UNIVERSITY OF KWAZULU NATAL

WASTE WATER TREATMENT OF EFFLUENTS FROM CORN PROCESSING PLANT

by

Vuyani Ndlovu

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College of Agriculture, Engineering and Science

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Supervisors: Dr Elena Friederich
Prof Cristina Trois

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ABSTRACT

South Africa is facing numerous challenges that pertain to increasing water deficit and pollution of water resources. Only 40 out of 821 wastewater treatment works in South Africa achieved Green Drop certifications in the 2010 Green Drop assessments (DWA, 2011). This is not only threatening net water availability but also human health. South African water sources are comprised of 77 % surface water, 14 % return flows and 9 % groundwater (van Vuuren, 2009). This study was therefore intended to explore the quality, quantity and treatability of corn wet milling effluent resulting from Tongaat Hulett Starch Pty Ltd (THS) operations.

THS is a major producer of corn derived starch and glucose in Africa. Amongst its three corn wet milling plants in Gauteng (Kliprivier, Germiston and Meyerton) and one in Western Cape (Bellville), 600000 tonnes of maize were processed in the 2011/2012 financial year.

The objective of the study was to establish the wastewater footprint of the corn wet milling process. To achieve this, qualitative and quantitative characterisation studies were completed on effluents generated from the Germiston and Meyerton corn wet milling plants, respectively. This characterisation study was focused on volumetric and organic load analyses of the various sections of the corn wet milling process. A full scale anaerobic digestion treatability study of the Meyerton plant effluent was also conducted.

The study results indicated that the combined effluent discharged to the Municipal sewer averaged between 2.9 and 3.1 m^3/tonne of corn processed. The effluent generated resulted in an average chemical oxygen demand (COD) concentrations of between 6211 and 7790 mg/L, with suspended solid concentrations of between 635 and 899 mg/L. From the full scale anaerobic treatability study, a minimum of 87 % COD removal at organic volumetric loading rates (OLR) of between 0.3 and 3.9 kg COD/m^3.d was achieved.

It was concluded that corn wet milling effluent can be categorised as high strength in terms of COD concentrations. This type of effluent proved to be amenable to anaerobic digestion treatment. Anaerobic pretreatment of corn wet milling effluent can proportionately reduce pollution loading into the receiving municipal conventional wastewater treatment systems.

DECLARATION

I, **Vuyani Derick Ndlovu**, declare that

1. The research reported in this dissertation, except where otherwise indicated, is my original research.

2. This dissertation has not been submitted for any degree or examination at any other university.

3. This dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

4. This dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a. Their words have been re-written but the general information attributed to them has been referenced

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5. This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.

Signed:……………………………………………..

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DEDICATION

To my wife, Nonjabulo Brenda Ndlovu and my late mother, Lindeleni Dorothy kaMjoli.

GLOSSARY

Acclimation:	The adaptation of a microbial community to degrade an inherently recalcitrant compound through prior exposure to that compound.
Acetogenesis:	The reaction that degrades short chain fatty acids such as propionic acid, butyric acid, or longer chain fatty acids, as well as other intermediates such as ethanol, to acetic acid and hydrogen.
Acidogenesis	The process in which long chain soluble monomers or dimmers, such as carbohydrates and amino acids, are reduced to short chain volatile fatty acids, such as acetic acid, propionic acid, butyric acid, lactic acid and ethanol or longer chain fatty acids.
Anaerobic Digestion:	The microbial degradation of an organic compound in an oxygen deficient environment.
Biochemical Oxygen Demand:	This is the measurement of the dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter.
Biogas:	The typical gas mixture produced by the anaerobic biodegradation of organic matter, and primarily comprises of methane and carbon dioxide.
Bushel:	It is a unit of measure of mass for grains for which shelled corn is equivalent to 25.4 kg of corn kernels at 15.5 % moisture.
Chemical Oxygen Demand:	It is a measure of the total organic material in a wastewater stream.

Cleaner Production:	A continuous application of an integrated preventative environmental strategy, applied to processes; products and services to increase eco-efficiency and to reduce risk to humans and the environment.
Clean Technology:	It is a fundamental appraisal of manufacturing processes which includes impact assessment of products and by-products.
Corn Syrup:	This is a corn derived glucose that is produced by partial hydrolysis of the corn starch slurry through the aid of cooking, acidification and/or enzymatic activity.
Dextrose:	This is a corn derived sweetener produced by complete hydrolysis of the corn starch slurry through the aid of cooking, acidification and/or enzymatic activity.
Dextrose Equivalent:	It is a measure of the total reducing substances present in a sugar product, relative to glucose.
Gluten:	High protein substance found in the endosperm of a corn kernel.
Hydrolysis:	Breakdown of complex long chain macro-molecules such as carbohydrates, lipids and proteins, to short chain compounds such as sugars, fatty acids, glycerol and amino acids.
Modified Starch:	A form of corn starch whose natural characteristics are chemically changed to achieve end-user specific functional needs.
Methanogenesis:	The process whereby low molecular weight substrates are degraded to form methane and carbon dioxide.
Pinch Technology:	It is a process integration tool to process design, retrofitting and operation which emphasises the

	unity of a process or processes to achieve overall eco-efficiency.
Steep Acid:	Wet mill process water into which sulphur dioxide is dissolved at a concentration of between 0.18 and 0.24 %, and is used in corn steeping.
Volatile Fatty Acid:	Short chain organic acid formed by the anaerobic digestion process.
Water Pinch Analyses:	It is a set of systematic formal mathematical techniques for handling the complex problem of hierarchical water allocation to a multi process system involving multiple contaminants, and choosing the best strategy according to selected priorities including overall cost minimisation.

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ABBREVIATIONS

ABR :Anaerobic Baffled Reactor

AD :Anaerobic Digestion

ADWF :Average Dry Weather Flow

AF :Anaerobic Filter

AFBR :Anaerobic Fluidised Bed Reactor

BOD :Biochemical Oxygen Demand

CAC :Command-And-Control Approach

CCSL :Concentrated Corn Steep Liquor

COD :Chemical Oxygen Demand

CPI :Corn Products International

CPV :Condensed Process Vapours

CRR :Cumulative Risk Rating

DAF :Dissolved Air Flotation

DE **:** Dextrose Equivalent

DWA **:** Department of Water Affairs

DWAF :Department of Water Affairs and Forestry

EGSBR :Expanded Granular Sludge Blanket Reactor

EMM :Ekurhuleni Metropolitan Municipality

GDC :Green Drop Certification

HRT :Hydraulic Retention Time

LCSL :Light Corn Steep Liquor

MLM :Midvaal Local Municipality

NEMA	**:**National Environmental Management Act
NWA	**:**National Water Act
NWS	**:**National Water Services Act
NWRS	:National Water Resource Strategy
OLR	:Organic Volumetric Loading Rate
PPP	:Polluter Pays Principle
PW	:Process Water
RVF	:Rotary Vacuum Filter
SMEWW	:Standard Method for Examinations of Water and Wastewater
TDS	:Total Dissoved Solids
THS	:Tongaat Hulett Starch Pty Ltd
THL	:Tongaat Hulett Ltd
SRT	:Sludge Retention Time
STD	:Standard Temperature and Pressure
TKN	:Total Kjeldahl Nitrogen
TOC	:Total Organic Carbon
UASBR	:Upflow Anaerobic Sludge Blanket Reactor
U.S EAP	:United States Environmental Protection Agency
VFA	:Volatile Fatty Acid
VOC	:Volatile Organic Compound
WDCS	:Waste Discharge Charge System
WGDF	:Water for Growth and Development Framework

WRC	:Water Research Commission
WWTW	:Wastewater Treatment Works

1. INTRODUCTION

Industrial processes usually require water with a range of qualities, and produce effluents with a range of qualities, which allows the possibility of a hierarchical water use (Brouckaert et al. 2005). Effluent from the corn milling industry is categorised as high strength due to its high protein and starch contents (Ozturk et al. 2005).

Wastewater engineering is that branch of Environmental Engineering in which the basic principles of Science and Engineering are applied to solving issues associated with wastewater treatment and reuse (Tchobanoglous et al. 2003). With industrialisation, increasing industrial effluent quantities are being generated and subsequently discharged into municipal collection systems. Wastewater treatment is the first barrier in a multi-barrier system of ensuring public and environmental health (Department of Water Affairs, 2011).

Economic growth, industrialisation and population growth are driving the increasing water demand, while climate change, pollution and regulatory factors are affecting water supply and costs (de Souza, 2012). This study aims to review the current state of water and wastewater in South Africa with special focus on the corn processing industry and the feasibility of wastewater minimisation in this industry.

1.1 Project background

Tongaat Hulett Starch Pty Ltd (THS), Starch and Glucose Division of the Tongaat Hulett Ltd group, is the only corn wet miller in South Africa. It operates three corn wet milling (processing) plants in Gauteng and one in the Western Cape. These four plants have a combined ‘nameplate’ design wet milling capacity of 2750 tonnes of corn per day (Tongaat Hulett Starch, 2008). THS processes corn through wet milling for the manufacture of a wide range of starches, dextrin, glucose syrups and co-products such as maize gluten and maize germ oil.

The composition of effluent generated from a typical corn wet milling process varies according to processing routes in terms of finished products. It generally consists of small quantities of soluble inorganic matter, protein, amino acids and other nitrogenous substances, lactic acid, carbohydrate, finely divided solids such as starch, gluten, fibre and activated carbon fines (Ross, 1989).

One of the typical waterborne wastes from a typical corn wet milling process is the condensate from steep liquor evaporation, which contains volatile organic compounds (VOCs) formed from the corn steeping process. Besides the VOCs, the waste streams might contain filtrates from the production of modified starches, with dissolved chemicals used in the modification process, and some soluble carbohydrates formed during this process. Another source of wastewater is the impurities removed during the refining of corn syrups and dextrose (Bensing et al. 1972).

Typical fresh water consumption in a corn wet milling process ranges from 12 to 15 gal/bushel of corn processed (Bensing et al. 1972). In this study, water consumption and effluent generation in a corn wet processing plant were analysed. Treatability of this type of effluent was evaluated in a full-scale anaerobic digestion process. Results from this study were to be used in the development of wastewater management and abatement strategies for the corn wet milling industry in South Africa.

1.2 Aim and objectives of the study

The aim of this study was to investigate the feasibility of water and wastewater minimisation through the treatment of corn wet processing effluent. The objectives of the study were:

- To identify and quantify major wastewater sources within a corn wet processing plant;
- To quantitatively and qualitatively characterise the identified wastewater streams;
- To assess the treatability of this type of effluent in an anaerobic digestion process; and
- To quantitatively profile overall water usage and wastewater generation in a corn wet processing plant.

1.3 Research study approach

A review of relevant, current and retrospective literature on corn wet milling technologies and wastewater management techniques was undertaken. Also, an overview of the current state of water resources in South Africa and the relevant legislative framework was explored. Lastly, previous studies on corn wet milling effluent and similar industries were reviewed. Special attention was given to methodologies followed and findings that were obtained.

Detailed qualitative and quantitative characterisation of effluent from two of THS corn processing plants was subsequently conducted. Various effluent sources from the corn wet processing plant were identified. Each identified stream was monitored for daily volumes of effluent generated and also sampled to establish its composition in terms of pollutant loading.

To profile overall freshwater usage and wastewater generation, data for water usage, tonnage of corn processed and wastewater generated during the study period was collected and analysed.

A full scale anaerobic treatability evaluation and assessment of the Meyerton plant effluent were completed. Results from this exercise were analysed and discussed in order to verify and validate the feasibility of corn processing effluent treatability in an anaerobic digestion process.

The research question examined in this study was the feasibility of wastewater minimisation through treatment of corn processing effluent. The results of this study were intended to establish both the qualitative and quantitative profiles of corn wet processing effluent.

Finally, recommendations into wastewater treatment and management options in a corn wet processing plant were summarised and presented for the development of a potential wastewater management plan.

1.4 Dissertation outline

Chapter one of this dissertation contains the introduction which presents background information on what motivated the need for this study, project background and the intended study objectives.

Chapter two explores relevant literature on the state of water and wastewater in South Africa, relevant legislative framework, corn wet processing technology and corn processing effluent management in terms of sources, treatment and disposal.

This is followed in **Chapter three** by the methodology that was used to conduct the study in terms of data collection, effluent sample collection and effluent sample analyses. Inherent study limitations are also herein discussed. The methodological approach adopted for the study was statistical analyses and critical assessment of the collected data.

Study results and their interpretations are presented in **Chapter four** (see Results and Discussion). Qualitative and quantitative effluent generation profiles of the different sections of the corn processing plant are herein presented and analysed. This chapter also presents corn processing effluent treatability results, overall water usage and wastewater generation profiles.

A summary and overview of significant findings and identified opportunities are summarised and analysed in **Chapter five** (see Conclusion and Recommendations).

The plan and structure of this study is depicted and outlined in Table 1-1.

Table 1-1: Outline of the Study

INTRODUCTION	• Background	• Rationale for the Study • Research question • Research Study Motivation
	• Aim and Objectives	• Intended Outcomes
	• Research Study Approach	• Adopted Study Approach
	• Dissertation Outline	• Plan • Structure
LITERATURE REVIEW	• State of Water in South Africa	• Water Security • Green Drop Assessment
	• Water and Wastewater Minimisation Techniques	• Cleaner Production • Clean Technology • Water Pinch Analysis • Water Management Hierarchy
	• Industrial Effluent Treatment	• Waste Discharge Charge System • Polluter Pays Principle • Effluent Discharge Tariff
	• Relevant South African Legislation	• Environment and Water related pieces of Legislation.
	• Corn Processing	• Corn Dry and Wet Milling • Corn Kernel Constituents. • Corn Cleaning. • Corn Steeping Process. • Corn Separation • Modified Starches • Corn Syrup Manufacture.
	• Corn Processing Effluent	• Typical Effluent Sources • Typical Effluent Profiles • Effluent Treatment Options • Biomass Disposal Options

	• Summary of Literature Review	• Conclusions from the explored literature. • Potential answers to the research question. • Material to be covered next.
METHODOLOGY	• Effluent Data Collection	• Hydraulic Data. • Effluent Sampling
	• Effluent Characterisation Study	• Effluent Sources. • Effluent Profiles. • Wastewater Networks.
	• Water Usage Data	• Process Water Usage • General Usage • Total Usage
	• Anaerobic Effluent Treatability Study	• Process Description. • Data Collection.
	• Analytical Methods	• pH • Conductivity • COD • TOC • Suspended Solids
	• Study Limitations	• Effluent Characterisation • Treatability Study
RESULTS & DISSCUSION	• Characterisation • Treatability	• Results and Analyses. • Results and Analyses.
CONCLUSION & RECOMMENDATIONS	• Summary of Significant Conclusions and Recommendations	• Quality and Quantity of Corn Wet Processing Effluent. • Recommended Treatment Options for Corn Wet Processing Effluent.

2. LITERATURE REVIEW

2.1 Introduction

This chapter aims to present the theoretical framework of this research study. As such, it explores and investigates the current state of water resources in South Africa; the concepts of wastewater minimisation techniques; and the regulatory framework with regard to conservation of water resources and the environment. Lastly, it explores corn processing and its wastewater footprint.

Advances in technological developments in manufacturing, inadvertently lead to adverse changes in wastewater characteristics. Numerous pollutants generated from some manufacturing processes are difficult and costly to treat by conventional treatment processes. A need for effective and efficient industrial wastewater pretreatment is hence becoming increasingly inevitable and essential as part of an overall wastewater management programme. This is undoubtedly the case with the corn processing industry.

2.2 State of water in South Africa

The issues of decreasing water quality; increasing water scarcity and deteriorating or dysfunctional municipal water infrastructure leading to a potential water crisis in the country, have featured strongly in the media (van Vuuren, 2009). These challenges are exacerbated by a low average annual rainfall of 450 mm, well below the world annual average of 860 mm (DWAF, 2004). South Africa is already categorised as water-scarce with an annual freshwater availability of below 1700 mm^3 per capita (van Vuuren, 2009).

This compelled the Department of Water and Environmental Affairs (DWAF) to take a long term view in conducting a detailed study of the assessment of water supply/demand, and addressing imbalances where they exist. According to the National Water Resource Strategy (NWRS) of 2004, the total annual freshwater demand in 2000 was 12871 million m^3 compared to the 13227 million m^3 that was available. This equated to 98 % of available national water resources that were already allocated for consumption, with a marginal (2 %) surplus left. Both base and high water supply/demand scenario by DWAF in 2009 illustrated that water consumption is projected to exceed demand by 2025 in South Africa. These scenarios are illustrated in Figure 2-1.

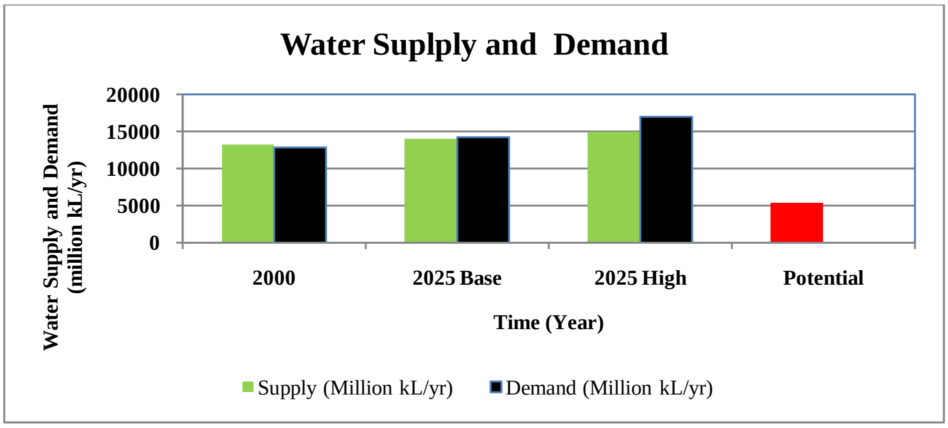

FIGURE 2-1: Water supply vs demand scenario (DWAF, 2009)

Based on the existing reconciliation strategies, water shortages in Gauteng could be experienced as soon as 2013, especially if drought conditions occur (DWAF, 2009). This could however be averted by expediting the second phase of the Lesotho Highlands Water Project, which is expected to be completed in 2019.

Sources of water in South Africa are comprised of 77 % surface water; 14 % return flows and 9 % groundwater (van Vuuren, 2009). Of the 821 wastewater treatment works (WWTW) in South Africa, only 40 achieved Green Drop certifications (GDC) in the 2010 Green Drop assessments (Department of Water Affairs, 2011). This points to the challenges most municipalities are facing in terms of excellence in wastewater treatment and management (Snyman, 2011).

The Green Drop (GD) process measures and compares the results of the performance of Water Service Authorities and Providers. The Municipality is subsequently rewarded or penalised based on evidence of excellence or failures according to the minimum standards or requirements that have been defined. The GD process focuses on both the business of wastewater services (the entire value chain) and the risk analysis of the wastewater treatment function (DWA, 2011). Risk analysis is used to identify, quantify and manage the corresponding risks according to potential impacts on the water resources and to ensure a prioritised and targeted regulation of high risk municipalities (DWA, 2011). This is defined and calculated by the Cumulative Risk Rating (CRR) equation 1.1.

$$\mathrm{CRR} = \mathrm{A} \times \mathrm{B} + \mathrm{C} + \mathrm{D} \qquad \textbf{(1.1)}$$

Where

A = Design capacity of plant which also represent the hydraulic loading onto the receiving water body, ML/d

B = Operational flow exceeding, on and/or below original ADWF design capacity, %

C = Number of non compliance trends in terms of effluent quality as discharged to the receiving water body.

D = Compliance or non compliance in terms of technical skills.

Based on the 2010 GD assessments, the average percentage deviation from the maximum CRR increased from 66.8 in 2009 to 69.2 % in 2010 (DWA, 2011). This indicates that WWTWs are continuing to move into higher risk space. The 821 WWTWs receive 5258 ML/day which have a collective hydraulic design capacity of 6614 ML/day (DWA, 2011). The reported 20 % surplus capacity may however not be readily available due to inadequate maintenance and operational deficiencies at lower capacity municipalities (DWA, 2011).

Factors that are likely to aggravate the South African water adverse situation are: the impact of climate change on precipitation and increasing water demand due to population and economic growths. Economic growth, industrialisation and population growth are driving the increasing water demand, while climate change, pollution and regulatory factors are affecting water supply and costs (de Souza, 2012). Analysis of the operational wastewater flows also indicated an uneven distribution of wastewater generation and treatment: Gauteng (49 %), Western Cape (17 %), KZN (14 %) and 20% distributed amongst the rest of the other provinces (DWA, 2011).

Water for Growth and Development Framework (WGDF) that was launched by the Department of Water and Environmental Affairs in 2009 was meant to give guidance in ensuring water security (quality and quantity) in South Africa. Some of the main recommendations of the framework are (van Vuuren, 2009):

- Mainstreaming – i.e., placing water at the heart of all development planning decisions;
- Diversifying the water matrix by significantly increasing return flows to 22 % and 3 %, through the treatment of effluents and desalination, respectively. Surface water as the current predominant source of water in South Africa, is expected to proportionately reduce to less than 65 % by 2040 (DWAF, 2009); and
- Promotion of water conservation and demand management.

2.3 Water and wastewater minimisation

In light of the steady deterioration of water quality in rivers, the Department of Water Affairs and Forestry (DWAF) adopted a pollution prevention approach called Cleaner Production to control hazardous pollutants (Sacks, 1997). This is a continuous application of an integrated preventative environmental strategy, applied to processes, products and services to increase eco-efficiency and to reduce risk to humans and the environment (Dlamini, 2009).

The concept of clean technology requires a fundamental appraisal of manufacturing processes which includes an assessment of the impact of the product and by-products. It encompasses the principle of sustainability which must be applied to all proposed developments, land use audits, manufacturing processes and wastewater generation. Clean technology (cleaner technology) is the avoidance of environmental damage at source (Kirkwood and Longley, 1995). It goes beyond ‘clean production’ which is defined as a conceptual and procedural approach to production that demands that all phases of the life cycle of a product or process should be addressed with the objective of prevention or minimisation of short- and long-term risks to human health and the environment (Kirkwood and Longley, 1995). Kirkwood and Longley (1995) differentiated between remediation, clean-up technology and clean technology:

- **Remediation** – repairing of damage caused by past human activity or natural disasters;
- **Clean-up technology** – reducing of environmental damage by retrofitting, modifying, or adding ‘end-of-pipe’ pollution abatement measures to an established plant or process;
- **Clean technology** – is the avoidance of environmental damage at source.

Industrial processes usually require water with a range of qualities, and produce effluents with a range of qualities, which allow the possibility of a hierarchical use of water (Brouckaert et al. 2005). Although industry accounts for approximately 11 % of South Africa’s direct water use, its impact is much higher because some of its effluents often contain toxic pollutants (Juana, 2008).

Before industrialisation, concentrations of organic chemicals in the environment remained more or less constant with biosynthesis. Biodegradation was held in equilibrium by the integrated natural activities of plants, animals and microbes. Today we are faced with certain industrial pollutants that do not readily participate in the global cycles of carbon, nitrogen or sulphur (Batchelor, 2002). Possible strategies for reducing the consumption of freshwater and the production of wastewater into the environment include (Brouckaert et al. 2005):

- **Reuse** - wastewater from one process can be directly reused in others, provided the level of contamination is sufficiently low to meet the requirements of the subsequent process;
- **Regenerative reuse** - wastewater can be treated to reduce the levels of contaminants before being reused in other processes. In this option, the water is not recycled to the process from which it came from;
- **Regenerative recycling -** after regeneration, water can be recycled to the process from which it came. This is generally more difficult than reuse, because recycling tends to build up contaminants within the system.

These are part of the hierarchy of water conservation priorities. Levels of the hierarchy from the top to the lowest priority for water conservation include elimination, reduction, reuse and regeneration (Manan et al. 2006). Figure 2-2 illustrates techniques for water and wastewater minimisation in a processing environment.

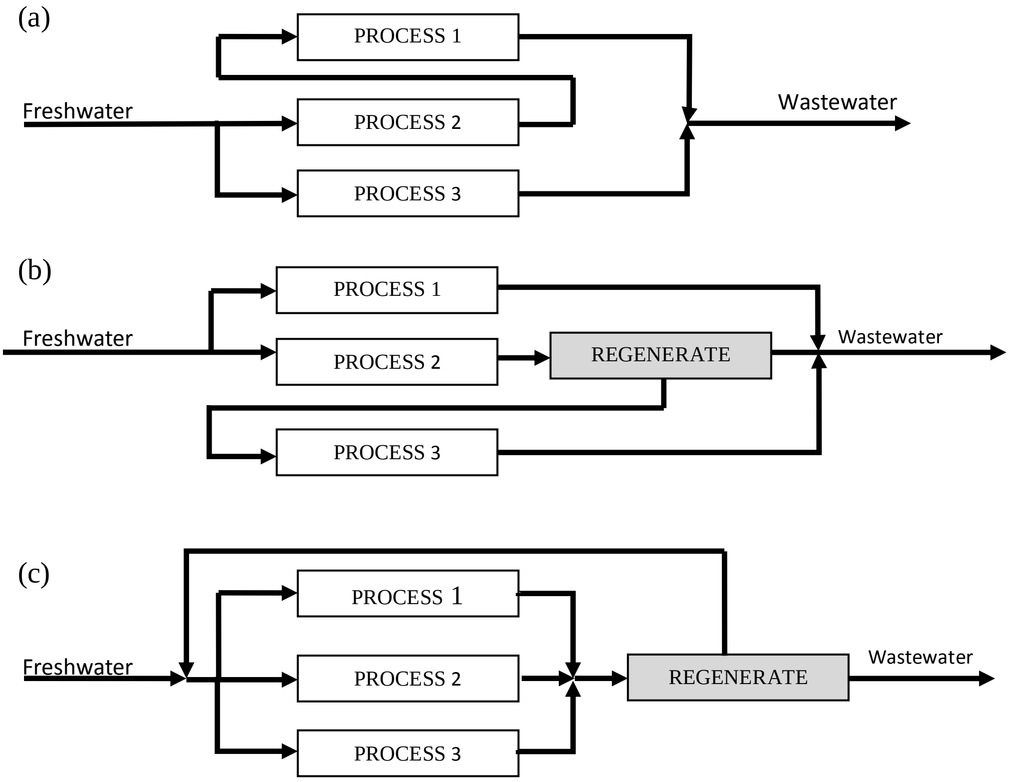

FIGURE 2-2: Water and wastewater minimisation techniques: (a) Reuse, (b) Regenerative Reuse, and Regenerative Recycling (Wang and Smith, 1995).

Pinch technology is one approach that is being adopted in the implementation of water management hierarchy. It is a process integration tool first developed for optimising the design of heat recovery systems. It is a holistic approach to process design, retrofitting and operation which emphasises the unity of a process or processes so that overall eco-efficiency can be sought (Brouckaert et al. 2005).

This technique has subsequently been theoretically extended by Brouckaert et al. (2005) to water-using systems. The intended objective was to promote widespread application of the technique in minimising water use, by maximising water reuse, refining the technique where necessary, and transfer of technology expertise to relevant stakeholders. Modern water pinch analysis is a set of systematic formal mathematical techniques for handling the complex problem of hierarchical water allocation to a multi process system involving multiple contaminants, and choosing the best strategy according to selected priorities including overall cost minimisation (Brouckaert et al. 2005).

Successes of the water pinch analyses were demonstrated at Sasol Polymers wherein 72 % potential water use savings and 45 % effluent reduction were identified (Brouckaert et al. 2005). Potential savings on the process' major raw material usage were also identified: HCl (2.9 %) and NaOH (4.2 %) in the same study. At Sanachem, manufacturer of agrochemicals such as pesticides and herbicides, similar studies identified potential water use reduction of around 40 %, proportionate reduction in effluent generation and 25 % increase in production capacity (Brouckaert et al. 2005).

2.4 Industrial effluent treatment

Since the 1972 world summit in Rio de Janeiro, environmental protection campaigns have raised awareness levels on the importance of ecosystem protection from industrial pollution (Mutombo, 2004). High strength industrial effluents may not be directly disposed off into the receiving environment, unless they have been pre-treated to acceptable levels of constituent pollutants (see **APPENDIX A** for treated effluent discharge limits). Effluent treatment can either be chemical, physical, biological (aerobic and/or anaerobic) or combination of these treatment methods (Batchelor et al. 2002). In general, aerobic treatment of effluent is applied when the chemical oxygen demand (COD) is lower than 2000 mg/L, whereas anaerobic is recommended in cases of higher COD concentrations (Batchelor et al. 2002).

Concentrated organic industrial wastes such as distillery and corn processing effluents resulting from the manufacture of various foodstuffs generally create serious treatment and/or end-of-pipe disposal problems for the industry or local authority because of their high organic loads. These wastes are normally soluble or colloidal and have COD concentrations varying from 2 to 200 g/L (Ross, 1989). Effluents of this type are thus reluctantly received into communal sewers by the controlling authority and the manufacturer is faced with heavy trade effluent charges and penalties.

The recent legislation places strong emphasis on equitable pricing strategies with a significant departure from the previous financing and accounting methods used by DWAF. The emphasis is on full recovery of water resource management, treatment and infrastructural costs from the water users (Kerdachi, 2002). The local authority is assigned the responsibility for the purification and disposal of effluent in accordance with the National Water Act (Act 36 of 1998). In fulfilling this responsibility, the local authority incurs expenditure to provide sewerage network and treatment/purification facilities to meet the additional hydraulic, and COD loads into the system. The local authority uses a tariff structure designed to ensure that the costs incurred are proportionately recovered from industry for services rendered.

Industry generally discharges its effluent to the municipal sewer (local authority) for treatment wherein a binding agreement with the local authority will be signed. This agreement, effluent discharge permit, will stipulate conditions under which the effluent may be discharged, as well as maximum acceptable pollutant limits (see **APPENDIX B** for the acceptable trade effluent discharge limits) in accordance with the applicable By Laws. In exceptional cases, industry may have its own treatment facility, and will then require a permit to discharge directly to the receiving water (Kerdachi, 2002).

The recommended tariff structure has three basic cost components: conveyance, treatment and fixed costs (Kerdachi, 2002). The local authority is generally the potential polluter of the receiving water, whereas industry is the polluter of the sewerage system into which industrial effluent is commonly discharged. The above recommended tariff structure is aimed at recouping the proportionate costs from industry in accordance with their hydraulic and pollutant contribution (Kerdachi, 2002). These are costs incurred annually in the operation and maintenance of the sewerage system and the treatment works in such a manner that is consistent with the defined standards and guidelines by the Department of Water and Environmental Affairs.

Equation 1.2 was recommended by Kerdachi (2002) for the calculation of basic effluent disposal tariffs to be charged to industrial wastewater dischargers:

$$\mathbf{Charge} = \mathbf{Conveyance} + \mathbf{Treatment\ (Variable)} + \mathbf{Fixed\ Costs} \quad \mathbf{(1.2)}$$

Where

Conveyance (c/kL) – unit cost to transport effluent from the industrial site to the treatment works using the sewer network

Treatment (c/kL) – variable unit cost to treat a kilolitre of effluent at a specified pollutant concentration(s)

Fixed cost (c/kL) – this is the portion of each kilolitre of the total cost that is due to fixed expenditure, independent of the effluent strength.

Trade effluent discharge tariffs are generally based on the above formula, but unit costs and actual tariffs may vary from one local authority to the next. Ekurhuleni Metropolitan Municipality (2011) and Midvaal Local Municipality (2013) use equation 1.3 for industrial effluent treatment and conveyance charge calculation:

$$\mathbf{Ti} = \left(\frac{\mathbf{C}}{\mathbf{12}}\right)\left(\frac{\mathbf{Qi}}{\mathbf{Qt}}\right)\left[\mathbf{a} + \mathbf{b}\left(\frac{\mathbf{CODi}}{\mathbf{CODt}}\right) + \mathbf{d}\left(\frac{\mathbf{Pi}}{\mathbf{Pt}}\right) + \mathbf{e}\left(\frac{\mathbf{Ni}}{\mathbf{Nt}}\right) + \mathbf{f}\left(\frac{\mathbf{SSi}}{\mathbf{SSt}}\right)\right] \qquad \mathbf{(1.3)}$$

The relevant effluent parameters and cost factors that are used in equation 1.3 are illustrated in Appendices **B**: Acceptable Trade Effluent Discharge Limits and **C**: Industrial Effluent Disposal Charge Calculation.

2.5 Relevant South African legislation

The initial response of governments around the world to environmental degradation was through a Command-and-Control approach (CAC). This generally meant dictating to industries what technologies and processes to use. This approach failed due to its lack of provisions for cost effective and efficient solutions to environmental management (Clement et al. 1999).

Since 1994, South Africa has embarked on the implementation of a new approach that is self-funding and relies on economic incentives rather than regulatory supervision (Clement et al. 1999). This is based on a Polluter-Pays-Principle (PPP).

In South Africa, the protection of water resources has become mandatory and is legislated in the following pieces of legislations: National Water Act 36 of 1998 (NWA), National Water Services Act 108 of 1997 (NWS), National Environmental Management Act 107 of 1998 (NEMA) and the National Environmental Conservation Act 73 of 1989.

As part of the PPP, waste discharge charge system (WDCS) has been proposed to promote water conservation and waste reduction. It forms part of the Pricing Strategy established under NWA (Clement et al. 1999).

This aims to:

- Promote sustainable development and efficient use of water resources;
- Promote the internalisation of environmental costs by polluters;
- Recover some of the costs of managing water quality; and
- Create financial incentives for dischargers to reduce waste and use water resources in a more responsible and sustainable way.

2.5.1 National Water Act (Act 36 of 1998)

The Preamble to the NWA recognises the following considerations in enacting the legislation:

- That the ultimate aim of water resource management is to achieve the sustainable use of water for the benefit of all users*;*
- That the protection of the quality of water resources is necessary to ensure sustainability of the nation's water resources in the interests of all water users;
- That there is a need for the integrated management of all aspects of water resources; and
- That, where appropriate, management functions are to be delegated to regional or catchment level so as to enable everyone to participate**.**

2.5.2 National Water Services Act (Act 108 of 1997)

This Act was adopted to provide for:

- The rights of access to basic water supply and sanitation services;
- The setting of national standards and norms relating to the amount and quality for basic water services;
- Standards to be set for water services tariffs;
- The preparation of water services developmental plans;

- A regulatory framework for those responsible for water services provision;
- Monitoring of water supply and sanitation services; and
- Promotion of effective water resource management and conservation.

2.5.3 National Environmental Management Act (Act 107 of 1998)

NEMA states that sustainable development requires that the cost of remedying pollution, environmental degradation and consequent adverse health effects, and of preventing, controlling or minimising further pollution, environmental damage or adverse health effects, must be paid for by those responsible for harming the environment.

2.5.4 National Environment Conservation Act (Act 73 of 1989)

This Act states that measures must be undertaken for the effective conservation of the environment; by implementing certain economic measures, namely:

- Support for economic growth and social welfare without affecting, overstraining or irreversibly damaging the environment and natural resources in the process;
- Ensuring that all communities have equitable access to resources without jeopardising the interests of future generations;
- Internalisation of environmental costs as part of the exploitation and production costs, having due regard to the economic implications;
- Promoting the reduction of waste streams and pollution to the levels that can be naturally absorbed without deleterious effects on the environment; and
- Promoting the usage of innovative technologies that can make a specific contribution towards sustainable development.

With the departure from CAC approach, the South African legislation now places strong emphasis on equitable pricing strategies for water use and wastewater discharge. The emphasis is on full recovery of water resource management, treatment and infrastructural costs from the water users (Kerdachi, 2002).

The corn processing industry is no exception, as it uses water in the production of its corn derived products, and inevitably generates high strength wastewater into the local Municipal collection and treatment systems. The next sections of the literature review are therefore intended to explore corn processing with special focus on the characteristics of resultant effluents that get generated.

2.6 Corn dry milling

Corn may be processed by either dry or wet milling. The production methods and final products of each process are distinctly different. Corn dry milling produces meal, grits, oil and flour. Principal products of corn wet milling are starch, germ oil, gluten, syrup and dextrose.

In corn dry milling, corn is first cleaned and then tempered to moisture of about 21 % (U.S EPA, 1974). The germ and bran are subsequently separated from the endosperm in a series of grinding, sifting, classifying and aspirating operations. Oil is mechanically extracted in a separate process. Figure 2-3 presents a typical process flow of corn dry milling.

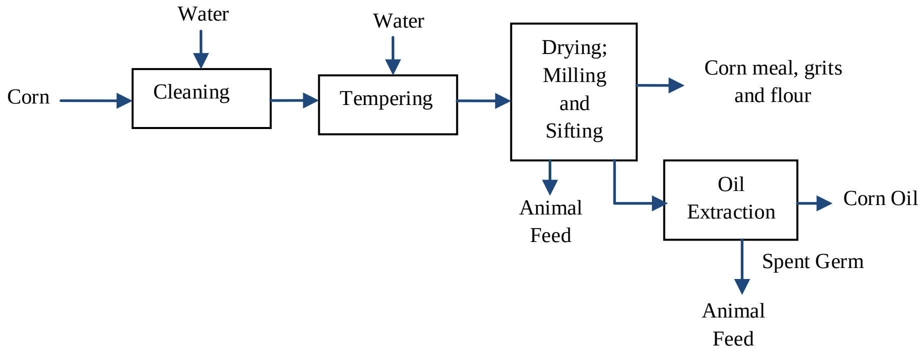

FIGURE 2-3: Corn dry milling, (U.S EPA, 1974)

Effluent generation from a dry corn mill as illustrated in **Figure 2-3,** ranges between 0.45 and 1.3 m^3/tonne corn processed, with an average COD concentration of 4.9 g/l and suspended solids of 3.5 g/l (U.S EPA, 1974). The only source of process wastewater is from the corn cleaning process step for which water usage is estimated at 0.45–1.20 m^3/tonne of corn processed (U.S EAP, 1974). For the tempering process step, only enough water to raise the corn moisture content to between 21 and 25 %, is added (U.S EAP, 1974).

This study is therefore only focused on the treatment and characterisation of effluents from a corn wet processing plant.

2.7 Corn wet milling

In corn wet milling process, a corn kernel is taken apart and purified to its different constituents. These are then conditioned for use in food and other industries. There are two distinct processes for corn wet processing, wet milling and starch slurry derivatives production (refinery), and each process generates unique co-products. Basic process flow in a typical corn wet milling process is illustrated in Figure 2-4.

