.1 g) Raw materials

Company A utilizes a wide range of raw materials to produce the final soft drink products. The major raw materials are listed below in **Table 6**, together with an indication of the contribution to COD load in the effluent.

TABLE 6: MAIN RAW MATERIALS LIST (INPUTS).

Raw Material (Input)	COD contributor
Water	✓
Sugar	✓
Preservatives	✓
Colourants	✓
Flavourants	✓
Acidulants	✓
Carbon Dioxide	✗

As indicated the majority of the main raw materials can contribute to COD and therefore a reduction in their consumption and wastage will result in a reduced COD load in the effluent.

5.3.2.1 h) Products

Company A produces an average of 11 200 kL/month of soft drink. Hot sunny weather is an effective driver in soft drink consumption which increases sales and hence increases production volume. This trend together with the average South African temperature (The World Bank Group, 2014) is shown in **Table B2**, **Appendix B** and displayed in **Figure 11**. A significant decrease in the production volume was observed for the month of June, which is attributed to a decreased demand due to the lower temperatures during the winter period. The increase in production for the months of October and November are attributed to the build-up of stock for the festive holiday season that occurs in December and January.

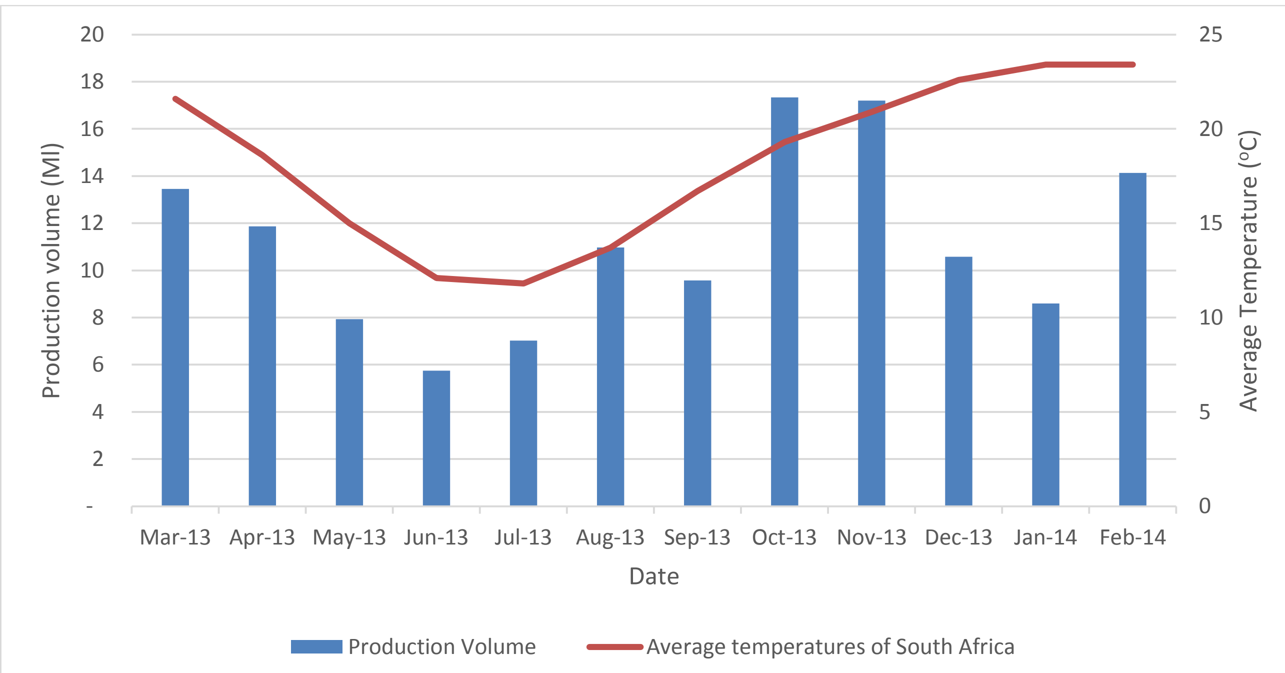


FIGURE 11: MONTHLY PRODUCTION VOLUME AND AVERAGE TEMPERATURES FOR SOUTH AFRICA (THE WORLD BANK GROUP, 2014).

The company produces a variety of carbonated soft drinks with 36 different flavours in 4 different pack sizes, each varying in composition and sugar content (**Table B3, Appendix B**).

Almost 40 ML/year of Flavour 1 is produced which accounts for 30% of the annual production volume making it the company's biggest selling product.

The sugar content of the flavours vary significantly as shown in **Figure 12**. This is dependent on the market demand the specific flavour and the targeted brand.

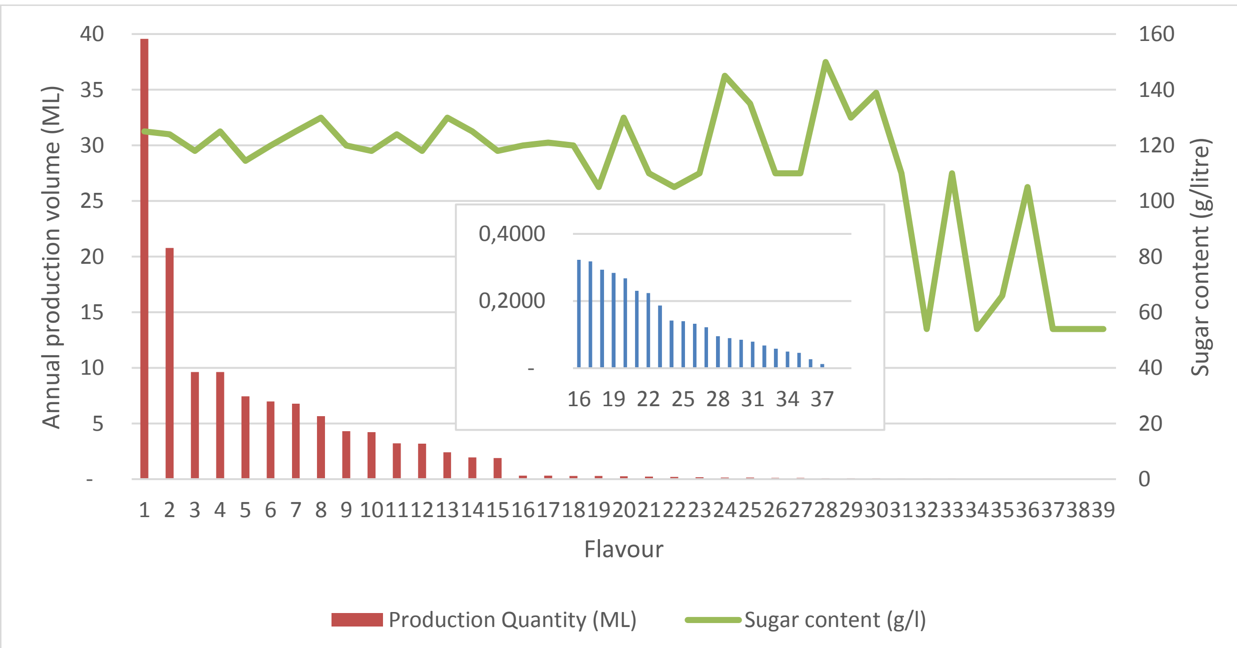


FIGURE 12: ANNUAL PRODUCTION VOLUME AND SUGAR CONTENT OF EACH FLAVOUR, COMPANY A. THE INSERT GRAPH SHOWS THE PRODUCTION VOLUME OF FLAVOURS 16-39.

5.3.2.2 STEP 2: GENERATING A MATERIAL BALANCE:

The goal of this step is to perform a material balance at a company level, by performing a global input/output analysis

Initially a list of all inputs or raw materials were generated and ranked according to the COD contribution per unit while considering their economic value. This is shown in **Table 7**.

TABLE 7: RAW MATERIALS INPUT WITH COST AND COD VALUES FOR THE YEAR 2014, COMPANY A.

Raw Material	Units	Input per year	Unit Cost (R/unit)	COD (COD/ unit)
Water	kL	200 397	14.59	0
Sugar	kg	16 459 316	6.85	1.123
Colouring	L	Unobtainable	Unobtainable	Unobtainable
Flavourings	L	Unobtainable	Unobtainable	Unobtainable
Preservatives	kg	Unobtainable	Unobtainable	Unobtainable
Chlorine	L	Unobtainable	Unobtainable	Unobtainable
Conveyor chain lubricants	L	Unobtainable	Unobtainable	Unobtainable

Some of the information in **Table 7** could not be obtained as it is of a proprietary nature, however, it must be noted that these raw materials (colouring, flavourings, preservatives and conveyor chain lubricants) are used in very small quantities and their effect on the effluent was, therefore, assumed to be negligible.

5.3.2.2 a) Global Sugar Balance

One of the first steps in this phase was to undertake a Global Sugar Balance in order to test the hypothesis that no loss of sugar occurs to the drain.

A global sugar balance was performed in order to test this hypothesis.

In order to perform the overall sugar balance the following data were collected:

- The historic sugar usage on a monthly basis (**Table C2**, **Appendix C**). This information was obtained from the accounting department which performs a daily physical stock count of the inventory of sugar.
- The historic production figures per flavour on a monthly basis (**Appendix C**) – obtained from the Sales and Distribution Department
- The target sugar content of the final product for each flavour was used as the actual sugar content of the final product dispatched for each flavour was not available (**Table B3**, **Appendix B**) – obtained from the Quality Assurance (QA) & Quality Control (QC) department
- The mass of conglomerated sugar granules removed and disposed as solid waste. This information was obtained by the collection and measurement of the conglomerated sugar over a period of 30 days (**Table C3**, **Appendix C**)

The historic production figures for each flavour and the recipe sugar content for each flavour were utilized to calculate the quantity of sugar in the dispatched product (**Table C2**, **Appendix C**). The difference between the sugar usage (input) (**Table C2**, **Appendix C**) and this figure is the sugar loss (**Table C2**, **Appendix C**). The solid sugar conglomerate disposed of as solid waste was quantified as 300 kg per month (**Table C3**, **Appendix C**), which is below 1% of the average monthly sugar usage. It was, therefore, assumed negligible and not included in the sugar balance.

Based on the sugar balance a calculated average monthly sugar loss of 11 073 kg is incurred. Disproportionately large sugar losses were experienced in the period January 2013 – February 2014 are experienced (**Figure 13**). The accuracy of the sugar balance could be compromised through any of the three types of uncertainties that may be present in this balance. These are outlined below:

1. Timing: This form of uncertainty could occur as a result of a time difference in the data provided. Since the production facility of the factory continues throughout the day and night there is a possibility that a stock count could have occurred during the early working hours of the day and the production figures were recorded during the late hours of the evening. This delay could significantly impact the results as an average of 46 000 kg of sugar is used daily.
2. Sugar content of the final product: The recipe sugar content and the actual sugar content of the final product could vary significantly and this is tested by the QA and QC departments. A tolerance of ± 0.2 ^{o}Brix (2.09 g sugar per L) is allowed. This means that if any product is produced with a sugar content exceeding either 0.2 Brix higher or lower than the target sugar content it will not be allowed to be dispatched (sold to the consumer) unless approved by the QA and QC Manager. For this approval to happen the QA and QC manager will taste the final product and observe its taste profile. If a variation in the taste is not apparent, the soft drink will be allowed to be dispatched. This uncertainty is estimated to contribute to approximately 24 000 kg/month.
3. Inventory changes: This is the quantity of sugar which is in the unit operations within the production facility (stock in tanks), in the form of simple syrup and final syrup. There is a constant variation in this uncertainty due to continuous production. The magnitude of the variation is dependent on the holding capacity or size of the unit operations in the production facility. It has been calculated that the maximum variation of this form of uncertainty is 96 500 kg/month.

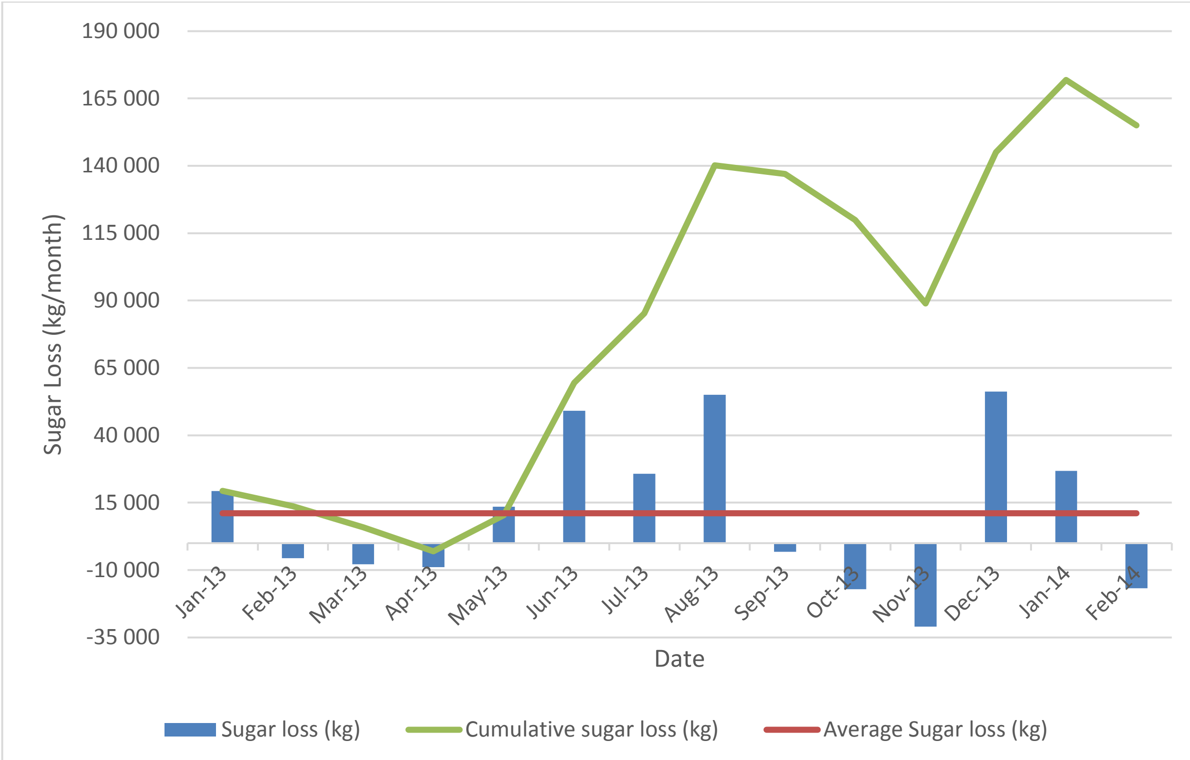


FIGURE 13: CALCULATED MONTHLY SUGAR LOSS AND CUMULATIVE SUGAR LOSS.

It was hypothesized that that no loss of sugar occurs to the drain, however taking into account the quantified uncertainty of 810 500 kg/month, it could not be concluded with certainty that there exists sugar losses to drain. Therefore chemical analysis was conducted on the effluent

5.3.2.2 b) Chemical Analysis

Hypothesis: It is hypothesized that there is no sugar in the effluent.

An investigation was conducted at the factory where effluent samples were collected at 15 min intervals for eight days of production to take into account the variation of the types of products and the maximum number of combination of polluting activities (**Appendix D: Chemical analysis**). It was assumed that the results obtained within this time period is representative of the repetitious rhythm of the factory. A total of 825 samples were collected and tested to determine the sugar concentration, the results of which are shown in **Appendix D** and displayed in **Figure 14**.

Large fluctuations in the COD concentration in the effluent are observed in the 15 minute effluent samples, with a maximum COD concentration of 85 g/L (**Appendix D: Chemical analysis**). It can, therefore, be concluded that a significant amount of sugar is present in the effluent. The large fluctuation in the results show that intermittent discharges of high strength effluent are being released causing the peaks (**Figure 14**). Therefore this hypothesis has been disproved.

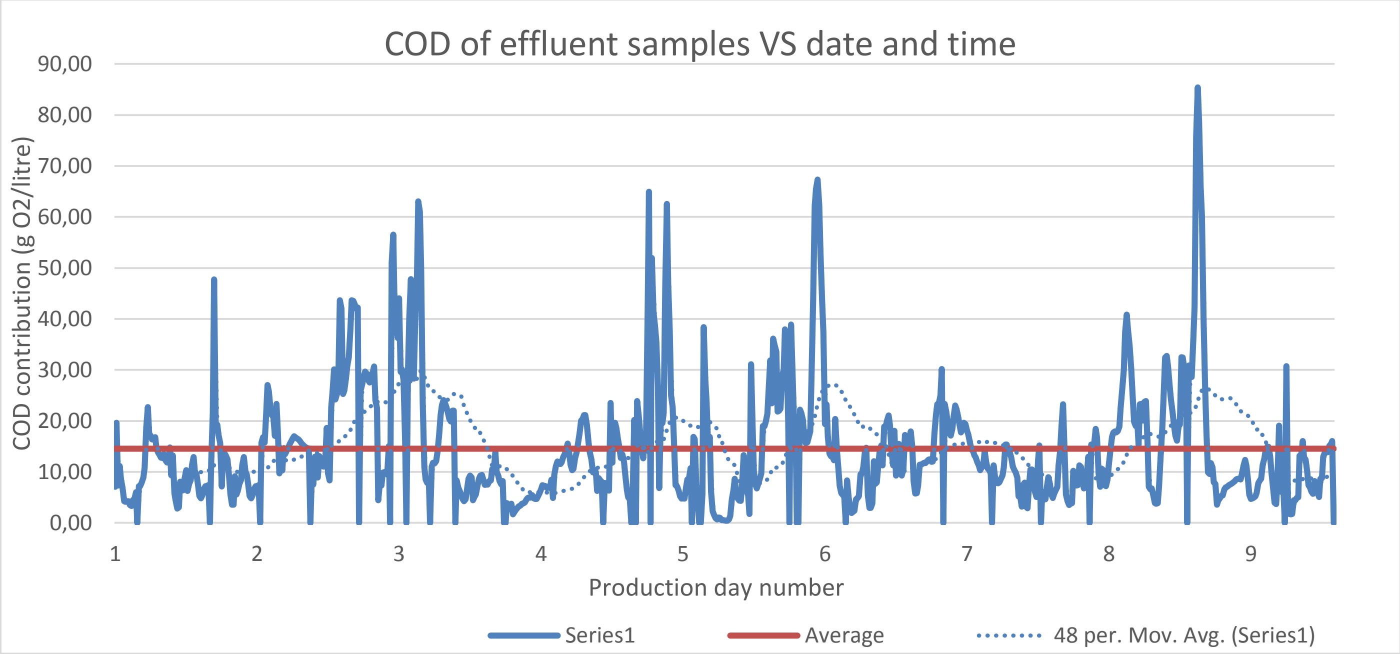


FIGURE 14: COD CONCENTRATION OF THE EFFLUENT SAMPLES. THE AVERAGE COD CONCENTRATION OF THE EFFLUENT IS 14.57 g/L. THE TOTAL NUMBER OF SAMPLES IS 825.

In order to regulate water pollution, wastewater discharge permits are issued to industries that discharge effluent. These permit holders are charged per kL of effluent discharged. If the permit holder discharges effluent with a strength exceeding that of standard domestic effluent additional charges calculated based on the COD and total suspended solids (TSS) concentrations are levied against the permit holder (for further details please see Section 3.4). To do this an authorised officer from the local municipality samples the effluent monthly. Chemical analysis is performed to determine the COD and TSS of the effluent. The effluent test results taken by eThekwini Municipality are depicted in **Figure 15** and shown in **Table D2**, **Appendix D**.

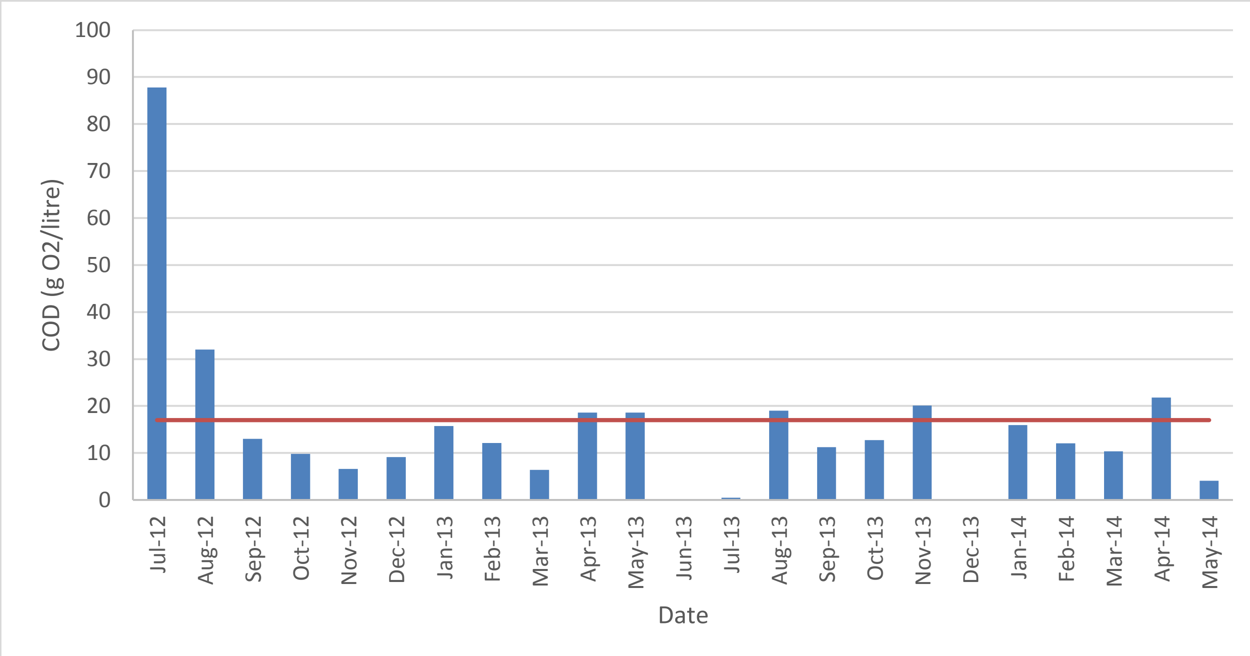


FIGURE 15: LABORATORY TEST RESULTS FOR THE TRADE EFFLUENT OF COMPANY A, OBTAINED FROM ETHEKWINI MUNICIPALITY.

A large variation in the results is observed over the months, specifically in the months of July 2012 and July 2013 where COD concentrations of 87.8 g O_2/L and 0.475 g O_2/L were observed respectively. Statistical analysis was performed where the outer fences of the data were calculated and considered as major outliers. The COD measurement for July 2012 lies well outside the outer fences therefore it is termed as a major outlier. The calculated mean of both the results obtained from the effluent sampling process used in this study and those from eThekwini are 14.6 g O_2/L and 17.0 g O_2/L respectively. This difference of 2.4 g O_2/L is significant as it could result in increased effluent discharge costs of R 3.51/kl or R 6 049 per month i.e. 10% of the bill.

The large variation in the results is associated with the intermittent discharges of high strength effluent that are released within the factory due to the batch operation of production. The grab sampling procedure, that captures a sample at a specific instant, can be construed to be quite biased. The bias by the municipal sampling can present as either positive or negative, as a large variation in the effluent COD is observed in **Figure 15**. A sampling procedure that is designed to eliminate this bias should thus be considered. Time composite samples consist of equal volume samples collected at defined time increments into a single container. It is recommended that time proportional composite sampling be undertaken using an automatic sampler capable of providing adequate refrigeration during the sampling period. This can be accomplished by using ice on site. Since no suspended solids are present, the flow velocity need not be considered. Time proportional composite sampling in theory should allow for a more representative sample of the wastewater to be obtained, since production undergoes large variations in short periods of time.

The time period over which the time composite samples should be collected was determined by an analysis of the data in Appendix D: Chemical analysis. A data smoothing technique called the "moving average technique" was used to determine the rolling average of the complete data set for defined time intervals (Appendix D: Chemical analysis). The standard deviation of the data for the moving average of each time interval was calculated (**Table D1**) and is shown in **Figure 16**. The gradient at each data point (shown in **Table D1** and plotted in **Figure 16**) was calculated using the backward difference finite difference formula. The period at which the gradient of the data changed minimally was selected as the optimum time period. It is thus recommended that composite samples be collected at 15 minute intervals for the optimum time period of 12 hours. In this manner the most representative sample can be achieved by collecting a reasonable number of samples.