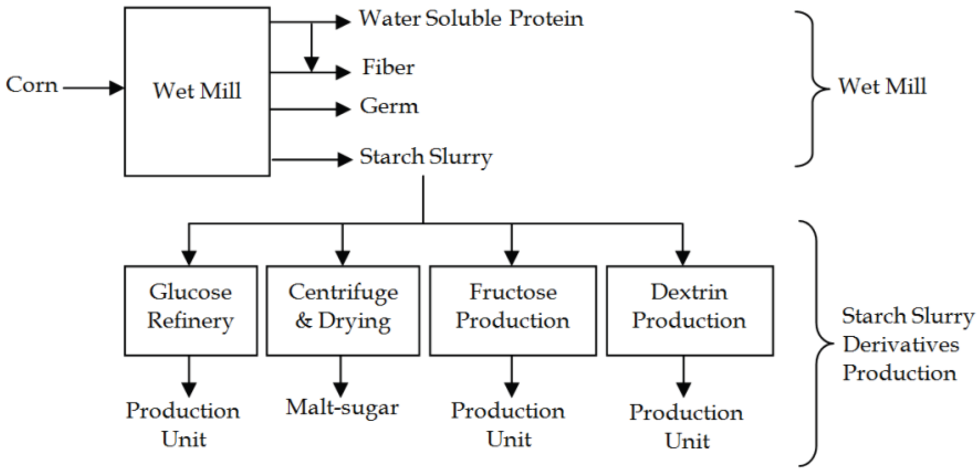

FIGURE 2-4: Basic process flow diagram for a typical corn wet processing industry, (Ozturk et al. 2005).

In the corn wet milling process, the corn kernel is separated into three principal constituents: outer skin (hull), endosperm (gluten and starch) and the germ containing most of the oil. These different components of a corn kernel are presented in Figure 2-5.

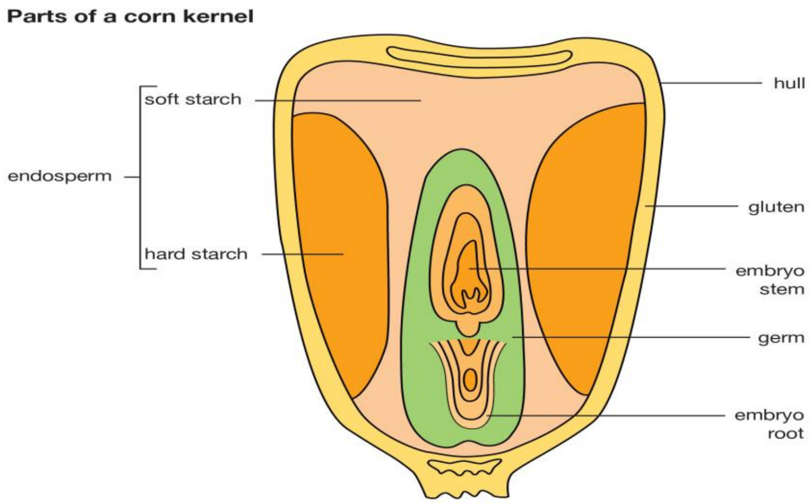

FIGURE 2-5: Corn kernel constituents (Encyclopedia Britannica, 2010)

Wet milling is therefore the breakdown and separation of the corn kernel into its constituents, to provide starch slurry of very high purity and co-products. From an average bushel (25.4 kg) of harvested corn, water constitutes not more 16 % by weight, with the balance being (Inglett, 1970):

- Starch granules (about 70 % by weight) which occur in the endosperm;

- Protein particles (Gluten-60) which also occur in the endosperm;
- Hull/husk (Fibre) which is the skin around the corn kernel; and
- Germ which is the seed-like pod within the kernel. It contains about 50 % by weight oil.

Detailed percentage composition of a normal dent corn kernel is presented in Table 2-1.

Table 2-1: Average percentage composition of normal dent corn kernel on a moisture free basis (Inglett, 1970)

Fraction	**Kernel**	**Starch**	**Protein**	**Lipids**	**Sugar**	**Ash**
Whole grain	-	71.5	10.3	4.8	2.0	1.4
Endosperm	82.3	86.4	9.4	0.8	0.6	0.3
Germ	11.5	8.2	18.8	34.5	10.8	10.1
Fibre	5.3	7.3	3.7	1.0	0.3	0.8
Tip Cap	0.8	5.3	9.1	3.8	1.6	1.6

2.7.1 Corn cleaning

There are three main functions of the wet milling step: Corn cleaning, separation and refining. Shelled corn is cleaned by passing through mechanical cleaners designed to remove broken corn kernels, dust and foreign bodies (like pieces of cobs, sticks, stones etc) from the bulk delivery before further processing.

This is achieved by sieving and blowing air through the corn kernels. Electromagnets may also be used to detect and remove bits of metals before going into steeping. After cleaning, the grains are conveyed to storage or directly to the corn refining process.

2.7.2 Corn steeping

This is the first step in the corn refining process which conditions the corn kernel to achieve optimum milling and separation into its constituents (see **Figure 2-5**). The main objectives of this process step are (Inglett, 1970):

- The softening of the kernel for effective grinding;
- The facilitation of the disintegration of the protein matrix that holds together the starch granules; and
- The removal of soluble fractions, mainly from the germ, making it more susceptible to recovery without breaking it.

This begins with the conditioning of the corn kernels, wherein the kernels are soaked in steep acid (sulphurous acid) at an SO_2 concentration of about 0.1–0.2 % (Inglett, 1970). This aqueous solution is strictly controlled and maintained at about 52 ^{o}C and the corn is soaked in it for 28–48 hours (Inglett, 1970). Under these conditions Lacto Bacillus is grown, which produces lactic acid. Lactic acid softens the maize kernel by dissolving protein matrix and other binding materials. Softened maize is easily separated into its constituents in the subsequent process stages.

At the end of the steeping process, excess light-corn steep liquor (LCSL) is separated and concentrated in the multi effect vacuum evaporators into concentrated corn steep liquor (CCSL), approximately 35 to 55 % solids on dry basis (Inglett, 1970). This concentrated steep liquor is used as an additive in the animal feed (corn fibre) or as a nutrient in certain fermentation media.

As the fully steeped corn is discharged for further processing, fresh corn is added into that steep vessel. Incoming water to the entire steeping system is derived from recycled wastewaters (process water) from other wet mill unit operations. Before being used in the steeping process, SO_2 is added in a separate absorption process. This is then introduced into the steep vessel with the corn that has been steeped the longest, and passes through the series of steep tanks to the newest batch of corn before it is discharged as LCSL.

2.7.3 Germ recovery

The softened corn kernels is ground just enough to crack and free the germ which still has some endosperm fragments (starch, gluten and fibre) clinging to it. The ‘degerminating’ mill contains one stationary and one rotating metal plate with projecting teeth designed for tearing the soft kernels apart, and freeing the germs without crushing them.

Germ is then separated from the pulpy material containing germs, fibre, starch and gluten, in a series of hydrocyclones and subsequently washed and dried to approximately 4 % moisture content (Inglett, 1970). Germ is now ready for oil recovery and subsequent refining.

2.7.4 Fibre recovery

After germ recovery, the main constituents of the corn kernel remaining are the starch particles; gluten and fibre. These are finely ground to reduce the size of the starch granules and gluten particles, which are then removed with sieves.

The fibre is washed, dewatered in screw presses, mixed with CCSL and dried to approximately 12 % moisture, forming what is referred to as Gluten-20 (Inglett, 1970). CCSL is rich in minerals and proteins (50 % crude protein on dry basis) that would have leached from the corn kernel during the steeping process (Inglett, 1970). CCSL is combined with the fibre to make protein-rich animal feed which is marketed as Gluten-20.

2.7.5 Starch-gluten recovery

Starch and gluten slurry (mill starch), now freed of the fibre, is ready for separation into individual components. In modern corn refinery, the mill starch is concentrated in a mill starch thickening centrifuge. The concentrated mill starch (heavy mill starch) is separated into lower density gluten as overflow stream, and starch slurry as underflow stream in a centrifugal separator (primary separator). Gluten overflow stream is further concentrated to 60–70 % protein at 1.5–2.0 % solids in a centrifuge (Inglett, 1970). The concentrated gluten is dewatered in a rotary vacuum filter (RVF) and subsequently dried in a rotary drum dryer to approximately 9 % moisture content. This is marketed as a Gluten-60.

Refining of starch is achieved with a battery of hydrocyclones which removes traces of gluten particles in a countercurrent washing process. Fresh water with absorbed traces of SO_2 is used as the washing medium (wash water) at a predetermined ratio of wash water-to-starch slurry, depending on the number of washing stages. This wash water works its way through the many operations as process water, only to be removed from the system finally as light corn steep liquor (LCSL).

The reuse of the resultant effluent wash water as process water in the various washing and steeping processes only commenced after 1920 (Bensing et al. 1972). This resulted in a now standard “bottled up” corn wet milling industry.

Washed starch slurry is dewatered to 35–42 % moisture content (U.S EAP, 1974). This dewatered starch cake may be flash dried into normal corn starch at approximately 12 % moisture content, or treated by various chemicals to make modified starches before being dried (Inglett, 1970). Some of the starch slurry may be hydrolysed with acid and/or enzymes to produce corn syrup or dextrose.

Detailed unit operations in a typical corn wet milling process are presented in Figure 2-6.

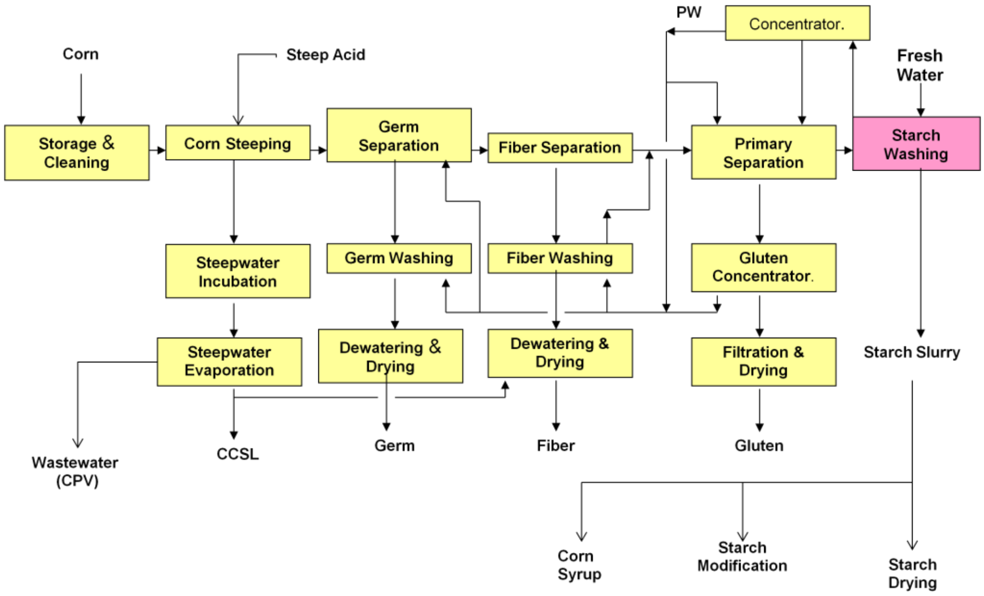

FIGURE 2-6: Unit operations in a typical corn wet mill

2.8 Starch derivatives production

Starch derivatives production is the modification and conversion of starch into a wide range of products including; corn syrups, dextrose, modified starches and dextrins which require the use of various reagents like acids, enzymes, modification chemicals and specific process technologies.

2.8.1 Modified starches

These are manufactured for various food and trade industries for special uses, for which unmodified starches are not suitable. Some of the special applications may include the manufacture of paper products in which modified starch act as a binding agent for the fibre.

The purpose of starch modification is to convert the resultant natural starch characteristics to conform to the specific end-user needs (Inglett, 1970). This is generally accomplished by chemically treating the raw starch slurry under controlled conditions. Some of the modifying chemicals include hydrochloric acid to produce acid modified starch, sodium hypochlorite for oxidised starch, ethylene oxide for hydroxyethyl starch, acetic anhydride for acetylated starch, etc.

After the modification process, the modified starch is washed, dewatered and dried. Modified starch filtrates may contain some of these residual chemicals and solubilised starch molecules (U.S EAP, 1974). For this reason, these wastewaters may not be recycled for reuse in other wet milling processes.

2.8.2 Dextrins

This is a low cost process for modifying starches to produce greater water solubility and improved adhesiveness, amongst other qualities (Inglett, 1970). The process involves heat treatment of dried starch in the presence of various catalysts such as gaseous hydrochloric acid (HCl) or weak aqueous mineral acid. The acid is sprayed onto the dried starch, which is then subjected to a controlled roasting process in a closed vessel.

There are different versions of dextrins, some of which only use heat treatment. The major applications of dextrins are for adhesives, fillers and binders (Inglett, 1970).

This is effectively a dry process, normally with no effluent generated and/or water usage required.

2.8.3 Glucose manufacture

Corn syrups and dextrose (sugar) are manufactured through acid and/or enzymatic conversion of starch slurry. Corn syrup is produced through partial hydrolysis whereas dextrose is through complete hydrolysis (Inglett, 1970). The process involves the cooking of starch slurry with the required amount of dilute mineral acid, typically HCl until the desired degree of conversion is reached. The conversion reaction may be terminated by neutralisation with soda ash (Na_2CO_3).

The enzymatic conversion, on the other hand, uses dual enzymes or an acid and an enzyme, to fulfill the conversion objective. This route has however been found to be more efficient because, amongst other factors, it uses more concentrated starch slurry (Inglett, 1970).

The enzymatic conversion requires that the starch slurry is cooked to temperatures in excess of gelatinisation point, and simultaneously partially converted to dextrose equivalent (DE) of 15–20 (Inglett, 1970). Partial conversion is either by acid or alpha-amylase enzyme, then pH adjusted to 4.0–4.5 (Inglett, 1970). Further conversion is accomplished by another enzyme, typically gluco amylase, which takes the conversion to desired saccharification point.

After the desired conversion is reached, suspended solids and other impurities are removed by filtration, and syrup is finally refined and concentrated into the desired density. When the solid form is required, the spray drying process is employed. In the case of dextrose, the conversion is allowed to go to completion, neutralised, filtered, clarified, concentrated and finally allowed to crystallize to form sugar crystals.

Degree of conversion is expressed as dextrose equivalent (DE). This is the determination of the total reducing substances expressed as dextrose (Inglett, 1970). Syrup has low DE of 30–70, whereas dextrose has a higher DE of 70–90 (Inglett, 1970).

A major source of effluent from this section is condensed process vapours (CPV) from the evaporators, equipment cleaning, filtrates and spent liquor from the regeneration process of the ion exchange resin beds.

2.9 Corn processing effluent: Sources and characterisation

Effluent from the corn wet milling industry is known as a high strength wastewater due to its high protein and starch content (Ersahin et al. 2006). The biodegradability of corn processing wastewaters is high in comparison to most of the other industrial effluents (Eremektar et al. 2002).

Typically, wastewater is mainly generated from evaporator vapour condensate, evaporator cleaning water, modified starch washing and grind mill cleaning water for wet milling process (Ersahin et al. 2006). Generally, wastewater generated from the thickening, washing and dewatering processes is reused as process water, e.g. in the preparation of steep acid for corn steeping (see **Figure 2-6**). For starch slurry derivatives production, the wastewater sources are mainly consisting of condensed process vapours, filtrate, activated carbon recovery water, and demineralisation unit cleaning water from dextrose and fructose refinery (Ersahin et al. 2006)

The high strength and biodegradable character of the corn processing wastewaters makes biological treatment systems appropriate for the treatment of this type of effluents (Howgrave-Graham et al. 1994). Generally, two stage biological treatments; anaerobic stage followed by an aerobic stage is applied for the treatment of corn processing effluents (Ersahin et al. 2006). For such soluble and easily biodegradable substrates, the acidogenic reactions can be much faster at high loading rates, and may increase the reactor volatile fatty acids (VFA) and H_2 concentrations, thus depressing the pH (Tchobanoglous et al. 2003). This will inevitably inhibit methanogenesis.

The presence of sufficient amount of macronutrients and trace elements is required for the granulation and stability of anaerobic reactors (Speece, 1996 and Ozturk, 2007). Rajeshwari et al. (2006) reported that an optimum Carbon (C): Nitrogen (N): Phosphorus (P) ratio of 100:2.5:0.5 is required for optimum methane yield in corn processing wastewater anaerobic treatment.

In Ersahin et al. (2006) corn processing effluent profile studies, corn wet milling and starch derivatives production generated 0.64 m^3/tonne corn processed and 0.80 m^3/tonne of commercial product produced, respectively. It was also reported that organic loads from wet milling and starch derivatives production were 2.65 kg COD/tonne corn processed and 1.41 kg COD/tonne commercial product produced, respectively. Table 2-2 presents detailed qualitative corn effluent characterisation study results.

Table 2-2: Corn processing effluent characterisation studies (Ersahin et al. 2006)

		References	
Parameter	Unit	(Ovez et al. 2001)	(Eremektar et al. 2002)
COD_{total}	mg/L	4850	3800
$COD_{soluble}$	mg/L	3850	3230
BOD_5	mg/L	3000	2800
TKN	mg/L	174	84
NH_4-N	mg/L	-	23
TP	mg/L	125	33
TSS	mg/L	650	400
pH	-	5.2	-

Ross (1989) completed a similar study on the Bellville (Cape Town) corn wet processing effluent at the Bellville Sewage Plant. The average influent was 500 m^3/day, with a mean COD concentration of 7.2 kg/m^3. Corn processing effluent characterisation study by Ross (1989) is summarised in Table 2-3.

Table 2-3: Bellville sewage plant effluent profile (Ross, 1989)

Effluent Analyses (1976 – 1984)				
Parameter	Mean	Maximum	Minimum	Standard Deviation
Flow (m^3/d)	454	1253	41	215
pH	4.36	9.99	3.30	0.82
$COD_{unfiltered}$ (mg/L)	6690	98960	1100	5812
$COD_{filtered}$ (mg/L)	5423	72920	830	4547
Dissolved Solids (mg/L)	4793	69220	570	4218
TS (mg/L)	5723	72550	800	4496
Conductivity (µS/cm)	1463	7330	300	812

2.10 Corn processing effluent treatment and disposal

Effluent hydraulic and pollutant loading rates from a corn wet processing plant are highly variable. This is, amongst other factors, due to intermittent discharges of ion exchange wastes from the refinery; occasional loads from process equipment cleaning; intermittent discharge of dewatered starch filtrates and process overflows and/or product spillages.

There are several possible treatment methods of such effluents reported in literature. In each treatment method, there are several processing steps involved, depending on whether pretreatment or complete treatment is envisaged: flow equalization, temperature control, pH control, biological treatment, clarification, disinfection and sludge disposal.

2.10.1 Flow equalisation

This is the dampening of variations to achieve a somewhat constant loading rate. It is a process of controlling flow velocity and/or composition (Goel et al. 2005).

Equalisation basins may be located in-line or off-line with respect to the rest of the unit operations. In in-line equalisation, 100 % of the influent enters the basin, and subsequently pumped into the treatment system at a controlled rate. In the off-line equalisation configuration, a flow diversion system for excess volumetric load is provided for. Excess load is diverted into the basin and subsequently pumped into the treatment system as and when it is required to augment the influent loading rate.

Some of flow equalisation principal benefits are enhanced biological treatment performance due to reduced shock loadings (Tchobanoglous et al. 2003). The sizing of an equalisation basin is based on two approaches, flow balance or composition balance (Goel et al. 2005). Flow balance approach is used when the influent quality is relatively constant but with high diurnal hydraulic variability (Goel et al. 2005). Composition balance approach is however preferred when there is relatively constant hydraulic variation, but high qualitative variations (Goel et al. 2005). The computation of the equalisation volume is therefore based on either characteristic diurnal flow pattern or mass loading pattern of a particular pollutant.

In a corn processing effluent treatment system, the equalisation basin should be agitated and have a 24 hr hydraulic retention time (HRT), operated at 50–60 % capacity (CPI, 1994). Tchobanoglous et al. (2003) recommend a 10–20 % overdesign factor of the theoretically determined flow equalisation volume. The theoretically computed volume from a hydrograph method is always smaller than the actual volume because of the following considerations (Goel et al. 2005):

- Minimum volume of wastewater is always required to maintain agitation and/or aeration in the basin;
- Some free board is to be provided for, to accommodate unforeseen changes in the diurnal flow pattern; and
- Sometimes, concentrated downstream wastewater is recycled into the basin. When this happens, dilution is needed to avoid odour problems.

Flow equalisation is more routinely employed in industrial effluent treatment systems than in municipal treatment facilities (Goel et al. 2005). This is attributed to the fact that most industries use batch production processes, cyclic nature of some industrial processes and seasonal production demand variations (Goel et al. 2005).

2.10.2 Temperature and pH controls

Corn processing effluent is generally hot (CPI, 1994). Biological treatment systems are susceptible to excessively high and/or low temperatures. Mixing of different effluent streams in the equalisation basin may assist in reducing the effluent temperature. The other alternative is to have a heat exchange system which maintains the effluent at the desired temperature before entering a biological treatment system.

Such effluents also have a highly variable acidity and/or alkalinity ranges. There are high and low pH streams from ion exchange, corn steep liquor evaporators and starch filtrates. Whether there is an on-site pretreatment system or the effluent is being discharged to the municipal sewer, pH control is inevitable. To minimise pH adjustment chemical costs, effluent streams may be mixed and/or segregated at source to exploit possibilities of self neutralisation.

Neutralisation is the process of adjusting water pH through the addition of an acid or base, depending on the target pH range and/or downstream process requirements (Goel et al. 2005).

2.10.3 Biological effluent treatment

There are two types of biological effluent treatment systems, namely anaerobic and aerobic treatment.

2.10.3.1 Anaerobic digestion

Anaerobic treatment is effectively accomplished through two main process steps, preceded by the hydrolysis process of complex organic materials. Equation 2.1 represents the acidogenesis process step:

STEP I:

$$\textbf{Soluble Organics} \xrightarrow{Nutrients + \ Acid\ Forming\ Bacteria} \textbf{Organic Acids} + \textbf{Biomass} \qquad \textbf{(2.1)}$$

Equation 2.2 represents the methanogenesis process step:

STEP II:

$$\textbf{Organic Acids} \xrightarrow{Nutrients + \ Methane\ Forming\ Bacteria} \boldsymbol{CH_4 + CO_2} + \textbf{Biomass} \qquad \textbf{(2.2)}$$

This has been identified as one of the biological treatment techniques that can be applied to industrial wastewater (Speece, 1996). Biological anaerobic technologies are widely used for the treatment of high strength industrial effluents (Mutombo, 2004). It is an energy generating process in terms of biogas estimated at 0.35 L CH_4/gCOD removed at standard temperature and pressure (STP) conditions (Tchobanoglous et al. 2003).

It leads to the ultimate gasification of soluble organics to carbon dioxide (CO_2), methane (CH_4), and hydrogen (H_2) (Burton et al. 2009).

In view of the current challenges, both in environmental protection and search for alternative energy sources, AD is seen as the most attractive wastewater treatment technology. This multistep process requires the presence of very different and yet closely dependent microbial populations (Ersahin et al. 2005). The basic metabolic pathway of AD process is illustrated in Figure 2-7.

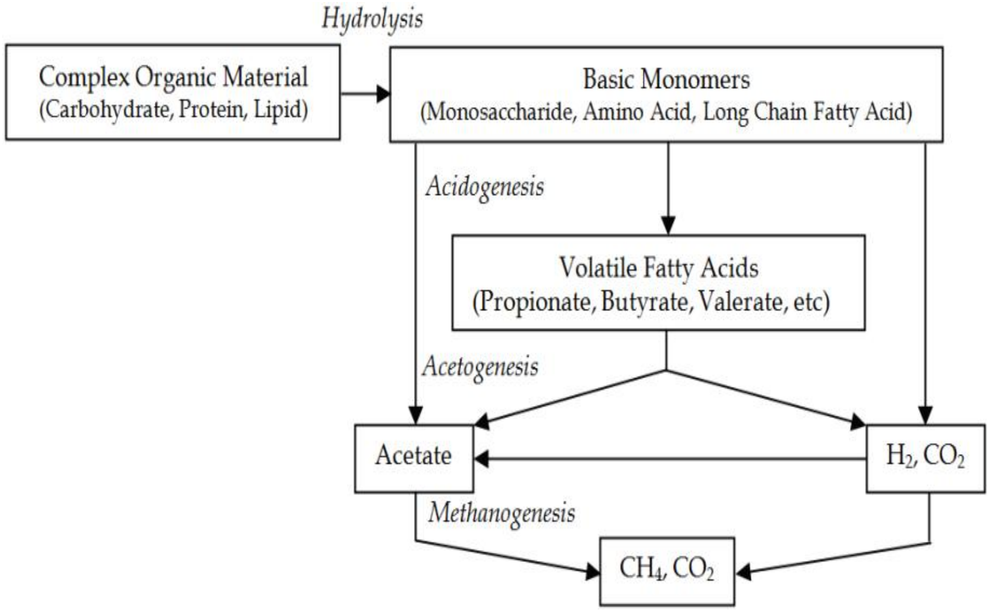

FIGURE 2-7: Anaerobic process steps (Ersahin et al. 2005)

The first step of the anaerobic degradation is the hydrolysis of complex organic material to its basic monomers by the hydrolytic enzymes. The simpler organics are then fermented into organic acids and hydrogen (H_2) by the fermenting bacteria (acidogens). The volatile organic acids are transformed into acetate and hydrogen by acetogenic bacteria. Methanogens use hydrogen and acetic acid produced by acetogens (H_2 producing) to convert them to CH_4 and CO_2.

AD has significant advantages over competing technologies for the treatment of carbonaceous municipal, industrial and agricultural effluents (Burton et al. 2009). These include low energy requirements, reduced biomass yield, higher organic loading rate (OLR) range of 3.2–32 kg COD/m^3.d and hence reduced reactor volume requirements (Tchobanoglous et al. 2003).

Some of the disadvantages of anaerobic digestion are (Tchobanoglous et al. 2003):

- Longer start up time to develop necessary biomass inventory and acclimation;
- Need for alkalinity (2000–3000 mg/L as $CaCO_3$) addition to maintain acceptable pH range (near neutrality, but not less than 6.8);

- Potential for odour generation;
- Susceptibility to toxicity upsets;
- Sensitivity to adverse effect of lower temperature to reaction rates. Reactor temperature of between 25 and 35 ^oC is generally preferred; and
- The possible requirement for post aerobic treatment to meet effluent discharge limits in terms of nutrient removal.

COD concentrations ranging from 3000 to 30000 mg/L, are typically found in food processing and distillery wastewaters, and can efficiently be treated in an anaerobic digestion process (Tchobanoglous et al. 2003). Influent flow and loading variations may however upset the balance between acidogenesis and methanogenesis (Tchobanoglous et al. 2003). This is normally circumvented by flow equalization to cater for peak loading conditions.

Some of the most commonly used anaerobic digester configurations are illustrated in Figure 2-8: completely mixed digester, upflow anaerobic sludge blanket reactor (UASBR), anaerobic fluidised bed (AFB), expanded granular sludge blanket reactor (EGSBR) and upflow anaerobic filter (UAF). These are categorised as suspended growth, sludge blanket and attached growth processes.

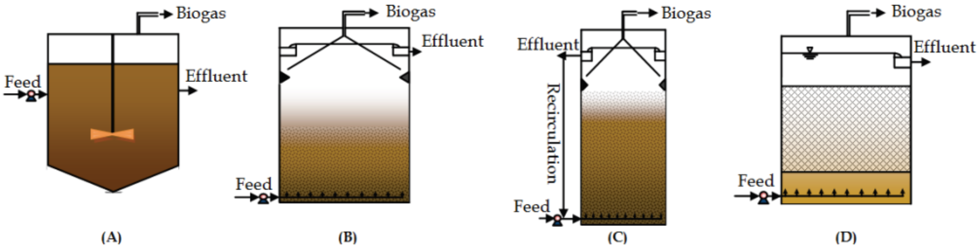

FIGURE 2-8: Anaerobic reactor types: (A) Completely mixed anaerobic digester, (B) UASBR, (C) AFB/EGSB, (D) UAF (Ersahin et al. 2005).

A. Completely Mixed Anaerobic Digester

Completely mixed anaerobic digester is one example of a suspended growth anaerobic process. It is the basic anaerobic treatment system with an equal HRT and SRT of 15–40 day (Ersahin et al. 2005). This provides sufficient retention time for both process and operational stability.

This digester type, without a recycle, is more suitable for wastewaters with high solid concentrations (Tchobanoglous et al. 2003). Its typical OLR range is 1.0–5.0 kg COD/m^3.d (Tchobanoglous et al. 2003).

B. Upflow Anaerobic Sludge Blanket Reactor

Amongst the sludge blanket anaerobic processes and anaerobic treatment process technologies, the UASBR is the notable technological development of the 1970s (Mutombo, 2004). This is considered a breakthrough, allowing high design OLR of between 12 and 20 kg COD/m^3.d at 30-35 ^{o}C (Tchobanoglous et al. 2003).

Influent flow is distributed at the bottom of the reactor, travels upwards through the sludge blanket and passes out around the edges. This provides a greater contact area for the effluent, reduced upflow velocity, enhanced SRT and improved solid separation efficiency from the outward flowing wastewater.

Granules which naturally form after several weeks of reactor start-up, consist primarily of a dense mixed population of methane-forming bacteria (Ersahin et al. 2006). COD degradation occurs as the wastewater comes into contact with sludge granules (Mutombo, 2004). Granulation is very successful with high carbohydrate or sugar wastewaters, but less so with waters which are high in proteins, fats and total suspended solids (Tchobanoglous et al. 2003). This results in a more fluffy flocculated sludge. The development of granulated solids is also affected by pH, upflow velocity, and nutrient addition (Tchobanoglous et al. 2003). The following conditions are recommended for an optimum UASBR performance (Tchobanoglous et al. 2003):

- Near neutral pH;
- Upflow velocity of plug flow hydraulic regime; and
- COD: N: P ratio of 300:5:1.

The other noted limitation of UASBR is related to wastewaters with high solid content (greater than 6 g/L) which prevents the dense granular sludge development (Tchobanoglous et al. 2003). Good sludge setteability, low retention times, packing material costs elimination, high biomass concentrations and high OLR can be achieved by UASBR (Speece, 1996). Critical elements of the UASBR design are the influent distribution system, gas-solids separator, and the effluent withdrawal design (Tchobanoglous et al. 2003).

The anaerobic baffled reactor (ABR) is another example of sludge blanket reactors which is being studied at bench and pilot scale for a wide range of wastewaters (Tchobanoglous et al. 2003). ABR has alternatively hanging and standing baffles which divide it into eight compartments (Bell et al. 2007). Effluent flows alternatively up and downwards through these compartments. ABR provides resilience to concentrated, intermittent organic and hydraulic loads typical to industrial effluents (Bell et al. 2007). A schematic example of a laboratory scale ABR is presented in Figure 2-9.

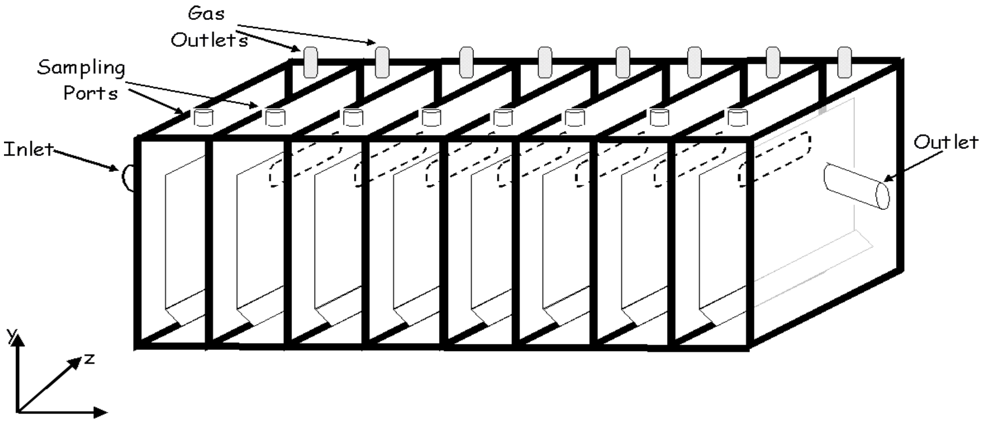

FIGURE 2–9: Anaerobic baffled reactor laboratory scale schematic (Dama et al. 2000)

It is similar in design and application to UASBR except that it requires no special biomass granulation for its efficient operation (Bell et al. 2007). This makes ABR amenable to concentrated and hydraulically variable industrial effluents which are intrinsically unsuitable for treatment in the completely mixed systems.

Movahedyan et al. (2007) investigated the feasibility of wheat flour starch wastewater treatment in a five compartment pilot scale ABR. This 13.5 L ABR was operated at a constant temperature of 35±0.5 °C (Movahedyan et al. 2007). After removal of suspended solids by gravity settling, starch wastewater influent COD was diluted to 4500 mg/L.

The qualitative profile of the wheat flour starch wastewater that was used by Movahedyan et al (2007) in the ABR pilot scale feasibility study is presented in Table 2-4.

Table 2–4: Wheat flour starch wastewater characteristics (Movahedyan et al. 2007)

Parameter (mg/L)	Raw Wastewater	Settled Wastewater
COD	16200–26500	12000–20 375
TSS	9440–11940	392-666
VSS	8930 –11 100	372-588
pH	3.5–4.2	3.5–4.2
TKN	-	50-100
Orthophosphate	-	25-35

At an OLR of 2.5 kg COD/m^3.d and HRT of 2.45 days, a 67 % COD removal was achieved (Movahedyan et al. 2007). Based on these observations, the ABR process has shown potential to pretreat high strength and variable food industrial wastewater. This type of wastewater is qualitatively similar to corn wet processing effluent.

C. Anaerobic Fluidised and Expanded Bed Reactor

AFBR falls under the attached anaerobic process group, and comprises of bed media such as sand or granular activated carbon to which bacteria attach (Ersahin et al. 2006). Some of its limitations are in the development of strongly attached biofilm containing the correct blend of methanogens, detachment risks of microorganisms, dilution effects of the influent flow by high recycled effluent stream and energy costs due to high recycle rate (Ersahin et al. 2006).

EGSBR is a modification of the AFBR with a lower up flow velocity to that of AFBRs (Ersahin et al. 2006). Ersahin et al. (2006) reported 85 % COD reduction in a full scale EGSBR treating corn processing effluent with an average influent COD concentration of 2750 mg/L at a pH of 6.9.

D. Upflow Anaerobic Filter

Anaerobic filter processes use column reactors filled with various types of solid media through which the influent flows and onto which anaerobic bacteria grow and get retained (Mutombo, 2004). This packed bed configuration offers a greater potential for clogging due to influent suspended solids and biosolids, thus causing short-circuiting.

This process is therefore suited for wastewaters with low suspended solid concentrations (Tchobanoglous et al. 2003). Tchobanoglous et al. (2003) reported process efficiency of up to 90 % at OLR of 1.0-6.0 kg COD/m^3.d, for high strength wastewaters.

Locally, Ross (1989) completed both corn wet processing effluent characterisation and anaerobic digestion treatability studies, respectively. This full scale treatability study was conducted using a modified clarigester at the Bellville Sewage Treatment Plant. The modified anaerobic digester configuration that was used in this study is illustrated in Figure 2-10.

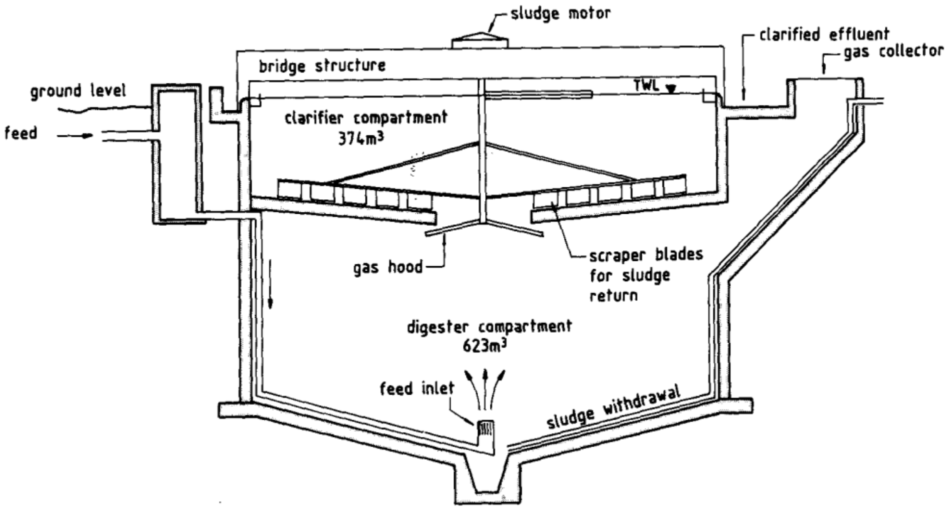

FIGURE 2-10: Modified clarigester at the Bellville Sewage plant (Ross, 1989)

The clarigester consists of a top compartment for effluent settling with an inlet at the centre and a circumferential overflow outlet weir for clarified effluent. The settling compartment is separated from the bottom digester by a diaphragm. Settled sludge is transferred to the bottom compartment by a rotating scraper and influent is fed from the bottom. Biogas is collected from the outer periphery of the clarigester.

The Bellville Sewage Treatment Plant process layout is presented in Figure 2-11.

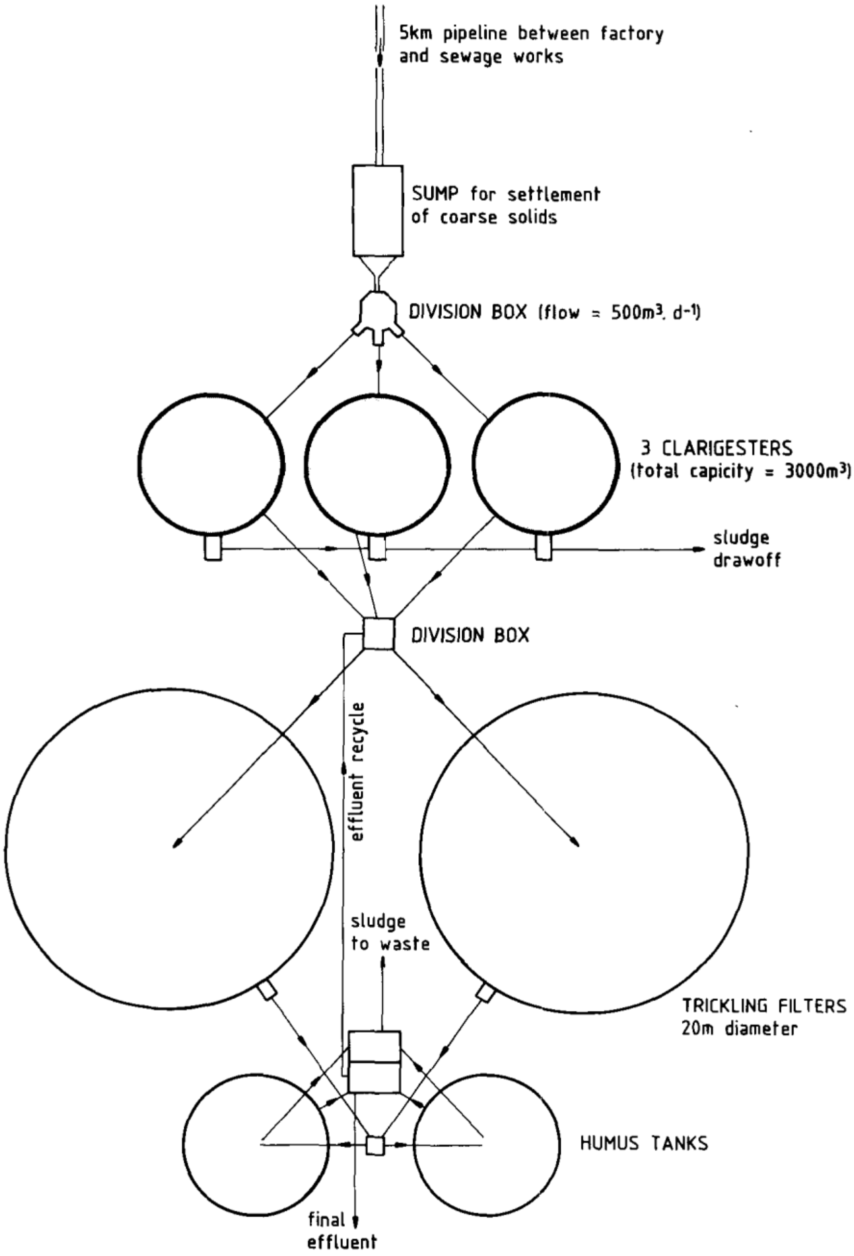

FIGURE 2-11: Bellville Sewage Plant Layout (Ross, 1989)

Ross (1989) also completed UASBR pilot plant study of the same effluent. Influent was preheated to 35 ^{o}C and the reactor was operated at OLR and HRT of 10–20 kg COD/m^3.d and 0.4 d, respectively.

The main objectives of this pilot scale study were to investigate the resultant sludge setteability and the phenomenon of sludge granulation. These phenomena had been witnessed in the clarigester at the Bellville Sewage Plant.

Using solids flux method, a maximum solids flux value of 4500 kg/m^2.d and a concentration of 90 kg/m^3 suspended solids were predicted, respectively.

The settling rate was established to range between 6 and 60 m/h due to the varying sizes of the sludge granules that were formed.

2.10.3.2 Aerobic digestion

The mechanism for aerobic treatment is that bacteria, when mixed with organic waste in the presence of O_2, use the organic carbon as an energy source, and convert the waste to CO_2, H_2O and biomass. Aerobic biodegradation is represented by equation 2.3.

$$\textbf{Soluble Organics} \xrightarrow{\boldsymbol{Nutrients + O_2 + Bacteria}} \boldsymbol{H_2O + CO_2} + \textbf{Biomass} \qquad \textbf{(2.3)}$$

There are numerous processing technologies that have been developed to accomplish this carbonaceous degradation as shown in the reaction above. These include activated sludge; extended aeration, aeration ponds; oxidation ditches and trickling filters.

In contrast to anaerobic systems, aerobic systems generally demand high energy input of 0.8 kg O_2/kg COD removed (Tchobanoglous et al. 2003).

2.10.3.3 Clarification

All aerobic wastewater treatment plants, and some types of anaerobic processes, require a separate clarifier to separate the biomass from the treated effluent stream. Clarification can be accomplished by either gravity settling or air flotation.

Gravity settling uses the principle of sufficiently reducing flow velocity to allow suspended particles of higher specific gravity to separate from the main body of the liquid and settle out as sludge (Freese and Nozaic, 2009).

Air flotation, typically Dissolved Air Flotation (DAF) systems, may be designed for pressurisation and air dissolution of the total wastewater flow. Commonly, the incoming flow enters the flotation vessel wherein it comes into contact with recycled air supersaturated effluent stream, and the released air bubbles carry with them solids onto the surface forming a sludge blanket (Freese and Nozaic, 2009).

2.10.3.4 Disinfection

This is only necessary when the treated effluent is to be discharged directly into the watercourse. For industrial wastewater treatment, disinfection may only be required if sanitary waste is included in the waste stream.

Chlorination has been a disinfectant of choice for many years (Tchobanoglous et al. 2003). It is the most commonly used disinfection technique. With increasing number of effluent discharge permits requiring low or non-detectable levels of residual chlorine in the treated effluent, dechlorination systems have had to be incorporated (Tchobanoglous et al. 2003). This has lead to the advent of other disinfection techniques. These include ozonation and ultra-violet (UV) radiation.

The goal of effluent disinfection is to remove or inactivate pathogenic microorganisms (Freese and Nozaic, 2009).

2.10.3.5 Sludge disposal

There are three available sustainable sludge disposal options (Freese and Nozaic, 2009):

- Using the calorific energy value of the sludge (e.g. heat generation);
- Using the useful components of the sludge (e.g. as a soil conditioner, composting); and
- Extracting useful constituents from the sludge.

Before any of these options can be considered, the sludge needs to be classified in terms of microbial activity, stability and pollution potential (Nozaic and Freese, 2009). AD remains the principal process for sludge stabilisation.

CPI (1994) reported that sludge biomass from a corn wet milling biological treatment system may contain between 40 and 50 % protein on dry basis. If the treated wastewater contained no sanitary waste, this biomass could be mixed and concentrated with LCSL to CCSL and added as an additive to the animal feed (CPI, 1994). The concern about the high bacterial count in the biomass was resolved by heat treatment in the evaporation process during the corn steep liquor concentration (CPI, 1994).

2.11 Summary of literature review

In South Africa, equitable accessibility and protection of water resources have become mandatory and strictly legislated. In the promotion of water conservation and wastewater reduction, the incentive based approach to legislation has been adopted. Some of these relevant legislations form the basis of the Pricing Strategy which was established under the NWA.

Some of the fundamental aims of these legislations are:

- Promotion of sustainable development and efficient use of water resources;
- Promotion of the internalisation of environmental costs by polluters;
- Full recovery of water quality management costs; and
- Creation of financial incentives for polluters to reduce waste and use natural resources sustainably and responsibly.

On the other hand, manufacturing methods have significantly advanced over the years, but their impact on the environment is seemingly becoming more severe. This is amongst other factors, due to the generation of high strength and sometimes toxic effluents. Besides incurring extra treatment costs; these waste streams may represent losses in raw materials and/or sellable products. Similarly, the corn wet processing industry generates high strength and highly variable volumes of effluent which end up in the local Municipal effluent collection systems.

With the increasingly more stringent effluent discharge regulation standards, traditional end-of-pipe treatment methods are no longer cost effective, and do not guarantee consistent compliance to effluent discharge limits. Regulatory standards are however important in ensuring effective and efficient delivery of sustainable water and wastewater services. They clarify the requirements and obligations that are placed on water and wastewater service institutions, thereby protecting water users and the environment from unsafe and unsustainable activities.

It is therefore prudent that the corn processing industry should also explore the exploitation of the principles of water management hierarchy. In pursuit of this, a well understood water and wastewater footprint is paramount. Amongst other recommended techniques like water pinch analyses, cleaner production, clean technology, etc. This will require comprehensive effluent characterisation studies to be conducted.

This study is therefore aimed at qualitatively and quantitatively identifying major sources of wastewater within a corn wet processing plant. Finally, the objective is to evaluate and assess the treatability of this type of effluent in an anaerobic digestion process. The next chapter outlines the approach and methodology that was used during course of this study for data collection and subsequent analyses.

3. METHODOLOGY

3.1 Introduction

This chapter seeks to give background information on the two corn wet processing plants that were covered in this study. It further outlines the scope of the study and the methodological approach that was adopted in data collection and analyses. Lastly, it presents potential limitations that may have compromised the integrity and accuracy of the study findings in terms of water usage profiles, wastewater characterisation and effluent treatability analyses.

Research methodology is thus the chronological arrangement of ideas, procedure and classification thereof to achieve a specified objective. Research is the practical application of science, engineering and management in the data collection, analyses and interpretation to produce results that in turn produce knowledge (Utting, 2003). To examine the proposed research question on the treatment of corn processing effluent, Germiston and Meyerton corn processing plants were identified and explored as case studies.

3.2 Case studies – Germiston and Meyerton plants

Effluent characterisation studies were conducted on effluents generated from two of THS corn wet milling plants: Germiston and Meyerton plants, respectively. Meyerton mill has a nameplate corn grind design capacity of 300 tonnes/day compared to Germiston's 1000 tonnes/day (Tongaat Hulett Starch, 2008). Due to changing wastewater characteristics, and imposition of stricter effluent discharge limits, greater emphasis is being placed on wastewater characterisation (Tchobanoglous et al. 2003).

Meyerton plant manufactures a wide range of unmodified and modified starches, acid glucose and co-products. Besides unmodified starches, acid glucose and co-products, Germiston plant also manufactures enzyme glucose.

For both plants, effluent streams that are generated from different sections of the plant are collected into dedicated collection points, and subsequently discharged into common effluent discharge/collection systems. At Germiston plant, pH is adjusted by lime slurry, before being discharged to the common effluent sump (E7) that overflows into the Municipal sewer.

At the Meyerton plant, pH is adjusted by sodium hydroxide solution at the common collection point. A limited volume of the pH adjusted effluent is treated in the anaerobic digester (clarigester) before being mixed with the rest of the effluent, and discharged into the Municipal sewer. This is due to the limited availability of the anaerobic digestion reactor capacity.

At Germiston plant, seven effluent collection points into which effluent streams are collected were identified. These collection points are identified according to their major sources of effluents: Wetmill (E1), Acid glucose (E2T and E2V), Spray dryer (E3), Loading bay (E4), Enzyme glucose (E5) and Stormwater drain system (E6).

In E1 and E5, effluent is collected, mixed, neutralised and intermittently discharged through a flow monitoring device into E7 that discharges to the Ekurhuleni Metropolitan Municipality's sewer. Figure 3-1 illustrates the process flow diagram (PFD) for E1 and E5 effluent collection and pH control systems, respectively.

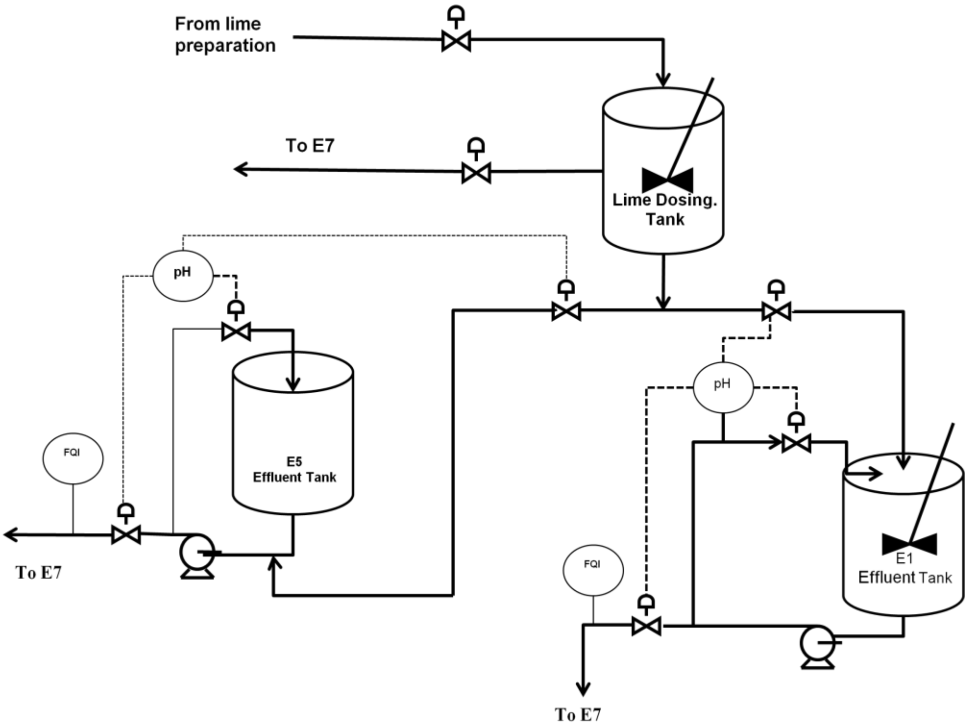

FIGURE 3-1: Process Flow Diagram for E1 and E5 effluent collection and pH control systems

E5 collects all effluent that gets generated during the manufacture of enzyme glucose. These may include wastewater from equipment cleaning, ion exchange waste regenerant, filtrates, cooling water blowdown, process vapour condensates, product spillages, etc. Due to high pH variability of this effluent, pH monitoring and adjustment was done in the collection tank (E5), before being discharged into E7.

E1 collects all effluent generated from the wet milling process. These may include wastewater from equipment cleaning, process overflows, condensed process vapours, etc. Similarly to E5, pH monitoring and adjustment was done in the collection tank (E1), before being discharged into E7.

The entire Germiston plant wastewater collection network is illustrated in Figure 3-2 and summarises the major sources of effluents into each stream collection point.

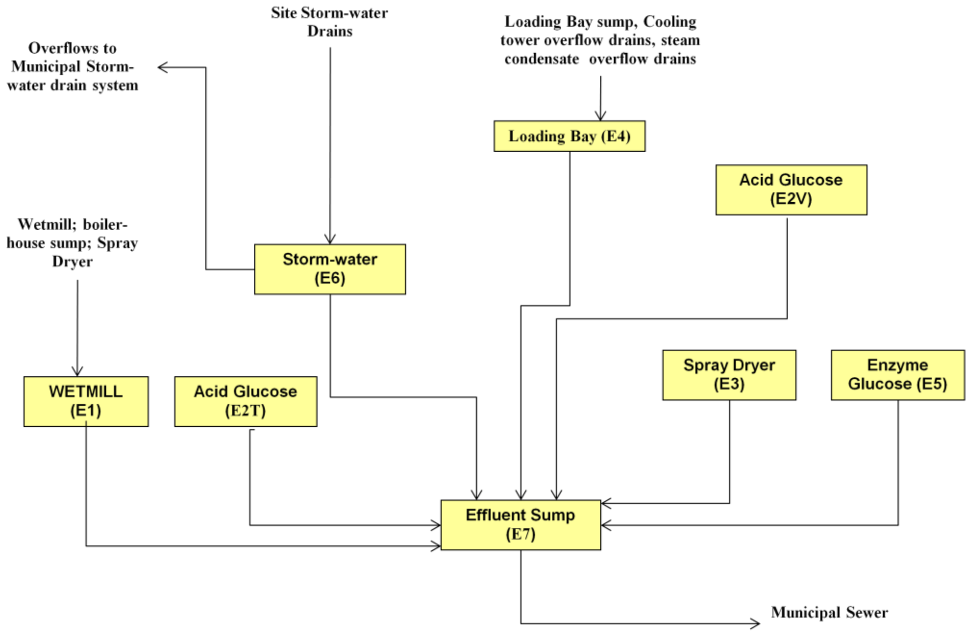

FIGURE 3-2: Germiston plant wastewater network and collection points

Similarly for the Meyerton plant, five plant effluent collection points were identified: Acid Syrup, Starch, CPV, Wetmill and Stormwater drain system. From each collection point, effluent is mixed and intermittently discharged through a flow monitoring device into the downstream collection points. Figure 3-3 presents the Meyerton plant wastewater collection network.

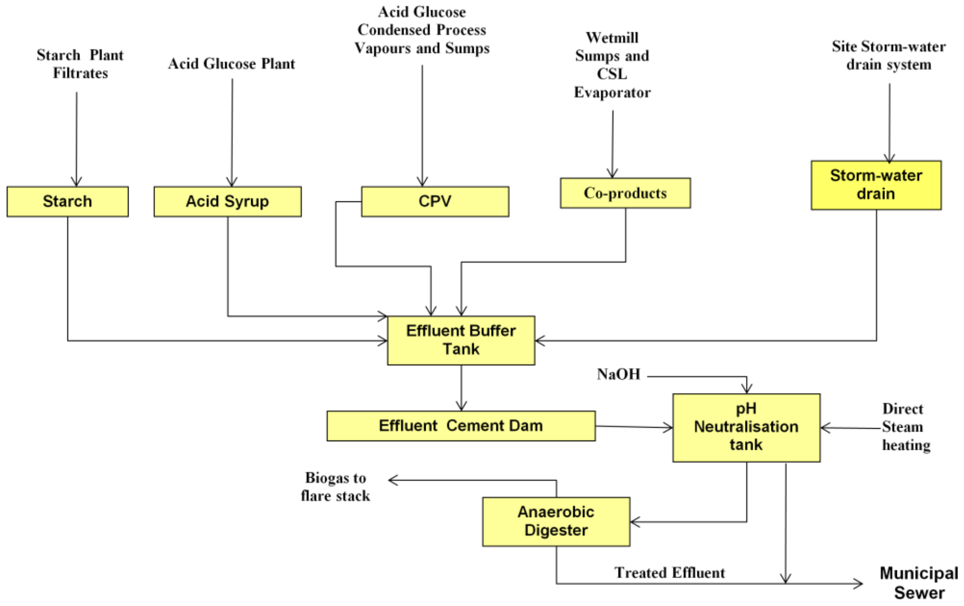

FIGURE 3-3: Meyerton plant wastewater network and collection points

During this study, the 30 m^3 buffer tank and 1200 m^3 cement dam (flow equalisation basin) were both out of service for maintenance. Effluent collected in each of these five identified points was independently and intermittently discharged directly into the pH neutralisation tank. From the pH neutralisation tank, a controlled fraction of the total effluent was treated in the anaerobic digester (clarigester) before being discharged into the Midvaal Local Municipality’s sewer. The balance of the effluent was mixed with anaerobically digested effluent before being discharged into the Municipal sewer.

3.3 Methological approach

A comprehensive literature review was undertaken on the state of water resources and regulation in South Africa. This was then followed by the review of the manufacture of corn derived products through wet milling and previous studies on corn processing effluents, respectively. Two of Tongaat Hulett Starch Pty Ltd’s corn processing plants were then used as case studies for this work. Effluent characterisation studies were subsequently conducted on Germiston and Meyerton corn processing plants, respectively.

Routine daily effluent samples were collected and analysed for each study. Corresponding daily effluent volumes, water usage volumes and corn tonnage processed were also recorded. The collected data was subsequently analysed and interpreted to establish effluent profiles for each of the studied plants’ streams.

The research method adopted for this study was both qualitative and quantitative analyses of the corn processing effluents. Both methods involve formulating a good research question, matching the question with appropriate methodology, collecting reliable data, data analyses and careful interpretation (Utting, 2003).

3.4 Sampling and data collection

Understanding of the nature of effluent being generated is fundamental to the design and operation of a wastewater collection, treatment and reuse facilities (Tchobanoglous et al. 2003). This needs to be supplemented by a sound effluent quality monitoring and quantity measuring programme. Effluent sampling programmes and/or techniques are undertaken for a variety of reasons (Tchobanoglous et al. 2003):

- To obtain routine operating data on overall plant performance;
- For process performance assessment and evaluation;
- For the implementation of new proposed programmes; and
- To report on regulatory compliance.

Data obtained from a sampling programme/technique, should be representative and reproducible (Tchobanoglous et al. 2003). This will be useful if the results obtained from data analyses are to serve as basis for the implementation of wastewater quality management programme.

Sample integrity is to be maintained during the interim periods between sample collection and analysis. Prompt sample analysis is undoubtedly the most positive assurance against sample deterioration (Tchobanoglous et al. 2003). The next subsections of this Methodology section outline the approach that was adopted and followed in data collection and analyses for effluent characterisation and treatability studies, respectively.

By means of literature study, plant site visits, plant personnel interviews and analyses of some of the existing data, a thorough understanding of the two plants' processes and layouts were obtained. This is demonstrated in the previous sections on corn wet milling technology and illustrations of wastewater networks in **Figure 3-2** and **Figure 3-3**, respectively.

Daily effluent flow rates from the identified effluent collection points (see **Figure 3-2 and Figure 3-3**) were metered and recorded. These were used to quantify total volumes of effluent collected and subsequently discharged from each point on a daily basis.

From each collection point, samples were taken at regular intervals for qualitative analyses. On-site laboratory facilities were used for sample analyses and these were promptly analysed after collection. Where prompt sample analysis was not possible, samples were preserved in the fridge at 4 ^{o}C. For intermittently collected/discharged effluent streams, grab samples at regular intervals were taken. Individual results from the grab sample analytical results were later averaged for a 24 hour day. Where continuous effluent flow existed, automatic sampling to collect a composite sample was used.

Flow meter readings were taken on daily basis from the installed flow recorders, and the total volumes of effluent generated and freshwater usage were accordingly determined. Flowmeter readings from consecutive days were taken and subtracted. The recorded flow volumes were calculated as the difference from those two consecutive daily readings.

3.4.1 Germiston Plant: Effluent characterisation study

Routine effluent samples were collected on two hourly basis from each effluent stream collection point (see **Figure 3-2** for the different collection points), and these were analysed for total organic carbon (TOC) and conductivity. These two hourly results were averaged for a 24 hour day.

Lime slurry was continually dosed at E1, E5 and E7 for pH neutralisation, respectively. As illustrated in Figure 3-1 and Figure 3-5a, respectively, each of these collection points were equipped with mixing facilities and automatic pH control systems. pH was maintained within 6.7 and 7.8, before being discharged to the downstream collection point. From E1 and E5, collected effluent was kept on recirculation until predetermined high tank level and pH specification were met.

Effluent flow recorders were installed on the outlet of each collection point. Daily flow readings were taken from each flow recorder to quantify daily volumes of effluent collected and discharged. Flow readings taken on two consecutive days, at six o'clock in the morning were subtracted. From this difference, a daily volume of effluent generated and/or discharged was established. E3, E4, E2T, E2V and E7 were equipped with 90^{o} V-notch weir flowmeters to record effluent being discharged from each point. Figure 3-4a illustrates one of the 90^{o} V Notch weir flowmeters installed at E4.

FIGURE 3-4a: E4 90^{o} V Notch weir flowmeter

FIGURE 3-4b illustrates the flow transmitter for the above flowmeter/sensor.

FIGURE 3-4b: E4 flow transmitter

Daily volume of effluent collected and discharged from E7 to the Ekurhuleni Metropolitan Municipality’s sewer was metered and recorded through a similar metering system in Figure 3-4a (90^{o} V notch weir flowmeter) and Figure 3-4b (flow transmitter and recorder).

E7 was also equipped with an automatic effluent sampler (E&H ISCO 3700) and an on-line pH monitoring (Mycom CPM 151p) system, respectively. Figure 3-5a illustrates an automatic sampler, pH monitoring and flow measuring sensor for E7.

FIGURE 3-5a: E7 Effluent monitoring system (E&H ISCO 3700 Auto sampler)

From the automatic sampler, a 24 hour composite effluent sample was collected into a 5 L container, and later analysed for COD, TOC, pH, conductivity and suspended solids (SS). pH was also monitored and adjusted based on the feedback signal from the on-line pH monitoring device as illustrated in Figure 3-5b.

FIGURE 3-5b: E 7 on-line pH meter (Mycom CPM 151p)

Additional effluent quality monitoring was conducted by the Ekurhuleni Metropolitan Municipality (EMM). Weekly routine grab samples were taken from E7 and independently analysed. These samples are analysed by EMM for pH, COD, conductivity, ammonia (NH_4-N), BOD, SS and orthophosphates. Using equation 1.3, the monthly trade effluent disposal charge and non compliance penalties are calculated based on a monthly average of these analytical results and the total effluent volume recorded to have been discharged for that particular month.

Effluent data collection for the study was between December 2011 and July 2012. This collected data was used for the Germiston plant effluent qualitative and quantitative characterisation study. Data for the daily total corn processed (tonnes/day) and freshwater usage (m^3/day) during the course of the study were also collected and analysed against volumes of effluent generated. Daily corn tonnages processed were obtained from production reports and freshwater usage was obtained from the freshwater supply flowmeters.

The next subsections of this chapter present the effluent characterisation and treatability studies for the Meyerton plant. These explore relevant data collection and sample analyses for the two effluent studies.

3.4.2 Meyerton Plant: Effluent characterisation study

Routine effluent samples were collected on a two hourly basis from each of the five streams' collection points, and analysed for total COD. An average daily total COD concentration was calculated from the two hourly sample analyses recorded over a 24 hour day. This was intended to ensure satisfactory representativity of the samples and results from these collection points.

Collected effluent from the different sections of the plant was mixed in each collection point. Prompt analyses, when convenient, were conducted on each sample collected to minimise the effect of sample deterioration. For illustration one of the effluent collection and metering systems is presented in Figures 3-6.

FIGURE 3-6: Starch plant effluent collection and discharge system

Daily effluent volume collected and subsequently discharged to the downstream collection point was metered and recorded on a flow recorder (magnetic flowmeter as illustrated in Figure 3-6). The collected effluent streams were intermittently discharged into the pH neutralisation basin. Effluent flow recorders were installed on the outlet of each collection point. Daily flow readings were taken from each flow recorder to quantify daily volumes of effluent collected and discharged. Flow readings taken on two consecutive days, at six o'clock in the mornings were subtracted. From this difference, a daily volume of effluent generated and discharged was calculated.

Total daily volume of effluent discharged into the Midvaal Local Municipality's sewer was similarly metered and recorded on a flow recorder. The daily volume of effluent that was fed into the digester was also similarly monitored and recorded.

Sodium hydroxide solution was used for pH neutralisation. From this pH neutralisation tank, some of the effluent was fed into the anaerobic digester whilst the rest was discharged into the Municipal sewer.

Composite samples of the digester feed and effluent to the sewer were collected at regular intervals on daily basis and immediately analysed for COD, pH and sometimes suspended solids, respectively. Digester feed rate was monitored and controlled by a flow control valve and flow monitoring device. Daily flow readings were taken on regular basis to work out the total volume of effluent fed into the digester.

Two hourly routine samples of digester effluent were taken on daily basis and immediately analysed for COD, pH and sometimes SS. These two hourly analytical results were averaged for the day. From these average daily analytical results, the performance of the digester was monitored and evaluated in terms of HRT, percentage COD removal and OLR.

The effluent characterisation study period was over a period of about seven months, from the end of December 2011 to the end of July 2012. Over the same period, data for the daily tonnage of corn processed and total freshwater usage (m^3/d) in the plant was collected and analysed against volumes of effluent generated. Daily corn tonnages processed during the course of the study were obtained from daily production reports, whereas freshwater usage data were collected from the installed flowmeters.

3.5 Anaerobic effluent treatability study

The clarigester at Meyerton plant was modified to an upflow anaerobic sludge blanket reactor. The modification adopted is as reported by Ross (1989) for the Bellville Sewage Treatment Plant, but also consists of an internal recirculation system.

3.5.1 Process Description

Wastewaters from the various sections of the plant were collected into level controlled effluent tanks and/or sumps. From each collection point (**Figure 3-3**), effluent was intermittently discharged into the pH neutralisation basin (digester feed tank).

Anaerobic digester pH was monitored and maintained between 6.7 and 7.7 by the addition of NaOH solution into the digester feed tank. Figure 3-7 illustrates an online pH meter for the digester feed tank.

FIGURE 3-7: Anaerobic digester feed on-line pH monitoring (E&H Liquisys M CPM transmitter)

In the same feed tank, dry saturated steam was directly injected to maintain the feed temperature between 27 and 37 ^{o}C. Both the reactor and digester feed temperatures were automatically monitored and controlled by steam injection into the digester feed tank. Similarly digester pH was monitored and controlled by the addition of NaOH solution.

The pH adjusted and steam preheated raw effluent was fed through the bottom of a 929 m^3 upflow sludge blanket anaerobic reactor at a flow controlled rate. Digested sludge slurry was continuously pumped into the 200 m^3 top clarification compartment. The reactor configuration is similar to the one illustrated in **Figure 2-10,** but also consists of an internal recirculation system**.** The reactor temperature and pH were automatically controlled and monitored by monitoring the digester feed pH and temperature, respectively. The generated biogas from the anaerobic COD degradation process was flared to atmosphere.

3.5.2 Sampling and data collection

Feed rate and pH into the digester were monitored and recorded from the flow totaliser and pH on-line analyser, respectively. Feed flow rate was adjusted and regulated by the feed flow control valve as required. Temperature was similarly monitored and controlled by the injection of steam into the digester feed tank. Data collection was over a period of about seven months, from the end of December 2011 to the end of July 2012.

Composite samples of the anaerobic digester feed and final effluent into the Municipal sewer were collected and analysed for COD, pH and sometimes SS on daily basis. The digester effluent was sampled on a two hourly basis, and immediately analysed for COD and pH. The two hourly analytical results were averaged for the day. From the influent and effluent COD data analyses, the anaerobic digester performance was evaluated in terms of percentage COD removal, HRT and OLR. From the performance data, biogas generation was estimated at average digestion temperature of 32 ^{o}C.

3.6 Data analyses

In profiling effluent qualities and quantities, total daily effluent volume recorded from each collection point was evaluated as a percentage of the total volume of effluent discharged into the sewer during the study period. From these evaluations, percentage volumetric effluent distribution loads were profiled for each plant. Similarly, organic percentage distribution loads in terms of average TOC or COD concentrations were also evaluated. Organic loads were calculated using equation 3.1 below.

$$\mathbf{Organic\ Load}\ \left(\frac{\mathbf{kg}}{\mathbf{d}}\right) = \frac{\mathbf{C \times Q}}{\mathbf{1000}} \tag{3.1}$$

Where

C is the organic content of effluent in terms of COD or TOC in mg/L

Q is the effluent volumetric flow in m^3/d

Then, percentage COD load distribution was calculated from equation 3.2.

$$\%\mathbf{Organic\ Load} = \frac{\mathbf{A}}{\mathbf{B}} \times \mathbf{100}\% \tag{3.2}$$

Where

A is the organic load in kg/d for an effluent collection point calculated using equation 3.1

B is the total organic load in kg/d for the combined effluent stream into the sewer calculated using equation 3.1

Volumetric percentage distribution load profiles were also evaluated in a similar manner. Total volumes of effluent recorded from each collection point were evaluated and analysed as a percentage of the total combined volume discharged into the sewer over the same period. Volumetric percentage load distribution was calculated for each collection point using equation 3.3.

$$\%\mathbf{Volumetric\ Load} = \frac{\sum_{i=1}^{n} \mathbf{Qin}}{\sum_{i=1}^{n} \mathbf{Qt}} \times \mathbf{100}\% \qquad (3.3)$$

Where

Qin is the effluent volume recorded from a collection point in m^3/d

Qt is the combined total volume of effluent discharged to the sewer in m^3/d

n is the number of recorded daily effluent volumes in m^3/d

From these analyses, qualitative and quantitative effluent profiles were evaluated in terms of the different sections of the corn wet milling process. Further analyses were evaluated from the recorded total corn tonnage, effluent volume recorded and freshwater water usage over the study period. Effluent generation as a fraction of corn processed was calculated in terms of m^3 effluent per ton of corn processed.

All the laboratory effluent sample analyses were conducted according to the Standard Method for Examination of Water and Wastewater (SMEWW) 21st ed. (Eaton et al. 2005).

Statistical analyses of each of the collected data were done to check and assess repeatability and representativity of the results. These analyses were done in terms of standard deviation, range, mean and variance. The following equations were used for the calculations:

$$\mathbf{Arithmatic\ Mean\ (X}\boldsymbol{a}\mathbf{)} = \frac{1}{n}\sum_{i=1}^{n} \mathbf{Xi} \qquad (3.4)$$

$$\mathbf{Flow-Weighted\ Mean\ (X}\boldsymbol{w}\mathbf{)} = \frac{\sum_{i}^{n} Qi.Ci}{\sum_{i}^{n} Qi} \qquad (3.5)$$

$$\mathbf{Variance} = \frac{1}{n-1}\sum_{i=1}^{n}(\mathbf{Xi} - \mathbf{Xa})^2 \qquad (3.6)$$

$$\mathbf{Standard\ Deviation} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\mathbf{Xi} - \mathbf{Xa})^2} \qquad (3.7)$$

Where

$\boldsymbol{Xi}$ is the value of the recorded data

$\boldsymbol{n}$ is the number of observations or data

Xa is the arithmetic mean of the observed or collected data

Xw is the flow-weighted mean of the observed or collected data

Ci is the mean concentration of the constituent during ith time period

Qi is the mean flowrate during ith time period

Tchobanoglous et al. (2003) recommends the use of flow-weighted mean for a more accurate evaluation of the actual effluent quality being treated or handled. This is obtained by multiplying the flowrate with the corresponding constituent concentration, summing the results, and dividing by the sum of the individual flowrates, as illustrated by Equation (3.5).

To establish the treatability of corn processing effluent, a full-scale anaerobic effluent digestion study was conducted at Meyerton plant. Digester influent and effluent qualitative data was collected and analysed. The digester was operated at predetermined feed flow rate, pH and temperature.

Influent and effluent digester COD concentration results were used to evaluate the digester performance in terms of percentage COD removal. Equation 3.8 was used in calculating percentage COD removal.

$$\%\mathbf{COD\ Removal} = \frac{\mathbf{CODin - CODout}}{\mathbf{CODin}} \times \mathbf{100}\% \qquad \mathbf{(3.8)}$$

Where

$\mathbf{COD_{in}}$ is the COD concentration in the digester feed in mg/L

$\mathbf{COD_{out}}$ is the COD concentration in the digester treated effluent in mg/L

Percentage COD removal was evaluated at different OLR and HRT, which were relatively kept constant for a predetermined period of time. OLR and HRT were calculated from equation 3.9 and equation 3.10, respectively.

$$\mathbf{OLR} = \frac{\mathbf{CODin \times Q}}{\mathbf{1000 \times V}} \qquad \mathbf{(3.9)}$$

$$\mathbf{HRT} = \frac{\mathbf{V}}{\mathbf{Q}} \qquad \mathbf{(3.10)}$$

Where

OLR is the organic volumetric loading rate into the digester in kg COD/m^3.d

HRT is the hydraulic retention time in days, in the anaerobic digester

COD_{in} is the COD concentration in the digester feed in mg/L

Q is the digester volumetric feed flow rate in m^3/d, and

V is the anaerobic digester volume which was equal to 929 m^3 for the Meyerton plant.

Theoretical methane generation was calculated from the above determined parameters, respectively. Equation 3.11 was used for calculating theoretical methane generation at STP (Tchobanoglous et al. 2003):

$$\mathbf{Methane\ Generated = COD\ load \times \%COD\ Removal \times 0.35} \qquad \mathbf{(3.11)}$$

Where

0.35 is the equivalent of CH_4 produced per COD removed under anaerobic conditions at STP, in $m^3\,CH_4$/kg COD removed,

Methane (CH_4) Generated is the amount of methane gas generated from the degradation of organics in the anaerobic digester at STP in m^3/d, and

COD Load is the amount of organic loading into the digester in kg COD/d.

To estimate biogas generation at any other conditions of pressure and temperature, equation 3.12 was used.

$$\mathbf{V = \frac{nRT}{P}} \qquad \mathbf{(3.12)}$$

Where

V is the volume of biogas at the prevailing temperature and pressure conditions, L

n is the number of moles, mol

R is the universal gas constant, 0.082057 atm.L/mole.K

T is the temperature, K

P is pressure, atm

The treatability of effluent was therefore determined in terms of percentage COD removal at predetermined operating conditions. The higher the percentage COD removal, the higher the biodegradability of the effluent being treated.

Mass-balance analysis is a fundamental engineering approach that is used when studying material changes within a system where reaction is taking place (Tchobanoglous et al. 2003). This is based on the principle of mass conservation. Equation 3.13 shows the general mass balance formula for a given constituent within a reaction system.

$$\mathbf{Accumulation = Inflow - Outflow + Generation} \qquad \textbf{(3.13)}$$

To determine a steady-state COD mass balance for an anaerobic digester, equation 3.14 was used, wherein the rate of accumulation is assumed to be constant (Tchobanoglous et al. 2003):

$$\mathbf{CODin = CODout + CODvss + CODmethane} \qquad \textbf{(3.14)}$$

Where

CODin is the influent COD, kg/d

CODout is the portion of influent COD in the digester effluent, kg/d

CODvss is the portion of influent COD converted to biomass, kg/d

CODmethane is the portion of influent COD converted to methane, kg/d

Equation 3.14 is based on the fundamental material balance calculation that accumulation at steady-state is equal to zero. Equation 3.15 was used to estimate the required anaerobic digestion volume at a specified OLR (Tchobanoglous et al. 2003):

$$\boldsymbol{Vn = \frac{Qin \text{ x } CODin}{OLR}} \qquad \textbf{(3.15)}$$

Where

Vn is the nominal liquid digester volume, m^3

Qin is the influent flowrate, m^3/d

OLR is the operating and/or recommended organic loading rate, kg COD/m^3.d

By stoichiometry, the COD equivalent of CH_4 is determined as the equivalent amount of O_2 required to oxidise CH_4 to CO_2 and H_2O as shown in equation 3.16.

$$\boldsymbol{CH_4 + 2O_2 \longrightarrow 2H_2O + CO_2} \qquad \textbf{(3.16)}$$

From equation 3.16, the COD per mole of CH_4 is equivalent to 2(32g O_2/mole), which equates to 64 g COD/ mol CH_4.

3.7 Analytical methods

Analytical methods for wastewater characterisation vary from precise quantitative chemical, to the more qualitative physical analyses. Between Germiston and Meyerton plants, the following effluent properties were monitored through their routine sampling and analytical programmes: pH, Conductivity, COD and TOC.

Additional routine monitoring was done by the respective municipalities, Ekurhuleni Metropolitan Municipality (EMM) for Germiston and Midvaal Local Municipality (MLM) for Meyerton. Besides the routine sample analyses conducted by the respective plants, the Municipalities also monitored the following effluent constituents: orthophosphates, ammonia, suspended solids (SS) and BOD. Together with monthly averages for COD concentration and effluent volume discharged, these were used to calculate the monthly effluent disposal charge using equation 1.3.

3.7.1 pH

This is expressed on a negative logarithmic scale of the hydrogen ion concentration as in equation 3.12 (Tchobanoglous et al. 2003):

$$\mathbf{pH} = -\mathbf{log_{10}}[\boldsymbol{H^+}] \qquad \mathbf{(3.17)}$$

Iyilade (2009) defines it as the measure of acidity or basicity of a solution with a commonly used scale 0 to 14.

A pH meter Cyberscan 510 was used for routine on site laboratory effluent sample analysis. To ensure the accuracy of the measurements, the probe was calibrated daily with pH standards of 4, 7 and 10, respectively. The electrode was also thoroughly rinsed with deionised water between sample measurements. For on-line pH monitoring and/or control, Mycom CPM 151p pH monitoring system was installed at Germiston, whilest Meyerton plant had E&H Liquisys M CPM 253 pH transmitter.