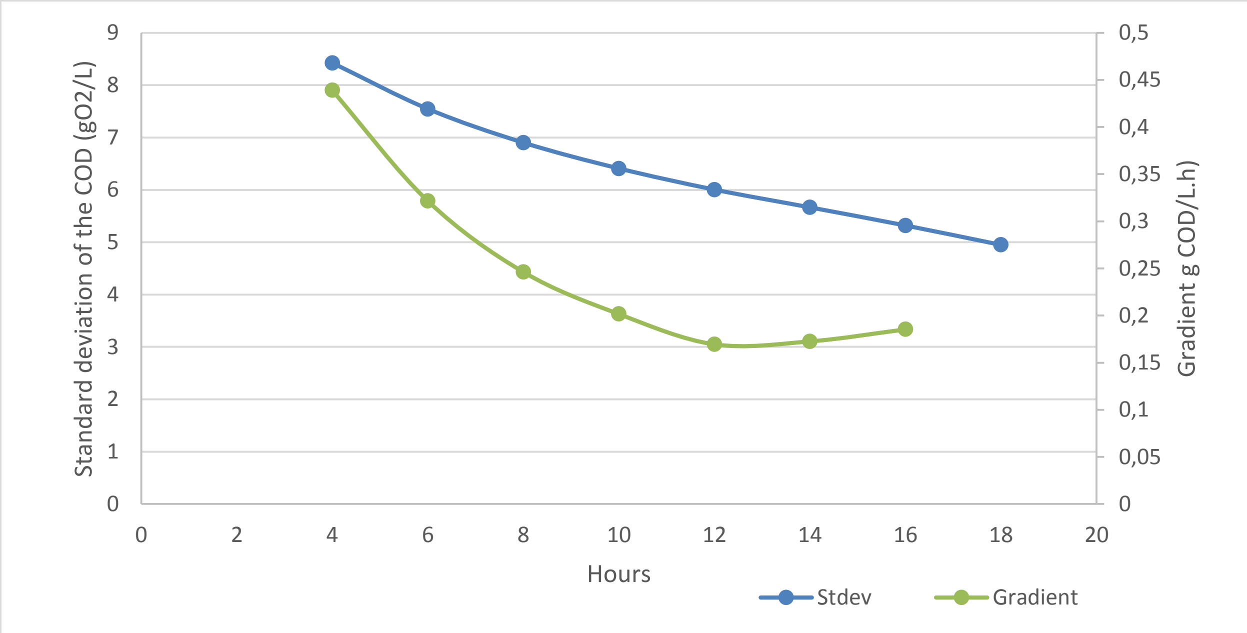


FIGURE 16: COD SENSITIVITY PLOT FOR THE DETERMINATION OF THE OPTIMUM TIME PERIOD OF COMPOSITE SAMPLING.

Due to the large fluctuations in the COD of the effluent shown in **Figure 14**, the sources of the effluent were therefore identified and the factors influencing the volume and concentration of the effluent were also determined (Step 3: Generation and consideration of options).

5.3.2.3 STEP 3: GENERATION AND CONSIDERATION OF OPTIONS

This step entails the interpretation of the flowchart (**Figure 6**) already developed. It consists of three steps which are explained in the RECP Assessment procedure in the Literature review section (Chapter 4). The application of these steps is described in this section.

5.3.2.3 a) Source identification and cause diagnosis

Source identification and cause diagnosis involved the identification of all sources of wastes and emissions and an investigation of the factors that influence them. The interpretation of the process flow diagram, retracing material flows and a site inspection contributed to the collection of the data. Measurements were then performed in order to quantify the waste at each point in order to complete the next task, which involved ranking the wastes and emissions in order of COD load contributions. A summary of the different type of losses that occur is shown in **Table 8** and a brief description of each of the sources of waste is provided in the following sections.

TABLE 8: SUMMARY OF THE TYPES OF LOSSES.

Loss category	COD concentration of waste (mg O_2/L)
Final syrup	656 925
Simple syrup	656 925
Ready to Drink (RTD)	141 005
i) Post sanitation losses	
ii) SOP losses	
iii) QA and QC losses	
iv) Under-fills and Over-fills	
v) Filler bowl losses	

(i) Final syrup losses

The final syrup losses occur after every flavour change and before the 3-step CIP. It occurs when the contents remaining in the final syrup buffer tanks of each line (E-16 to E-27) and the final syrup tanks of the drink mix of each line (E-35 to E-40) are emptied and discharged before the initial rinse of the 3 step CIP occurs. This disposal does not occur into any drainage line but the remaining final syrup is drained on to the factory floor which then flows into either Drain 1 or Drain 2 (**Figure 7**). The level sensors in the final syrup drink mix tanks (E-53 to E-58) control the flow of the final syrup to the proportioner (**Section 5.3.2.1**). The volume of the loss of the final syrup drained from the final syrup drink mix tanks is constant and is determined by the process controls within this section of the plant (**Section 5.3.2.1**).

(ii) Dumped batches

Dumped batches occur due to negligence or human error. It occurs when incorrect ingredients are added to the simple syrup in the final syrup buffer tank (E-16 to E-27) and the error is irreversible. The-off specification final syrup is then discharged to drain on the factory floor surface and into either Drain 1 or Drain 2 (**Figure 7**).

(iii) Simple syrup losses

The simple syrup losses occur once a week prior to the sanitation or 5-step CIP, when the contents of the simple syrup tanks are discharged to the factory floor which then flow into either Drain 1 or Drain 2 (**Figure 7**).

This applies to the:

- Simple syrup mixing tanks (E-7 and E-6)
- Simple syrup buffer tanks (E-1 and E-2)
- Simple syrup tanks of each production line (E-10 to E-15)

(iv) Ready to drink losses

Ready to drink (RTD) losses occur when final product with an average concentration of 12 ^{o}Brix is discarded as effluent. The COD of the RTD product is calculated to be 141 g O_2/L. RTD losses are observed to occur as a result of post sanitation losses, QA and QC losses and under-fills and over-fills losses. under-fills and over-fills losses are those losses that occur as a result of the bottles being either under-filled or over-filled.

Post sanitation losses

Post sanitation losses occur after every flavour change. Once the sanitation or 3-step CIP has been carried out. It is performed in order to remove any water that remains in the pipes after sanitation to ensure product quality. At the beginning of each batch the line operator starts the process and allows a certain quantity (percentage) of the production lines drink mix tank (E-53 – E-58) to fill with the RTD product which is then dumped or allowed to go to drain via drainage pipes D-107, D-113, D-123 and D-127 (**Figure 7**) thereby removing any water that remained in the pipes. It is essential for the blended RTD product to be on specification to maintain product quality and brand reputation.

Standard operating procedure losses

Standard operating procedure (SOP) losses also occur at the beginning of a batch but after the water remaining in the pipes from the 3-step CIP is removed. According to the SOPs of Company A it is mandatory that two bottles of the final (RTD) product be filled by each filler head of the filling machine (E-59 – E-64). The content of these bottles are then decanted at the decanting station of each production line (**Figure 7**) and allowed to go to drain via the drainage lines shown in D-110, D-124, D-126 and D-130 (**Figure 7**). This is done as a precautionary measure to ensure product quality and consistency.

Quality Assurance and Quality Control losses

QA and QC losses occur due to the samples taken by these departments of Company A. The contents of the samples are decanted in the Q&A laboratories via the drainage lines D-111, D-120 and D-131 (**Figure 7**). The batch size and the volume of the final product being produced are the primary factors influencing the volume of this waste.

Under-fills and Over-fills losses

Under-fills and over-fills losses occur due to the bottles being either under-filled or over-filled. A visual inspection is performed on the filled bottles after emergence from the filler and prior to labelling and packaging. Any under-filled or over-filled bottles are removed and decanted via the decanting stations of each production line (**Figure 7**) and allowed to go to drain via the drainage lines shown in D-110, D-124, D-126 and D-130 (**Figure 7**). It was found, after consultation with factory personnel, that the primary factor causing the increased quantity of under-fills and over-fills is due to the wearing away of the dummy rubbers that seal the filling valves.

Filler bowl losses:

These losses occurs after every flavour change and before the 3- step CIP occurs, when the remaining contents of the bowl of the filling machine is disposed of. The contents remaining in the filler bowl are not filled into bottles as the quantity is too small to completely fill a single revolution of the bottles. This RTD is then discarded via drainage lines D-107, D-113, D-123 and D-127 (**Figure 7**). The liquid level of the remaining contents of the filler bowl is shown (as a percentage of the volume of the filler bowl) on an interactive display interface which is mounted on the filling machine.

5.3.2.3 b) Quantification of waste sources

Quantification of the sources of waste was performed with the aim of ranking them in order of COD contribution. The COD of each of the different types of waste, namely; RTD, final syrup and simple syrup were estimated by considering the sugar content and volumes of these solutions. The sources of waste that contribute the most to the COD are given priority and analysed first. The results of this quantification are shown in **Table 8**. The methods used to quantify the sources of waste are outlined in the next section.

(i) Final syrup losses

The final syrup losses were quantified by collecting and measuring all the remaining final syrup in each of the production lines final syrup buffer tanks (E-16 – E-22) and final syrup tank of the drink mix (E-47 – E-52), after every production batch for 13 days (**Table E1** and **Table E2**, **Appendix E**). The average loss of final syrup for a flavour change was determined for each production line (**Table E1**and **Table E2**, **Appendix E**) and was used to determine an estimate of the monthly volume of final syrup to drain (**Table E3**, **Appendix E**).

The measurements were taken only on the day shift (within working hours) for 16 consecutive flavour changes. Each production line is controlled by its own operator during each shift. It is shown that there exists a large variation of losses for each flavour change where no losses are observed for some production lines at specific flavour changes (**Figure 17**). Significant losses were observed for Production Line 3 and 1 with maximum loss of 31.1 L and 14.8 L respectively (**Table E1**, **Appendix E**). Production Line 2 has a maximum loss 1.8 L (**Table E1**, **Appendix E**) which is just a fraction of the losses experienced on Production Lines 3 and 1, although they comprise of the same standard of technology. This shows that the system is not operating as intended most likely as a result of a lack of control. The large fluctuation in losses can therefore be associated with a lack of staff training or staff negligence. The final syrup and simple syrup solutions are 48 ^{o}Brix solutions which has a COD of approximately 656 g/L, hence minor losses of these syrups have the potential to increase the effluent COD significantly.

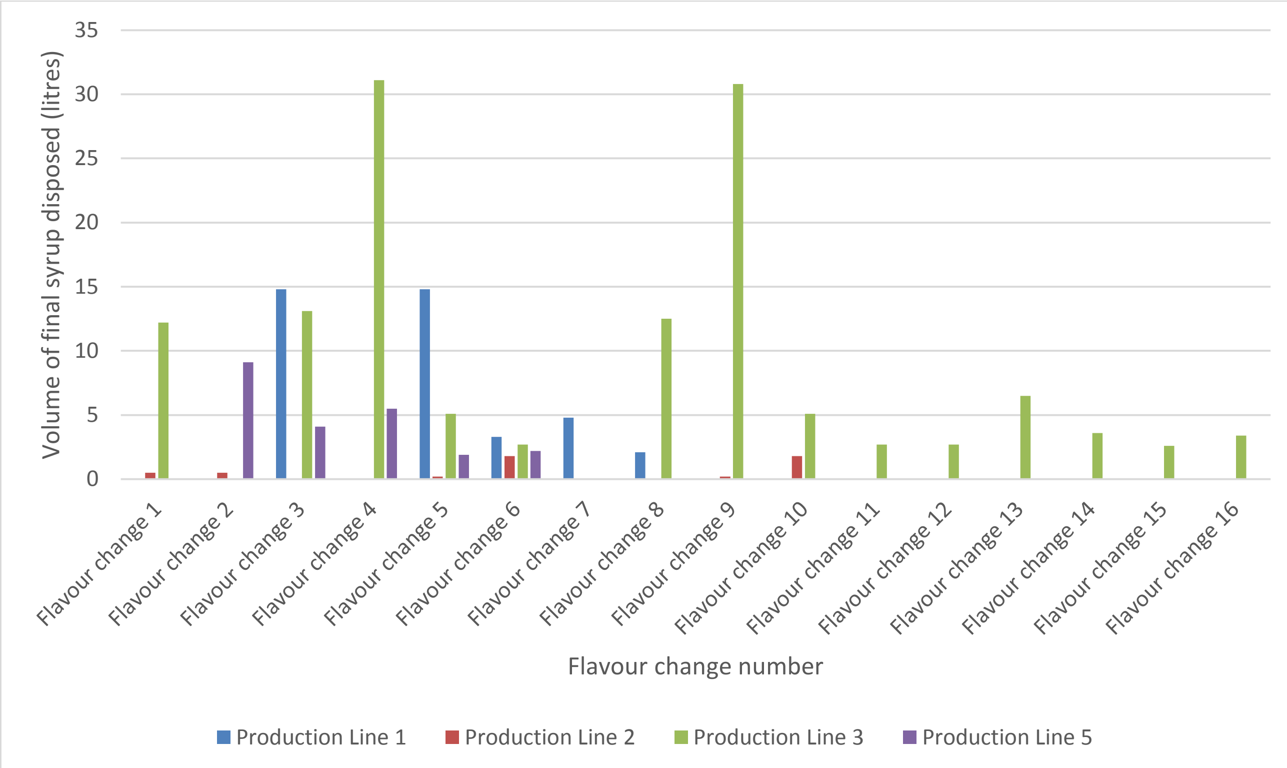


FIGURE 17: QUANTIFICATION RESULTS OF FINAL SYRUP DISPOSED FROM THE FINAL SYRUP BUFFER TANK OF EACH PRODUCTION LINE.

(ii) Simple syrup losses

The simple syrup losses were also quantified by collecting and measuring the remaining simple syrup drained before the 5-step CIP for nine consecutive weeks. The results of these measurements are shown in **Table E4** in **Appendix E**. The source of the simple syrup occurs from each of the following unit operations:

- Simple syrup buffer tanks (E-1 and E-2)
- Simple syrup tanks of each production line (E-10 – E-15)

Only one syrup mixing tank is operational (E-7) while the other remains on standby as a back-up or fail safe. It should be noted that the simple syrup mixing tanks are conical-bottomed and therefore all the simple syrup is removed from the simple syrup mixing tanks (E-7 and E-8) to the simple syrup tanks (E-1 and E-2). Therefore no losses occur at these mixing tanks (E-7 and E-8).

Weekly simple syrup losses that occur during the first step of the 5 step CIP (**Section 5.3.2.1**) could not be quantified as information was not provided due to the proprietary nature of this business.

Throughout the 9 week period during which the quantification occurred, all production lines were operational. The weekly simple syrup losses vary significantly with a minimum of 72.7 L to a maximum of 332.2 L (**Figure 18**). This indicates that the system is not operating as designed. The reason for the large difference in the results is an excess of simple syrup is being produced (more than the required amount) which cannot be used to produce soft drink, hence it has to be disposed during the 5-step CIP.

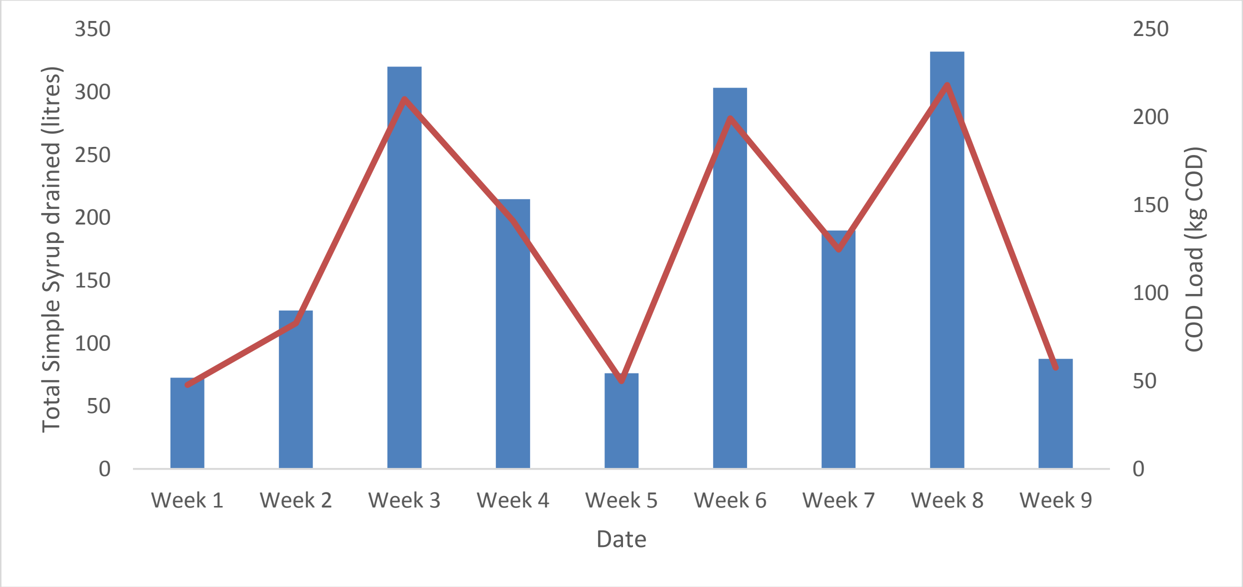


FIGURE 18: SIMPLE SYRUP LOSSES QUANTIFICATION RESULTS AND COD LOAD OF THE LOSSES.

(iii) Dumped batches

Historical data from the QA and QC department regarding the details of the dumped batches for the year 2013 (**Table E5**, **Appendix E**) was used to estimate the quantity of final syrup disposed to drain from these departments.

(iv) Post sanitation losses

Post sanitation losses vary depending on the skill, care or ability of the operator. The operators are instructed to allow 10% of the volume of the drink mix tank to discharge to drain so as to displace the CIP rinse water from the pipes. During site inspections it was observed that the losses varied from 10% to 15% of the volume of the drink mix tank of each production line. In order to obtain a more accurate estimate interviews were conducted with all line operators. A prudent estimate of 10% of the drink mix tank (E-53 – E-58) was established to be most commonly dumped to drain. The following data were also required in order to quantify the waste generated at this point:

- The number of flavour changes that occurred for a representative month (**Table E6**, **Appendix E**).
  - This was collected from the production department
- The volume of the drink mix tank of each line (**Table E7**, **Appendix E**)
  - This was obtained from the documentation of equipment

(v) Standard operating procedure losses

Standard operating procedure losses were quantified by using the following information:

- Production schedules for the representative weeks which contained information regarding the number of batches produced and the production used to produce that specific batch for the required weeks, as well as the packaging size of the final product for each batch, for each production line. (**Table E8**, **Table E9**, **Table E10** and **Table E11 in Appendix E**).
  - This information was obtained from the production department
- The number of filler nozzles (heads) for each filling machine of each line (**Table E12**, **Appendix E**).

  - This was collected from the Engineering and maintenance department

(vi) Quality assurance and Quality control losses

The samples taken by the QA & QC departments are as follows:

- The QA and QC departments endeavour to sample two bottles each from all production lines every 1 hour and 45 minutes respectively.
- Three units per batch are retained for microbiology
- One unit per batch is retained for sensory evaluation

Information regarding the number of batches produced on each production line for three consecutive weeks (**Table E19**, **Table E20**, **Table E21** and **Table E22 in Appendix E**) as well as the time taken to complete the batches (**Table E13**, **Table E14**, **Table E15**, **Table E16**, **Table E17** and **Table E18 in Appendix E**) were collected from the Production Department and utilized to quantify this type of loss.

(vii) Under-fills and Over-fills

The quantification of the Under-fills and Over-fills (**Table E23**, **Appendix E**) was accomplished with staff cooperation, by placing forms at the decanting stations of each production line for a month. These forms were then completed by the personnel responsible for performing the manual checks on the bottled product and disposing of them.

(viii) Filler bowl losses:

Filler bowl losses were also quantified also with the help of the line operators, who were responsible for completing forms placed at the filling machine of each production line. The quantity of residual RTD (displayed as a percentage of the volume of the filler bowl) was recorded for every flavour change that occurred for a week (**Table E24**). The average loss per flavour change was determined for each production line (**Table E24**) using the volumes of the respective filler bowls (**Table E25**) and an estimate of the monthly loss to drain was calculated based on the production schedule figures (**Table E26**).

(ix) Summary of waste quantification

A summary of the quantification of the sources of waste (**Section 5.3.2.3**) is shown in Table 9.

TABLE 9: QUANTIFICATION OF WASTE SOURCES.

Type of loss	Quantity to drain (litres/month)	COD (mg COD/litre)	COD load (kg COD/month)
Final Syrup losses	1 405	656 925	923
Dumped batches	1 175	656 925	772
Simple Syrup losses	763	656 925	501
Post Sanitation losses	27 600	141 005	3 892
SOP losses	26 720	141 005	3 768
QA and QC losses	13 133	141 005	1 852
Under-fills and over-fills	9 450	141 005	1 332
Filler Bowl Losses	1 416	141 005	200
Total	81 662		13 240

(x) Valuation of the quantified waste

The main components of the effluent leaving each of the waste source were determined using the information from the recipes for the final product and a cost associated with it as shown in Table 10. The cost of sugar is R6.85 per kg and that of water is R14.59 per kL, while the effluent disposal cost is calculated at R1.56/kL.

TABLE 10: COST OF PRODUCT AND PRIMARY RAW MATERIALS TO DRAIN FROM THE VARIOUS WASTE SOURCES IDENTIFIED PER MONTH.

Type of loss	Sugar content (kg/mth)	Water content (kL/mth)	Cost of sugar (R/mth)	Cost of water (R/mth)	Effluent disposal cost (R/mth)	Product value (R/mth)	Total value of waste (R/mth)
Final Syrup losses	822	0.6	5 629	9	1 436	28 091	35 165
Dumped batches	738	5.2	5 504	75	1 289	117 500	123 918
Simple Syrup losses	446	0.3	3 056	5	779	15 250	19 090
Post Sanitation losses	3 466	24.3	23 743	354	6 056	110 400	140 552
SOP losses	3 356	23.5	22 986	343	5 682	106 880	136 071
QA and QC losses	1 649	11.6	11 298	169	2 881	52 533	66 880
Under-fills and over-fills	1 187	8.3	8 129	121	2 073	37 800	48 124
Filler Bowl Losses	178	1.2	1 218	18	311	5 665	7 212
Total	11 841	69	81 112	1 095	20 688	474 119	577 014

5.3.3 STEP 4: OPTION GENERATION

Option generation entails developing solutions that will either eliminate or reduce the generation of wastes or emissions. Two types of solutions were developed which are categorised as either end-of-pipe treatment or source elimination/reduction. Only where source elimination or reduction techniques could not be implemented, were end-of-pipe treatment options considered.

5.3.3.1 SOURCE ELIMINATION/REDUCTION TECHNIQUES:

Source elimination techniques are the most favoured as they maximise production without requiring more raw materials. These techniques intend to reduce, eliminate or prevent the generation of waste at source. Source elimination or reduction techniques are explained below and can be applied to the following types of losses:

5.3.3.1 a) Post sanitation losses

Post sanitation losses occur with the purpose of removing any water remaining in the pipework after the CIP has occurred, resulting in monthly product losses of 26 720 L of 12 ^{o}Brix product. A pigging system could be installed to virtually eliminate all current post-sanitation product losses. A pigging system can be easily implemented in the factory as it meets all the criterion for the application of pigs (**Table 2**). A pig is a plug made of materials that are tough and flexible. It fits into the pipework through which it is propelled, thereby emptying the pipes of any residual content, by pushing the liquid through the pipe (Section 2.3). To eliminate post sanitation losses, the pigging system should be activated immediately after the CIP occurs, hence removing any remaining water in the pipe, and allowing for an additional 26 720 L of soft drink to be bottled and sold, reducing the sugar loss to effluent by 3 466 kg/month. This pigging system also allows for quicker product changeovers and reduces the quantity of water used in the cleaning process (CIP).

5.3.3.1 b) SOP losses

SOP losses occur due to the need to maintain product quality. According to the SOPs of Company A, it is mandatory to dispose of the first two revolutions of bottles filled by the filling heads in the filling machine. Although the first two revolutions of bottles filled are disposed, they are still examined by the QA and QC department to ensure that the subsequent product is of the required standard. It is recommended that the first revolution of bottles are discharged to drain as before and that a bottle from the second revolution of bottles filled be sampled and tested by the QA and QC departments. If these products meet the required standards, they should not be disposed of but rather allowed to reach the consumer. In doing so, it is estimated that the COD load could be reduced by 1 678 kg sugar per month and an additional 13 800 L of soft drink could be bottled as final product.

5.3.3.1 c) Under-fills and Over-fills

Excessive Under-fills and Over-fills are caused by the wearing away of the dummy rubbers on the filling valves of the filling machines (E-20, E-31, E-42, E-53, E-64 and E-75). It is therefore essential that regular maintenance be performed on the filling machine and that spare dummy rubbers be stocked in-house due to their scarcity locally.

5.3.3.1 d) Final syrup losses

The final syrup losses occurring at the final syrup drink mix tanks (E-47 to E-52) of each production line remains unchanged. This type of loss can be reduced by altering the settings of the drink mix system of each production line. As shown in **Table E1 in Appendix E** the quantities drained for production line 1, 2 and 3 vary although the production lines are technically similar. By communication with the production foreman and other production line operators it has been established that the settings of the drink mix section of the production lines have been altered by factory staff. By changing the settings of production lines 1 and 2, making them similar to that of production line 3, a loss equal to that of production line 3 (3 L per flavour change, **Table E2 in Appendix E**) can be easily achieved. This would result in a decrease of 573.5 kg O_2 per month and savings of 873 L of final syrup monthly, hence an additional 4 365 L could be sold as final product. Ideally the settings of the drink mix section of each production line should be altered in such a manner, that the pump that controls the flow of syrup to the proportioner, only switches off once the level of the final syrup in the final syrup drink mix tank has reached a minimum, therefore, ensuring minimum loss.