3.7.2 Conductivity

Water conductivity is a measure of the water sample's ability to conduct electrical current (Tchobanoglous et al. 2003). It may serve as an indication for the total dissolved solids (TDS) concentration (Iyilade, 2009).

A Mettler Toledo FE 30 Bench top conductivity meter, which was calibrated daily for conductivity measurements, was used for on-site routine measurements. Between sample measurements, the probe was also rinsed with deionised water.

3.7.3 COD

COD test is a measure of the oxygen equivalent of the chemically oxidisable organic material that is in an effluent sample (Tchobanoglous et al. 2003). The HATCH DR/2010 spectrophotometer was used for COD analysis. The effluent samples were analysed as is, and were well mixed before inserting into the COD vials.

3.7.4 TOC

TOC is instrumentally measured to determine the total organic carbon in an aqueous solution (Tchobanoglous et al. 2003). This test method utilises combustion, UV, chemical oxidation or some combination of these for the conversion of organic carbon to CO_2 (Tchobanoglous et al. 2003). Resultant CO_2 may be measured with an infrared analyser or any other means (Tchobanoglous et al. 2003).

The Tekmar Appolo 9000 TOC analyser was used for TOC routine effluent sample analysis. This instrument was calibrated daily to ensure high accuracy of the analytical results.

3.8 Data accuracy analyses

Material balance analysis was used to assess the accuracy and consistency of the collected data. The measured data was compared to calculated results, and discrepancies were accordingly analysed.

Measured volumetric loads from each effluent stream were summed up, and compared to the measured combined stream volumes. Similarly, organic loads from each collection point were summed up, and compared to the measured organic load in the combined effluent stream.

For the Germiston and Meyerton plants, equation 3.18 and 3.19 were used for the mass balance analyses.

$$\sum_{i=1}^{n} \mathbf{Qin} = \mathbf{Qt} \tag{3.18}$$

$$\sum_{i=1}^{n} (\mathbf{Qin.Cin}) = \mathbf{Qt.Ct} \tag{3.19}$$

Where

Qin is the measured volumetric flow from each effluent collection point, m^3/d

Qt is the volumetric flow for the combined effluent stream, m^3/d

Cin is the measured organic concentration in the each effluent collection point, mg/L

Ct is the organic concentration for the combined effluent stream, mg/L

Qt.Ct is the organic load, kg TOC or kg COD

3.9 Limitations

Effluent characterisation studies were conducted for only two corn wet processing plants, Meyerton and Germiston, respectively. These two plants have different corn processing capacities and some manufacturing differences in terms of product portfolios. This may have some bearing in their water usage, effluent generation patterns, and effluent characteristics. Also, the study period was limited to between December 2011 and July 2012. The effects of seasonal production demand and weather pattern variations were therefore not eliminated in the profiling studies.

From literature, it was found that corn wet milling effluent generation is highly variable in terms of composition and volumetric loads. This is amongst other factors, attributable to the intermittent discharge of effluent of variable composition and quantities from the different collection points. Real time data collection and/or sampling were not possible due to the cyclic nature of the corn wet milling process and sometimes sporadic process wastewater releases from equipment cleaning, ion exchange regeneration, product overflows, filtrates' release, etc.

The collected effluent samples into the auto-sampling systems, were subject to potential degradation prior to being analysed. The auto samplers did not have the facility to preserve the collected samples. The samples were collected over a 24 hour period, before they were analysed. The representativity and accuracy of results from such composite samples may have been compromised due to sample quality deterioration.

Composition and volumetric loads from the plant were hence highly variable, which made it difficult to maintain a constant loading rate into the digester at the Meyerton plant. Also, during this effluent treatability study period, the buffer tank and the equalisation basin were out of service for maintenance.

The other limitation was due to the limited capacity (929 m^3) of the anaerobic digester, into which only a fraction of the generated effluent could be handled in the reactor. This meant that some of the untreated Meyerton plant's effluent was blended with the anaerobically treated effluent before discharging into the MLM's sewer system.

The effect of weather conditions due to seasonal changes could not be eliminated due to the limited period of the study. The possible impact of variations in production demand throughout the year was also not assessed. The data for the study were collected between December 2011 and July 2012. Only a limited number and type of effluent analyses were done on the collected routine samples, due to the limited capacity of the on-site laboratory facilities and human resources' constraints.

To evaluate theoretical flow equalisation volume requirements, hourly flow and COD data from a single 24 hr-day of monitoring were used for Germiston (11 December 2013) and Meyerton (4 December 2013) plants, respectively. This limited data may have compromised the accuracy and representativeness of the results due to possible unique diurnal loading variations throughout the year.

The collected data from routine sample analyses, routine effluent volume monitoring, recorded freshwater usage and recorded corn tonnage processed are discussed, interpreted and critically assessed in the next section of **Results and Discussion**.

4 RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the summary and interpretation of the results obtained from the effluent characterisation for the Germiston and Meyerton plants, respectively.

The first two characterisation studies were focused on qualitative and hydraulic analyses of the effluent from these two plants. Finally, a full-scale anaerobic treatability study of the Meyerton plant effluent was conducted, and the results are also presented in this chapter.

4.2 Germiston plant: Effluent characterisation analyses

4.2.1 Plant volumetric load distribution

Figure 4-1 shows variation of effluent generation with water consumption in the wetmill section of corn processing.

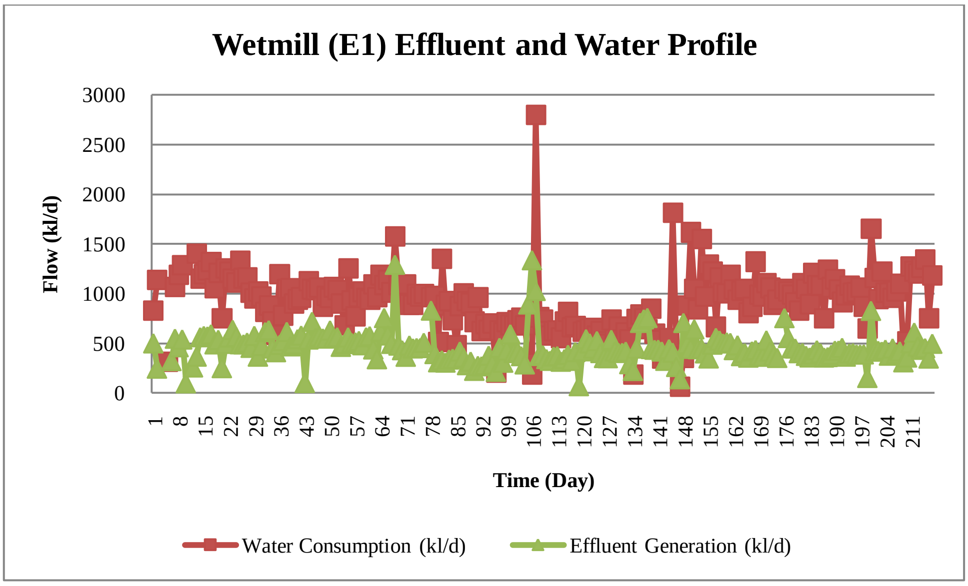

FIGURE 4-1: Germiston plant wetmill (E1) effluent generation and water consumption

It is evident in this graphical representation that when more water was used in the process, increased effluent was proportionally generated. In the wetmill section, freshwater is mainly used for the steeping process to condition the maize kernels for downstream separation processes. Most of the used freshwater was transferred with the starch slurry into the downstream processing like starch and glucose manufacturing processes. Some of the used freshwater in the wetmill, formed part of the CCSL that ended up in gluten-20 as an additive for animal feed (corn fibre). The recorded volumetric data during this study period, equated to 51 % of the used freshwater that was discharged as effluent from the wetmill.

Figure 4-2 illustrates the profile trend of effluent generation to freshwater consumption in the glucose manufacturing process.

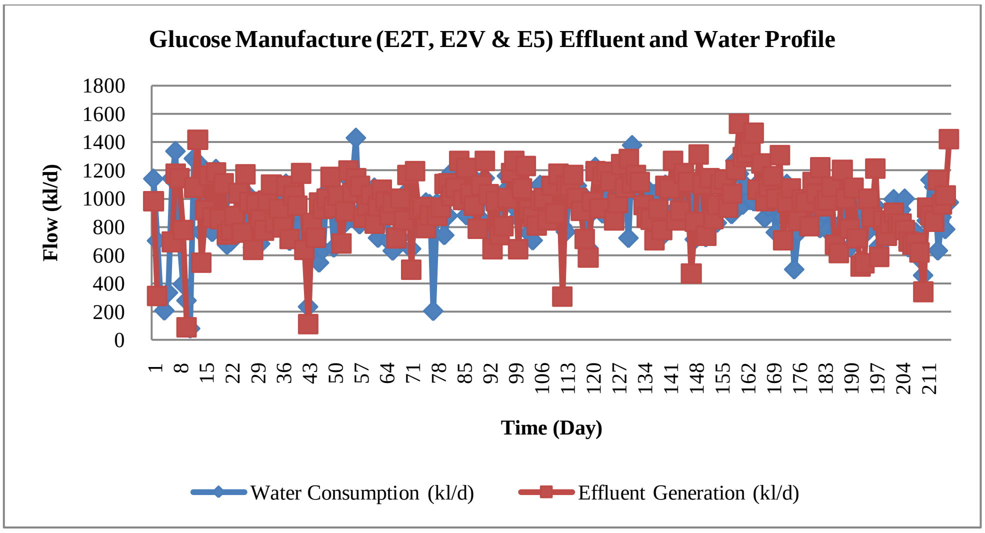

FIGURE 4-2: Germiston plant glucose manufacture effluent generation and water consumption

Glucose manufacturing process involved the acid and enzymatic conversion of starch slurry from the wetmill, to glucose syrup. After the starch slurry conversion to desired DE, the syrup was refined. The refinery included syrup concentration in the evaporators, activated carbon filtration and ion exchange to remove unwanted ions.

Besides all the freshwater that was used in this process, condensed process vapours were discharged as effluent. The average total daily effluent volume equated to about 103% of the used freshwater. Additional effluent was generated from the CPV, over and above that which results from freshwater used in the process. Most of the water was used for process equipment cleaning, regenerant chemical preparation, etc.

Figure 4-3 shows all other generated effluent streams, other than from wetmill and glucose sections. These effluent streams are collectively compared to the other water consumption quantities that were not accounted for in the wetmill and glucose sections.

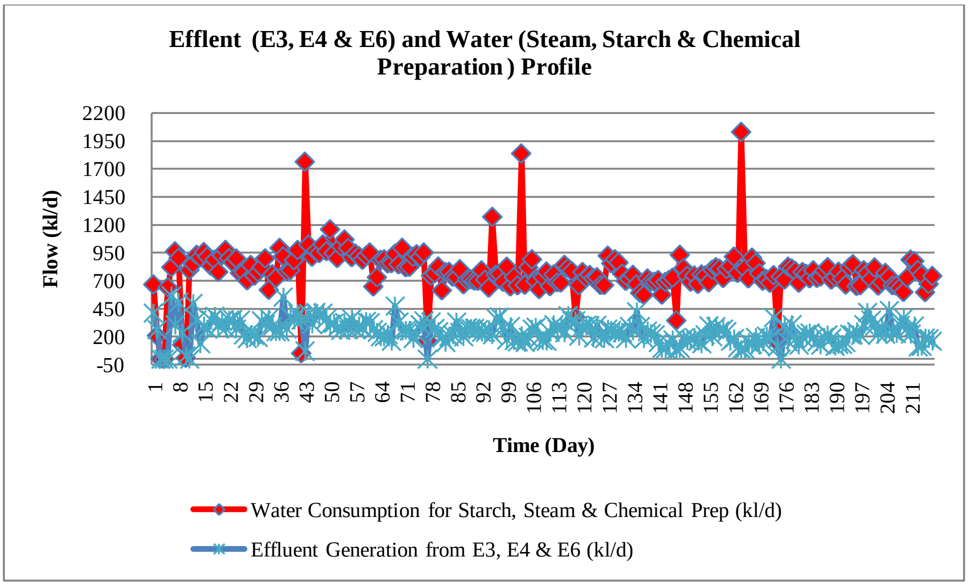

FIGURE 4-3: Germiston plant other effluent generation and other water consumption

Based on the recorded data during this study period, effluent generated from the spray drier (E3), loading bay (E4) and stormwater drainage system (E6), equated to about 31 % of the freshwater that was used in the starch plant, steam generation and chemical preparation, collectively.

Figure 4-4 summarises the overall effluent generation and water consumption against the total amount of corn that was processed during the study period.

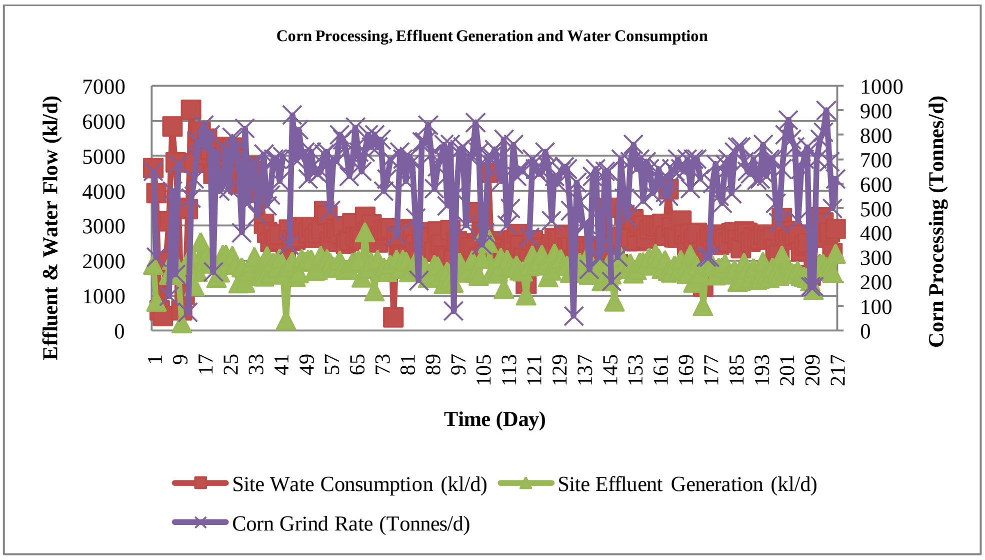

FIGURE 4-4: Germiston plant site effluent generation, corn processing and site water consumption

There is an obvious direct relationship between daily corn processing throughput, daily water usage and daily effluent generation rates. It was however evident that sometimes water was used for equipment and/or process cleaning, during which time water usage and effluent was recorded without any corn being processed. A lot of fluctuation in the daily corn grind rate is quiet evident in figure 4-4. This is due to unplanned stoppages in the corn processing.

Germiston plant effluent volumetric analyses indicated that the major contributor into the effluent sump (E7) that discharges to the EMM's sewer is the enzyme glucose effluent stream (E5) at 44.1 %, followed by the wetmill section (E1) at 27.5 % of the total effluent volume generated over the study period. Acid glucose (E2T and E2V) and stormwater drain system contributed 13.3 % and 10.9 %, respectively.

A pollution profile study for the corn processing industry conducted by Ersahin et al. (2006) indicated that the glucose refinery process produced more effluent than wet milling. This was confirmed by these results from the Germiston plant effluent volumetric load profile. This is attributable to the high levels of process water recycling in the wetmill, compared to the glucose manufacturing section. Glucose effluent is generally contaminated with impurities that are removed from activated carbon filtration, ion exchange and residual conversion chemicals. This contaminated stream may not be re-introduced or reused into the process without some prior regeneration.

Figure 4-5 illustrates the percentage volumetric load distribution from the various sections of the Germiston plant.

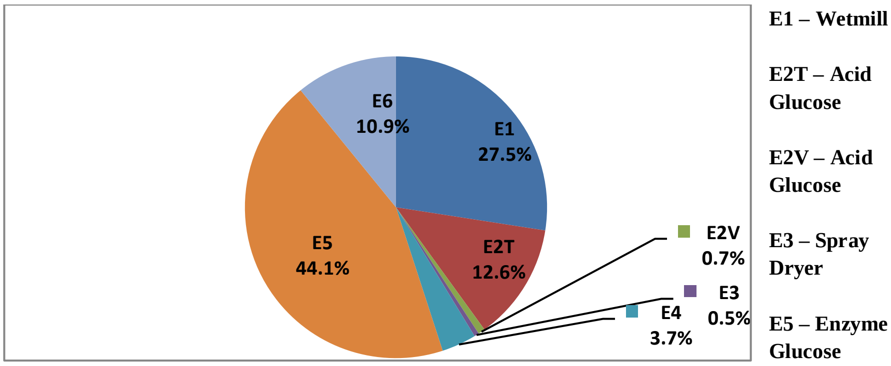

FIGURE 4-5: Germiston plant: Effluent volumetric load distribution profile

4.2.2 Plant organic load distribution

Figure 4-6 illustrates the effluent organic loading profile of the wetmill effluent stream.

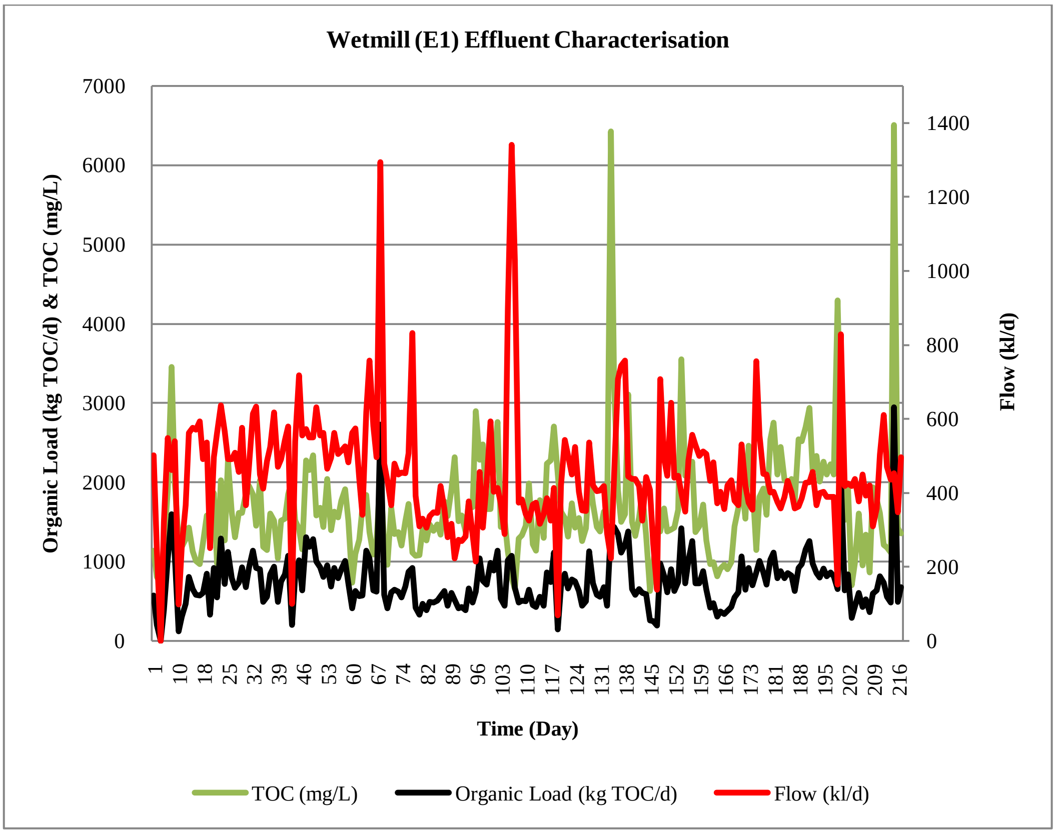

FIGURE 4-6: Germiston plant wetmill effluent organic load

Throughout the study period, the organic loading was relatively constant, averaging at 753 kg TOC/d. The spikes were however observed between days 1–10, days 67–74, days 131–138, and days 216–217. These spikes could be attributed to sporadic equipment cleaning and/or product spillages into the effluent stream (E1).

Figure 4-7 and 4-8 show the organic load profiles of the acid glucose effluent (E2T& E2V) and enzyme glucose (E5) effluent streams, in terms of TOC concentrations, daily organic loads and daily effluent volumes that were generated.

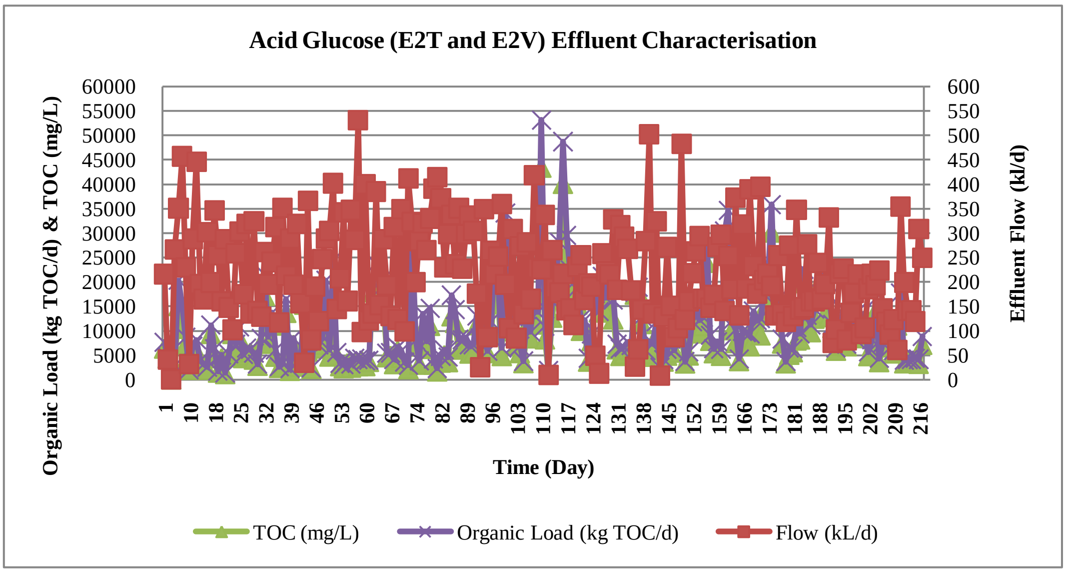

FIGURE 4-7: Germiston plant acid glucose effluent organic load

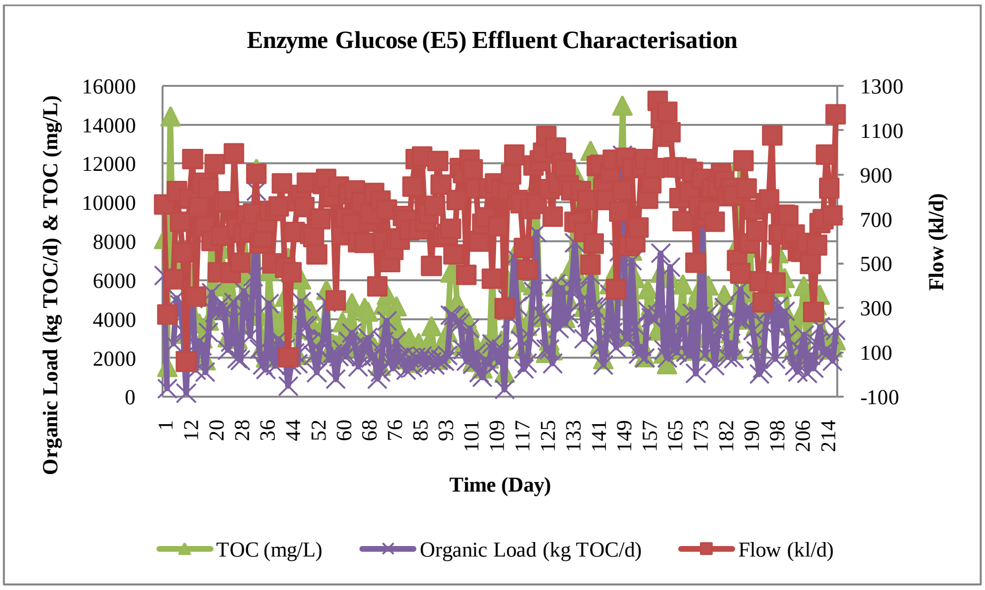

FIGURE 4-8: Germiston plant enzyme glucose effluent organic load

Glucose manufacturing generated the bulk of its effluent from the cleaning of the saccharisation tanks, evaporator cleaning, cooling tower blowdown, condensed process vapours from the evaporation processes, spent liquor from the ion exchange resin beds' regeneration, etc.

During the study period, the two Acid Glucose effluent streams (E2T and E2V) recorded an average of 209 kL/d and 12 kL/d effluent, respectively. In terms of organic content of these effluent streams, E2T had an average TOC concentration of 9703 mg/L, compared to 2590 mg/L for E2V. The organic loads for E2T and E2V were calculated to average at 1924 and 33 kg TOC/d, respectively.

Using material balance, the total effluent from the Acid Glucose streams, was calculated to average at 220 kL/d, at a TOC concentration of 9121 mg/L and an organic load of 1947 kg TOC/d. It was however concluded that E2T effluent stream was more concentrated and generated a much higher volume of effluent compared to E2V.

During the same study period, the enzyme glucose effluent stream (E5) recorded an average effluent flow of 733 kL/d, at a TOC concentration of 4484 mg/L and organic loading of 3209 kg TOC/d. Based on these analyses, E5 generated more effluent, compared to E2T and E2V combined, in terms of organic and volumetric loading.

Figures 4-9, 4-10 and 4-11 show the organic load profiles of the loading bay (E3), spray drier (E4) and stormwater drainage system (E6) streams, in terms of TOC concentrations, daily organic loads and daily effluent volumes generated, respectively.

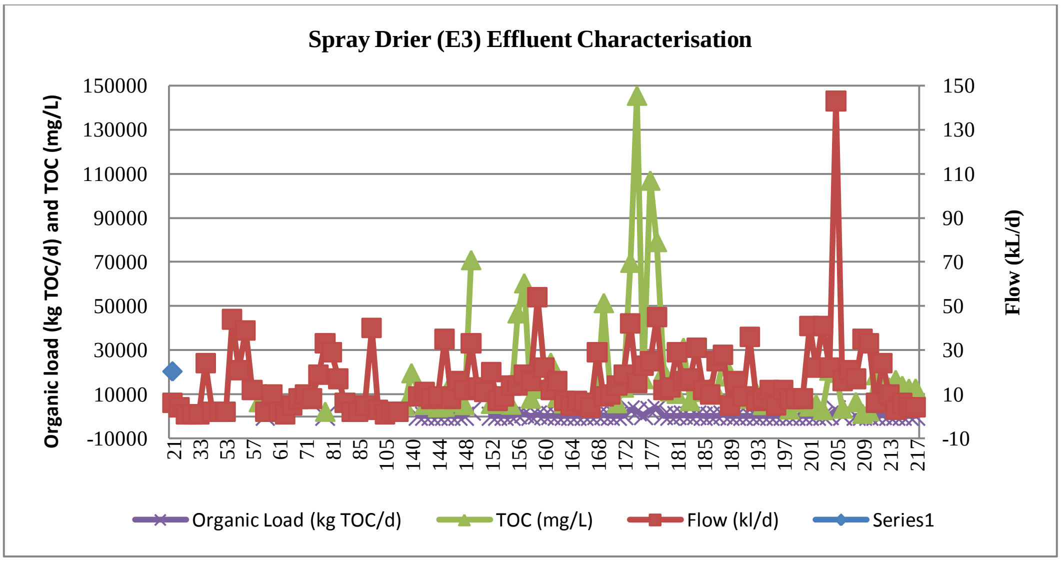

FIGURE 4-9: Germiston plant spray drier effluent organic load

Effluent generation for this stream (E3) is mainly from equipment cleaning. During the study period, an average of 16 kL/d of effluent, at an average TOC concentration of 17022 mg/L was recorded. This equated to an organic load of 382 kg TOC/d. This stream is highly concentrated with low volumetric loading.

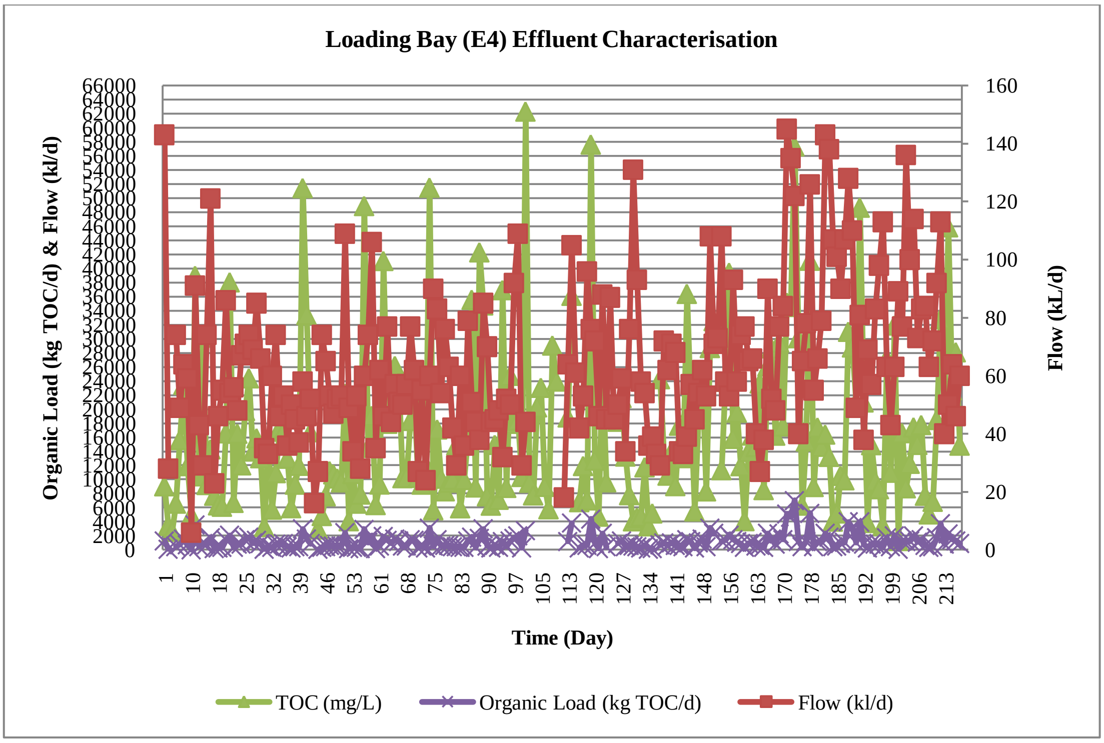

FIGURE 4-10: Germiston plant loading bay effluent organic load

E4 collected effluent from the bulk loading area which was characterised by frequent incidents of product spillages. Effluent was from floor cleaning, equipment cleaning, steam condensate overflows, centrifuge washwater overflow, etc. As a result, high effluent flows and TOC concentrations were evident in figure 4-10, but organic mass loading were reasonably constant.

E4 recorded an average of 65 kL/d effluent, at an average TOC concentration of 17017 mg/L. This equated to an average organic loading of 1164 kg TOC/d. This stream is also highly concentrated with relatively low volumetric loading.

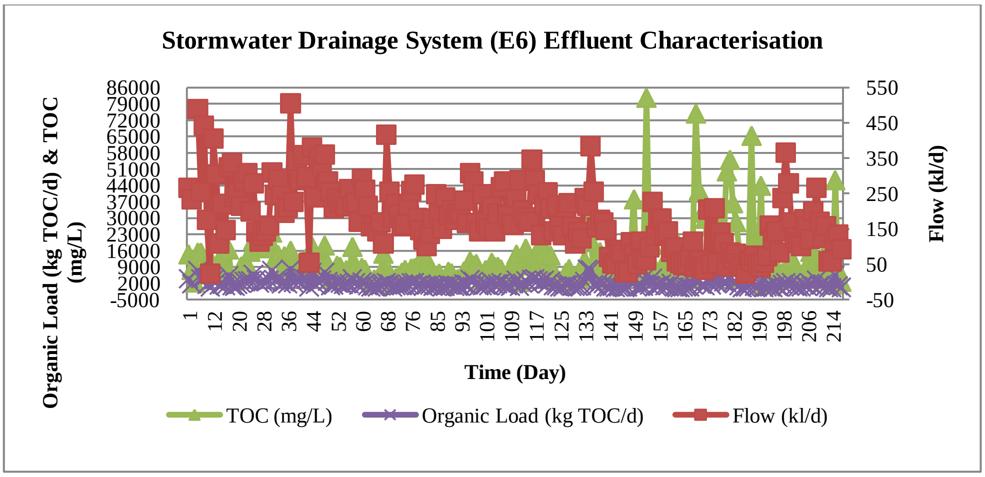

FIGURE 4-11: Germiston plant stormwater drainage system effluent organic load

E6 collected run-off wastewater from bunded areas, stormwater when it was raining from the entire site. During the study period, an average effluent flow of 181 kL/d, at a TOC concentration of 11846 mg/L was recorded from E6. This equated to an organic load of 1914 kg TOC/d. This stream was relatively concentrated, with a higher volumetric loading, compared to E3 and E4, respectively.

Figure 4-11 shows that the effluent volumes from days 1–140 of the study were much higher, averaging at 223 kL/d, compared to the rest of the period when it averaged at 106 kL/d. This could be attributable to the rainy season (Dec 2011 to April 2012) in the first part of the study period, and the dry season for the other part of the study (May 2012 to July 2012).

Figure 4-12 and 4-13 summarise the overall effluent generation for the site, with TOC concentrations and organic loads for the combined streams.

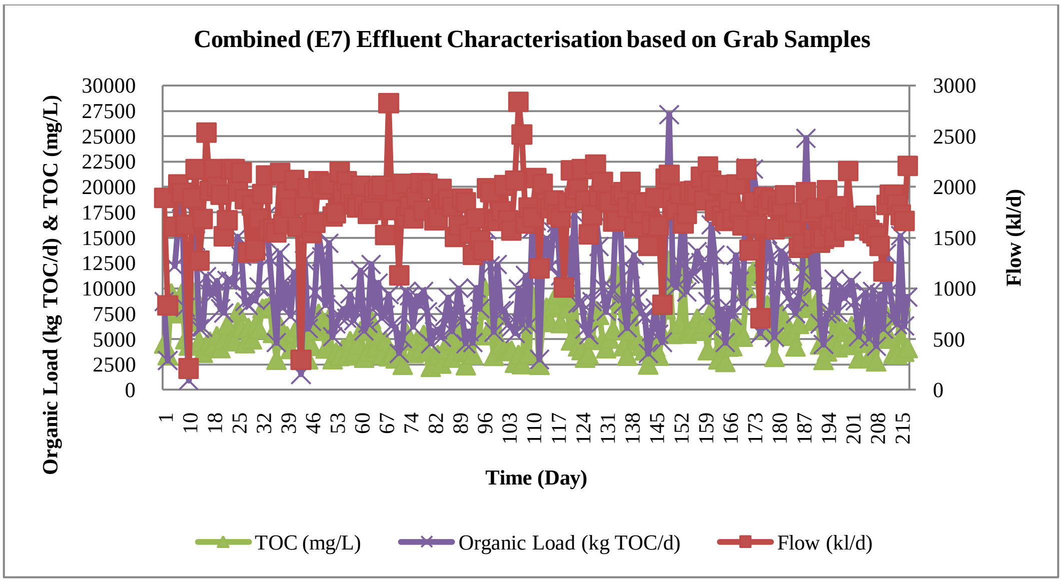

FIGURE 4-12: Germiston plant site effluent organic load based on grab TOC sample analyses

Figure 4-12 shows the effluent characterisation profile of the combined effluent stream (E7), based on the averaged TOC concentration of the routine sample analyses. Figure 4-13 shows a similar profile, but based on composite COD routine sample analyses.

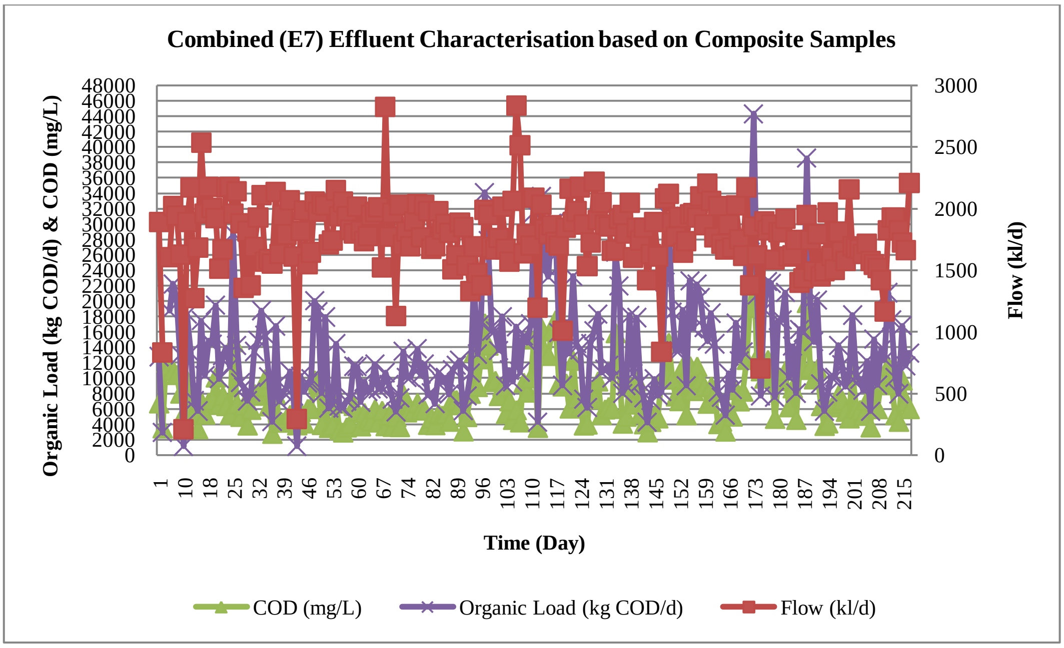

FIGURE 4-13: Germiston plant site effluent organic load based on composite COD sample analyses

Based on the TOC sample analyses of the effluent streams discharging into E7 during the study period, the highest organic loading was found to be from the enzyme glucose section (E5) at 33.9 %, followed by stormwater drain system (E6) at 22.0 % of the total mass TOC loads generated per day. Acid glucose (E2T and E2V) and loading bay (E4) contributed an average of 21.2 % and 12.1 %, respectively.

From a similar study by Ersahin et al. (2006), wet milling generated more organic pollution load than the glucose refinery sections. Germiston plant effluent profile analyses showed a different pollution profile. This can however be due to product spillages that infiltrate the effluent streams. Figure 4-13 illustrates the percentage organic load distribution from the different sections of the plant in terms of mass TOC loads per day.

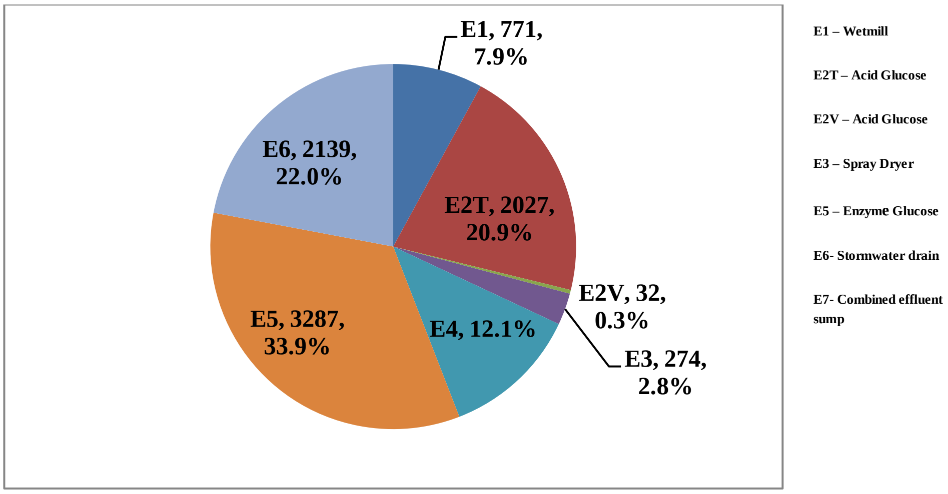

FIGURE 4-14: Germiston plant Effluent TOC load distribution profile

4.2.3 Plant effluent characterisation results summary

Routine analytical TOC results from the daily averages of the two hourly grab samples taken from each effluent collection point and corresponding daily volumetric flow data are further summarised in Table 4-1.

Table 4-1: Germiston plant: Effluent characterisation summary

Effluent Source	Volume (kL/d)	TOC (mg/L)	TOC Load (kg/d)
Wetmill (E1)	456	1690	771
Acid glucose (E2V)	209	9703	2027
Acid glucose (E2T)	12	2590	32
Spray Dryer (E3)	16	17022	274
Loading bay (E4)	65	18129	1177
Enzyme glucose (E5)	733	4484	3287
Stormwater (E6)	181	11846	2139
Combined Stream (E7)	1782	5603	9984
CPV: CSL	-	2512	-
Acid glucose	-	2995	-
Enzyme glucose	-	1127	-

Daily composite samples from the automatic sampler (E&H ISCO 3700 Sampler) installed on the combined effluent sump (E7) outlet were analysed for TOC, COD and pH (see **Appendix E**). Conductivity was analysed from the two hourly grab samples taken from the same point and averaged for the day. Daily effluent volumes discharged into the EMM's sewer were recorded on a 90° V-notch weir flow recorder.

The summarised results in Table 4-1 were based on the mean values calculated from the data collected during the course of the study. From this study, an average of 1782 m^3/d of effluent was recorded to have been generated from the Germiston plant. In this effluent stream, the organic load was estimated at about 9.98 tonnes per day, in terms of TOC.

Ersahin et al. (2006) reported organic loading rates of 2.65 kg per tonne of corn processed in the wetmill and 1.41 kg per tonne of commercial production, respectively. This equates to about 4.06 kg of organics in the effluent per tonne of corn processed and converted to various products. Based on the collected data from the Germiston plant, about 16 kg of organics were discharged in the effluent per tonne of corn processed and converted into various products. This is significantly higher than data from literature, and could be representing material losses in terms of sellable products due to product spillages and/or poor equipment recovery efficiencies.

4.2.4 Data analyses

Statistical analysis of the effluent generated, water plant usage and tonnage of corn processed is summarised in Table 4-2.

Table 4-2: Germiston plant: Water usage, effluent generation and corn processing statistical data analyses

Parameter	Mean	Minimum	Maximum	Std Deviation
Corn grind (tonnes/d)	622	60	900	162
Freshwater usage (kL/d)	2564	210	4523	532
Effluent Generation:				
Volume (kL/d)	1782	211	2838	318
TOC (mg/L)	6363	2128	21189	3168
COD (mg/L)	7790	2968	23893	3695
*pH	9.7	5.1	11.4	1.2
SS (mg/L)	635	90	2541	461
Conductivity (mS/m)	420	113	1611	217

*Mean pH was calculated from the negative logarithm of the mean of $[H^+]$ using equation 3.17.

4.2.4.1 Effluent Characterisation

Over the study period (December 2011–July 2012), the Germiston plant processed a total of 128 665 tonnes of corn and recorded a total of 377725 kL of effluent that was discharged into the sewer. This equated to 2.94 kL of effluent generated per tonne of corn processed. Ersahin et al. (2005) reported an equivalent of 1.44 kL of effluent generated per tonne of corn processed into various corn derived products.

During the same study period, a total of 617182 kL of freshwater were recorded to have been used. This equated to approximately 4.8 kL of freshwater per tonne of corn processed. This is more than the 2.2–2.7 kL/tonne (12-15 gal/bushel) reported by Bensing et al. (1972). The data recorded and analysed for this study period indicated that about 54.7 % of used freshwater was being discharged as effluent.

Average TOC of the combined effluent into the sewer ranged between 5603 mg/L and 6363 mg/L, depending on whether the analyses were from a grab or composite sample. Average TOC concentration which was measured from the composite samples was about 11.9 % higher than the analytical results from the average of the two hourly grab samples.

Based on the effluent flow readings over the study period, hydraulic loading from the Germiston plant is highly variable. The effluent daily volumes that were recorded during the study period ranged between 211 kL/d and 2838 kL/d, with an average of 1782 kL/d.

Due to pH neutralisation at source, pH was found to be fairly stable. It ranged between a recorded minimum of 5.1 and a maximum of 11.4. The average pH recorded was 9.7 with a standard deviation of only 1.2.

Based on the analytical data in **Appendix E,** TOC concentration from the E7 composite sample analyses ranged between 2128 mg/L and 21189 mg/L, with an average of 6 363 mg/L. The calculated standard deviation from this data is 3168 mg/L. COD concentration ranged between 2968 mg/L and 23893 mg/L, with an average of 7790 mg/L. The standard deviation was calculated at 3695 mg/L. The recorded average COD concentration was higher than the acceptable trade effluent discharge limit of 5000 mg/L (EMM, 2011). Based on this average COD concentration, at least 64 % COD removal will be required to meet the COD concentration trade effluent discharge limit. As reported by Movahedyan et al.

(2007), even a simple ABR could be considered for this application. But higher efficiency configurations like UASBR may be the best alternative to cater for a wider range of OLR as reported in this study.

TOC analyses from daily grab samples indicated a somewhat similar trend, TOC ranged between 2297 mg/L and 12810 mg/L with an average of 5603 mg/L. The standard deviation from this data was calculated at 2187 mg/L.

Suspended solids ranged between 90 mg/L and 2541 mg/L, with an average of 635 mg/L. Suspended solids' standard deviation was calculated at 461 mg/L. To ensure consistent compliance to the acceptable trade effluent discharge limit of 100 mg/L, a solid recovery system like a gravity settling or DAF will need to be incorporated (EMM, 2011).

Effluent quality in terms of COD and/or TOC also showed a high level of variability, irrespective of whether grab or composite samples were analysed. Another high variability was observed in the suspended solids' concentration. High variability in composition of this effluent was confirmed by the high standard deviation values.

The accuracy of the collected data was assessed using equations 3.18 and 3.19, respectively. The consistency of the recorded effluent volumes over the study period showed a 7 % error. The total effluent volume recorded from each stream over the study period amounted to 350406 kL, compared to 377725 kL measured volume from E7.

Also, the organic mass loading from E7, amounted to 2338729 kg TOC, compared to 1703761 kg TOC for the individual streams. This equated to a 27 % error or discrepancy between combined stream and individual streams results. These discrepancies could be attributed to errors from the individual flowmeters, which will need to be calibrated regularly, in order to minimise the inaccuracies. Measurement errors from the TOC results are expected to be minimal, since the same instrument was being used for all the analyses, and the instrument was being calibrated on daily basis.

4.2.4.2 Potential for anaerobic effluent digestion

Using the data in Table 4-2, and equation 3.15, the nominal UASB reactor volume to treat Germiston plant effluent was evaluated. The arithmetic mean COD (7790 mg/L) and influent flowrate (1782 m^3/d) were used. To achieve a COD reduction of 85–95 %, a minimum OLR of 10 kg COD/m^3.d was assumed for the Germiston plant effluent (Tchobanoglous et al. 2003). Based on these effluent parameters, the required nominal UASB reactor was evaluated at 1388 m^3 to achieve an 85 % minimum COD reduction, at a minimum operating temperature of 35 ^{o}C.

Using the same data in table 4-2 and equation 3.14, the potential COD conversion to biogas was estimated. The biomass synthesis (CODvss) was calculated based on the typical net biomass yield of 0.08 kg VSS/kg COD reduced, and 1.42 kg O_2 equivalent/kg COD incorporated into biomass (Tchobanoglous et al. 2003). Based on these effluent parameters and minimum percent COD reduction of 85 % as reported by Tchobanoglous et al. (2003), the potential COD conversion to biogas was estimated at 10457 kg/d.

Using equation 3.12 and minimum methane content of 65 %, a potential methane generation of 1699 kg/d, at a temperature of 35 ^{o}C and pressure of 0.85 atm, was calculated (Tchobanoglous et al. 2003).

Based on the methane energy content of 50.1 kJ/g as reported by Tchobanoglous et al. (2003), the potential energy generation was estimated at 85133 MJ/d, equivalent to 23.6 MWh/d of electricity. This is potential energy that could be realised if Germiston plant effluent was to be anaerobically treated in an UASBR.

Germiston plant is estimated to consume 288.45 kWh of electricity per tonne of corn processed (Tongaat Hulett Starch, 2012). At the average grind rate of 622 tonnes per day, the daily electricity consumption was estimated at 179.4 MWh/d. It is therefore concluded that 13.2 % of equivalent electrical energy could be derived from the anaerobic treatment of effluent at the Germiston plant.

4.2.4.3 Flow equalisation basin evaluation

As recommended by Goel et al. (2005), flow equalisation should be routinely employed when treating this type of effluent where there is high variability in volumetric and organic loadings. Currently, Germiston effluent streams are collected into a 20.4 m^3 sump (E7) that discharges into EMM's sewer system.

Table 4-3 illustrates the effluent hourly data that was collected at the Germiston plant, and the calculated data that was used for the determination of a theoretical equalisation basin volume.

Table 4-3: Germiston plant effluent hourly monitoring for flow equalisation analyses, 11th December 2013

Time of day	Average Effluent Flow (m^3/hr)	Cumulative volume at end of time period (m^3)	Volume in basin at end of time period (m^3)	Average COD (mg/L)	Equalised COD (mg/L)	Unequalised COD Loading (kg/hr)	Equalised COD Loading (kg/hr)
06:00	79	79	5	6750	6358	532	471
07:00	35	114	0	3510	3860	122	286
08:00	67	181	0	12038	12038	806	891
09:00	84	265	10	11670	11670	984	864
10:00	81	346	17	10986	11063	890	819
11:00	68	414	11	10440	10567	707	782
12:00	9	422	0	8020	9434	71	698
13:00	79	501	5	5446	5446	429	403
14:00	91	592	21	9659	9446	875	699
15:00	53	645	0	6114	7071	324	523
16:00	70	715	0	5540	5540	388	410
17:00	106	820	32	3400	3400	359	252
18:00	82	902	39	6880	5908	562	437
19:00	91	993	56	5280	5470	479	405
20:00	84	1076	66	6840	6290	572	466
21:00	80	1157	72	7180	6779	576	502
22:00	63	1220	61	10117	8339	638	617
23:00	70	1289	56	6550	7385	456	547
00:00	91	1380	73	7710	7585	698	561
01:00	91	1470	90	6400	6929	580	513
02:00	82	1552	97	5260	6134	429	454
03:00	89	1641	112	14700	10234	1311	757
04:00	78	1720	117	6650	8761	521	648
05:00	57	1776	99	5000	7534	283	558
Mean	**74**			**7589**	**7635**	**566**	**565**
Max	**106**			**14700**	**12038**	**1311**	**891**
Min	**9**			**3400**	**3400**	**71**	**252**

Hourly effluent flow rates and grab samples (for COD analyses) were taken from this stream; from which the relevant parameters were accordingly calculated as per the recommended method by Tchobanoglous et al. (2003). The data in Table 4-3 were used to draw up the hydrograph in figure 4-15, for the determination of the theoretical equalisation basin volume.

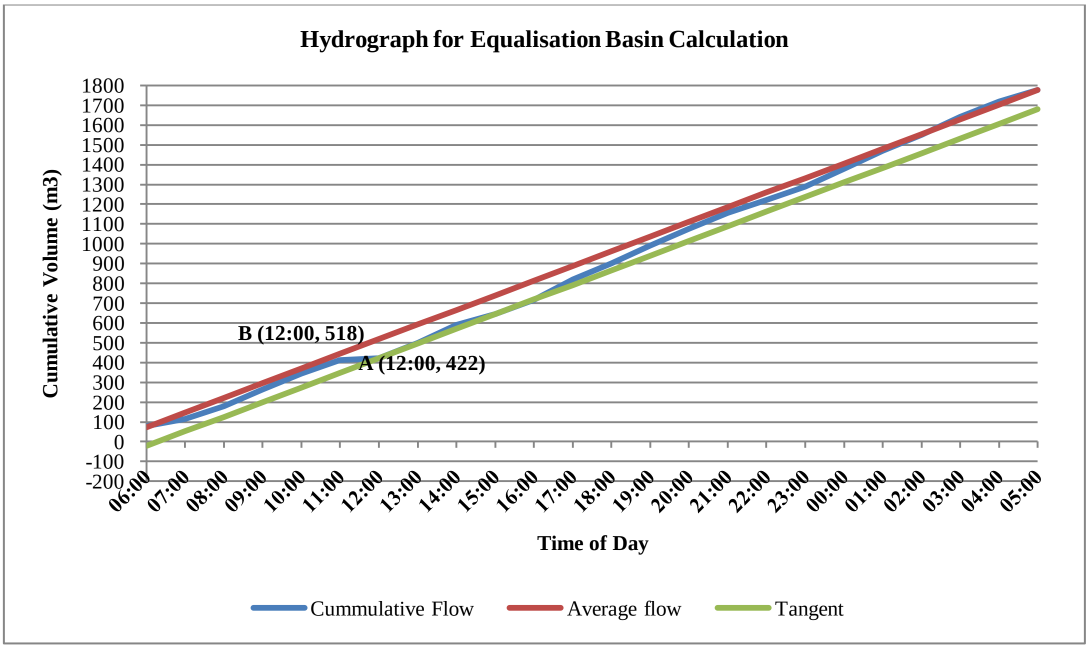

FIGURE 4-15: Hydrograph for the evaluation of the required equalisation basin storage volume for Germiston plant effluent streams

The point of tangency was established at A (12:00, 422 m^3), which vertically intercepted the average flow graph at point B (12:00, 518 m^3). Using Goel et al. (2005) and Tchobanoglous et al. (2003) graphical methods, the required theoretical equalisation storage volume was calculated to be 96 m^3. This is almost five times the size of the current E7 volume of 20.4 m^3.

The potential benefits for the installation of the correctly sized equalisation basin are illustrated by figure 4-16, that shows the dampening effect on COD loading.

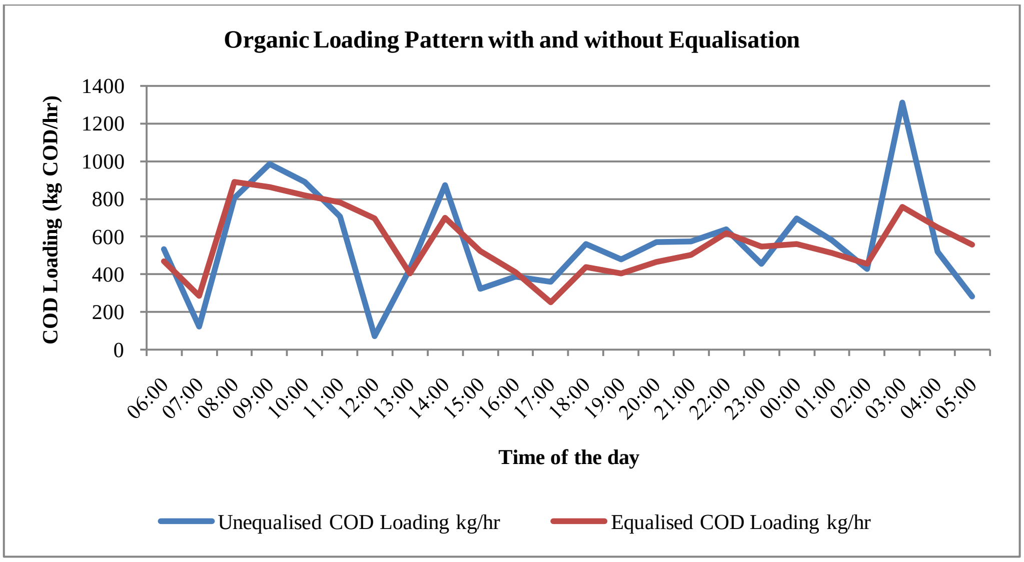

FIGURE 4-16: COD loading patterns for equalized and unequalised flow

Figure 4-16 indicates that the effects of shock/peak loading and under loading are minimised. The peak COD loading of 1311 kg COD/hr was dampened to 891 kg COD/hr. Similarly, the minimum loading of 71 kg COD/hr was equalized to 252 kg COD/hr. This will inevitably reduce variability into a treatment system which will ensure a more stable operation of a downstream treatment system.

4.3 Ekurhuleni Metropolitan Municipality effluent quality monitoring

The quality of Germiston plant effluent was also routinely monitored by the Ekurhuleni Metropolitan Municipality (EMM). Weekly grab samples were taken from E7 and analysed for ammonia (as nitrogen), orthophosphate (as phosphorus), pH, BOD, COD, conductivity and SS in their laboratory.

Monthly averages from these analyses and the monthly total volume of effluent discharged to the sewer were used to calculate the monthly effluent disposal charge and non compliance penalties, using equations C.2 and C.4, respectively. The data analysed was collected over a 25 week period, between November 2011 and May 2012. This raw secondary data is presented in **APPENDIX D,** Table D.1 and the statistical analysis of the same data is summarised in Table 4-4.

Table 4-4: Ekurhuleni Metropolitan Municipality effluent monitoring statistical data analyses

Parameter	Mean	Minimum	Maximum	Std Deviation
Ammonia (mg/L as N)	46	0.1	750	171
Orthophosphate (mg/L as P)	7.2	0.1	66	19
*pH	5.0	3.7	12.1	3
BOD (mg/L)	3425	100	25000	5678
COD (mg/L)	9652	2770	45500	8887
Conductivity (mS/m)	487	64	1029	246
SS (mg/L)	728	126	2903	625

*Mean pH was calculated from the negative logarithm of the mean of [H^+] using equation 3.17.

From these analyses (see **Table 4-4**), COD/Nitrogen/Phosphorus (COD: N: P) ratio was found to be 673:3:0.5. This ratio is not in line with 300:5:1 or 100:2.5:0.5 recommended for optimum biogas yields in the anaerobic effluent digestion treatment (Tchobanologous et al. 2003 and Rajeshwari et al. 2000). This indicates some deficiency of sufficient nutrients which are required for optimum microbial activity. If anaerobic digestion system is considered for this effluent stream, nitrogen and phosphorus nutrients may need to be supplemented into the system to enhance biomass growth rates.

An average BOD: COD ratio of 0.4 was calculated from this same data in Table 4-4. It ranged between 0.04 and 0.55. For untreated effluent, Tchobanologous et al. (2003) recommends a ratio of at least 0.5, for the effluent to be considered easily biodegradable. A ratio of below 0.3 may be an indication of the presence of toxic components or that acclimation of microorganisms may be required for its stabilisation (Tchobanologous et al. 2003).

Qualitative effluent variability was also demonstrated by high standard deviation values calculated from this data. Due to on-line pH monitoring and control, relative consistency was observed in this effluent pH data.

4.3.1 Effluent disposal charges

Based on the collected data in Table D.1, a high frequency of non compliance in terms of the acceptable trade effluent discharge limits stipulated by EMM (2011) was recorded. Over this study period (25 weeks), the number of non compliance incidents was estimated at 64, equating to about 10 incidents per month.

Using equation C.4, the non compliance monthly charge was estimated at R11.8/kL. Using equation C.2 for the same data (Table D.1), the effluent treatment charge was estimated at R9.88/kL. Using the average effluent generation rate of 1782 kL/d (54 203 kL/month) that was recorded over the study period, effluent disposal charge for the Germiston plant was estimated at R1.2 m per month, including non-compliance penalties.

4.4 Meyerton plant: Effluent characterisation analyses

4.4.1 Plant volumetric load distribution

Figure 4-17 shows effluent generation variations with water consumption in the wetmill section of the corn processing.

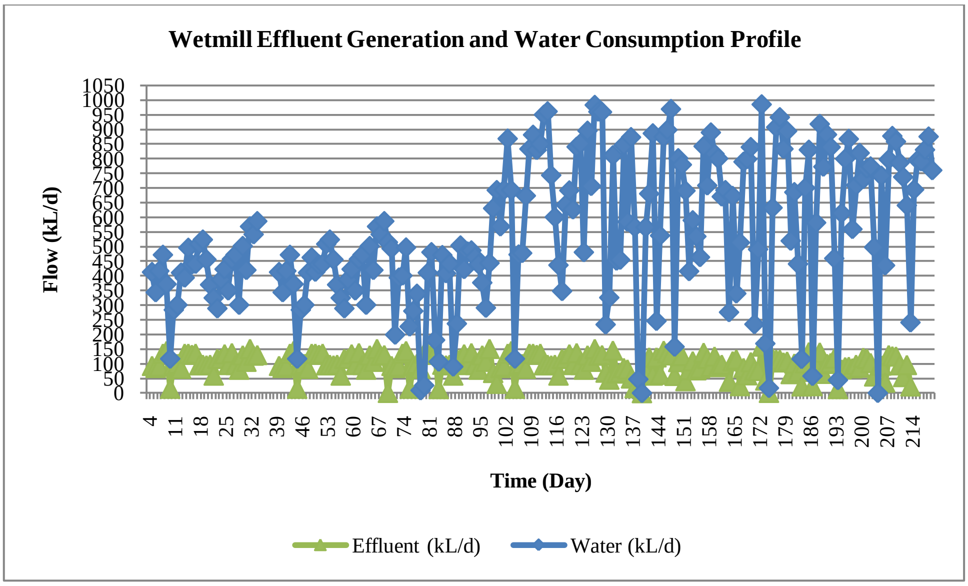

FIGURE 4-17: Meyerton plant wetmill effluent generation and water consumption

In the wetmill section, freshwater was mainly used for steep acid preparation, which is used for the conditioning of the maize kernels for downstream processing. Most of the used freshwater was transferred with the starch slurry (+/- 66 % water) into the downstream processes, like starch and acid glucose manufacturing. Some of the used freshwater formed part of the CCSL that ended up in the gluten-20 as an additive for animal feed (dried corn fibre). The recorded data during the study period, equated to 18 % of the used freshwater that was discharged as effluent from the wetmill.

Over the entire study period, effluent generation was relatively constant at an average of 98 kL/d, whereas water usage seemed to increase to an average of 649 kL/d after day 102 onwards, from an average of 402 kL/d before that. This increase in freshwater usage coincided with commissioning of a new disc-nozzle centrifuge for primary separation. For this new centrifuge, freshwater was being for its emergency and normal shutdown, respectively. This was necessary to prevent the centrifuge nozzles from get clogged with mill starch solids.

Figure 4-18 shows effluent generation variations with water consumption in the starch plant section of the corn processing.

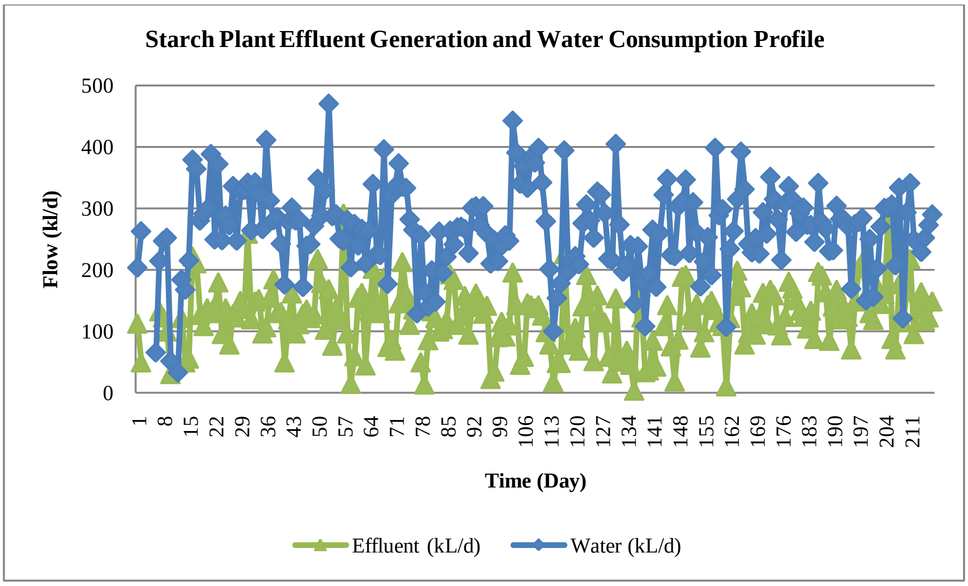

FIGURE 4-18: Meyerton plant starch effluent generation and water consumption

In the starch plant section, freshwater was mainly used to prepare the chemicals that are used in the starch modification process, cleaning of the process equipments, and starch counter-current washing in the multi-stage hydrocyclonette system. The recorded data during the study period, equated to 46 % of the used freshwater that was discharged as effluent from the starch plant.

Effluent was mainly generated from the starch filtrate from the starch dewatering basket centrifuge, and overflow from the multi-stage hydrocyclonette system. The resultant starch filtrate was first concentrated to 34–37 % solids in the nozzle disc-stack centrifuge. The concentrate (34-37 % solids) was recycled into the counter-current washing system, whilst the dilute overflow was discharged as effluent. The resultant daily effluent volume averaged at 123 kL/d, compared to 266 kL/d of water usage.

This clarified overflow stream was however not reusable or recyclable, because it contained dissolved impurities from the starch washing system. There is however a potential to reuse the clarified filtrate from the dewatering centrifuge, because it is not expected to have any other contaminants, besides solubilised starch solids and dissolved residual starch modification chemicals which may have escaped from the hydrocyclonette washing system.

Figure 4-19 shows effluent generation variations with water consumption in the Acid Glucose plant section of the corn processing.

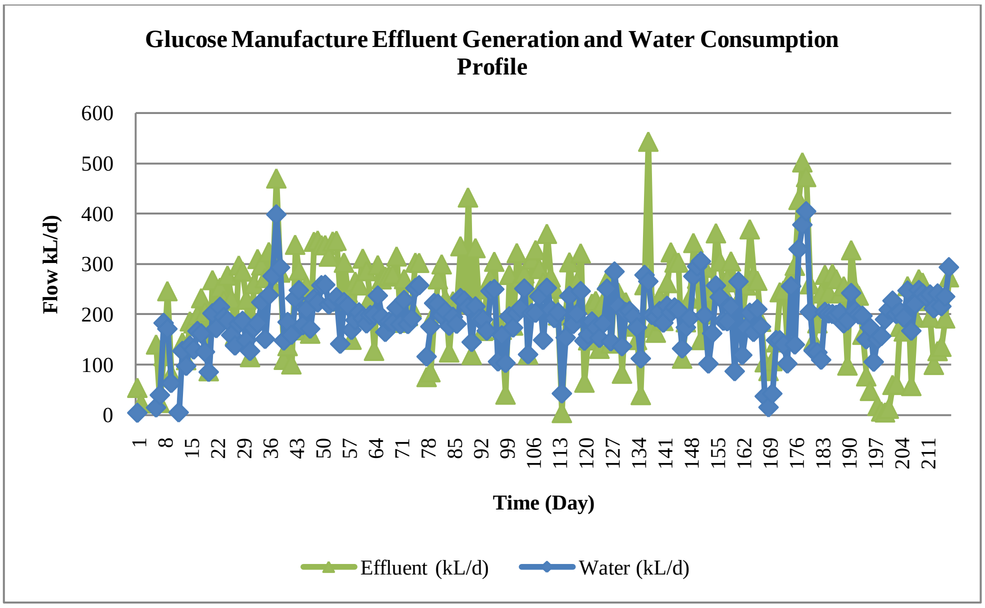

FIGURE 4-19: Meyerton plant glucose manufacture effluent generation and water consumption

At the Meyerton plant, glucose manufacturing process only involved the acid (HCl) conversion of starch slurry from the wetmill to glucose syrup. There was no enzymatic conversion for glucose manufacturing. After the starch slurry was converted to the desired DE, the syrup was refined. The refinery process only included syrup concentration in the multi-effect evaporators and activated granular carbon filtration.

Effluent generated from this section was about 17 % more than the water fed into the process. Most of the water was used mainly for process equipment cleaning. Most of the effluent generated was from the cleaning water and condensed process vapours (CPV). The effluent stream for glucose manufacturing consisted of the summation of CPV and glucose manufacture streams, respectively. The additional 17 % was attributed to the evaporated water from the concentrated glucose syrup, over and above the water that was fed into the process.

Due to the presence of VOCs in the CPV and impurities removed from the refinery processes, this effluent was not being reused or recycled. Only regenerative reuse or recycling could be considered, if cost effective.

Figure 4-20 shows the other effluent stream (Stormwater drainage system) generation variations with water consumption in the steam generation plant.

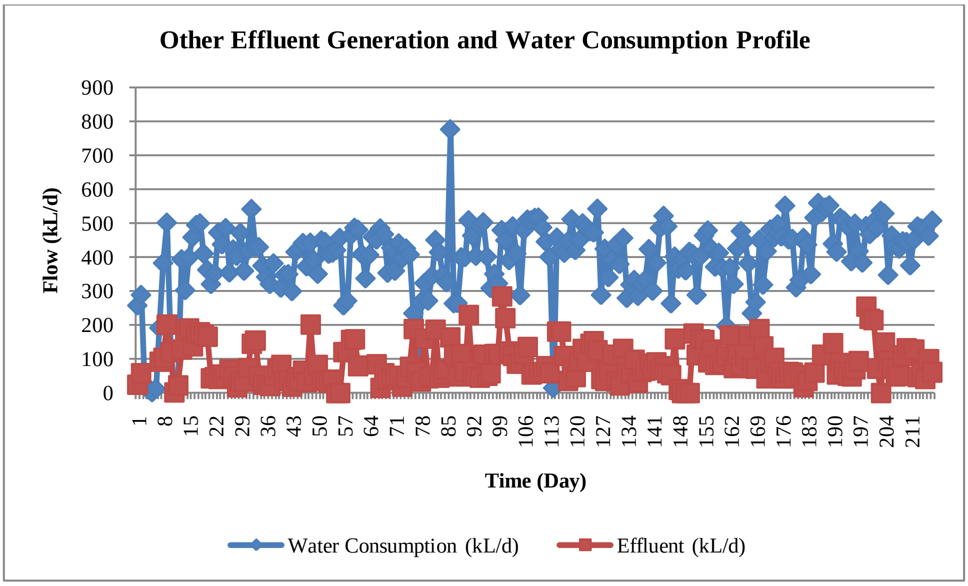

FIGURE 4-20: Meyerton plant other effluent generation and water consumption

All other effluent streams are accounted for in the wetmill, starch and glucose sections, except for the stormwater drainage system. This stream was comprised of the entire plant's overflow from product tanks' bunded areas, run-off from rain water, etc. This stream was trended against boiler feedwater consumption, as this was the only metered water consumption that was not accounted for in the wetmill, starch and glucose manufacturing water consumption data.

Figure 4-21 summarises the overall effluent generation, daily average water consumption and average daily corn processed.

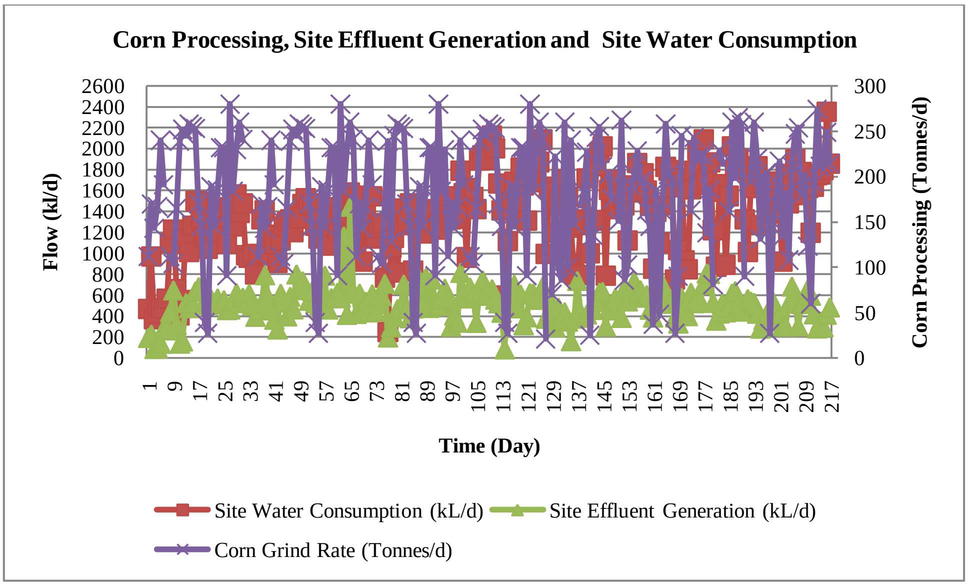

FIGURE 4-21: Meyerton plant site effluent generation, corn processing and site water consumption

There was an obvious direct relationship between corn processing, site water consumption and effluent generation rates. It was however evident that sometimes water was used for equipment and/or process cleaning, during which time water usage and effluent were recorded without any corn being processed.

Meyerton plant effluent hydraulic distribution analyses indicated that the major contributor into the total effluent generation was the Syrup refinery process (42 %): Acid syrup (4 %) and CPV (38 %). The balance of the effluent volumes was found to be from the Starch (23 %), Wetmill (18 %) and Stormwater drainage system (17 %) sections.

A similar pollution profile study by Ersahin et al. (2006) indicated that the glucose refinery process produced more effluent volumes than wet milling. This was confirmed by these results from the Meyerton plant effluent volumetric load distribution profile. Figure 4-22 illustrates the percentage volumetric load distribution from the various sections of the Meyerton plant.

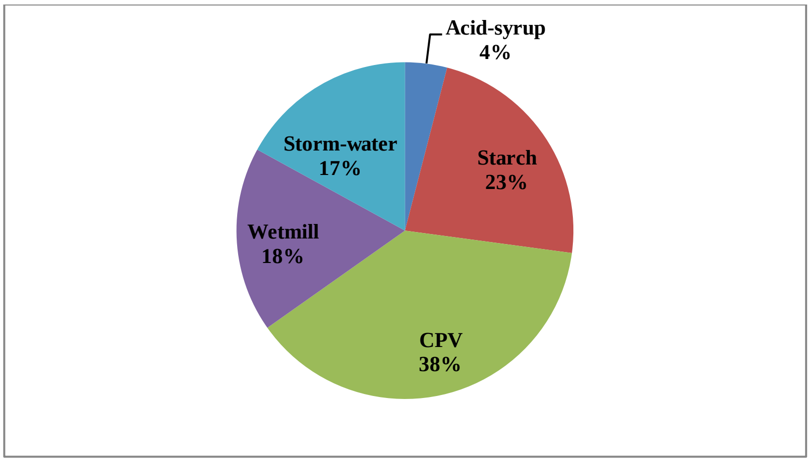

FIGURE 4-22: Meyerton plant effluent volumetric load distribution profile

4.4.2 Plant organic load distribution

Figure 4-23 illustrates the effluent organic loading profile of the Wetmill effluent stream at the Meyerton corn processing plant.

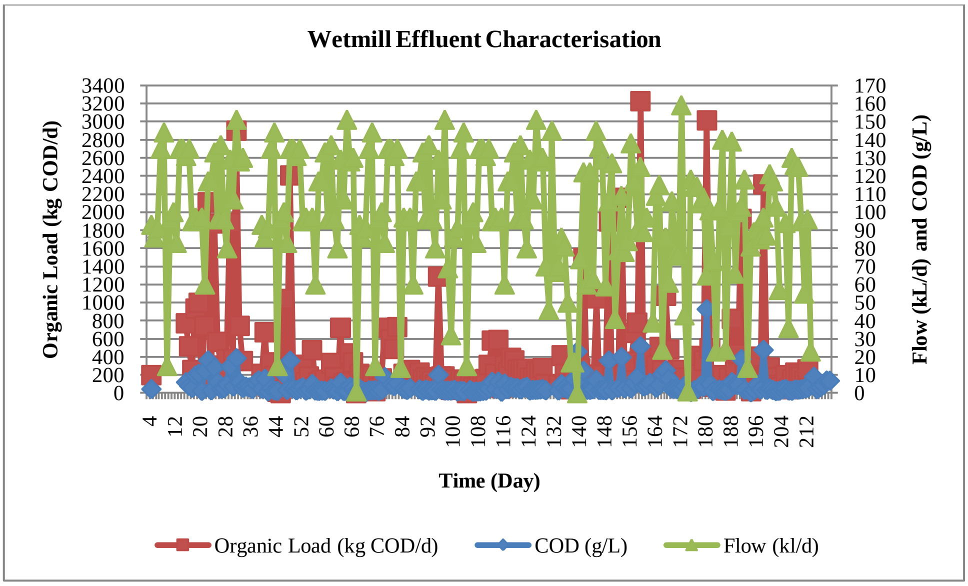

FIGURE 4-23: Meyerton plant wetmill effluent organic load

Throughout the study period, the daily COD concentration was relatively constant, averaging at 4.2 g/L. Due to frequent start/stop of the process, there was high variability in the daily effluent generation rates as well as daily organic loading. Over this period, daily effluent generation rate averaged at 98 kL/d, at an average organic loading of 408 kg COD/d.

Wetmill effluent generally emanated from process water overflows, equipment cleaning, etc. This stream was generally high in protein (gluten) and starch solids. Most of the resultant wastewater in the Wetmill was recycled for steep acid preparation, and/or as washwater in the other separation processes like fibre washing, primary separation, starch counter-current washing, germ washing, etc.

Figure 4-24 shows the organic load profile of the Starch plant effluent stream, in terms of COD concentration, daily organic loads and daily effluent volumes generated.