The final syrup losses at the final syrup buffer tank (E-16 to E-27) of each production line occur as a result of a lack of staff training or staff negligence. Staff negligence is a management issue that should be addressed through a continuous appraisal programme that entails monitoring, assessing and improving. Monitoring will involve implementing a measurement system to measure the loss of final syrup (or any other loss) which can then be used as benchmarks to monitor staff performance. With staff cooperation and by equipping staff with the necessary skills, virtually all of these losses can be eliminated. It is recommended that production line operators ensure that the syrup within the final syrup buffer tank (E-16 to E-22) is completely depleted before halting production. This is achievable as, at specific flavour changes, no loss occurred from each of the final syrup buffer tanks (**Table E2**, **Appendix E**). This would result in a small reduction of 9.95 kg sugar per month and savings of 17 L of final syrup monthly.

5.3.3.1 e) Simple syrup losses

The simple syrup losses occur once a week before the 5-step CIP. The sources of the simple syrup losses are the simple syrup buffer tanks (E-1 and E-2) and simple syrup tanks of each production line (E-10 – E-15). There are large variation in results (**Table E4**, **Appendix E**) with weekly losses of simple syrup varying from 73 L to 332 L. This also indicates that there is a lack of control. This matter was further investigated and it was found that one shift before the weekly 5 step CIP occurs, the quantities of simple syrup being produced was vastly in excess of that required for production purposes. In order to perform the 5 step CIP the unused simple syrup has to be discarded. If the quantity of simple syrup required for production is calculated using the production plan, and only the requisite amount is produced, this loss could be eliminated altogether, thereby reducing the effluent load by 500.9 kg O_2 per month and saving 3 813 litres of 12 ^{o}Brix product. An alternate solution is to install a storage vessel which functions as an intermediate storage tank, where the excess syrup can be temporarily stored instead of being disposed of before the 5 step CIP.

5.3.3.2 END-OF-PIPE TREATMENT

The three possible end-of-pipe treatment options were identified; (i) the transportation of high strength COD effluent to an anaerobic digester at a municipal wastewater works, (ii) the installation of an on-site anaerobic digestion and (iii) implementing a buffer system.

5.3.3.2 a) Transportation of high strength effluent for co-digestion

This option entails the segregation and collection of high strength COD effluent and the transportation of this effluent to a waste water treatment works in close proximity to Company A. This high strength effluent is to be utilized in the anaerobic digester which will result in the production of methane. eThekwini municipality have put incentives in place to encourage the disposal of high strength effluent into the digester. The digester has a volume of approximately 2 000 m^3 and has the potential to accept 1 800 kg COD per day. In order to collect this high strength effluent, these effluent streams need to be segregated from the low strength COD effluent at Company A. As outlined previously three primary types of high strength COD effluent are generated within this factory namely; simple syrup, final syrup and RTD. Both the simple syrup and final syrup are 48 ^oBrix solutions and have a COD loading of 656.93 g O_2 per L. The RTD is a 12 ^oBrix solution and has a COD loading of 141 g O_2 per L. The sources that generate this effluent have already been identified and discussed in detail. There currently exists two main drains within the production facility (**Figure 7**).

It is recommended that two new drains be installed adjacent to the existing Drain 1 and Drain 2, as shown as proposed Drain 3 and proposed Drain 4 in **Figure E1**. Currently the final syrup and simple syrup are drained from their respective sources onto the factory floor and flow into one of the existing main drains (**Figure 7**). It is also recommended that piping systems be installed from these respective sources to either of the proposed drains (**Figure E1**). The drainage lines of the decanting stations (**Figure 7**) and QA and QC Laboratories (**Figure 7**) could be rerouted to either of the proposed drains as shown in **Figure E1**.

After the 3 step CIP occurs a certain amount of RTD product is dumped in order to remove any residual water in the pipelines. During this process the RTD product (which is a 12 ^oBrix solution) is used as the water chaser resulting in some mixing of product and water at the interface. Initially all the water remaining in the pipeline exits the drainage line followed by a mixture of water and RTD, then RTD. To segregate the these post sanitation losses it is recommended that Drainage lines D-107, D-112, D-121 and D-124 be reconfigured as shown in **Figure E1** to redirect the high strength effluent to either of the proposed Drains 3 or 4 (**Figure E1** and **Figure E2**). On the existing drainage lines D-107, D-112, D-121 and D-124 (**Figure 7**), a coriolis density meter coupled with an automatic three-way valve should be installed at the source of the effluent. A sump should be used to temporarily collect the high strength effluent, thus allowing the usage of a float-actuated pump, to transport the effluent to a storage tank. This will provide on-line monitoring of the sugar content of the effluent. The function of the density meter is to allow the segregation of the effluent by toggling the aforementioned three-way valve. The density meter will thus prompt the valve to allow flow through the proposed drainage lines D-107, D-112, D-121 and D-124 (**Figure E1**), via the proposed drains 3 and 4,upon the detection of a high strength effluent stream (above set-point). The storage facility is located outside the facility enabling easy transferal of the effluent into the tanker (**Figure E1**). Under conditions of a low strength effluent stream, the three-way valve will allow all effluent to be disposed of into the existing drainage lines D-107, D-112, D-121 and D-124 (**Figure 7**) and subsequently into the municipal drainage system.

5.3.3.2 b) On site anaerobic digestion

The anaerobic treatment system utilizes a combination of microorganisms including acetogens and methanogens, which are responsible for breaking down complex organics into volatile fatty acids (VFAs), followed by conversion into CO_2 and methane respectively. Anaerobic digestion is carried out in a specifically designed reactor.

Results from sampling procedures conducted at Company A indicate that the process should begin with pre-screening of the effluent to remove large debris items (such as caps), which could block effluent plant auxiliary equipment. Effluent is then directed into an agitated buffer tank that serves to provide a more uniform inflow to the reactor, and to partially acidify the effluent. This in turn provides a more even operation in the reactor, and a superior sludge quality. The screened wastewater flows from the buffer tank into the bottom of the reactor through a distributor, which allows for the wastewater to rise through a region of active sludge under anaerobic conditions. A separator at the top of the reactor separates the suspended solids, liquids and biogas. The biogas may be used directly, upgraded or discharged into the atmosphere. The high COD removal (up to 98%) allows for discharge of the clarified waters into surface waters or reuse.

5.3.3.2 c) Buffer system

The proposed buffer tank system serves the purpose of smoothing out the variances in the pollution load or COD concentration of the effluent which occurs as a result of intermittent discharges of high-strength effluent (high concentrations of syrup or detergents). This system facilitates a controlled discharge of effluent with a constant pollution load which allows for easier treatment of the effluent.

(i) Proposed buffer system 1

Figure 19 depicts a control system for proposed system 1. The coriolis meter measures the density of the effluent exiting the buffer tank, while the recycle system promotes intimate mixing, thereby reducing the possibility of concentration gradients developing within the buffer tank, and eliminating the need for mechanical agitation. A maximum-level override protection system ensures that, in the event of a large high-strength effluent inflow into the buffer tank, the possibility of tank overflow is eliminated. The set point of the buffer outlet valve is set by a computational algorithm, utilizing inputs from the low-strength effluent density meter and flow meter, and the buffer tank outlet coriolis meter. In this way, the final (combined) effluent COD can be tightly controlled to maintain a reliable estimate of the average COD.

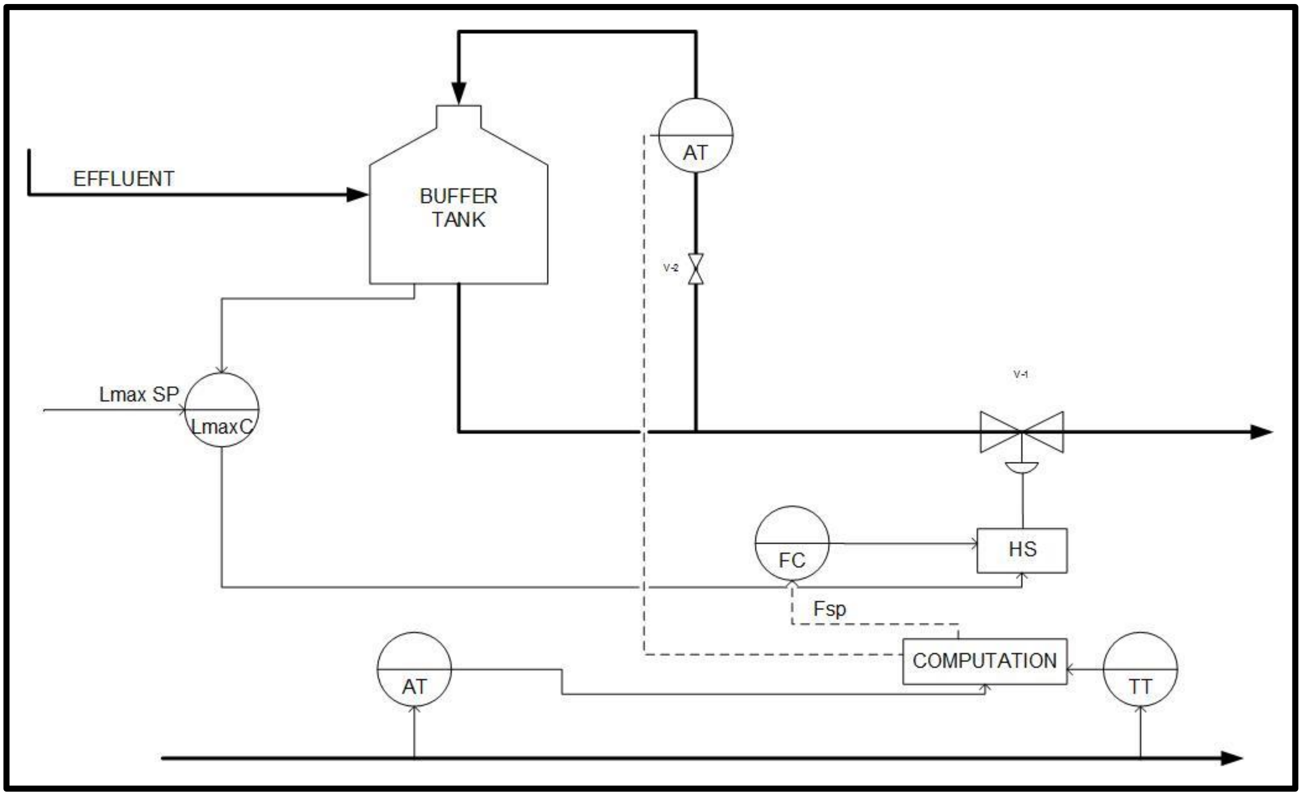


FIGURE 19: PROPOSED BUFFER SYSTEM 1.

(ii) Proposed buffer system 2

The high strength effluent is temporarily stored in the buffer tank (E-1, **Figure 20**) and the low strength effluent stream is the uncontrolled stream and flows uninterrupted. The proposed buffer system 2 (**Figure 20**) consists of a small effluent sump which is used for measurement purposes. The coriolis meter (CM) continuously measures the concentration of the mixed effluent in the sump and has the function of controlling or setting the position of the valve on the exit stream P-2 of the buffer tank in order to obtain the desired COD concentration. If the concentration measured in the measurement sump is lower than the required concentration, the valve V1 will open, increasing the flow of the high strength effluent. The low level controller (LminC) and high level controller (LmaxC) ensure that a specified minimum level and maximum level in the buffer tank is maintained. The purpose of maintaining a minimum volume in the buffer tank is to provide some residual capacity.