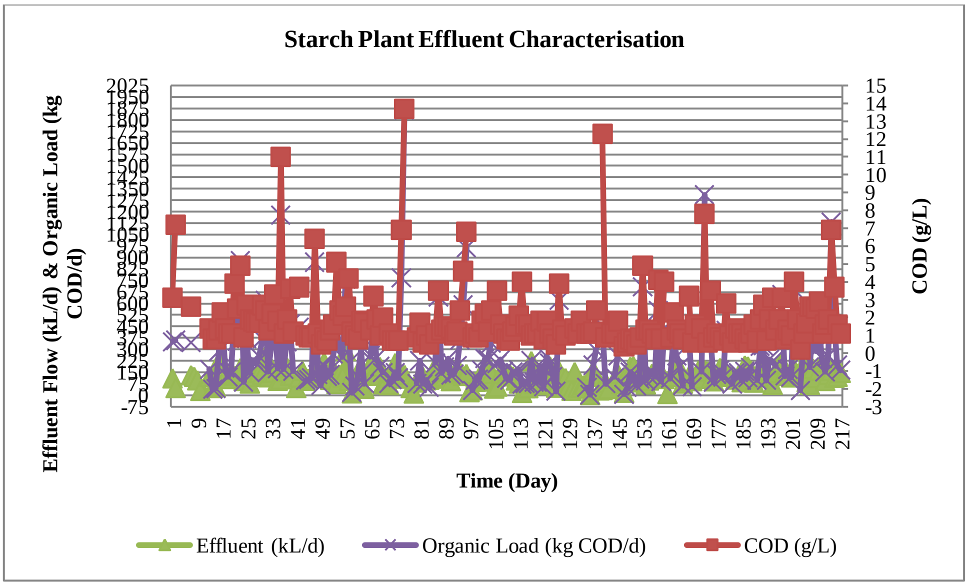

FIGURE 4-24: Meyerton plant starch effluent organic load

Daily effluent generation from the Starch plant section was relatively constant, averaging at 123 kL/d, but the organic loading showed high variability in terms of daily COD concentrations and organic loading. During the study period, daily COD concentration averaged at 2.0 g/L, with an average organic loading of 260 kg COD/d.

The high variability in organic loading was attributed to wide variety of chemically modified starches that are manufactured at the Meyerton plant. Modification of starch leads to solubilisation of some of the starch solids, and the formation of salts as a result of starch slurry neutralisation during pH adjustments. In the Meyerton Starch plant, the resultant filtrates from starch counter-current washing and dewatering centrifuge, were concentrated from 10-14 % to 34-37 % solids in the nozzle disc-stack centrifuge for the recovery of starch solids from the filtrate streams. This effectively reduced the organic content of the final wastewater that got discharged as effluent.

Figure 4-25 shows the organic load profile of the Acid glucose effluent stream, in terms of COD concentrations, daily organic loads and daily effluent volumes generated.

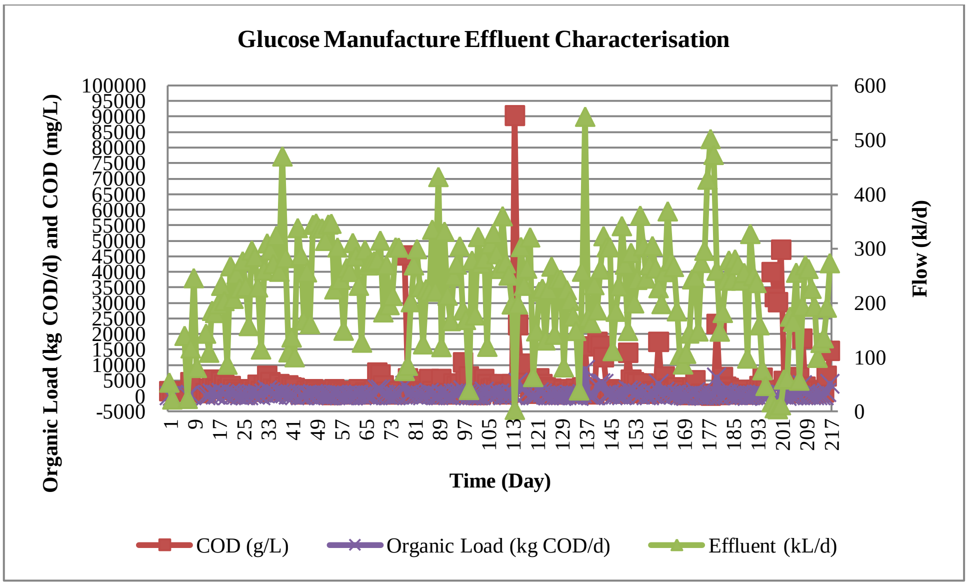

FIGURE 4-25: Meyerton plant glucose manufacture effluent organic load

Glucose manufacturing process generated the bulk of its effluent from the cleaning of the saccharisation tanks, evaporator cleaning, cooling tower blowdown, condensed process vapours from the evaporation processes, etc.

During this study period, the Acid glucose effluent streams, including the CPV stream, recorded an average of 223 kL/d of daily effluent generation. In terms of organic content of this effluent stream, the daily flow-weighted average concentration of 3.04g/L was calculated using equation 3.5. The average daily organic loading was similarly calculated at 693 kg COD/d.

The daily flow patterns showed irregular spikes due to sporadic need for equipment and/or process cleaning requirements. The major source of organic pollution in this stream was from the VOCs in the CPV.

Figure 4-26 illustrates the organic loading patterns of the Stormwater drainage system effluent stream, in terms of COD concentrations, daily organic loads and daily effluent volumes generated.

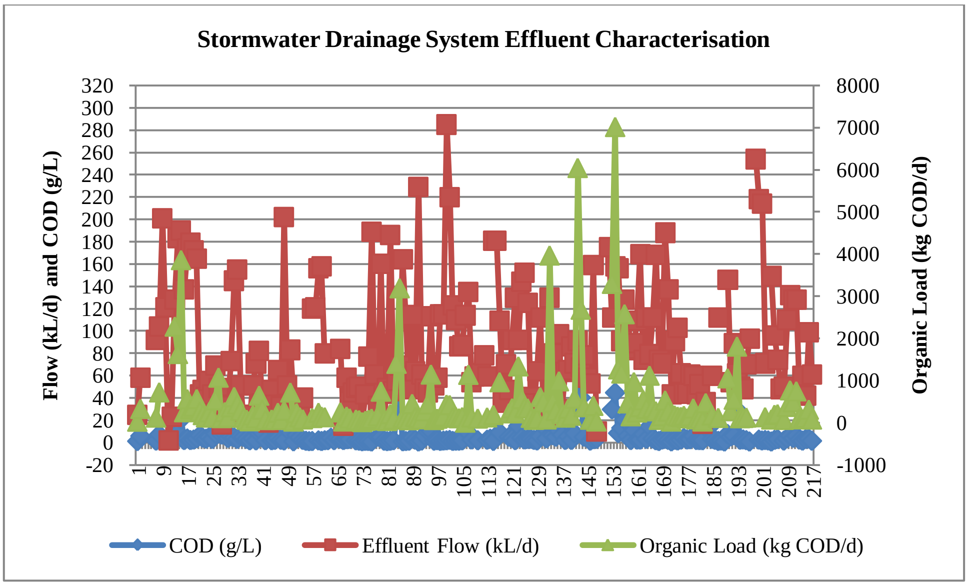

FIGURE 4-26: Meyerton plant stormwater drainage system effluent organic load

The Stormwater drainage system collected all the run-off wastewater from product tank overflows and stormwater from the entire site when it rained. During the study period, a daily average of 88 kL/d of effluent, at a COD average concentration of 5.3 g/L was recorded. This equated to an average organic load of 492 kg COD/d. This stream was relatively concentrated with a lower volumetric loading, compared to Glucose and Starch effluent streams, respectively.

Figure 4-27 summarises the overall effluent generation patterns for the Meyerton site, with COD concentrations and organic loads for the combined streams.

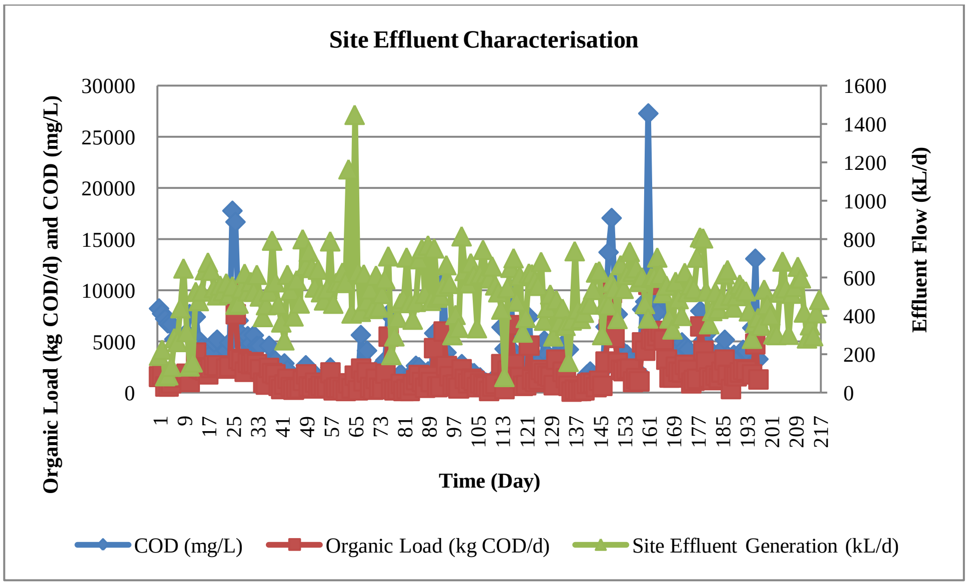

FIGURE 4-27: Meyerton plant site effluent organic load

Analyses of the COD effluent data in **Appendix F** is summarised in **Figure 4-28**. Figure 4-28 illustrates the percentage organic load distribution from the different sections of the plant in terms mass COD loads per day.

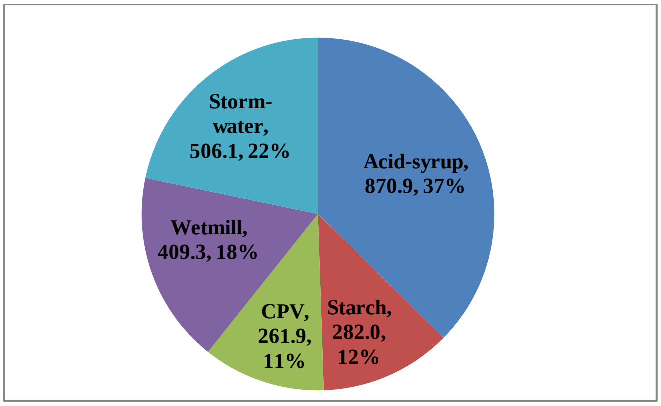

FIGURE 4-28: Meyerton plant Effluent COD load distribution profile

Based on these analyses, 48 % of the total mass COD load was found to be generated from the Syrup refinery section: Acid syrup (37 %) and CPV (11 %), respectively.

A similar study was conducted by Ersahin et al. (2006) from which wet milling was found to be generating more organic pollution load than the glucose refinery sections. Meyerton plant effluent profile analyses showed a different pollution profile wherein more organic load was found to be from the glucose refinery sections.

4.4.3 Plant effluent characterisation results summary

Routine analytical COD results from the daily averages of the two hourly grab samples taken from each effluent collection point and corresponding daily volumetric flow data are further summarised in Table 4-5.

Table 4-5: Meyerton plant: Effluent characterisation summary

Effluent Source	Volume (kL/d)	COD (mg/L)	COD Load (kg COD/d)
Syrup Refinery	25	34700	871
Starch Plant	123	2300	282
CPV	205	1300	262
Wetmill	98	4200	409
Stormwater	95	5300	506
Combined Stream	513	6211	3189

From these average flow and COD data results, COD loading rates (kg COD/d) were calculated for each effluent collection point. The summarised results in Table 4-5 are based on the mean values calculated from the data collected during the course of the study. From this study, an average of 513 kL/d of effluent was recorded to have been generated from the Meyerton plant. In this effluent stream, the organic load was estimated at about 3.20 tonnes per day, in terms of COD.

Ersahin et al. (2006) reported organic loading rates of 2.65 kg per tonne of corn processed in the wetmill and 1.41 kg/tonne of commercial production, respectively. This equates to about 4.06 kg of organics in the effluent per tonne of corn processed and converted to various products. Based on the collected data from the Meyerton plant, about 18 kg of organic mass load was discharged with the effluent per tonne of corn processed and converted into various products. This is significantly higher than the reported rates in literature. As reported by Brouckaert et al. (2005), this could be representing material losses in terms of sellable products.

4.4.4 Data analyses

Statistical analyses for water usage, effluent generation and daily tonnage of corn processed are summarised in Table 4-6.

Table 4-6: Meyerton plant: Water usage, wastewater generation and corn processing statistical data analyses

Parameter	Mean	Minimum	Maximum	Std Deviation
Corn grind (tonnes/d)	180	21	280	67
Freshwater usage (m^3/d)	941	30	5030	371
Effluent Generation:				
Volume (m^3/d)	513	82	1447	165
COD (mg/L)	6211	1590	19520	3008
SS (mg/L)	899	749	1048	211
*pH	6.2	4.5	10.1	1.4

*Mean pH was calculated from the negative logarithm of the mean of $[H^+]$ using equation 3.17.

These statistical analyses illustrated high compositional and volumetric variations in the combined effluent generated from the Meyerton plant.

4.4.4.1 Effluent characterisation

Based on the collected data in **Appendix F-1**, a total of 36034 tonnes of corn were processed during the course of the study. During this period, a total effluent volume of 111424 m^3 was recorded to have been generated. This equated to 3.09 m^3 of effluent generated per tonne of corn processed. This was higher than the reported rate by Ersahin et al (2006) of 1.44 m^3 of effluent generated per tonne of corn processed into various corn derived products.

During the same study period, a total of 299330 m^3 of freshwater were recorded to have been used. This equated to approximately 8.3 m^3 of freshwater per tonne of corn processed. This is significantly more than the 2.2–2.7 m^3/tonne (12-15 gal/bushel) reported by Bensing et al (1972). The data recorded and analysed for this period also indicated that about 37.2 % of used freshwater was discharged as effluent. Data analyses in Table 4-6 are showing high variability in most of the parameters that were monitored over the study period (December 2011–July 2012).

The accuracy of the collected data was assessed using equations 3.18 and 3.19, respectively. The consistency of the recorded effluent volumes over the study period showed a 14 % error. The total effluent volume recorded from each stream over the study period amounted to 109801 kL, compared to 111424 kL measured volume from the combined stream into the MLM's sewer.

Also, the organic mass loading from the combined stream upstream of the digester, amounted to 359802 kg COD, compared to 346895 kg COD from the individual streams. This equated to a 4% error or discrepancy between the combined stream and individual streams. These discrepancies could be attributed to errors from the individual flow recorders, which will need to be calibrated regularly, in order to minimise the inaccuracies. Measurement errors from the COD results are expected to be minimal, since the same instrument was being used for all the analyses for the respective streams, and the instrument was being calibrated on daily basis.

4.4.4.2 Flow equalisation basin evaluation

As recommended by Goel et al. (2005), flow equalisation should be routinely employed when treating effluent where there is high variability in volumetric and organic loadings. Currently, Meyerton plant effluent streams are collected into a 1200 m^3 cement dam, which was under maintenance during the study period.

Table 4-7 illustrates hourly Meyerton plant effluent data that was collected on the 4th December 2013, and the calculated that was used for the determination of its flow equalisation basin volume requirements.

Table 4-7: Meyerton plant effluent hourly monitoring for flow equalisation analyses, 04th December 2013

Time of day	Effluent Flow (m^3/hr)	Cumulative volume at end of time period (m^3)	Volume in basin at end of time period (m^3)	Average COD (mg/L)	Equalised COD (mg/L)	Unequalised COD Loading (kg/hr)	Equalised COD Loading (kg/hr)
06:00	22	22	0	8250	8250	180	178
07:00	20	42	0	7750	7750	154	167
08:00	22	64	0	7240	7240	159	156
09:00	27	90	5	6770	6770	180	146
10:00	28	119	12	6710	6719	190	145
11:00	26	145	17	5250	5700	139	123
12:00	23	168	18	5860	5793	133	125
13:00	18	186	14	7710	6768	141	146
14:00	27	213	20	7430	7199	200	155
15:00	13	226	11	5150	6382	68	138
16:00	6	232	0	4430	5732	25	124
17:00	7	238	0	3450	3450	23	74
18:00	22	260	0	2700	2700	59	58
19:00	20	280	0	3830	3830	76	83
20:00	22	302	0	4920	4920	108	106
21:00	27	329	5	5210	5210	138	112
22:00	28	357	12	4 130	4 293	117	93
23:00	26	383	17	4910	4721	130	102
00:00	23	406	18	17790	12277	404	265
01:00	21	427	17	16700	14684	353	317
02:00	23	451	19	7080	10319	165	223
03:00	22	473	19	5690	7828	125	169
04:00	24	496	22	3270	5319	78	115
05:00	21	518	21	5550	5434	119	117
Mean	**22**			**6574**	**6637**	**144**	**143**
Max	**28**			**1790**	**1684**	**404**	**317**
Min	**6**			**2700**	**2700**	**23**	**58**

Hourly effluent flow rates and grab samples (for COD analyses) were taken from this stream; from which the relevant parameters were accordingly calculated as per the recommended method by Tchobanoglous et al. (2003). Using Table 4-7 data, the hydrograph in figure 4-29 was plotted, for the determination of the required theoretical equalisation basin volume.

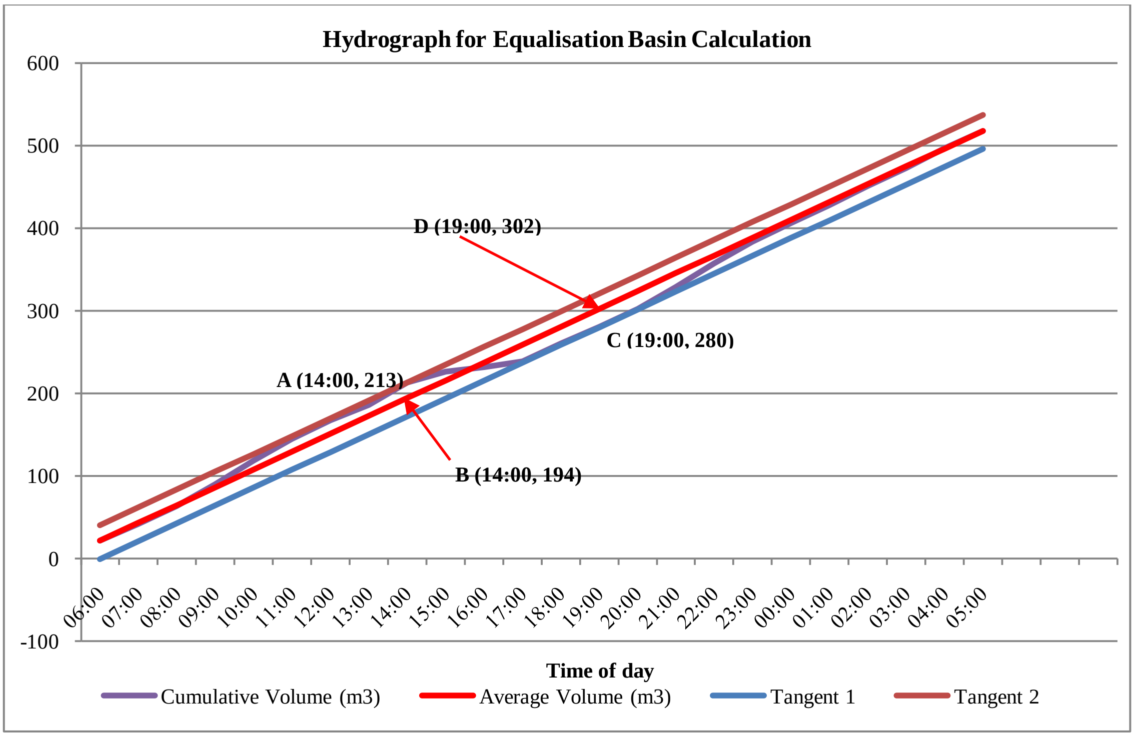

FIGURE 4-29: Hydrograph for the evaluation of the required equalisation basin storage volume for Meyerton plant effluent streams

There were two points of tangency established at A (14:00, 213 m^3), which vertically intercepted the average flow graph at point B (14:00, 194 m^3), and C (19:00, 280 m^3), intercepting at D (19:00, 302 m^3). Using Goel et al. (2005) and Tchobanoglous et al. (2003) graphical methods, the required theoretical equalisation storage volume was calculated to be 41 m^3. This is almost twenty nine times the cement dam's volume of 1200 m^3.

Effective and adequate mixing is critical for a flow equalisation system, to ensure homogeneity of the resultant effluent stream (Tchobanoglous et al. 2003). This could be easily and cost effectively achieved in a nominal basin volume of 41 m^3.

The potential benefits of installing such an equalisation basin are illustrated by figure 4-30, that shows the dampening effect on COD loading.

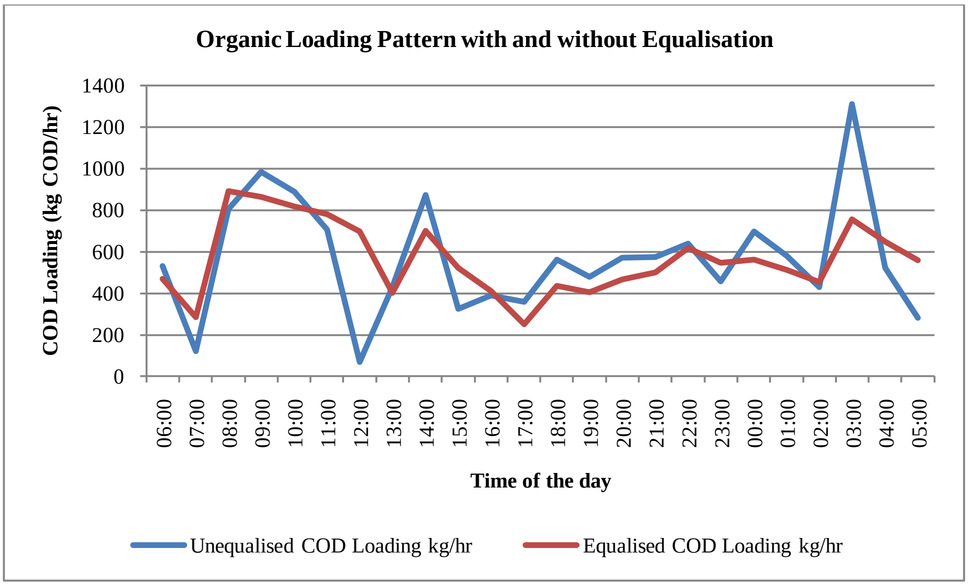

FIGURE 4-30: COD loading patterns for equalized and unequalised flow

Figure 4-30 indicates that the effects of shock/peak loading and under loading are minimised when there is flow equalisation in the system. The peak COD loading of 404 kg COD/hr could be dampened to 317 kg COD/hr. Similarly, the minimum loading of 23 kg COD/hr could be equalized to 58 kg COD/hr. This could effectively reduce variability into the existing anaerobic digester, thus ensuring a more stable operation of the system.

4.5 Anaerobic effluent treatability analyses

The data collected from the full-scale anaerobic effluent digestion study that was conducted at Meyerton plant is presented in **APPENDIX F-2**, and the statistical analysis of the same data is summarised in Table 4-8.

Table 4-8: Anaerobic digester influent and effluent statistical data

Parameter	Mean	Minimum	Maximum	Std Deviation
Feed (m^3/d)	222	37	501	115
COD_{in} (mg/L)	6211	1590	19520	3008
COD_{out} (mg/L)	149	25	566	63
*pH_{in}	6.4	4.4	12.3	1.4
*pH_{out}	7.2	6.7	7.4	0.1
SS_{in} (mg/L)	899	749	1048	211

*Mean pH was calculated from the negative logarithm of the mean of [H^+] using equation 3.17.

Table 4-9 summarises the performance of the anaerobic digester in terms of percentage COD removal, hydraulic loading rate (HRT), organic volumetric loading rate (OLR) and theoretical biogas generation.

Table 4-9: Anaerobic digester performance data

Parameter	Mean	Minimum	Maximum	Std Deviation
HRT (d)	5.9	1.9	25.1	4.3
OLR (kg COD/m^3.d)	1.4	0.3	3.9	0.7
%COD Removal	97.2	87.3	99.7	1.5
Biogas (m^3/d)	561	89	1443	246

Rearranging equation 3.15, the nominal required digester volume to treat the Meyerton plant full average volumetric load (513 kL/d), at the current average OLR (1.36 kg COD/m^3.d), was estimated at 2352 m^3. This is about twice the available digestion volume of 929 m^3. COD reduction efficiencies of 90-95 %, at OLR of 12-20 kg COD/m^3.d, and temperatures of 30-35 ^{o}C, have been achieved with an UASBR (Tchobanoglous et al. 2003). Using equation 3.15, the nominal required digester volume at OLR of 10 kg COD/m^3.d and 513 kL/d influent, was calculated at 319 m^3.

4.5.1 Hydraulic retention time

Wastewater discharged from the plant was subject to wide day-to-day fluctuation in terms of volume and organic strength as reported in Table 4-8. The flow rate into the digester was however regulated and controlled by a flow control valve. During this study period, the hydraulic retention time (HRT) varied between 1.9 and 25.1 days. This was evaluated from a volumetric flow rate and the digester volume of 929 m^3 as illustrated in APPENDIX G, equation G.2.1. The mean HRT over the study period was 5.9 days, which was higher than the 3.7 days reported by Ross (1989) at the Bellville Sewage Plant.

4.5.2 Anaerobic effluent digestion performance

Figure 4-31 presents the effluent treatability trend in terms of percentage COD removal and organic volumetric loading rate (OLR).

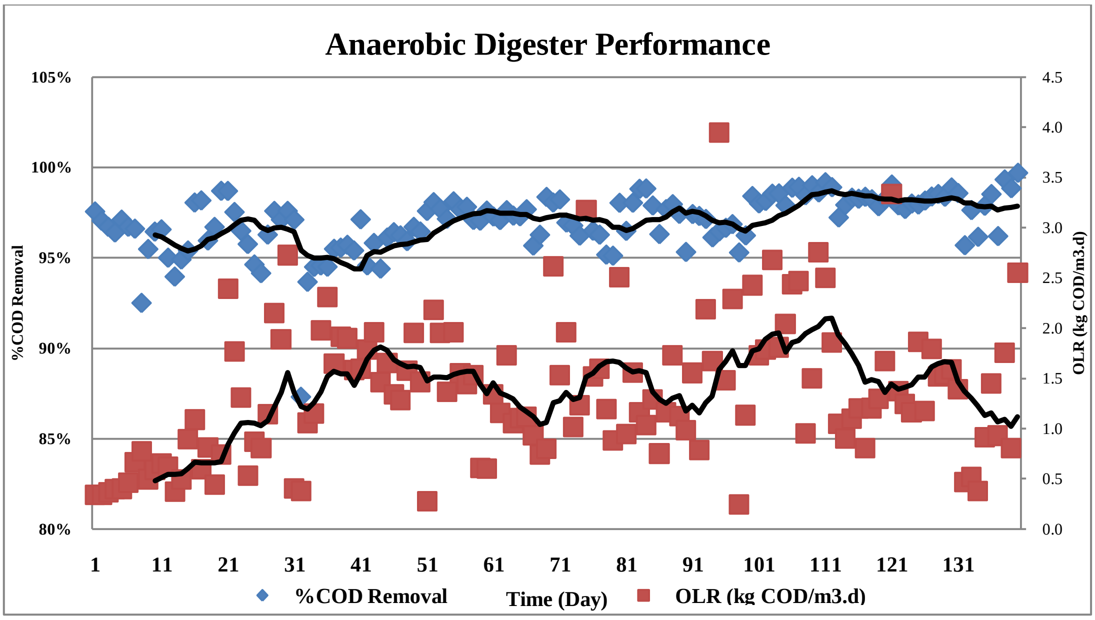

FIGURE: 4-31: Anaerobic effluent treatability trend

A ten day moving average trend was used to illustrate the relationship between OLR and percentage COD removal for the studied corn processing effluent in an anaerobic digester. During the course of this study, operating parameters were relatively kept constant in terms of digestion temperature and pH, respectively. The trend in Figure 4-31 shows that up to day 41 of the study, % COD removal was relatively decreasing as the OLR was being increased. Around day 71, the average % COD removal was relatively high. It is however evident from this trend that, a change in OLR did not have an immediate effect on the % COD removal. This could be attributed to the high hydraulic retention time, an average of six days, at which the digester was being run.

At an average OLR of 1.36 kg COD/m^3.d, the average percentage COD removal was 97 %, with a minimum of 87 % removal recorded. This compares favourably with the 96 % COD removal, at 2 kg COD/m^3.d OLR that was reported by Ross (1989) for a similar study at the Bellville Sewage Plant.

4.5.3 Theoretical biogas estimation

Theoretical methane generation was estimated using equations 3.14 and G.6 to calculate the portion of influent COD converted to CH_4, and the volume of CH_4 generated under the prevailing conditions, respectively. As illustrated in APPENDIX G, an average daily biogas of 561 m^3/d was calculated.

Using equation G.6.2, the density of CH_4 at the prevailing pressure of 0.85 atmospheres (atm) and temperature of 32 ^{o}C was calculated. Tchobanoglous et al. (2003) estimated the typical energy content of 50.1 kJ/g for CH_4 and biogas purity of 65-70 % $CH_{4.}$ Based on these typical values, the amount of CH_4 and energy generated were estimated at 198 kg/d and 9904 MJ/d, respectively. This is the amount of energy that is currently being flared to atmosphere, which is equivalent to 2.8 MWh/d of electricity. This could be significantly increased if all the generated effluent was to be anaerobically pretreated.

Only about 40 % of the total Meyerton plant effluent was anaerobically treated during this study period. Given that a minimum of 87 % COD removal was achieved, a potential of 20023 MJ/d of energy generation exists if all the generated effluent is anaerobically pretreated. This equates to about 5.6 MWh/d of electricity. This could be used as an alternative source of energy for steam and/or electricity generation.

Meyerton plant is estimated to consume 293.59 kWh of electricity per tonne of corn processed (Tongaat Hulett Starch, 2012). At the average grind rate of 180 tonnes per day, the daily electricity consumption is estimated at 53 MWh/d. At this consumption rate, it is estimated that an equivalent of almost 11 % of Meyerton plant's electricity, could be recovered from its effluent anaerobic digestion, if all the generated effluent is anaerobically treated.

The use of wastewater as a renewable energy resource can improve energy security, whilst reducing the environmental burden of waste disposal (Burton et al. 2009). This will facilitate the integration of water, waste and energy management within a model of sustainable development (Burton et al. 2009). An estimated 7 % of Eskom electrical power supply can be recovered from wastewaters in South Africa through anaerobic effluent treatment (Burton et al. 2009).

4.5.4 Anaerobic effluent treatability study summary

The study was conducted under relatively constant temperature and pH conditions. The digester temperature was maintained between 27 and 37 ^{o}C and digester effluent pH was controlled and maintained between 6.7 and 7.4. The acceptable pH range for trade effluent is 6–10 (EMM, 2011).

Corn processing effluent was confirmed to be biodegrable in an anaerobic digestion process. This was validated by the high percentage COD removal results that were achieved in this study. At varying OLR, a minimum of 87 % COD reduction was achieved.

Although wide compositional and volumetric variations of corn processing effluents might make them extremely difficult to bioremediate, its successful biological treatment is reported in literature and confirmed by the results from this study. Batchelor et al. (2002) recommended that effluents with COD concentrations higher than 2000 mg/L should be anaerobically treated. The COD concentrations recorded from this study fall within this range. Amongst all the anaerobic digester configurations that were reviewed from literature and results from the Meyerton effluent treatability study, UASBR gave the best results in terms of percentage COD removal and OLR.

4.6 Midvaal Local Municipality effluent quality monitoring

Meyerton plant effluent quality was also monitored by the Midvaal Local Municipality (MLM). Weekly grab routine samples were taken from the combined stream into the sewer and analysed for ammonia (as nitrogen), orthophosphate (as phosphorus), pH, COD, conductivity and SS.

4.6.1 Effluent disposal charges

Using equations C.3 and C.4, monthly effluent average volume and analytical results in Table D.2 were used to calculate the monthly effluent disposal charge and non compliance penalties. This routine analytical data was collected over an eight-month period. This raw data is presented in **APPENDIX D,** Table D.2 and the statistical analysis of the same data is summarised in Table 4-10.

Table 4-10: Midvaal Local Municipality effluent monitoring statistical data analyses

Parameter	Mean	Minimum	Maximum	Std Deviation
Ammonia (mg/L as N)	40.7	0.5	123.0	37.2
Orthophosphate (mg/L as P)	19.8	3.7	51.6	17.8
pH*	5.1	7.2	4.3	4.8
COD (mg/L)	3732	1157	9310	2706
Conductivity (mS/m)	246	32	530	165
SS (mg/L)	642	195	1475	454

*Mean pH was calculated from the negative logarithm of the mean of $[H^+]$ using equation 3.17.

From these analyses (see **Table 4-10**), COD/Nitrogen/Phosphorus (COD: N: P) ratio was found to be 189:2:1. This is reasonably comparable with 300:5:1 or 100:2.5:0.5 recommended for optimum biogas yields in the anaerobic effluent digestion treatment system (Tchobanologous et al. 2003 and Rajeshwari et al. 2000).

Qualitative effluent variability was also demonstrated by high standard deviation values calculated from this data. Due to on-line pH monitoring and control, relative consistency was observed in this effluent pH data.

Based on the collected data in Table D.2, a low frequency of non compliance in terms of the acceptable trade effluent discharge limits as stipulated in EMM (2011) was recorded. Over this study period (8 months), the number of non compliance incidents was recorded at 18, averaging at 2 incidents per month. Using equation C.4, the non compliance monthly charge was estimated at R2.4/kL. Using equation C.3 for the same data (Table D.2), the effluent treatment charge was estimated at R1.6/kL. Using both these charge rates and the average effluent generation rate of 513 m^3/d that was recorded over the study period, effluent total disposal charge for the Meyerton plant was estimated at R 62415 per month.

5 CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter intends to summarise the main conclusions from the study key findings. It finally aims to present key recommendations for future research and further investigations.

From literature review, South Africa is already categorised as water-scare, with water demand expected to exceed supply by 2025 if serious interventions in water resource management are not made. Water for Growth and Development framework recommends the diversification of the water matrix by amongst other things, increasing return flows from 14 % to 22 %.

In view of this, equitable access to water and protection of water resources have become mandatory and strictly legislated in South Africa. In pursuit of water conservation and wastewater minimisation, the incentive based approach to legislation has been adopted. This legislative approach is aimed at ensuring the internalisation of environmental costs and creating financial incentives for polluters to use natural resources responsibly and sustainably.

It is therefore prudent for the corn processing industry to explore the application of the principles of water management hierarchy. The more stringent effluent discharge regulation standards mean that this industry will continue incurring high effluent disposal costs if no serious interventions are undertaken. These high strength effluent streams may also represent material losses in sellable products.

In response, the corn processing industry needs to invest some of its resources in establishing better understanding of its wastewater footprint by completing comprehensive effluent characterisation and treatability studies.

5.2 Corn processing effluent characterisation

Corn processing effluent qualitative and quantitative profiles showed a high level of variability. The standard deviations that were calculated from the daily effluent volumetric flow rates ranged between 165 and 318 m^3/d. This high variability is attributed to the intermittent discharge of dewatered starch filtrates, product spillages, sporadic equipment cleaning, cyclic nature of the process, etc.

From the two characterisation studies that were conducted, the mean effluent volumetric flow rates ranged between 2.9 and 3.1 m^3 per tonne of corn processed. It was also established that overall water consumption in the corn wet milling industry ranged between 4.8 and 8.3 m^3 per tonne of corn processed.

From the same study, generated effluent COD average concentrations were higher than the stipulated acceptable trade effluent discharge limit of 5000 mg/L. The calculated standard deviations ranged between 3008 and 3695 mg/L. Mean mass organic loads in the generated effluent ranged between 3.19 and 11.34 tonnes COD per day. These organic loads were estimated to range between 16 and 18 kg COD per tonne of corn processed.

The high level of suspended solids in the effluent confirms that a solid recovery system is recommended for such effluents. An average of 2512 mg/L was recorded at the Germiston plant instead of the acceptable trade effluent discharge limit of 100 mg/L. The average recorded at the Meyerton plant was within the acceptable discharge limit at 41 mg/L, which is attributable to the clarification system of the clarigister.

Although these wide variations in the composition of corn processing effluents might make them extremely difficult to bioremediate, its successful anaerobic treatment has been widely reported in literature, and confirmed by results from these case studies. Such variations could be minimised by the installation of an adequately sized and properly located flow equalisation basin.

Based on the analyses for the Germiston and Meyerton plants' effluent streams, there are significant potential savings if all their effluent streams were to be anaerobically treated. For Germiston, monthly effluent disposal costs were estimated at R1.2m. This is in comparison to Meyerton's monthly charge of about R62415, where partial anaerobic effluent treatment was practiced.

The following subsection presents a summary of the successful study in the assessment and evaluation of corn processing effluent treatability in an anaerobic digestion process. This study was conducted on a full-scale anaerobic digester at the Meyerton plant.

5.3 Corn processing effluent treatability

Anaerobic effluent digestion process has shown to be ideal for the pretreatment of a wide spectrum of high strength organic industrial effluents, including corn processing effluents. These wastewaters are essentially biodegradable and their degree of biodegradation in terms of percentage COD removal can be as high as 97 %. This was evidenced in this study, where a minimum of 87 % COD removal was achieved at the Meyerton plant.

Pretreatment of corn processing effluent has a potential to significantly reduce its organic load into the receiving wastewater treatment works, whilst presenting an alternative source of energy. Based on the anaerobic treatability study at Meyerton plant, an average of 9922 MJ/d of energy was estimated to be flared to atmosphere. This could be increased to an average of 20023 MJ/d if all the generated effluent was to be anaerobically treated, under the current operating conditions. This is equivalent to a total electrical energy of 5.8 MWh/d.

Germiston plant's energy potential from the anaerobic treatment of its effluent, was estimated at 85133 MJ/d. This could be equivalent to about 23.6 MWh/d of electricity.

5.4 Summary

The characterisation studies conducted at Germiston and Meyerton plants confirmed and highlighted the significance of variability in the characteristics of corn processing effluent. This high variability was confirmed in terms of both composition and hydraulic loads.

Due to the emphasis of the current regulations on the equitable recovery of water quality management costs, more efforts are to be channeled into the pretreatment of such effluents. The feasibility of anaerobic pretreatment will be based on the potential cost savings from effluent disposal charges and the biogas generation. The biogas could be used as an alternative energy source for steam generation, digester heating or electricity generation.