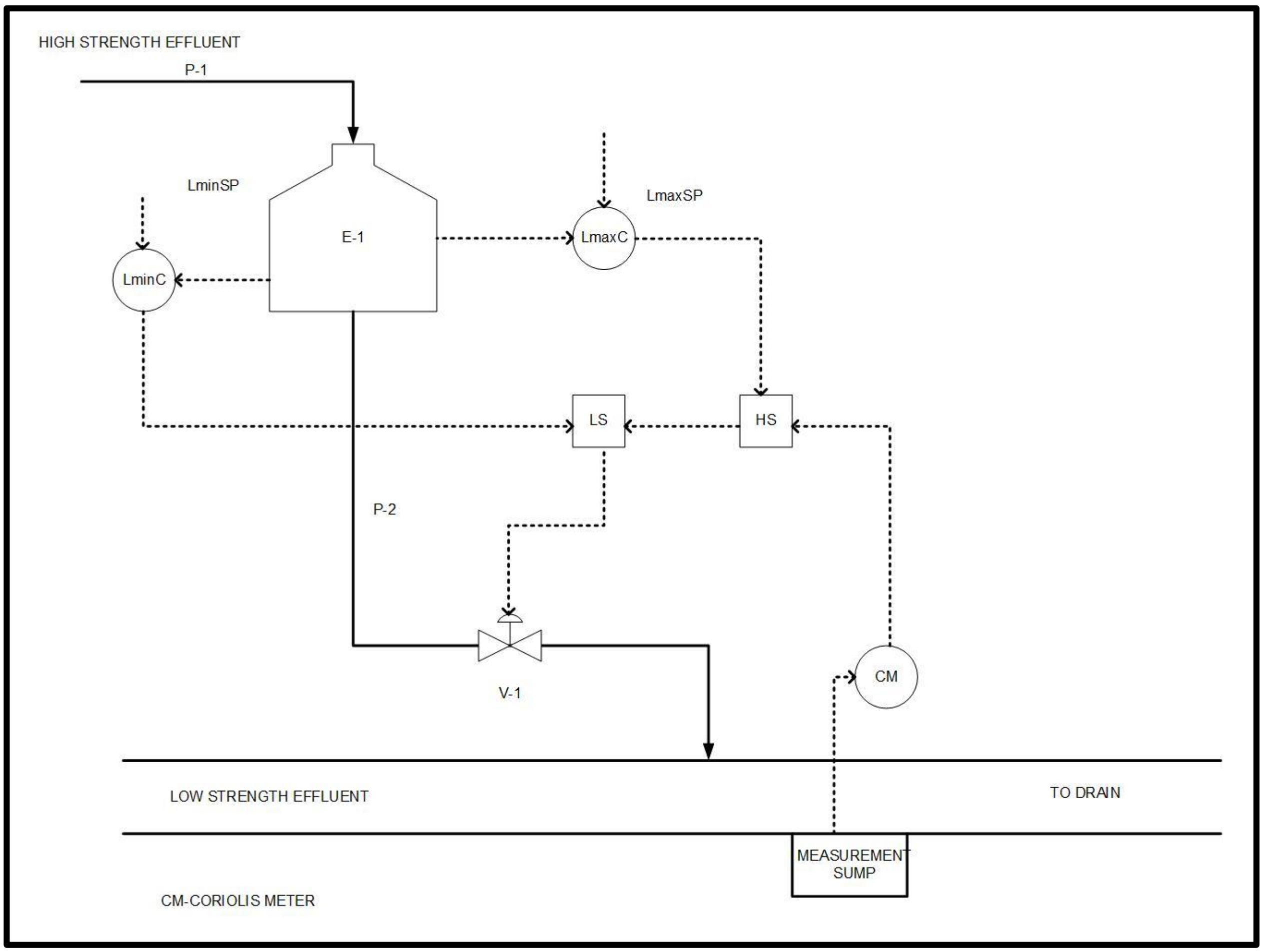


FIGURE 20: PROPOSED BUFFER SYSTEM 2.

This depends on the tank capacity, and the rates of change of the inflow concentration/flow to that tank.

5.3.4 STEP 5: FEASIBILITY ANALYSIS

The final stage in the selection of the options focuses on analysing the options from an environmental perspective.

The environmentally optimum solution consists of a combination of the options generated and prioritizes the reduction of waste at source rather than end-of-pipe treatments. This entails the implementation of source elimination or reduction techniques to increase materials efficiency by transforming waste into final product. To deal with the inevitable losses (QA and QC losses, filler bowl losses and part of the SOP losses), effluent segregation techniques should be utilized, where the high strength effluent should preferably be transported to the anaerobic digester at the local municipality (eThekwini Municipality) where energy will be produced. The less environmentally friendly alternative is that the high strength effluent be transferred to either of the proposed buffer systems and into the municipal sewage system.

The implementation of the optimum solution would result in:

- enhanced sustainability and profitability of the business,
- a reduction in the impact of the company's activities on the environment,
- improved competitiveness in the market place,
- higher output per unit input,
- a reduction in production cost per unit,
- a reduction in the volume of waste, hence lower treatment and disposal costs,
- Improved public image for the company,
- effective employee motivation as a result of improved working environment and motivation.

Chapter 6: CONCLUSIONS

The objectives of this thesis were given in Section 1.1. The main focus of this thesis was reducing the environmental impact of soft drink manufacturing plants.

These objectives were achieved by the implementation of the 5-step RECP assessment methodology combined with the methodology to improve materials efficiency. These methodologies were then applied to a privately owned beverage company with the primary focus being to improve the quality of the final effluent. This company was consistently out of specification with respect to COD, sugar concentration and pH value of their effluent, resulting in trade effluent charges in excess of R 70 000 per month. During the study at this company a process flow diagram and a site drainage plan were prepared. Thereafter, the effluent sources were identified, quantified and a cause diagnosis was performed on each of the effluent sources to determine the factors influencing them.

A global sugar balance and the collection and laboratory testing of effluent samples confirmed that the primary component influencing the COD of the effluent is sucrose. Two types of high COD effluent in the form of liquid wastes that are produced from the process were identified. These are syrup solutions of 48 ^{o}Brix (656 925 mg O_2/L) and 12 ^{o}Brix (141 005 mg O_2/L) and were quantified to contribute 3 343 L and 78 319 L to the effluent per month respectively. The total approximate cost of the quantified losses is valued at R 577 000 per month. Approximately 11% of the identified losses occur as a result of staff negligence or a lack of staff training and 29% occur due to less frequent testing of the second revolution of bottles filled at the beginning of each batch.

Solutions to reducing the COD content of the effluent were developed in the categories of source elimination or reduction and end-of-pipe treatment. Source elimination or reduction included the use of a pigging system, regular maintenance of equipment and improving staff scheduling. End-of-pipe treatment included the transportation of high strength effluent for co-digestion, on-site anaerobic digestion and the implementation of a buffer system. A feasibility analysis from an environmental aspect was performed on the generated solutions and the environmentally optimum solution recommended. The optimum solution consists of a combination of all source elimination and reduction techniques and one of the end-of-pipe treatments (transportation of high strength effluent for co-digestion where energy will be produced in the form of methane). The implementation of this environmentally optimum solution has the potential to reduce the COD load of the effluent to the wastewater works by 13 240 kg COD/month and a large portion of this waste could be transformed into final product of approximately 52 000 L/month. The transformation of this waste into final product results in increased materials efficiency and profitability. The ongoing application of the RECP concept could help further reduce the strength and volume of the effluent, resulting in further cost savings and limiting environmental damage, leading to sustainable development.

As shown in this thesis, the implementation of RECP results in water, effluent and cost savings, as well as a minimisation of waste produced. RECP is a globally proven approach, however, there are certain limitations, or barriers, in the implementation of this concept within industry, such as; a lack of time, withholding of information and data, lack of commitment and lack of resources. Some of these barriers were experienced during this investigation, particularly the lack of information and data. However, the unwavering commitment of factory management allowed for the concept to be easily accepted by other staff members thus ensuring their cooperation.

The eThekwini Municipality is the legislative authority within the Durban region and is at the forefront of change for the preservation of the environment. As discussed in Section 3.4, legislation has been developed by the eThekwini municipality in the form of by laws which regulates the discharge of industrial effluent. This municipality encourages RECP as a means of reducing effluent concentrations and maintains good relationships with industries in order to find sustainable solutions. eThekwini Municipality has also embarked on a joint project with the University of KwaZulu-Natal to treat high strength effluent through the use of co-digestion (Section 2.2.3).

Despite environmental pressure from legislative authorities and RECP being a globally proven concept that results in both economic and environmental gains, the experience from this case study is that it is still a concept that has achieved limited application within South African industry due to a lack of knowledge and understanding. The National Cleaner Production Centre of South Africa

(NCPC-SA) is a government backed programme that aims to overcome the limitations in the implementation of RECP, by providing RECP-related services to industries at little or no cost.

Chapter 7: RECOMMENDATIONS:

There are two types of recommendations relevant to this study; (i) environmental improvement recommendations for Company A to improve their raw material consumption and waste generation and (ii) recommendations for future RECP investigations to be conducted.

KEY RECOMMENDATIONS FOR FUTURE RECP INVESTIGATIONS:

- Ensure the commitment of senior management is obtained, by emphasizing the economic advantages of RECP. This will aid in attaining the required information from the company to conduct the study.
- Request a confidentiality agreement to be drafted and signed by the person conducting the study in order to gain easier access to information.
- Select a project team that consists of people from various disciplines which have sufficient authority to implement and maintain the recommended changes. Maintaining relations with all team members is vital in developing solutions.
- Have regular feedback meetings to update management and to maintain the momentum of the project.
- Target low cost or no-cost opportunities before more financially intensive options. After these opportunities are implemented successfully, the results will encourage the implementation of other more financially intensive options.
- Information should be shared with all relevant stakeholders.
- Monitoring should occur frequently (daily, weekly or monthly).
- Site visits should not interfere with daily operations in any way. Any recommendations should be compiled into a report for submission to senior management.
- Collect data from staff on a day-to-day basis in order to ensure that further techniques to improve the efficiency of the process can be easily developed.
- Elicit comments and feedback from staff, and implement monitoring and appraisal systems for staff.

RECOMMENDATIONS FOR COMPANY A

- The implementation of the optimum solution entails implementing all identified source elimination and reduction techniques and the transportation of the high strength effluent to an anaerobic digester at a nearby wastewater treatment works.
- A feasibility analysis from an economic perspective should be conducted.
- Regular maintenance should occur on the filling machine and spare dummy rubbers should be stocked as they are not readily available locally.
- The issue of staff negligence should be addressed by management through a continuous appraisal program that entails monitoring, assessing and improving.
- Personnel from the QC department should accompany the person adding ingredients to the simple syrup to minimize the risk of adding incorrect ingredients added which could result in dumped batches.
- Install automatic timers on each production line to optimize the water used in the rinse phases of the CIP processes.
- Final rinse water of the CIP process should be stored temporarily to be used for housekeeping operations.
- Install spray nozzles with automatic shutoffs that are properly sized and well aligned to distribute the required amount of conveyor chain lubricant. Excess should not be used.
- A flow meter should be installed at the effluent outlet.
- Time proportional sampling instead of the current grab sampling procedure should be conducted by eThekwini municipality in order to obtain a more accurate representation of the wastewater characteristics.
- A coriolis meter should be installed before the filling machine of each production line to reduce the uncertainties in the sugar balance.
- Train workers in correct use of machinery to avoid generation of effluent at source.
- Investigate the use of brown sugar for dark coloured soft drinks as brown sugar is significantly less expensive.

Recommendations to achieve water conservation thereby reducing the effluent volume

- Implement a maintenance program that gives priority to the repairs of water leaks.
- Install pressure operated nozzles on all water hoses to prevent the hoses from running without operator involvement.
- Reduce the use of hose pipes by using squeegees and hard brooms.
- Automatic shut-off valves and high pressure, low-volume jets for hose pipes should be utilized to reduce water consumption.
- Staff training and awareness programs should be implemented with the focus of creating awareness among the employees on the impact of the effluent, how to handle wastes and reduce them at source.
- Collect water from the final rinse of the CIP and use it for the pre-rinse in the CIP process.
- Storm water collection to be used for non-product areas of the bottling plant, such as irrigation or truck washing.
- Fit meters to measure the water use for individual high consumption process areas.
- Develop an environmental management system.
- Replace the spray ball static tank washers with high-pressure, low-volume rotating tank washers which will wash the residual product down the sides reducing the amount of water required.
- Optimise backwash cycles on sand filter and carbon filters. Install backwash recovery system in the water treatment plant to direct the initial flush to drain while the rinse phase would return to a raw water tank.
- Frequent and simple water monitoring techniques should be implemented in the water intensive areas of the plant to assist in monitoring of water usage and to provide information regarding the state of equipment e.g. pipes, taps and valves.

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APPENDIX A: EFFLUENT BILL ANALYSIS

TABLE A1: MONTHLY WATER CONSUMPTION AND TRADE EFFLUENT CHARGES.