Anaerobic biotechnology has been confirmed to have a significant potential for biomethane recovery, when such high strength effluents are treated. The current perception about corn processing effluents is that they generally represent a burden to the environment and may incur energy costs in pretreatment before they can be safely released to the environment. An opportunity exists to improve the current pretreatment processes by applying new solutions and technologies that can also reduce energy inputs and/or generate energy for other processes. Some of these technologies and potential solutions are widely reported in the reviewed literature.

5.5 Recommendations

5.5.1 This study should be repeated for an extended period of time, covering a wider number of corn processing plants. This will ensure that a greater knowledge base in terms of corn effluent characteristics and anaerobic treatability is developed.

The proposed duration for such a study is at least a full calendar year, to ensure that all possible seasonal production and weather variations are covered. Bellville and Kliprivier plants will need to be included as well.

5.5.2 Due to high organic loads in effluent streams as reported in the study, the application of wastewater minimisation strategies like pinch analyses, clean technology, cleaner production, etc, need to investigated further. This may have significant economic and environmental benefits in terms of wastewater minimisation and effluent discharge limit compliance.

At the Meyerton plant, wastewater minimisation opportunity exists, if its starch filtrate streams are clarified in separate dedicated concentrators. Unlike, the overflow filtrate from the hydrocyclonette system, the basket centrifuge filtrate could be recycled as washwater. This could potentially reduce wastewater from the starch plant by about 50 %. This is being practiced at the Germiston plant, because they only handle unmodified starches, which do not get washed in the hydrocyclonette system.

5.5.3 The use of freshwater as washwater for the nozzle disc stack primary separator needs to be replaced with gluten concentrator clarified overflow. Freshwater usage may only be left for emergency shutdown, when the clarified overflow pump could be affected as a result of power failure. This will reduce resultant wastewater from primary separator washing.

5.5.4 Germiston plant has the potential to significantly reduce its R1.2m monthly effluent disposal charge. This could be achieved by the installation of a nominal volume of 1388 m^3 UASB reactor, operated at 10 kg COD/m^3.d and 35 ^oC as recommended by Tchobanologous et al. (2003). At these minimum operating conditions, at least 85 % COD reduction will be expected.

The capital budget for this size UASB reactor needs to be evaluated, to establish the cost benefits and viability of such a proposal.

5.5.5 For Meyerton to treat its full effluent volumetric flow (513 kL/d), the operating OLR is to be increased from the current average of 1.36 kg COD/m^3.d, to at least 3.43 kg COD/m^3.d. Otherwise, at the current average OLR of 1.36 kg COD/m^3.d, an additional digester capacity of 1423 m^3, will be required.

At an OLR of 10 kg COD/m^3.d, a nominal digester volume of 319 m^3, based on the UASB reactor configuration, will be required to treat all the generated effluent. At full volumetric load into the current anaerobic digester, an equivalent of 5.6 MWh/d of electrical energy will be generated.

The most cost effective option for Meyerton is to increase the current OLR to at least 3.43 kg COD/m^3.d. The resultant biogas must be used for digester heating, which will eliminate the need for steam usage as currently being used.

5.5.6 To minimise the high effluent variability in terms of organic loading and flowrates, adequately sized equalisation basins are recommended for both Germiston and Meyerton plants, respectively. The theoretical nominal volume for the Germiston plant was estimated at 96 m^3.

An in-line flow equalisation system is best suited for both Meyerton and Germiston plants. This can ensure that all the effluent streams are properly mixed and aerated, before being discharged into the downstream anaerobic treatment system at a controlled flowrate, and equalised organic loading. This will minimise shock loading of the anaerobic treatment system, and stabilise its performance.

5.5.7 The Meyerton plant's 1200 m^3 equalisation basin is oversized for the current average effluent flowrate. This leads to excessive HRT and odour generation due to the effluent becoming septic. To mitigate this, the basin needs to be adequately aerated and mixed, to ensure homogeneity of the effluent from the basin.

The proposed nominal equalisation basin for the Meyerton effluent stream was estimated at 41 m^3.

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APPENDIX A

EFFLUENT DISCHARGE LIMITS INTO THE RECEIVING WATER RESOURCE

Table A-1: Effluent discharge limits into the receiving water resources (Nozaic, Freese, 2009).

Parameter/Substance	UOM	GENERAL	SPECIAL
Faecal Coliforms (per 100ml)	Count	1 000	0
COD	mg/L	75	30
pH	-	5.5 – 9.5	5.5 – 7.5
Ammonia (as N)	mg/L	36	2
Nitrogen (Nitrates or nitrites)	mg/L	15	1.5
Chlorine (Free)	mg/L	0.25	0
Suspended Solids	mg/L	25	10
Electrical Conductivity	mS/m	*70 - 150	#50 - 100
Orthophosphate (as P)	mg/L	10	1(median) – 2.5 (maximum)
Fluoride	mg/L	1	1
Soap or Oil or Grease	mg/L	2.5	0
Arsenic	mg/L	0.02	0.01
Cadmium	mg/L	0.005	0.001
Chromium (IV)	mg/L	0.05	0.02
Copper	mg/L	0.01	0.002
Cyanide	mg/L	0.02	0.01
Iron	mg/L	0.3	0.3
Lead	mg/L	0.01	0.006
Manganese	mg/L	0.1	0.1
Mercury	mg/L	0.005	0.001
Selenium	mg/L	0.02	0.02
Zinc	mg/L	0.1	0.04
Boron	mg/L	1	0.5

**above intake; #above background receiving water.*

APPENDIX B

ACCEPTABLE TRADE EFFLUENT DISCHARGE LIMITS

Table B-1: Acceptable trade effluent discharge limits (EMM, 2011).

Determinants	UOM	Lower Limit
pH @25^{o}C	-	6.0
		Upper Limits
pH @25^{o}C	-	10
Electrical Conductivity at 250	mS/m	500
Caustic Alkalinity (as $CaCO_3$)	mg/L	2000
Substances not in solution (including fats; oil; grease; waxes) and where volume does not exceed 10 000kl/month.	mg/L	500
Sulphides (as S)	mg/L	10
Hydrogen Sulphide (as H_2S)	mg/L	5
Substances from which hydrogen cyanide can be liberated (as HCN)	mg/L	20
Formaldehyde (HCHO)	mg/L	20
Non organic substances in suspension	mg/L	100
Chemical Oxygen Demand	mg/L	5000
All sugars and/or starch (as glucose)	mg/L	1500
Available chlorine (as Cl)	mg/L	100
Sulphates (as SO_4)	mg/L	1800
Sodium (as Na)	mg/L	500
Fluorine containing compounds (as F)	mg/L	5
Anionic Surface Active Agents	mg/L	500
Ammonium Nitrogen (as N)	mg/L	200
Orthophosphate (as P)	mg/L	50
Phenols	mg/L	150
Chloride (as Cl)	mg/L	500
Nickel (as Ni)	mg/L	20
Zinc (as Zn)	mg/L	20
Cobalt (as Co)	mg/L	20
Chromium (as Cr)	mg/L	20
Lead (as Pb)	mg/L	5
Copper (as Cu)	mg/L	5
Cadmium (as Cd)	mg/L	5
Arsenic (as As)	mg/L	5

Boron (as B)	mg/L	5
Selenium (as Se)	mg/L	5
Mercury (as Hg)	mg/L	5
Molybdenum (as Mo)	mg/L	5

APPENDIX C

INDUSTRIAL EFFLUENT DISPOSAL CHARGE CALCULATION

Conveyance and Treatment Charge Formula (EMMT, 2011 and MLM, 2013)

$$\mathbf{Ti} = \left(\frac{\mathbf{C}}{\mathbf{12}}\right)\left(\frac{\mathbf{Qi}}{\mathbf{Qt}}\right)\left[\mathbf{a} + \mathbf{b}\left(\frac{\mathbf{CODi}}{\mathbf{CODt}}\right) + \mathbf{d}\left(\frac{\mathbf{Pi}}{\mathbf{Pt}}\right) + \mathbf{e}\left(\frac{\mathbf{Ni}}{\mathbf{Nt}}\right) + \mathbf{f}\left(\frac{\mathbf{SSi}}{\mathbf{SSt}}\right)\right] \qquad \text{C-1}$$

Where

$\mathbf{T_i}$ = monthly charges for industrial effluent treatment and conveyance of industrial effluent

C = Total annual operational and maintenance budget (R) for treatment works

$\mathbf{Q_i}$ = monthly average flow (kL/d) originating from the relevant premises

$\mathbf{Q_t}$ **=** five year average total inflow (kL/d) into the treatment works

$\mathbf{COD_i}$ = monthly average COD (mg/L) originating from the relevant premises

$\mathbf{COD_t}$ **=** five year average COD (mg/L) entering into the treatment works

$\mathbf{P_i}$ = monthly average ortho-phosphate (mg/L as P) originating from the relevant premises

$\mathbf{P_t}$ **=** annual average ortho-phosphate (mg/L as P) entering the treatment works

$\mathbf{N_i}$ = monthly average ammonia (mg/L as N) originating from the relevant premises

$\mathbf{N_t}$ **=** five year average ammonia (mg/L as N) entering the treatment works

$\mathbf{SS_i}$ = monthly average suspended solids (mg/L) originating from the relevant premises

$\mathbf{SS_t}$ **=** five year average suspended solids (mg/L) entering the treatment works

a = portion of the fixed cost of treatment and conveyance

b = portion of the costs directly related to COD removal

d = portion of the costs directly related to phosphate removal

e = portion of the costs directly related to ammonia removal

f = portion of the costs directly related to suspended solids’ removal

Table C-1: Parameters and cost factors for trade effluent tariff charge calculation

	Germiston Plant (EMM, 2011)	Meyerton Plant (MLM, 2013)
C (R/yr)	**R470000000**	**R32500**
Q_t (kl/d)	**607400**	**7000**
COD_t (mg/L)	**803**	**551**
P_t (mg/L)	**5.7**	**5.8**
N_t (mg/L)	**23.4**	**25.5**
SS_t (mg/L)	**304**	**259**
a	**0.50**	**0.29**
b	**0.26**	**0.46**
d	**0.16**	**0.05**
e	**0.15**	**0.05**
f	**0.14**	**0.15**

Using the above factors in Table C-1 and equation C.1, equation C.2 for the Germiston plant was derived. Equation C.2 is used in the calculation of industrial effluent discharge tariff in the Ekurhuleni Metropolitan Municipality area.

$$\mathbf{Ti} = (\frac{\mathbf{R470m}}{\mathbf{12}})(\frac{\mathbf{Qi}}{\mathbf{607400}})[\mathbf{0.5} + \mathbf{0.26}\left(\frac{\mathbf{CODi}}{\mathbf{803}}\right) + \mathbf{0.16}\left(\frac{\mathbf{Pi}}{\mathbf{5.7}}\right) + \mathbf{0.15}\left(\frac{\mathbf{Ni}}{\mathbf{23.4}}\right) + \mathbf{0.14}\left(\frac{\mathbf{SSi}}{\mathbf{304}}\right)] \quad \text{(C.2)}$$

Similarly, equation C.3 for the Meyerton plant was derived. Equation C.3 is used in the calculation of industrial effluent discharge tariff in the Midvaal Local Municipality area.

$$\mathbf{Ti} = (\frac{\mathbf{R32500}}{\mathbf{12}})(\frac{\mathbf{Qi}}{\mathbf{7000}})[\mathbf{0.29} + \mathbf{0.46}\left(\frac{\mathbf{CODi}}{\mathbf{551}}\right) + \mathbf{0.05}\left(\frac{\mathbf{Pi}}{\mathbf{5.8}}\right) + \mathbf{0.05}\left(\frac{\mathbf{Ni}}{\mathbf{25.5}}\right) + \mathbf{0.15}\left(\frac{\mathbf{SSi}}{\mathbf{259}}\right)] \quad \text{(C.3)}$$

Additional charges are calculated based on the number of parameters exceeding the stipulated limits in Table B.1, the tariff rate (0.18/kL) and the total effluent for that month. Equation C.4 is used in the calculation of additional non compliance charges.

$$\mathbf{Charge} = \mathbf{QT} \times (\sum \mathbf{Number\ non\ complying\ parameters}) \times \mathbf{1.18} \quad \text{(C.4)}$$

Where

QT is the total effluent volume for that month in m^3.

The total monthly effluent disposal charge is based on the two charges: C3 and C2.

APPENDIX D

MUNICIPALITY EFFLUENT QUALITY MONITORING DATA

Table D.1: EMM Effluent Monitoring Results for Germiston plant

	Ammonia (mg/L as N)	**Orthophosphate (mg/L as P)**	**pH**	**$[H^+]$ (mol/L)**	**BOD (mg/L)**	**COD (mg/L)**	**Conductivity (mS/m)**	**SS (mg/L)**
01/11/2011	2.1	2.1	11.1	7.9E-12	2050	3410	428	534
09/11/2011	0.1	0.9	4.5	3.2E-05	1750	4560	150	229
15/11/2011	0.8	0.9	3.7	2.0E-04	1800	2770	844	267
21/11/2011	1.3	0.1	12.1	7.9E-13	1700	4580	64	648
30/11/2011			9.4	4.0E-10		4513	381	520
05/12/2011	1.2	0.1	12.1	7.9E-13	300	5810	306	496
13/12/2011	5.6	0.2	9.4	4.0E-10	1400	7380	475	511
19/12/2011			9.4	4.0E-10		7053	365	636
02/02/2012	0.6	0.2	7.9	1.3E-08	1400	13270	612	624
09/02/2012	1.1	0.1	12	1.0E-12	750	3260	654	662
15/02/2012	2.9	0.2	10.6	2.5E-11	320	4900	300	314
20/02/2012	4.6	0.5	11	1.0E-11	3200	14760	510	545
29/02/2012			9.6	2.5E-10		5160	405	449
01/03/2012	12	9.8	5.5	3.2E-06	3600	4560	398	126
08/03/2012	2.1	52.6	8.4	4.0E-09	10400	17300	617	2903
13/03/2012	1.3	0.1	7	1.0E-07	2600	9990	348	478
26/03/2012	750	1.5	10.3	5.0E-11	25000	45500	1029	2171
30/03/2012			10.1	7.9E-11		7186	382	750
03/04/2012	3	0.3	11.3	5.0E-12	1700	3900	333	423
12/04/2012	9.8	0.2	11.5	3.2E-12	2900	17780	520	811
17/04/2012	60	66	4.5	3.2E-05	3100	17850	890	1585
23/04/2012	4.9	0.2	12.1	7.9E-13	100	5210	1011	871
30/04/2012			9.6	2.5E-10		8760	466	802
16/05/2012	4.5	0.3	11.7	2.0E-12	1000	13730	230	167
21/05/2012			9.6	2.5E-10		8100	445	673
Mean	**46**	***7.2**	**5.0**	**1.1E-05**	**3425**	**9652**	**487**	**728**
Minimum	**0.1**	**0.1**	**3.7**	**7.9E-13**	**100**	**2770**	**64**	**126**
Maximum	**750**	**66**	**12.1**	**2.0E-04**	**25000**	**45500**	**1029**	**2903**
StDev	**171**	**19**	**3**	**4.0E-05**	**5678**	**8887**	**246**	**625**

*Mean pH was calculated from the negative logarithm of the mean of $[H^+]$ using equation 3.17.

Table D.2: MLM Effluent Monitoring Results for Meyerton plant

Month	Conductivity (mS/m)	SS (mg/L)	pH	$[H^+]$ (mol/L)	Ammonia (mg/L as N)	ortho-Phosphates (mg/L as P)	COD (mg/L)	Number of Non Compliances
Dec-11	530	935	6.6	2.6E-07	123.0	43.4	5435	3
Jan-12	32	245	6.4	3.8E-07	23.6	7.5	2250	0
Feb-12	32	195	7.2	6.2E-08	38.0	3.7	1157	0
Mar-12	177	875	5.0	9.3E-06	0.5	6.1	4540	2
Apr-12	340	335	5.4	4.1E-06	59.8	15.8	3590	1
May-12	293	795	4.3	4.6E-05	27.7	51.6	9310	4
Jun-12	274	280	6.1	7.9E-07	31.5	14.9	2070	0
Jul-12	289	1475	6.5	3.2E-07	21.5	15.3	1501	2
Mean	**246**	**642**	***5.1**	**7.6E-06**	**40.7**	**19.8**	**3731.6**	**2**
Minimum	**32**	**195**	**7.2**	**6.2E-08**	**0.5**	**3.7**	**1157.0**	**0**
Maximum	**530**	**1475**	**4.3**	**4.6E-05**	**123.0**	**51.6**	**9310.0**	**4**
StDev	**165**	**454**	**4.8**	**1.6E-05**	**37.2**	**17.8**	**2705.9**	**2**

*Mean pH was calculated from the negative logarithm of the mean of $[H^+]$ using equation 3.17.

APPENDIX E

GERMISTON PLANT EFFLUENT CHARACTERISATION DATA

E.1: Germiston Plant Effluent Volumetric and Corn Processing Data

E.2: Germiston Plant Effluent Quality Monitoring Data

E.3: Germiston Plant Water Usage Data

TABLE E.1: GERMISTON PLANT EFFLUENT VOLUMETRIC AND CORN PROCESSING DATA

	EFFLUENT DAILY VOLUMES (m^3/d)								
	E1	E2T	E2V	E3	E4	E5	E6	E7	Corn Grind (tonnes/d)
Day	Wetmill	Starch Derivatives Production							
1	501	211	5		143	766	266	1893	650
2	246	41			28	271	234	833	300
6	322	252	15		74	428	489	1606	140
7	548	333	18		49	826	256	2023	570
8	462	444	13		64	687	442	1944	230
9	540	224	6		59	549	176	1625	680
10	98	31	1		6	59	23	211	
12	258	276	12		91	792	405	1892	75
13	367	432	14		43	971	305	2173	540
14	563	185	11		29	351	109	1272	620
15	576	153	12		74	754	220	1682	770
16	571	289	13		121	862	147	2536	760
17	593	178	21		23	668	324	1960	840
18	491	333	13		46	839	337	2178	760
19	536	241	14		55	602	241	2007	800
20	251	148	12		86	947	252	1924	240
21	496	274	13	6	54	461	216	1513	730
22	562	134	14	4	56	625	285	1670	570
23	637	86	16		48	776	308	2173	590
24	566	247	12		67	780	200	2176	740
25	492	286	17		71	458	279	1957	580
26	491	164	11	1	74	997	142	2141	790
27	509	307	12		69	658	114	1882	740
28	456	124	12		85	504	131	1357	680
29	577	313	11		66	638	144	1816	400
30	367	129	11	1.0	35	716	159	1378	825
31	475	101	28		33	647	309	1689	520
32	615	250	11		60	724	246	1929	680
33	634	180	15	1.0	74	903	290	2111	690
34	449	225	16		46	590	244	1570	470
35	412	294	18		53	617	195	1589	570
36	486	106	11		36	682	210	1553	720
37	525	339	13		50	737	506	2136	510
38	617	201	12		45	501	226	1632	555
39	471	273	16		37	736	343	1946	700
40	492	181	13		58	756	289	1790	700
41	544	305	14		46	860	359	2066	610
42	580	143	13		52	482	296	1609	710
43	101	32	3		16	78	55	294	
44	540	351	15		27	460	380	1819	350
45	718	68	13		74	642	239	1986	880
46	555	174	17		65	780	351	1548	700
47	573	108	12		53	808	327	1645	820
48	551	232	15		47	755	361	2056	710
49	550	277	12	24	52	863	285	1976	730
50	632	292	13	2	53	634	256	2036	620
51	555	389	13	2	109	620	208	2028	730
52	563	134	11		49	540	238	1711	650
53	466	197	11	2	34	701	223	1742	640
54	494	325	17	44	53	858	228	2148	650

Day	E1	E2T	E2V	E3	E4	E5	E6	E7	Corn Grind (tonnes/d)
	Wetmill	Starch Derivatives Production							
55	562	149	12	21	28	881	213	1938	720
56	506	335	12	39	60	797	262	2055	730
57	513	274	12	12	37	803	216	1939	490
58	526	519	12		74	334	225	1831	700
59	482	86	12	2	106	847	171	1796	690
60	563	388	12	10	35	627	292	2014	800
61	574	109	12	2	62	705	260	1818	780
62	440	124	11	1	46	813	216	1736	730
63	341	372	13	5	77	679	158	1776	630
64	620	140	13		44	830	158	1946	690
65	757	272	15		57	596	143	1972	830
66	581	181	12		51	776	168	2009	730
67	496	118	12		50	592	109	1524	650
68	1294	298	14		57	689	416	2824	730
69	479	111	12		77	724	256	1774	800
70	432	338	11	8	62	818	182	1965	750
71	366	88	11	10	27	397	221	1129	800
72	480	404	8	8	55	782	191	2029	750
73	450	308	15		24	600	158	1707	780
74	455	186	14		60	742	163	1812	570
75	454	276	8		90	508	217	1693	620
76	507	305	15		83	561	257	1898	700
77									
78	832	249	16		54	612	275	2038	390
79	393	316	14	19	76	607	181	1767	730
80	310	379	12	33	63	714	147	2029	700
81	331	403	12	29	42	696	119	1979	610
82	307	359	12	17	29	650	101	1675	710
83	338	219	11	6	60	847	136	1697	690
84	347	283	15	2	36	969	179	1979	460
85	346	322	15	2	79	653	248	1828	205
86	419	227	9		51	982	190	1878	770
87	357	338	13	5	44	687	150	1805	770
88	281	210	17		38	723	239	1508	840
89	317	281	17		85	489	188	1620	720
90	224	323	13		70	759	204	1886	580
91	274	291	14	40	44	961	176	1849	670
92	270	163	13		45	854	194	1539	710
93	282	11	14		48	620	193	1332	760
94	377	334	15		32	632	230	1692	510
95	288	75	12		52	657	166	1476	760
96	214	248	16		50	540	308	1376	80
97	457	203	13		92	787	284	1989	560
98	306	241	11		109	930	167	1950	740
99	429	347	12		29	907	143	1686	750
100	593	184	11		44	449	248	1667	430
101	403	95	10			966	166	1762	710
102	413	296	12			924	152	2015	710
103	372	78	7			837	213	1671	850
104	289	269	4	3		600	144	1571	730
105	894	121	13	1		678	193	2061	350

	E1	E2T	E2V	E3	E4	E5	E6	E7	Corn Grind (tonnes/d)
Day	Wetmill	Starch Derivatives Production							
106	1340	265	16			707	268	2838	400
107	1030	149	16			838	284	2516	710
108	374	406	12			431	188	1639	710
109	383	216	13	2		861	164	1794	740
110	343	216	10			669	162	1700	670
111	325	326	11			838	238	2090	610
112	368	2	8		18	298	287	1197	780
113	373	254	11		64	828	202	2030	430
114	316	177	11		105	902	182	1832	500
115	343	164	14		61	989	171	1791	760
116	386	203	14		42	786	346	1867	630
117	325	131	11		53	773	288	1728	660
118	413	134	12		96	571	248	1699	650
119	69	106	6		76	472	132	1011	
120	421	214	17		72	746	220	1846	380
121	544	245	10		46	942	254	2161	700
122	502	151	12		88	768	208	1891	660
123	449	186	11		45	963	143	1977	640
124	525	177	13		87	1000	217	2174	650
125	403	32	17		45	1074	158	1869	730
126	353	8	5		50	836	132	1532	670
127	351	253	5		59	711	210	1724	450
128	537	200	22		34	1021	223	2218	630
129	420	201	14		76	862	156	1908	600
130	405	313	15		131	953	108	2050	650
131	406	172	12	2	93	924	142	1869	670
132	418	305	11		58	851	123	1856	660
133	291	281	11		54	828	237	1660	490
134	223	254	14		36	687	216	1663	60
135	449	177	6		39	684	384	1917	605
136	708	23	4		33	826	256	1949	525
137	744	50	12		29	643	154	1798	430
138	758	129	14		72	785	176	2049	435
139	444	270	13		62	496	168	1603	250
140	437	491	11		71	589	147	1845	630
141	438	122	13	9	68	938	70	1742	660
142	419	314	10	11	34	944	53	1845	300
143	325	4	4	8	33	840	51	1417	350
144	443	118	11	9	39	785	90	1630	650
145	408	259	12	35	57	908	80	1891	650
146	263	145	6	8	45	967	30	1614	200
147	139	80	7	16	54	384	27	836	
148	707	94	11	12	62	734	112	2083	300
149	493	470	13	33	53	829	79	2118	700
150	446	113	10	13	108	977	50	1886	540
151	643	146	14	11	71	578	114	1771	460
152	442	206	12	20	73	929	66	1930	690
153	447	249	13	7	69	595	62	1641	760
154	400	283	11	9	108	663	98	1734	660
155	349	154	12	14	58	935	226	1955	700
156	488	152	14	14	53	969	131	1964	530
157	557	135	12	19	93	791	179	1928	690
158	530	148	25	16	58	862	179	2097	660
159	500	260	12	54	74	931	137	1868	560

	E1	E2T	E2V	E3	E4	E5	E6	E7	Corn Grind (tonnes/d)
Day	Wetmill	Starch Derivatives Production							
160	512	292	5	22	77	1232	143	2203	580
161	506	121	20	12	65	1154	85	2064	660
162	433	240	13	16	66	1071	98	1769	610
163	482	173	12	7	40	1183	58	2020	565
164	372	361	12	5	27	1092	53	1713	550
165	403	120	12	7	38	933	48	1667	660
166	357	305	13	6	90	932	51	1869	650
167	421	177	10	4	52	794	73	1682	700
168	434	378	12	29	48	692	114	2025	660
169	379	222	11	9	77	927	42	1750	650
170	366	161	15	10	84	822	61	1619	700
171	531	382	13	14	145	913	44	2173	580
172	419	194	10	19	135	503	35	1378	700
173	374	204	13	42	122	756	205	1855	700
174	354	181	11	15	40	881	51	1620	620
176	756	113	18	23	65	711	209	1895	300
177	555	240	14	25	78	740	52	1822	300
178	451	123	12	45	126	838	139	1871	600
179	449	105	13	12	55	689	111	1585	680
180	402	259	15	13	66	845	44	1807	550
181	404	116	14	29	79	907	84	1809	520
182	375	337	11	16	143	872	65	1918	680
183	359	131	13	17	138	804	80	1611	700
184	389	133	15	31	107	840	53	1620	560
185	432	265	12	12	101	807	43	1746	730
186	401	140	20	10	90	514	24	1401	750
187	358	147	14	25	107	456	62	1435	750
188	363	227	12	28	128	963	60	1947	690
189	386	151	13	5	110	838	74	1747	650
190	428	183	13	16	49	591	48	1490	640
191	429	320	12	9	81	743	42	1793	700
192	456	63	12	36	38	646	55	1449	615
193	367	91	12	7	69	420	73	1492	620
194	399	206	11	8	57	326	159	1970	760
195	403	215	12	12	83	771	122	1618	630
196	389	70	11	5	98	789	143	1505	700
197	389	120	17	12	113	1076	84	1811	700
198	390	165	12	8	63	413	237	1652	520
199	152	204	11	8	43	630	366	1574	440
200	829	80	13	8	63	645	279	2155	660
201	418	93	13	41	89	718	169	1693	800
202	426	176	10	22	77	716	126	1678	860
203	418	204	12	41	136	608	110	1672	780
204	438	180	13	22	100	631	101	1634	750
205	377	210	13	143	114	555	178	1716	450
206	450	134	12	16	73	552	155	1574	660
207	393	106	12	21	83	559	122	1546	700
208	420	81	11	17	84	594	199	1517	750
209	310	112	11	35	63	498	267	1418	180
210	358	50	11	33	72	281	170	1166	180
211	504	341	13	6	92	583	126	1822	700
212	610	187	12	24	113	682	157	1926	780
213	471	129	12	10	40	699	58	1926	810
214	436	132	10	3	50	991	59	1826	900
215	453	108	11	6	64	839	118	1725	690
216	348	297	11	4	46	716	134	1663	500
217	497	239	10	4	60	1172	93	2207	620
TOTAL	96209	44085	2609	1769	12989	154654	38091	377725	128665
Mean	456	209	12	16	65	733	181	1782	622
Max	1340	519	28	143	145	1232	506	2838	900
Min	69	2	1	1	6	59	23	211	60
StdDev	157	102	3	17	27	192	94	318	162

TABLE E.2: GERMISTON PLANT EFFLUENT QUALITY MONITORING DATA

Day	EFFLUENT GRAB SAMPLE ANALYSES FOR EACH STREAM									E7 Composite Sample					CPV TOC ANALYSES (mg/L)		
	Wetmill	TOC Analyses - Starch Derivatives Production (mg/L)						TOC (mg/l)	Conductivity (mS/m)	mg/L	mg/L		mol/L	mg/L	Steep Liquor	Acid Glucose	Enzyme Glucose
	E1	E2T	E2V	E3	E4	E5	E6	E7 (Combined Streams)		TOC	COD	pH	[H$^+$]	SS			
1	1140	6427	1360		9069	8131	14558	4599	424	5080	6750	10.8	1.6E-11	228	1469	3730	606
2	806	4339			3450	1558	7823	3448	366	2512	3510	5.7	2.0E-06	340	715	376	200
3	726	2399			2610	14429	2471	9554	425	9554	12038	3.4	4.0E-04	284	1965	814	265
6	1204	2090	6776		6602	6380	15338	7584	344	11629	11670	8.2	6.3E-09	670		5503	1202
7	1892	15562	5211		15625	6157	15327	7945	405	8789	10986	9.3	5.0E-10	1030	3091	1809	900
8	3453	10505	5279		23485	6897	9378	9553	292	8376	10440	9.2	6.3E-10	962	1370	6279	1770
9	1989	7253	1929		11932	6128	9079	5020	336	7824	8020	9.2	6.3E-10	914	1160	732	1095
10	1253	2025			4918	3258	12450	4392	267	4392	5446	11.2	6.3E-12	894	918	603	768
12	1184	5447	1657		38967	6494	8148	9825	465	7914	9659	9.2	6.3E-10	2199		2382	1143
13	1280	5724	2902		10483	5222	8232	6751	315	5030	6114	8.7	2.0E-09	341	2539	438	1499
14	1428	3313	1812		30200	3924	12454	4745	148	4691	5540	10.3	5.0E-11	226	1792	459	599
15	1131	2817	1814		9248	3794	6532	3682	426	2941	3400	9.4	4.0E-10	180	982	403	374
16	1013	2005	1122		14327	3030	6213	4407	530	5931	6880	6.7	2.0E-07	1096	877	438	666
17	968	10124	2376		7724	1898	16638	4814	298	4465	5280	8.6	2.5E-09	550	980	307	336
18	1233	4771	2935		6358	3940	3245	4349	331	4865	6840	7.9	1.3E-08	520	1032	357	410
19	1581	1318	2761		6166	8912	3389	5346	340	5015	7180	10.9	1.3E-11	430	1192	1528	1338
20	1332	4453	2979		16592	4566	6171	4146	583	7816	10117	10.9	1.3E-11	597		1930	505
21	1862	1078	1511		38045	9434	9385	5011	368	4325	6550	10.2	6.3E-11	341	1401	933	645
22	980	4814	2334		6711	7630	9934	6452	459	5844	7710	9.1	7.9E-10	1842	1499	1386	750
23	2030	10826	1169		16539	5699	9968	4940	606	4816	6400	7.1	7.9E-08	440	1097	2652	870
24	1268	5951	2181		12043	3081	15655	4826	196	4279	5260	9.1	7.9E-10	280	1060	940	573
25	2278	8661	1614		19778	6155	20700	7710	363	12398	14700	10.2	6.3E-11	1060	1327	8587	1190
26	1615	4215	6653		24405	4855	25945	6164	451	5653	6650	8.9	1.3E-09	611	1149	2330	1217
27	1312	4791	7201		14008	2997	18334	4630	274	4930	5000	10.1	7.9E-11	310	1493	4831	596
28	1613	5384	6680		15884	3735	20129	6153	287	5565	6480	9.4	4.0E-10	520	1189	1151	649
29	1613	3814	10994		13055	8540	17191	5008	503	3640	3880	10.2	6.3E-11	160	1801	1008	931
30	1855	2760	3226		3268	6506	20996	6393	247	4807	5914	9.9	1.3E-10	282	1753	925	3805

	EFFLUENT GRAB SAMPLE ANALYSES FOR EACH STREAM									E7 Composite Sample					CPV TOC ANALYSES (mg/L)		
	Wetmill	TOC Analyses - Starch Derivatives Production (mg/L)						TOC (mg/l)	Conductivity (mS/m)	mg/L	mg/L		mol/L	mg /L	Steep Liquor	Acid Glucose	Enzyme Glucose
Day	E1	E2T	E2V	E3	E4	E5	E6	E7 (Combined Streams)		TOC	COD	pH	$[H^+]$	SS			
31	1957	9180	1422		15409	4824	23893	6007	380	7248	7964	9.2	6.3E-10	361	1463	979	2462
32	1847	17762	2306		5753	8534	12910	8065	402	6295	7740	10.	5.0E-11	463	1390	10713	2467
33	1456	7745	2017		10934	11736	14218	8092	384	7148	8890	9.9	1.3E-10	420	1350	2953	2336
34	2023	11584	3244		17324	4176	7623	8269	323	8547	9912	9.2	6.3E-10	543	1125	9245	896
35	1187	4848	1462		16830	2648	13787	5644	206	4412	6370	10.	7.9E-11	196	1196	737	765
36	1147	2508	851		12983		8573	3000	350	2291	2800	9.2	6.3E-10	163	1139	1253	455
37	1603	1873	16730		5961	6511	16146	6311	218	5837	7850	10.	5.0E-11	400	1228	1008	1188
38	1518	14274	2827		9301	4385	10426	4964	429	3385	4250	10.	5.0E-11	280	770	656	876
39	1041	1796	1069		11982	2173	9060	5352	1521	3207	4256	10.	6.3E-11	340	857	508	586
40	1520	7483	2172		51422	3932	9577	4060	560	3577	4760	9.0	1.0E-09	361	794	564	640
41	1545	2692	1494		33410	3139	11632	5609	599	4366	5250	9.8	1.6E-10	380	917	929	689
42	1852	3741	1032		16742	5165	12861	6216	342	3449	4770	9.4	4.0E-10	466	1389	7193	5742
43	2038	16634	1041			7168	6139	5216	229	3552	3900	10.	3.2E-11	570		3361	5944
44	1516	5641	6569		2944	3558	17744	7004	379	4958	5640	9.5	3.2E-10	103	3613	15464	4618
45	1417	2218	1977		4846	3519	6383	3038	496	3386	4148	5.7	2.0E-06	574	1745	751	796
46	1157	9408	3183		7650	2170	7039	4359	360	4747	6025	9.6	2.5E-10	593	1441	4881	1001
47	2280	6611	3722		11218	6055	10108	5846	232	4812	6021	8.8	1.6E-09	583	1995	2616	1117
48	2157	7391	2869		10766	4873	18371	7566	534	8832	9740	9.3	5.0E-10	886	1995	1962	1256
49	2338	16348	2756		10181	4211	10393	6648	356	8507	9446	10.	6.3E-11	428	2660	5314	2863
50	1585	4415	10686		9627	4448	4106	4104	369	2933	3940	10.	1.3E-11	811	3530	1686	1901
51	1678	17914	2742		22234	3436	6214	7133	303	7588	8840	10.	1.6E-11	616	979	998	1173
52	1435	5104	1925		4105	2305	9737	3050	487	3231	3560	9.5	3.2E-10	102		1192	1670
53	2041	2786	1484		10823	3466	9235	3737	243	3412	3820	10.	1.6E-11	240	1731	2449	684
54	1395	2351	1181		6602	3458	6733	3365	546	5294	6730	10.	5.0E-11	400	2678	2545	1653
55	1633	3319	3416		7896	5520	7842	4126	513	3033	3280	10.	7.9E-11	390	1609	1190	1406
56	1560	2395	2617		48886	2378	7337	3436	319	2254	2968	10.	6.3E-11	155	2267	3081	2073
57	1765	3491	1706		84343	2761	17755	4864	291	3220	3629	7.4	4.0E-08	180	2439	9943	1326
58	1915	2723	1551	6333	14519	2689	9646	3720	421	3352	4062	10.	2.0E-11	142	2656	4264	1017

	EFFLUENT GRAB SAMPLE ANALYSES FOR EACH STREAM									E7 Composite Sample					CPV TOC ANALYSES (mg/L)		
	Wetmill	TOC Analyses - Starch Derivatives Production (mg/L)						TOC (mg/l)	Conductivity (mS/m)	mg/L	mg/L		mol/L	mg/L	Steep Liquor	Acid Glucose	Enzyme Glucose
Day	E1	E2T	E2V	E3	E4	E5	E6	E7 (Combined Streams)		TOC	COD	pH	[H$^+$]	SS			
59	1516	4029	2625	10143	19076	2455	6598	4474	465	5002	6420	9.4	4.0E-10	341	2699	947	1046
60	737	2747	1999		6404	3855	8802	5848	218	4735	5690	10.	5.0E-11	210	2280	1450	962
61	1099	3509	4351		9322	2928	8022	3198	286	2984	3770	9.9	1.3E-10	350	2616	2863	988
62	1279	19239	1997		41075	3519	4020	3765	341	4256	5500	8.3	5.0E-09	410	4785	1972	834
63	1677	17678	1249		17947	4841	2374	6973	302	3566	4640	9.7	2.0E-10	484	6388	540	1064
64	1837	17345	2797		21539	3127	3808	4190	323	3236	4405	10.	3.2E-11	355	2969	10653	684
65	1376	16843	2055		26161	2602	3712	5343	308	4716	5985	10.	6.3E-11	383	2318	3642	661
66	1094	4774	1032		23737	2646	6338	3515	550	3738	4270	9.8	1.6E-10	496	2565	494	552
67	1251	5156	2011		10224	4600	14852	4842	324	4676	5782	9.7	2.0E-10	368	2111	505	709
68	2107	3219	1350		10267	4400	5805	3335	739	3156	3790	9.1	7.9E-10	390	2643	2163	852
69	1208	6155	3780		18353	2777	6398	3589	922	4802	5170	9.2	6.3E-10	710	1838	3877	821
70	961	4542	1496		21417	2560	2391	3127	552	2951	3700	9.2	6.3E-10	360	1528	1561	569
71	1679	3297	2868		10267	2302	4334	3194	230	4162	4968	9.8	1.6E-10	268	2349	2863	836
72	1345	2032	5813		9307	1622	5450	2498	335	2128	3670	9.9	1.3E-10	961	2894	1737	853
73	1375	22932	4275		12116	4758	6788	5688	494	6625	7882	9.9	1.3E-10	872	2014	1896	637
74	1200	6917	4176		51489	5265	7934	5105	364	4806	5580	10.	2.0E-11	454	1545	1236	748
75	1514	3030	2619		5672	3766	6382	3664	175	4957	5961	11.	5.0E-12	467	1718	557	375
76	1726	10709	879		17135	2617	8517	4862	339	5214	5840	11.	1.0E-11	500	2626	10015	762
78	1111	6551	1418		10150	4673	8675	4058	301	5488	6780	9.0	1.0E-09	513	2374	20402	
79	1071	11372	1675		8353	3345	6144	5479	274	4870	5940	9.8	1.6E-10	810	1606	1805	661
80	1082	2963	4713	1982	9589	2885	12365	3792	250	4042	5820	11.	1.0E-11	540	1741	1130	1319
81	1423	1643	1448		10018	1953	6165	2297	267	3960	3960	10.	7.9E-11	280	1687	1546	436
82	1270	3242	9540		14872	3059	12341	3409	405	3014	4810	11.	1.0E-11	722	2147	869	635
83	1466	5111	2253		5943	1771	8192	3502	388	2901	3920	10.	1.3E-11	660	1151	521	813
84	1386	3654	1341		9966	2097	4333	2621	329	3217	5380	9.6	2.5E-10	340	891	424	875
85	1469	13474	1144		16124	2788	4011	3975	347	4016	5162	11.	7.9E-12	620	1489	356	671
86	1342	11976	1355		35569	2123	6376	4848	563	4682	5350	9.9	1.3E-10	770	1277	9911	784
87	1758	6274	1817		8904	2437	3636	3202	277	3653	4370	10.	4.0E-11	310	1972	702	1074
88	1574	7049	1969		42301	2795	3042	4946	454	6001	7340	10.	3.2E-11	481	2176	4572	684
89	1912	6957	1500		34760	3652	7146	6175	287	5700	7184	11.	1.0E-11	600	2115	1923	589