Date	Water consumption (kL)	Trade eff Charges (Rand)
Mar-13	20 315	27 291
Apr-13	18 232	24 491
May-13	14 902	20 018
Jun-13	8 985	12 070
Jul-13	11 327	36 835
Aug-13	15 379	50 012
Sep-13	17 321	56 328
Oct-13	21 396	69 580
Nov-13	22 539	73 295
Dec-13	15 729	51 151
Jan-14	14 451	46 993
Feb-14	19 821	64 459

APPENDIX B: OUTPUTS

TABLE B1: MONTHLY PRODUCTION FIGURES.

Date	Production (L)
Mar-13	13 450 316
Apr-13	11 862 230
May-13	7 937 546
Jun-13	5 744 016
Jul-13	7 023 344
Aug-13	10 968 365
Sep-13	9 572 834
Oct-13	17 340 689
Nov-13	17 199 648
Dec-13	10 583 055
Jan-14	8 590 114
Feb-14	14 136 397

TABLE B2: MONTHLY PRODUCTION VOLUME AND AVERGAE TEMPERATURES OF SOUTH AFRICA (THE WORLD BANK GROUP, 2014).

Date	Production Volume (L)	Average monthly temperatures of South Africa (^{O}C)
Mar-13	13 450 316	21,6
Apr-13	11 862 230	18,6
May-13	7 937 546	15
Jun-13	5 744 016	12,1
Jul-13	7 023 344	11,8
Aug-13	10 968 365	13,7
Sep-13	9 572 834	16,7
Oct-13	17 340 689	19,3
Nov-13	17 199 648	20,9
Dec-13	10 583 055	22,6
Jan-14	8 590 114	23,4
Feb-14	14 136 397	23,4
Total	134 408 555	

TABLE B3: ANNUAL PRODUCTION VOLUME AND SUGAR CONTENT FOR EACH FLAVOUR, COMPANY A.

Flavour	Annual Production Volume (L)	Sugar content (g/L)
1	35 571 130	125
2	18 872 832	124
3	8 674 187	118
4	8 645 594	125
5	6 496 422	114,5
6	6 326 447	120
7	6 026 656	125
8	5 209 677	130
9	3 933 344	120
10	3 768 317	118
11	2 899 233	124
12	2 915 138	118
13	2 171 582	130
14	1 756 832	125
15	1 746 377	118
16	323 010	120
17	300 214	121
18	271 931	120
19	227 770	105
20	250 787	130
21	230 691	110
22	223 710	105
23	186 405	110
24	122 616	145
25	119 100	135
26	131 802	110
27	122 018	110
28	77 424	150
29	71 703	130
30	68 985	139
31	58 268	110

32	24 816	54
33	57 593	110
34	11 772	54
35	6 048	105
36	12 420	54

APPENDIX C: SUGAR BALANCE

The following calculation was performed to find the COD contribution of the sugar:

The COD of sugar (sucrose) can be calculated according to the following equation:

$C_{12}H_{22}O_{11} + 12O_2 \rightarrow 12\ CO_2 + 11H_2O$

TABLE C1: MOLECULAR WEIGHTS OF COMPONENTS.

Component	Molecular weight (g/mole)
$C_{12}H_{22}O_{11}$	342
O_2	384

Assuming a quantity of 1 gram of sucrose is added to 1 L of water the COD can be calculated as:

$$1\ \frac{g}{L} \times \frac{384}{32\times 12} = 1.123\ \frac{gO_2}{L}$$

This value is also agreement with that of the literature (Htec Systems Inc, 2012).

Hence the following ratio is determined:

$$\frac{kg\ COD}{kg\ sugar} = 1.123$$

TABLE C2: SUGAR BALANCE AND COD LOADING.

Date	Sugar Usage (kg)	Sugar in Product (kg)	Sugar loss (kg)	COD load (kg COD)
Jan-13	1 499 752	1 480 425	19 327	21 704
Feb-13	1 328 247	1 333 869	-5 622	-6 314
Mar-13	1 622 002	1 629 835	-7 833	-8 797
Apr-13	1 430 899	1 439 891	-8 992	-10 098
May-13	976 395	962 950	13 445	15 098
Jun-13	737 819	688 715	49 104	55 144
Jul-13	881 992	856 236	25 756	28 924
Aug-13	1 393 180	1 338 198	54 982	61 745
Sep-13	1 154 270	1 157 498	-3 228	-3 625
Oct-13	2 077 839	2 094 925	-17 086	-19 188
Nov-13	2 074 747	2 105 741	-30 994	-34 807
Dec-13	1 331 234	1 275 010	56 224	63 140
Jan-14	1 066 708	1 039 981	26 727	30 014
Feb-14	1 712 231	1 729 021	-16 790	-18 855
Total	19 287 315	19 132 296	155 019	174 086

TABLE C3: QUANTIFICATION OF CONGLOMERATED SUGAR DISPOSED AS SOLID WASTE.

Day	Sugar disposed (kg)
1	0,00
2	0,00
3	19,89
4	0,00
5	16,22
6	18,10
7	0,00
8	0,00
9	37,58
10	22,46
11	0,00
12	17,01
13	0,00
14	14,20
15	0,00
16	0,00
17	0,00
18	0,00
19	6,98
20	23,06
21	11,68
22	14,88
23	0,00
24	0,00
25	0,00
26	6,28
27	17,11
28	45,06

29	25,06
30	4,46
31	0,00
	300,03

The Historic production figures have been submitted separately as an electronic copy on a CD.

APPENDIX D: CHEMICAL ANALYSIS

The raw chemical analysis data and the analysed data have been submitted separately as an electronic copy on a CD.

CHEMICAL ANALYSIS TEST METHODOLOGY:

The experiment performed at the factory entailed the collection of samples of the effluent from the municipal sampling point (**Figure 6**) in 15 minute intervals. The experiment continued for 8 days of production. These samples were then analysed for sugar concentration in order to predict the COD of the effluent.

TABLE D1: DATA ANALYSIS OF THE CHEMICAL ANALYSIS DATA.

Time interval (hours)	Standard deviation	Gradient
4	8,42	-
6	7,55	0,44
8	6,90	0,32
10	6,41	0,25
12	6,01	0,20
14	5,67	0,17
16	5,32	0,17
18	4,95	0,19

ETHEKWINI EFFLUENT TEST RESULTS:

TABLE D2: ETHEKWINI EFFLUENT LAB TEST RESULTS.

Date	COD (mg/L)
Jul-12	87 800
Aug-12	32 010
Sep-12	13 040
Oct-12	9 827
Nov-12	6 641
Dec-12	9 101
Jan-13	15 760
Feb-13	12 140
Mar-13	6 406
Apr-13	18 580
May-13	18 600
Jul-13	475
Aug-13	18 990
Sep-13	11 270
Oct-13	12 710
Nov-13	20 090
Jan-14	15 930
Feb-14	12 050
Mar-14	10 350
Apr-14	21 790
May-14	4 078

APPENDIX E: LOSS QUANTIFICATION DATA

TABLE E1: MEASURE VOLUME OF FINAL SYRUP DRAINED FROM THE FINAL SYRUP BUFFER TANK OF EACH PRODUCTION LINE.

	Production Line			
Flavour change	1 (L)	2 (L)	3 (L)	5 (L)
Flavour change 1	0,0	0,5	12,2	0,0
Flavour change 2	0,0	0,5	0,0	9,1
Flavour change 3	14,8	0,0	13,1	4,1
Flavour change 4	0,0	0,0	31,1	5,5
Flavour change 5	14,8	0,2	5,1	1,9
Flavour change 6	3,3	1,8	2,7	2,2
Flavour change 7	4,8	0,0	0,0	0,0
Flavour change 8	2,1	0,0	12,5	0,0
Flavour change 9	0,0	0,2	30,8	0,0
Flavour change 10	0,0	1,8	5,1	0,0
Flavour change 11	0,0	0,0	2,7	0,0
Flavour change 12	0,0	0,0	2,7	0,0
Flavour change 13	0,0	0,0	6,5	0,0
Flavour change 14	0,0	0,0	3,6	0,0
Flavour change 15	0,0	0,0	2,6	0,0
Flavour change 16	0,0	0,0	3,4	0,0
Average	4,0	0,4	8,4	3,8

TABLE E2: MEASURED VOLUME OF FINAL SYRUP DRAINED FROM FINAL SYRUP TANK OF THE DRINK MIX OF EACH PRODUCTION LINE.

Line Number	Quantity Drained (L)
1	20
2	5
3	3
5	2
Total	28

TABLE E3: FINAL SYRUP QUANTIFICATION AND FLAVOUR CHANGES FOR EACH PRODUCTION LINE.

Production Line	Flavour Changes				Monthly Flavour changes	Quantity to Drain (L)
	week 1	week 2	week 3	Weekly Average		
Line 1	17	5	11	11	44	176
Line 2	9	6	5	7	27	10
Line 3	13	13	15	14	55	461
Line 5	26	26	26	26	104	394
Total						1 041

TABLE E4: SIMPLE SYRUP QUANTIFICATION RESULTS.

Date	Quantity in simple syrup tank (L)							
	Line 1 (L)	Line 2 (L)	Line 3 (L)	Line 4 (L)	Line 5 (L)	Line 6 (L)	Buffer Tank (L)	Total (L)
Week 1	11,8	4,3	0,0	0,0	0,0	0,0	56,6	72,7
Week 2	9,2	7,0	16,4	0,0	0,0	0,0	93,5	126,1
Week 3	13,8	10,3	17,2	0,0	14,8	5,6	258,4	320,1
Week 4	2,9	0,0	84,1	0,0	3,0	0,0	124,7	214,7
Week 5	3,5	5,0	0,0	0,0	0,0	0,0	67,7	76,2
Week 6	69,1	0,0	105,0	0,0	0,0	0,0	129,2	303,3
Week 7	46,0	9,7	106,7	0,0	0,0	27,4	0,0	189,8
Week 8	51,2	0,0	0,0	0,0	0,0	0,0	281,0	332,2
Week 9	31,9	0,0	0,0	0,0	0,0	0,0	55,8	87,7
Total								1722,9

TABLE E5: QUANTIFICATION OF DUMPED BATCHES.

	Flavour	Volume of dumped batch (L)
1	1	3 600
2	5	3 600
3	11	6 900
Total		14 100

TABLE E6: NUMBER OF FLAVOUR CHANGES PRODUCED FOR A SINGLE MONTH FOR EACH PRODUCTION LINE.

Line Number	No of Batches
1	44
2	27
3	55
5	104
Total	230

TABLE E7: VOLUME OF THE DRINK MIX TANK OF EACH LINE.

Line Number	Volume of drink mix tank (L)
1	1 200
2	1 200
3	1 200
5	1 200

TABLE E8: NUMBER OF BATCHES PRODUCED ON PRODUCTION LINE 1.

	Product size	
Week	1,25 L	1,5 L
1	7	10
2	5	0
3	0	11

TABLE E9: NUMBER OF BATCHES PRODUCED ON PRODUCTION LINE 2.

	Product size		
Week	1,25 L	0,5 L	0,3 L
1	0	4	5
2	0	0	6
3	5	0	0

TABLE E10: NUMBER OF BATCHES PRODUCED ON PRODUCTION LINE 3.

	No of Batches
	Product size
Week	2 L
1	13
2	13
3	15

TABLE E11: NUMBER OF BATCHES PRODUCED ON PRODUCTION LINE 5.

Line Number	5
	No of Batches
	Product size
Week	2 L
1	26
2	26
3	26

TABLE E12: NUMBER OF FILLER NOZZLES (HEADS) IN EACH PRODUCTION LINE.

Production Line Number	Number of Filler Nozzles (heads)
1	40
2	32
3	40
5	54
Total	166

TABLE E13: TIME REQUIRED TO PRODUCE VARIOUS BATCH SIZES FOR 0.3 L PRODUCT, LINE 2.

Product volume (L)	0,3
Line Number	2
Blend Size (L)	Time required (hours)
1 200	2,7
3 600	8,0
4 800	10,7
7 200	16,0
9 600	21,3
15 000	33,3

TABLE E14: TIME REQUIRED TO PRODUCE VARIOUS BATCH SIZES FOR 0.5 L PRODUCT, LINE 2.

Product volume (L)	0,5
Line Number	2
Blend Size (L)	Time required (hours)
1 200	1,6
3 600	4,8
4 800	6,4
7 200	9,6
9 600	12,8
15 000	20,0

TABLE E15: TIME REQUIRED TO PRODUCE VARIOUS BATCH SIZES FOR 1.25 L PRODUCT, LINE 2.

Product volume (L)	1,25
Line Number	2
Blend Size (L)	Time required (hours)
1 200	1,0
3 600	3,0
4 800	4,0
7 200	6,0
9 600	8,0
15 000	12,5

TABLE E16: TIME REQUIRED TO PRODUCE VARIOUS BATCH SIZES FOR 1.5 L PRODUCT, LINE 2.

Product volume (L)	1,5
Line Number	2
Blend Size (L)	Time required (hours)
1 200	0,8
3 600	2,5
4 800	3,3
7 200	5,0
9 600	6,7
15 000	10,4

TABLE E17: TIME REQUIRED TO PRODUCEVARIOUS BATCH SIZES FOR 2L PRODUCT, PRODUCTION LINES 1,2 AND 3.

Product volume (L)	2,0
Line Number(s)	1,2,3
Blend Size (L)	Time required (hours)
1 200	0,6
3 600	1,9
4 800	2,5
7 200	3,8
9 600	5,0
15 000	7,8

TABLE E18: TIME REQUIRED TO PRODUCE VARIOUS BATCH SIZES FOR 2L PRODUCT, PRODUCTION LINE 5.

Product volume (L)	2,0
Line Number	5
Blend Size (L)	Time required (hours)
1 200	0,3
3 600	0,9
4 800	1,3
7 200	1,9
9 600	2,5
15 000	3,9

TABLE E19: PRODUCTION SCHEDULE LINE 1.

Product Volume (L)	**1,25**					
	Batch Size (L)					
Date	1200	3600	4800	7200	9600	15000
Week 1	2	1	-	3	-	1
Week 2	-	-	-	4	-	1
Week 3	-	-	-	2	-	9
Total	2	1	0	9	0	11
Product Volume (L)	**1,5**					
	Batch Size (L)					
Date	1200	3600	4800	7200	9600	15000
Week 1	-	-	-	8	-	2
Week 2	-	-	-	-	-	-
Week 3	-	-	-	-	-	-
Total	0	0	0	8	0	2

TABLE E20: PRODUCTION SCHEDULE LINE 2.

Product Volume (L)	**0,5**					
	Batch Size (L)					
Date	1200	3600	4800	7200	9600	15000
Week 1	-	1	3	-	-	-
Week 2	-	-	-	-	-	-
Week 3	-	-	-	-	-	5
Total	0	1	3	0	0	5
Product Volume (L)	0,3					
	Batch Size (L)					
Date	1200	3600	4800	7200	9600	15000
Week 1	-	-	2	3	-	-
Week 2	-	6	-	-	-	-
Week 3	-	-	-	-	-	-
Total	0	6	2	3	0	0
Product Volume (L)	1,25					
	Batch Size (L)					
Date	1200	3600	4800	7200	9600	15000
Week 1	-	-	-	-	-	-
Week 2	-	-	-	-	-	-
Week 3	-	-	-	-	-	5

TABLE E21: PRODUCTION SCHEDULE LINE 3.

Product Volume (L)	**2**					
	Batch Size (L)					
Date	1200	3600	4800	7200	9600	15000
Week 1	-	-	-	-	-	13
Week 2	-	-	-	-	-	13
Week 3	-	1	-	3	3	8
Total	0	1	0	3	3	34

TABLE E22: PRODUCTION SCHEDULE PRODUCTION LINE 5.

Product Volume (L)	**2**					
	Batch Size (L)					
Date	1200	3600	4800	7200	9600	15000
Week 1	-	-	-	-	-	26
Week 2	-	-	-	-	-	26
Week 3	-	-	-	-	-	26
Total	0	0	0	0	0	78

TABLE E23: UNDER-FILLS AND OVER-FILLS QUANTIFICATION RESULTS.

Production Line	Volume Decanted (L)
Line 1	3 000
Line 2	950
Line 3	3 500
Line 5	2 000
Total	9 450

TABLE E24: RAW DATA FOR PERCENTAGE REMAINING IN THE FILLER BOWL.

Flavour Change	Production Line 1 (% remaining)	2 (% remaining)	3 (% remaining)	5 (% remaining)
1	4	6	10	0
2	10	2	13	1
3	6	4	8	1,5
4	5	16	12	-
5	8	3	10	-
6	12	22	10	-
7	8	0	-	-
8	10	0	-	-
9	20	2	-	-
10	14	-	-	-
11	1	-	-	-
12	6	-	-	-
Average	8,67	6,11	10,50	0,83

TABLE E25: FILLER BOWL VOLUMES FOR EACH PRODUCTION LINE.

	Production Line			
	1	2	3	5
Filler bowl Volume (L)	117	117	117	117

TABLE E26: QUANTIFICATION OF FILLER BOWL LOSSES.

	No of Flavour Changes				
Production Line	Week 1	Week 2	Week 3	Weekly Average	Quantity to Drain (L)
Line 1	17	5	11	11	111,5
Line 2	9	6	5	6,7	47,7
Line 3	13	13	15	13,7	167,9
Line 5	26	26	26	26,0	25,4
Total	65	50	57	57,0	352,5

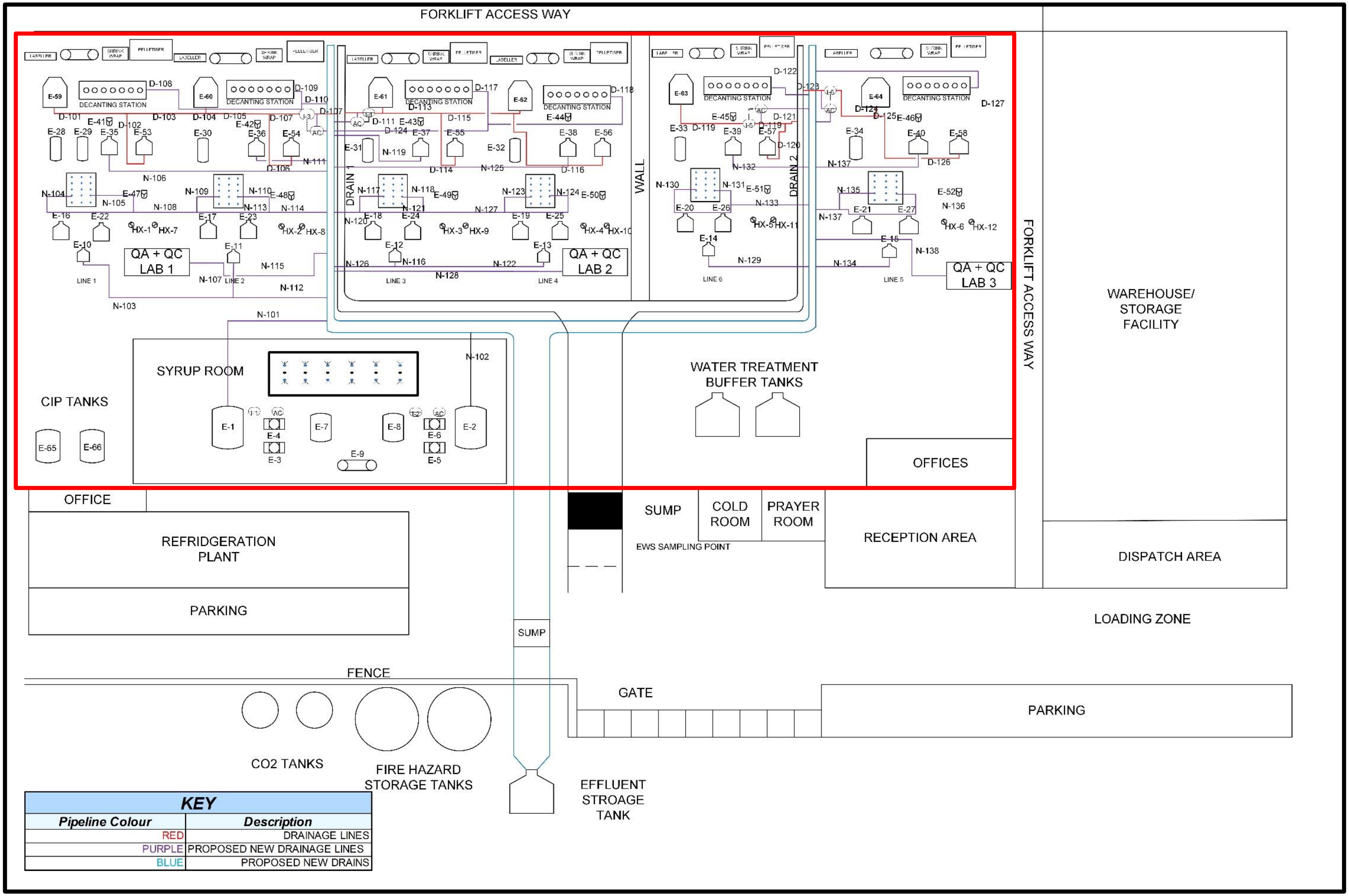

FIGURE E1: PROPOSED SITE DRAINAGE PLAN, COMPANY A.

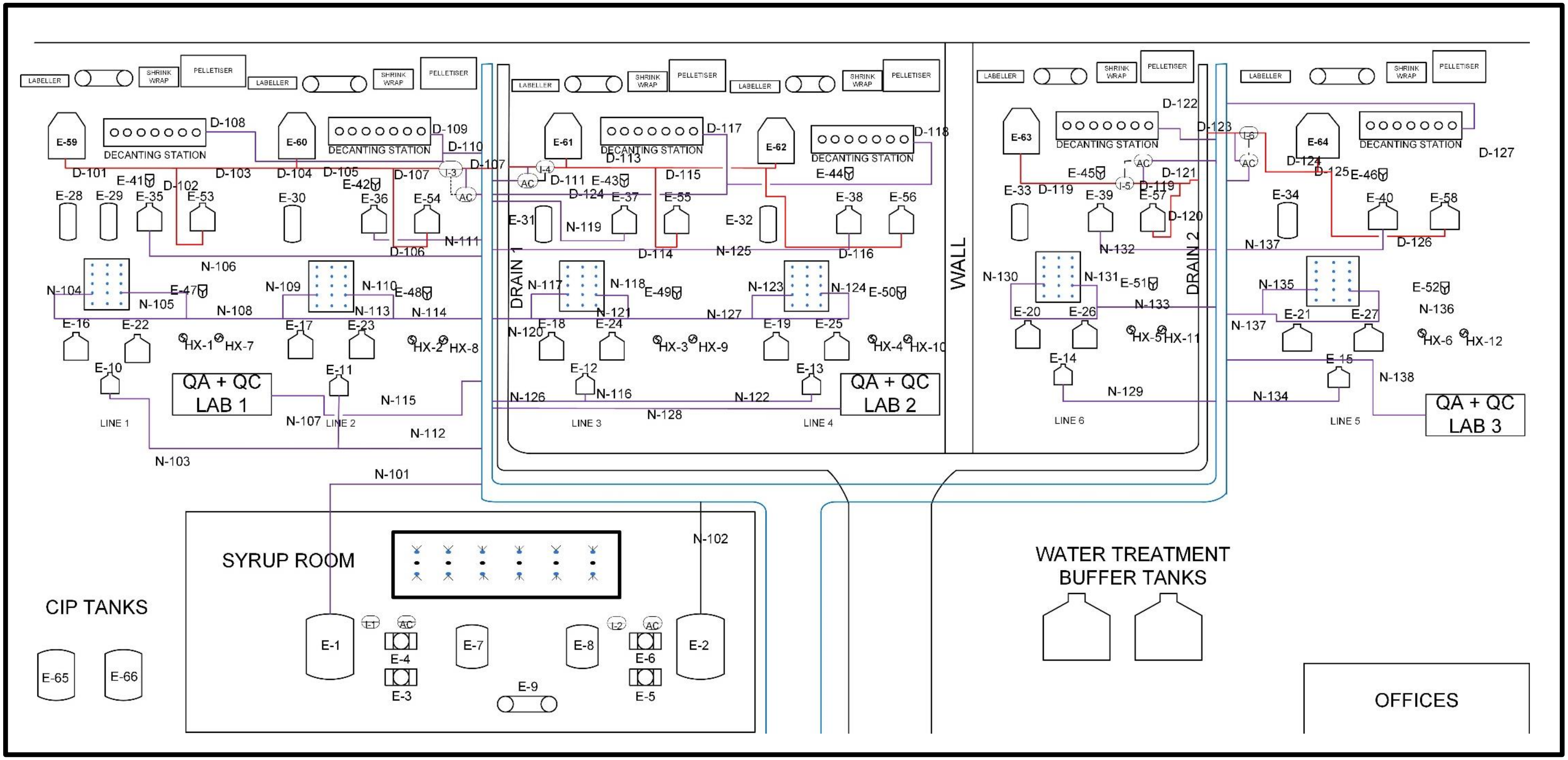

FIGURE E2: CLOSE-UP VIEW OF THE PROPOSED DRAINAGE SITE PLAN.