	EFFLUENT GRAB SAMPLE ANALYSES FOR EACH STREAM									E7 Composite Sample					CPV TOC ANALYSES (mg/L)		
	Wetmill	TOC Analyses - Starch Derivatives Production (mg/L)						TOC (mg/l)	Conductivity (mS/m)	mg/L	mg/L		mol/L	mg/L	Steep Liquor	Acid Glucose	Enzyme Glucose
Day	E1	E2T	E2V	E3	E4	E5	E6	E7 (Combined Streams)		TOC	COD	pH	$[H^+]$	SS			
90	2315	5450	1399		7647	2168	6472	3840	262	5158	6516	10.	6.3E-11	660	1628	457	904
91	1506	5653	2198		6318	1935	3230	2460	328	2551	3110	9.0	1.0E-09	560	985	531	618
92	1579	11792	2384		14953	2257	4028	3732	511	3817	4977	10.	2.0E-11	672	1552	450	653
93	1379	14249	3598		7152	2966	4201	3495	234	5620	8001	10.	4.0E-11	2541	1867	744	762
94	1753	10302	2527		36928	3346	7245	5932	362	11065	13400	9.9	1.3E-10	801	1335	1093	626
95	1685	5657	3704		8838	6408	8025	5420	333	8332	8880	10.	2.5E-11	958	1018	637	1165
96	2895	7936	32493		24762	7702	11593	10289	540	10485	12480	10.	2.0E-11	1884	983	152	1344
97	2286	21369	2601		17947	4882	9851	7936	230	14610	17145	10.	5.0E-11	1040	2005	1750	3008
98	2480	16025	2128		18400	4050	10467	6258	447	11007	14260	11.	6.3E-12	890	1728	956	1490
99	1666	4918	1047		10392	2662	7305	3380	1040	6351	9527	6.2	6.3E-07	400	1744	2203	797
100	1664	30051	3511		62301	4070	3731	7412	439	7808	9670	9.8	1.6E-10	561	1578	1404	754
101	2209	21956	2819			3639	7879	4443	648	5816	7710	8.3	5.0E-09	1354	1561	1186	893
102	2764	10157	2539		9576	1820	6257	3869	318	7463	8932	9.0	1.0E-09	494	1408	458	669
103	1437	7316	3030		7773	2660	11003	3860	121	3470	5372	9.7	2.0E-10	392	1443	341	300
104	1538	5475			20283	2088	9182	3932	186	5206	7025	8.4	4.0E-09	559	1383	1188	443
105	1134	3692			23055	1482	9240	2701	507	3886	4610	10.	1.3E-11	950	1721	503	737
106	800	11681	2518		8989	2726	8148	3515	243	4135	5869	10.	1.3E-11	687	2890	9689	781
107	653	9177	1266		5803	1990	4791	2566	348	3611	4287	9.1	7.9E-10	90	1704	453	410
108	1289	12159	1201		29061	6305	5814	6880	253	7724	9429	9.3	5.0E-10	220	1314	599	522
109	1336	11838	1228		23952	2708	3528	3563	365	6608	8160	9.6	2.5E-10	180	2164	1488	420
110	1453	45245	2405			2654	11354	9338	503	9771	10020	9.2	6.3E-10	1400	13018	209	1105
111	1989	8380	2835		110477	2913	14508	7975	857	13104	15060	10.	1.0E-10	900		747	926
112	1220	5863	883			1258	2744	2499	337	3018	3570	10.	3.2E-11	450	2278	8712	323
113	1140	13141	902		18846	6016	9768	6821	608	13549	16540	7.4	4.0E-08	2470	1921	27685	637
114	1775	18543	8256		36130	4486	17073	8153	610	12399	13420	10.	1.3E-11	610	1991	10296	1615
115	1298	25806	873			7278	10380	6716	520	10933	12920	9.6	2.5E-10	730	2636	8954	4142
116	2235	42629	2439		6817	5911	10598	8350	502	13773	16100	9.7	2.0E-10	1590	2584	6008	738
117	2279	27859	2277		11948	3771	13340	9539	495	14042	17540	10.	7.9E-11	1030	2527	1392	659
118	2708	21077	2351		7061	2495	12271	6608	775	8790	9353	9.5	3.2E-10	1750	2830	4553	463

	EFFLUENT GRAB SAMPLE ANALYSES FOR EACH STREAM									E7 Composite Sample					CPV TOC ANALYSES (mg/L)		
	Wetmill	TOC Analyses - Starch Derivatives Production (mg/L)						TOC (mg/l)	Conductivity (mS/m)	mg/L	mg/L		mol/L	mg/L	Steep Liquor	Acid Glucose	Enzyme Glucose
Day	E1	E2T	E2V	E3	E4	E5	E6	E7 (Combined Streams)		TOC	COD	pH	$[H^+]$	SS			
119	2103	18735	1512		57618	3666	19545	11673	572	6473	8951	10.	1.0E-10	1246		3719	255
120	1630	16393	1831		12707	4106	14791	8043	659	7756	9340	10.	1.0E-10	2306		1001	1382
121	1552	10325	743		4759	5751	6594	4900	880	4330	6090	9.9	1.3E-10	400	2586	556	2947
122	1318	11144	1965		26369	11014	14106	9168	212	9547	12280	10.	3.2E-11	429	2987	659	899
123	1734	3832	451		9634	4458	7263	4314	283	5860	7310	8.2	6.3E-09	485	3414	1666	851
124	1428	8377	639			4180	3823	3950	1203	4146	6270	9.7	2.0E-10	483	4065	783	865
125	1554	25674				2278	3200	3201	180	3139	3880	9.7	2.0E-10	420	1997	4333	764
126	1261	17890	7078		18240	2919	3449	3521	467	3233	4010	9.4	4.0E-10	514	1363	5678	1139
127	1418	17042	1881		21615	2415	6695	5060	222	6001	8380	8.8	1.6E-09	868	2554	1473	795
128	2110	15064	1277		13292	5686	8308	7866	465	5551	7290	9.5	3.2E-10	971	1742	19153	1330
129	1726	22466	1587		7808	4087	4377	7417	448	7697	9599	10.	7.9E-11	405	1838	1425	936
130	1435	12837	1020		4092	5861	5215	4948	313	4067	5230	10.	5.0E-11	452	2095	6209	731
131	1378	6526	861		4601	4072	4229	4136	527	4912	5960	9.1	7.9E-10	588	1951	1841	883
132	1630	4958	671		4760	5027	8411	5087	772	4562	6280	9.1	7.9E-10	761	1296	597	556
133	1528	5333	681		11766	6736	11933	5905	539	4984	6030	10.	7.9E-11	778	1639	1224	845
134	6425	6385	1298		3382	11534	37452	11505	353	13612	15870	9.6	2.5E-10	2247	2621	1398	2770
135	3208	6107	910	4959	5211	7983	20595	8893	563	10750	11460	7.2	6.3E-08	525		676	795
136	1908	20383				5964	6003	4334	302	3446	4120	8.7	2.0E-09	246	1341	777	1085
137	1499	21376	2799		24287	4639	6300	3394	647	3870	5020	8.8	1.6E-09	430	2716	6683	1199
138	1599	11718	7850		13343	5183	15543	5813	408	7652	8860	10.	2.5E-11	440	1921	2221	1563
139	3105	4781	1887		10581	12664	10146	8282	316	5286	6605	10.	1.3E-11	870		951	1274
140	1501	5280	819	19488	13996	7870	3682	4841	172	5956	9670	10.	1.3E-11	560	1661	539	870
141	1326	7090	991	12210	9093	4692	4604	4382	250	4403	5410	9.2	6.3E-10	240	1621	6058	940
142	1558	9166	2200	5100	17676	2722	11990	3913	212	3135	4040	11.	1.0E-11	350		1155	1253
143	1873	4902		5372	13073	1955	4812	2528	1426	2548	2990	10.	2.0E-11	850	1872	435	348
144	1327	3943	476	4005	36401	4173	3681	3524	264	3582	4340	10.	3.2E-11	320	1305	1139	532
145	629	5071	424	4254	20233	5806	4330	4262	414	4670	5218	9.9	1.3E-10	570	2155	330	410
146	962	7464	1901	15322	5496	3414	5241	3395	541	3826	4800	10.	1.0E-10	120	1947	395	521
147	1417	5671	3361	6324	19038	6589	18117	5612	170	8021	9860	10.	1.3E-11	150			

	EFFLUENT GRAB SAMPLE ANALYSES FOR EACH STREAM									E7 Composite Sample					CPV TOC ANALYSES (mg/L)		
	Wetmill	TOC Analyses - Starch Derivatives Production (mg/L)						TOC (mg/l)	Conductivity (mS/m)	mg/L	mg/L		mol/L	mg/L	Steep Liquor	Acid Glucose	Enzyme Glucose
Day	E1	E2T	E2V	E3	E4	E5	E6	E7 (Combined Streams)		TOC	COD	pH	$[H^+]$	SS			
148	1378	12243	2354	5032	24183	10156	19421	7967	447	8619	10774	9.9	1.3E-10	1205		11271	3987
149	1674	9283	1301	70834	8347	14984	38172	12810	440	12285	14620	9.5	3.2E-10	390	1445	5995	13170
150	1381	3448	1272		28711	3120	6386	5537	498	8461	9850	8.8	1.6E-09	490	2647	3646	648
151	1407	5232	1470		32538	5198	5396	5701	255	6642	7657	9.6	2.5E-10	360	3523	3520	1257
152	1430	9969	5463	5553		7535	8475	6494	229	5969	7040	9.1	7.9E-10	630	3256	1199	735
153	1654	13469	1028	9171	81769	6122	81751	11521	366	9260	11500	9.6	2.5E-10	420	4133	955	541
154	3555	9544	6215	6192	11358	3327	13038	5571	278	3985	5210	8.9	1.3E-09	490	3710	614	302
155	2082	11787	369	5209	23912	2766	18598	5845	333	9178	11580	9.2	6.3E-10	580	5756	4244	363
156	2075	25951	1328	46650	39417	2057	6527	5850	365	6676	8359	10.	5.0E-11	1862	5665	285	116
157	2258	8163	5012	60319	15804	5551	6026	7078	421	9721	11517	8.5	3.2E-09	1143	2295	526	339
158	1373	6026	1475	7935	19534	4707	9441	5986	903	7374	9752	10.	1.6E-11	1215	4165	659	3469
159	1448	6380	749	12860	11929	4280	7697	6548	448	6389	8860	10.	5.0E-11	686	2372	784	414
160	1722	4902	673	12399	4115	3428	6204	3942	417	4174	6710	8.5	3.2E-09	560	2845	547	338
161	1271	30781	1442	24321	13960	6403	24781	7885	607	7198	8930	8.5	3.2E-09	856	3137	7315	613
162	971	28986	2150	8505	16280	2246	4200	7519	450	6363	8160	9.1	7.9E-10	511	2610	429	476
163	991	10664	1545	5848	14672	1700	2200	3029	309	3620	4061	8.6	2.5E-09	290	2550	13113	747
164	816	7597	2542	6285	23677	6116	3099	4618	490	3886	4380	8.1	7.9E-09	100	1842	1333	352
165	913	4043	856	5623	8529	2682	6268	2784	113	2591	3090	9.5	3.2E-10	327	1923	420	432
166	959	7744	1401	5731	26103	2453	10233	4293	443	4987	5680	10.	4.0E-11	563	3050	5038	440
167	905	8558	495	6434	28665	4270	4270	4334	338	4816	5040	10.	3.2E-11	220	2286	446	521
168	996	6977	424	9692	16263	5796	14124	6548	444	6891	8480	9.9	1.3E-10	140	3065	582	2163
169	1442	11913	855	51329	29493	2481	74983	6136	253	6342	7010	9.6	2.5E-10	190	4240	561	1674
170	1677	11145	971	9252	17576	2573	41999	5268	264	6600	8274	9.6	2.5E-10	1120	4341	13030	491
171	2011	9243	2220	5875	35162	4689	32445	10063	452	9999	12400	9.6	2.5E-10	690	4335	2226	480
172	1542	15116	2423	12931	34545	2391	29823	11266	284	14573	19147	9.9	1.3E-10	390	3400	6599	611
173	2464	16132	1495	69618	57362	5482	15047	11723	519	21189	23893	8.6	2.5E-09	420	4093	19147	1115
174	1988	31787	1623	145485	30104	10866	26595	11779	425	10971	12827	10.	7.9E-11	591	3916	4678	1079
176	1146	16088	1541	16822	6323	3049	27268	6022	284	8743	9967	9.5	3.2E-10	942		8068	1583

	EFFLUENT GRAB SAMPLE ANALYSES FOR EACH STREAM									E7 Composite Sample					CPV TOC ANALYSES (mg/L)		
	Wetmill	TOC Analyses - Starch Derivatives Production (mg/L)						TOC (mg/l)	Conductivity (mS/m)	mg/L	mg/L		mol/L	mg/L	Steep Liquor	Acid Glucose	Enzyme Glucose
Day	E1	E2T	E2V	E3	E4	E5	E6	E7 (Combined Streams)		TOC	COD	pH	$[H^+]$	SS			
177	1817	13682	4096	106931	15436	5744	32907	8408	346	11257	12383	5.1	7.9E-06	323	3911	2378	1648
178	1924	7745	3135	79035	41113	3621	24576	6977	221	10028	11930	7.7	2.0E-08	480	2947	1133	1014
179	1591	3587	916	20348	8965	2344	22329	3281	1157	3987	4746	9.3	5.6E-10	160		546	899
180	2542	5219	2281	11183	17423	3830	50166	5715	386	8901	9660	8.3	5.0E-09	855	4233	5548	1577
181	2754	6129	951	10132	14685	4164	55100	7559	1611	8197	9697	8.3	5.0E-09	1160	3203	8829	1693
182	2101	8124	3141	31094	16414	5256	36479	6901	290	9574	11010	7.7	2.0E-08	100	2465	1698	1786
183	2444	8773	2329	6837	13247	2540	28369	5661	706	5089	6250	9.8	1.6E-10	550	2917	9716	827
184	2036	21832	997	15086	4051	3290	16214	5363	247	7148	8720	10.	5.0E-11	463	3637	1244	1608
185	1987	10684	3096	10963	5205	2445	4227	4309	304	3801	4610	9.5	3.2E-10	561	3510	670	577
186	2046	10157	6238	12474	10554	7821	11981	6526	477	9329	11660	9.9	1.3E-10	596	2089	620	747
187	1753	12908	7414	10734	9923	12162	8269	8116	183	9148	11100	8.6	2.5E-09	740	2908	1013	975
188	2545	20182	3073	25063	31016	3991	65423	12739	488	16160	19798	10.	1.6E-11	598	3935	1406	1452
189	2521	19428	2473	18025	28795	5394	8724	8129	240	8552	11433	9.2	6.3E-10	1010	4922	1031	940
190	2700	14316	1908	11404	21036	7688	9644	6827	517	9004	9870	10.	3.2E-11	766	4653	1150	1265
191	2935	13176	1505	10777	48651	4593	43977	8702	658	9316	11240	9.1	7.9E-10	220	3592	2075	1055
192	2138	11962	2994	7879	20982	3672	1688	4503	221	5081	6400	9.7	2.0E-10	100	1944	2497	1949
193	2336	6415	1767	10609	3852	2781	3974	2981	321	2707	3830	8.7	2.0E-09	140	1004	7103	827
194	2007	7198	1977	5028	14909	4496	3415	3811	729	3816	4150	9.5	3.2E-10	210		5199	2275
195	2259	12327	1444	5290	9765	4696	2268	4740	363	5660	6242	9.7	2.0E-10	200	6582	1408	4551
196	2099	7620	1434	6808	8655	5710	9110	7248	477	5576	6710	10.	7.9E-11	204	5673	3185	2082

	EFFLUENT GRAB SAMPLE ANALYSES FOR EACH STREAM									E7 Composite Sample					CPV TOC ANALYSES (mg/L)		
	Wetmill	TOC Analyses - Starch Derivatives Production (mg/L)						TOC (mg/l)	Conductivity (mS/m)	mg/L	mg/L		mol/L	mg/L	Steep Liquor	Acid Glucose	Enzyme Glucose
Day	E1	E2T	E2V	E3	E4	E5	E6	E7 (Combined Streams)		TOC	COD	pH	[H$^+$]	SS			
197	2225	1123	1331	5532	3433	4893	5305	4219	223	7006	7874	9.2	6.3E-10	510	2016	1069	1152
198	2099	8914	2075	3038	27195	4718	6627	6086	406	6423	7103	9.2	6.3E-10	854	771	817	967
199	4297	1198	1205	6313	10996	7398	6436	5734	634	5561	5657	8.6	2.5E-09	260	2674	2317	932
200	2516	1359	3882	6250	31909	5673	4748	4453	586	4535	4800	9.2	6.3E-10	930	2192	818	1103
201	1530	9254	7994	4365	1295	6124	12866	6343	290	8982	10740	8.6	2.5E-09	100	1939	636	766
202	1976	4977	1153	5525	16614	4168	6328	5211	451	4717	6043	8.9	1.3E-09	174	2393	778	853
203	703	7155	331	2737	8785	3690	4718	3132	277	5201	5893	9.4	4.0E-10	570		331	389
204	988	1488	499	20629	12266	2536	5122	4672	444	3774	5137	10.	3.2E-11	620	1148	826	405
205	1607	3519	3938	19683	17444	2304	7424	5588	344	5672	7130	9.8	1.6E-10	1250	1055	1103	825
206	951	7045	1265	3400	14951	4264	4214	3209	193	3240	3630	10.	2.0E-11	358	2146	535	767
207	1338	9978	1371		17771	5712	15672	6266	437	6978	9730	9.2	6.3E-10	200	1052	351	1225
208	864	8293	870	6341	7726	2051	4811	2837	156	4216	6000	10.	1.3E-11	900	1028	1725	331
209	1934	5767	784	1061	5073	4287	12587	6643	402	7770	9630	8.7	2.0E-09	1980	568	309	619
210	1782	1326	865	2235	6868	5220	6515	5141	270	8584	10640	11.	4.0E-12	190	8957	10368	6562
211	1618	1355	860	18612	18483	4726	13740	7375	274	8312	11570	9.9	1.3E-10	540	1391	2436	1889
212	1209	3396	1805	16515	32814	5270	4036	5074	437	7209	9110	10.	1.0E-10	517	1227	974	781
213	1175	3913	735	13075	21226	3252	3794	3635	430	3406	5220	9.8	1.6E-10	580	986	646	811
214	1116	3863	696	16462	45860	2450	1590	3523	485	3338	4360	8.4	4.0E-09	370	983	398	603
215	6507	4238	884	13778	22700	2777	46372	8804	462	7531	9740	8.2	6.3E-09	980	1673	608	764
216	1424	3277	728	12482	28106	2568	7778	3789	350	4971	6970	10.	1.0E-10	877	1964	1326	544
217	1358	7353	662	12575	14844	2927	2797	4151	430	4296	6010	10.	1.0E-10	583	1470	778	495
Mean	1690	9703	2590	17022	18129	4484	11846	5603	420	6363	7790	9.7	0.01844	635	2512	2995	1127
Max	6507	4524	3249	145485	110477	14984	81751	12810	1611	21189	23893	11.		2541	13018	27685	13170
Min	629	1078	331	1061	1295	1258	1590	2297	113	2128	2968	5.1		90	568	152	116
StDev	723	7204	2998	23926	14980	2372	11691	2187	217	3168	3695	1.0		461	1504	4151	1250
Number	212	212	204	78	203	212	212	213	180	170	170			170	156	168	167

TABLE E.3: GERMISTON PLANT WATER USAGE DATA

Day	Water Usage By Plant Sections					Total Domestic Usage	Total Process Usage	Total Site Water Usage
	Wetmill	Starch Plant	Glucose Manufacture	Steam Generation	Chemical Preparation			
1	832	32	1142	418	218	0	2642	4648
2	1137	40	704	43	127	0	3932	3932
3	0	2	290		0	0	584	584
4	0	0	210		0	0	420	420
5	317	8	337	527	108	25	1959	1984
6	0	3	1145	700	119	5	3115	3120
7	1067	54	1337	716	194	11	5826	5837
8	1188	49	736	718	138	8	4802	4810
9	1287	8	397	64	56	0	3504	3504
10	0	11	281		0	0	584	584
11	0	63	83	570	165	0	1027	1027
12	0	28	1285	680	144	27	3450	3477
13	1404	37	1258	798	98	11	6294	6305
14	1152	33	764	738	140	13	4776	4789
15	1196	70	985	782	106	16	5390	5406
16	1233	48	1127	798	70	0	5684	5684
17	1317	21	765	669	143	0	5018	5018
18	1057	28	1211	717	144	25	5453	5478
19	1212	54	960	589	137	9	5178	5187
20	752	29	1005	798	102	8	4472	4480
21	1256	79	675	761	137	9	4918	4927
22	1219	67	697	669	167	13	4802	4815
23	1149	34	872	722	110	0	4942	4942
24	1112	27	1046	696	177	0	5243	5243
25	1334	30	818	609	132	25	5105	5130
26	1155	39	1046	631	108	12	5219	5231
27	1165	34	913	571	99	13	4894	4907
28	1009	10	656	689	143	12	4182	4194
29	953	73	860	584	88	11	4444	4455
30	1023	41	683	612	126	0	4232	4232
31	971	73	934	619	132	0	4707	4707
32	815	65	949	690	146	27	4494	4521
33	881	46	1066	474	99	18	4559	4577
34	718	47	847	606	106	27	3936	3963
35	585	55	983	596	75	32	3917	3949
36	1195	83	834	805	107	32	3024	3056
37	781	40	1107	806	73	0	2807	2807
38	1046	27	702	608	151	0	2534	2534
39	1053	41	854	615	140	58	2703	2761
40	898	33	797	710	142	24	2580	2604
41	942	14	809	848	114	18	2727	2745
42	962	52	746			19	1760	1779
43	1	24	237	1530	212	9	2004	2013
44	1124	50	739	809	165	0	2887	2887
45	1045	87	628	682	146	0	2588	2588
46	1038	17	549	787	164	35	2555	2590
47	1060	74	641	706	167	14	2648	2662
48	867	90	1050	751	185	14	2943	2957
49	977	32	1015	771	162	11	2957	2968
50	956	181	655	818	162	17	2772	2789
51	1065	70	948	741	137	0	2961	2961
52	1035	55	707	738	110	0	2645	2645
53	899	55	829	774	180	39	2737	2776

Day	**Water Usage By Plant Sections**					**Total Domestic Usage**	**Total Process Usage**	**Total Site Water Usage**
	Wetmill	**Starch Plant**	**Glucose Manufacture**	**Steam Generation**	**Chemical Preparation**			
54	684	46	1138	868	156	16	2892	2908
55	1257	64	1147	783	147	12	3398	3410
56	932	39	1431	742	130	19	3274	3293
57	770	28	819	797	119	12	2533	2545
58	963	42	933	721	158	0	2817	2817
59	1019	19	993	737	132	0	2900	2900
60	956	58	858	743	125	32	2740	2772
61	938	67	1079	749	138	9	2971	2980
62	1095	3	724	524	122	16	2468	2484
63	963	1	881	625	106	10	2576	2586
64	1187	2	977	790	96	15	3052	3067
65	1087	0	701	766	127	0	2681	2681
66	1141	0	633	745	109	0	2628	2628
67	1013	3	720	745	109	34	2590	2624
68	1575	139	727	651	153	13	3245	3258
69	1088	36	898	712	99	15	2833	2848
70	975	51	1056	789	156	15	3027	3042
71	1096	23	647	722	75	21	2563	2584
72	891	49	802	668	107	0	2517	2517
73	887	78	923	712	125	0	2725	2725
74	994	69	916	698	171	22	2848	2870
75	973	64	974	696	154	9	2861	2870
76	999	41	963	767	146	9	2916	2925
77	0	30	207	103	33	5	373	378
78	965	33	969	561	152	13	2680	2693
79	977	32	958	551	184	0	2702	2702
80	514	55	743	475	298	0	2085	2085
81	1351	37	880	578		54	2846	2900
82	884	38	1187	585	155	12	2849	2861
83	925	33	1102	586	162	11	2808	2819
84	734	21	987	578	137	17	2457	2474
85	479	46	1024	495	191	12	2235	2247
86	873	20	883	566	218	0	2560	2560
87	1006	0	1014	537	131	0	2688	2688
88	928	53	1145	464	193	35	2783	2818
89	904	27	1028	516	170	16	2645	2661
90	717	57	856	500	144	0	2274	2274
91	962	36	1146	545	118	24	2807	2831
92	626	95	1028	526	173	13	2448	2461
93	695	96	753	486	128	0	2158	2158
94	637	20	803	534	84	0	2078	2078
95	699	35	864	959	279	33	2836	2869
96	207	52	1043	486	217	15	2005	2020
97	628	66	1162	514	181	15	2551	2566
98	612	58	1048	552	80	13	2350	2363
99	714	73	942	658	96	15	2483	2498
100	685	39	866	488	122	0	2200	2200
101	679	81	962	550	102	0	2374	2374
102	735	64	955	485	110	43	2349	2392
103	759	88	759	1637	115	15	3358	3373
104	679	69	706	487	108	14	2049	2063
105	299	53	978	588	179	9	2097	2106
106	184	48	1098	678	166	0	2174	2174
107	2801	25	1024	533	140	0	4523	4523
108	762	11	887	504	110	0	2274	2274
109	737	78	1096	475	180	0	2566	2566

Day	**Water Usage By Plant Sections**					**Total Domestic Usage**	**Total Process Usage**	**Total Site Water Usage**
	Wetmill	**Starch Plant**	**Glucose Manufacture**	**Steam Generation**	**Chemical Preparation**			
110	623	70	977	488	225	34	2383	2417
111	579	61	1111	459	131	9	2341	2350
112	626	82	807	447	228	12	2190	2202
113	627	77	767	450	159	12	2080	2092
114	556	38	1070	519	127	0	2310	2310
115	718	64	1043	569	210	0	2604	2604
116	817	72	1093	530	212	31	2724	2755
117	661	83	983	561	144	10	2432	2442
118	674	54	1016	225	97	20	2066	2086
119	0	36	655	492	133	17	1316	1333
120	616	19	903	631	129		2246	2246
121	629	54	1225	523	154	0	2585	2585
122	647	47	950	504	202	0	2350	2350
123	656	37	895	542	146	91	2276	2367
124	580	42	1037	559	132	13	2350	2363
125	623	49	887	465	148	13	2172	2185
126	523	55	947	461	145	11	2131	2142
127	494	66	1048	675	184	0	2467	2467
128	736	49	1059	627	181	0	2652	2652
129	539	106	1129	628	159	71	2561	2632
130	667	159	723	555	150	33	2254	2287
131	540	92	1379	552	120	33	2683	2716
132	608	69	1067	508	122	0	2374	2374
133	541	74	1122	452	191	5	2380	2385
134	186	44	1097	500	210	7	2037	2044
135	747	37	945	549	84	22	2362	2384
136	792	33	867	453	106	0	2251	2251
137	753	51	1033	442	81	11	2360	2371
138	645	34	1037	537	150	11	2403	2414
139	849	35	733	575	84	11	2276	2287
140	600	24	1100	544	124	20	2392	2412
141	535	37	1055	600	70	16	2297	2313
142	346	33	1048	452	91	0	1970	1970
143	374	49	934	546	95	0	1998	1998
144	552	65	1047	539	104	25	2307	2332
145	1814	58	964	565	106	0	3507	3507
146	365	39	1025	254	52	29	1735	1764
147	61	52	1036	739	142	8	2030	2038
148	357	5	713	672	136	11	1883	1894
149	883	37	1039	608	99	19	2666	2685
150	1618	4	1002	563	124	0	3311	3311
151	1046	36	728	593	119	32	2522	2554
152	843	12	1105	499	160	18	2619	2637
153	1552	64	865	554	139	15	3174	3189
154	973	36	830	547	164	14	2550	2564
155	1294	26	988	547	112	0	2967	2967
156	1224	47	995	656	98	0	3020	3020
157	666	63	1125	661	98	16	2613	2629
158	1167	51	891	616	142	25	2867	2892
159	1010	53	1269	547	124	10	3003	3013
160	1006	57	1177	603	146	0	2989	2989
161	1188	83	957	600	149	0	2977	2977
162	1040	97	1089	673	147	0	3046	3046
163	939	2	990	623	145	0	2699	2699
164	1030	32	981	1877	124	0	4044	4044
165	1049	74	1033	581	156	67	2893	2960

Day	Water Usage By Plant Sections					Total Domestic Usage	Total Process Usage	Total Site Water Usage
	Wetmill	Starch Plant	Glucose Manufacture	Steam Generation	Chemical Preparation			
166	807	22	1132	545	154	12	2660	2672
167	870	37	864	703	168	15	2642	2657
168	1322	97	940	654	108	15	3121	3136
169	988	59	977	579	129	16	2732	2748
170	975	38	763	526	136	0	2438	2438
171	1107	21	946	578	116	0	2768	2768
172	1058	22	875	534	125	0	2614	2614
173	888	55	1105	585	111	46	2744	2790
174	937	36	984	30	87	15	2074	2089
175	4	71	501	547	120	13	1243	1256
176	1045	23	759	608	79	16	2514	2530
177	1025	60	880	664	103	0	2732	2732
178	990	58	854	659	94	0	2655	2655
179	913	35	843	638	115	34	2544	2578
180	829	18	919	551	113	13	2430	2443
181	1109	49	842	625	105	9	2730	2739
182	1046	39	792	631	93	37	2601	2638
183	892	14	900	644	64	13	2514	2527
184	1206	35	777	668	91	0	2777	2777
185	1086	13	996	636	76	0	2807	2807
186	1082	39	745	603	95	47	2564	2611
187	754	22	810	665	104	13	2355	2368
188	1241	88	769	632	103	7	2833	2840
189	1065	45	1021	578	87	6	2796	2802
190	1145	42	655	573	119	6	2534	2540
191	1041	20	841	658	104	0	2664	2664
192	917	20	981	603	96	0	2617	2617
193	987	16	913	520	130	26	2566	2592
194	1078	81	841	609	132	8	2741	2749
195	1007	27	772	667	155	4	2628	2632
196	1018	29	907	517	107	12	2578	2590
197	1059	9	950	544	106	6	2668	2674
198	872	31	665	648	116	0	2332	2332
199	649	27	761	601	142	0	2180	2180
200	1654	50	835	557	110	12	3206	3218
201	1157	18	776	701	101	4	2753	2757
202	945	56	997	505	95	6	2598	2604
203	1223	32	923	521	137	11	2836	2847
204	1011	68	923	594	109	2	2705	2707
205	1012	40	1001	618	78	0	2749	2749
206	956	11	656	552	96	0	2271	2271
207	1026	38	738	525	93	10	2420	2430
208	1102	10	763	516	110	4	2501	2505
209	398	8	579	503	89	3	1577	1580
210	518	9	459	632	88	16	1706	1722
211	1276	57	846	707	126	5	3012	3017
212	1225	61	1134	711	105	0	3236	3236
213	1205	22	1085	659	116	0	3087	3087
214	1261	27	634	636	91	7	2649	2656
215	1347	19	871	516	63	5	2816	2821
216	755	36	785	566	70	4	2212	2216
217	1181	38	975	598	108	5	2900	2905
TOTAL	**190328**	**9677**	**194808**	**131260**	**27665**	**2595**	**612581**	**617182**

APPENDIX F

MEYERTON PLANT EFFLUENT CHARACTERISATION DATA

F.1: Meyerton Plant Corn Processing and Effluent Characterisation Data

F.2: Meyerton Plant Anaerobic Effluent Treatability Data

F.3: Meyerton Plant Water Usage Data

TABLE F.1: MEYERTON PLANT CORN PROCESSING AND EFFLUENT CHARACTERISATION DATA

DAY	GRIND (tonnes/d)	EFFLUENT COD_{total} ANALYSES (g/L)					Effluent Flowrate (m^3/d)							
		Acid-syrup	Starch	CPV	Wetmill	Storm-water	Acid-syrup	Starch	CPV	Wetmill	Storm-water	pH Neutralisation Basin	Digester	Total
1	112	14.5	3.1	1.5		0.9		113	54		25	251	30	192
2	170	222.2	7.2	1.5	2.1	5.6		50	23	93	58	368	33	224
3	143									86			37	86
4	167									91			40	91
5	240									135		40	44	135
6	191								140	144		62	51	284
7		34.1	2.6	1.4		1.3		133	24	15	92	771	55	264
8	112	97.2		4.4		6.9		123	117	96	104	635	64	440
9	104							100	246	100	201	885	60	647
10	165							31	81	83	121	352	74	316
11	239									135	2	136	84	137
12	252									135	23	114		158
13	245	41.6	1.4	1	5.9	17.8		122	144	131	128	593	89	525
14	258	8.8	0.8	2.3	3.8	8.9		50	109	135	183	620	95	477
15	255	14.3	0.8	5.2	2.7	20.3		56	186	95	190	943	94	527
16	253	100.8	1.3	2.4	9.6	1.8		222	182	97	137	718	99	638
17	170	28.3	2.3	2.2	10.5	3.2		211	198	95	174	778	105	678
18	145		1.4	4.7	1.1	1.8		127	232	97	179	990	108	635
19	39		1.1	3.7	12.4	2.2		109	204	60	172	959	108	545
20	27		1.1	2.1	18	3.4		138	87	117	165	569	119	507
21	189	195.9	3.9	3.3	1.4	6		130	268	117	43	799	129	558
22	145	80.2	2.5	2.1	14.1	3.8		141	208	133	47	654	133	529
23	185	20	4.9	1.4	5.9	3		180	253	96	41	733	57	570
24	232	27.9	0.9	0.9	2.2	4.5		96	227	137	55	373	140	515
25	232	10.3	2.7	1	2.5	2.8		138	277	96	43	564	158	554
26	91	38.8	1.9	0.7	4.7	7.7		79	230	80	69	644	163	458
27	280	175	1.8	1.6	14.6	21.8		128	158	129	49	688	69	464
28	184		1.7	2.2	3.5	6.7		123	297	107	16	659	49	543
29	230		1.7	1.3	19.2	7.4		150	285	151	34	684	133	620

		EFFLUENT COD_{total} ANALYSES (g/L)					Effluent Flowrate (m^3/d)							
DAY	GRIND (tonnes/d)	Acid-syrup	Starch	CPV	Wetmill	Storm-water	Acid-syrup	Starch	CPV	Wetmill	Storm-water	pH Neutralisation Basin	Digester	Total
30	260	152.4	2.7	1.6	5.8	3.7	3	137	226	128	33	638	181	527
31	241	28.1	2.4	1.5	2.7	5		259	115	130	73	402	195	577
32		69.4	1.3	3.5	3.4	4.2		120	260		145	1009	99	525
33		96.7	2.2	3.4	3	2.8	10	149	300		155	999	211	614
34		42.5	3.3	2.2	2.1	5.5	16	153	281		51	758	219	501
35		22.9	1.8	1.5	5.6	4.6	12	97	260		25	704	223	394
36	112	15.1	11	1	6.9	2.8	21	107	303		25	501	238	456
37	170	10	1.1	1.8	2.3	1.6	63	155	195	93	20	754	249	526
38	143	1.6	1.9	1.8	7.8	3.4	90	185	380	86	51	766	302	792
39	167	51.6	3.6	1.5	0.8	1.5	8	130	275	91	71	900	53	575
40	240	92.6	1.2	1.2	2.5	7.8	3	132	107	135	82	548	220	459
41	191	37.4		1.7	1.3	8.8	4	50	133	144	35	609	284	366
42		26.1	3.7	1.7	1.1	1.7	4	120	97	15	37	402	254	273
43	112						3	162	335	96	18	670	374	614
44	104	3.6	1	0.6	10.4	1.6	1	97	286	100	47	709	395	531
45	165	22.3	0.9	0.5	1.6	1.9	2	112	166	83	34	670	369	397
46	239	52.7	0.9	1.1	17.8	3.6	4	129	253	135	65	618	430	586
47	252	4.5	6.4	1.6	2.3	2	8	136	154	135	32	448	384	465
48	245	9.4	1.1	1	1.4	1.4	45	122	299	131	202	555	448	799
49	258	7.4	0.5	0.4	2.3		59	128	288	135	51	622	419	661
50	255	1.8	0.9	0.4	3	8.6	97	218	240	95	83	712	417	733
51	253	2.9	0.7	0.3	1.2	0.7	53	179	285	97	36	1019	420	650
52	170	2.7	1.3	0.7	1.9	6.5	50	103	265	95	35	661	478	548
53	145	1.4	1.6	0.5	4.9	4.3	50	169	295	97	30	601	436	641
54	39	0.8	5.1	0.3	1.2	1.9	44	77	302	60	40	801	440	523
55	27	4.1	2.4	0.2	1	1.1	110	138	115	117		696	480	480
56	189	10.9	2.1	0.3	1.2	0.8	38	119	265	117			321	539
57	145	3.2	2.6	0.8	1.1	0.9	54	292	189	133	120	1036	267	788
58	185	0.9	4.2	1.2			16	97	133	96	121	499	314	463
59	232	3.6	1.2	0.9	2.4	1.5	2	15	263	137	156	982	283	573
60	232	5.8	1	0.6	1.8	0.9	2	60	256	96	158	546	316	572
61	91	2.3	0.8	0.8	0.9	1.6	1	155	310	80	80	691	354	626
62	280	2.2	1.8	1.5	5.6	1.7	1	163	285	129		939	442	578

		EFFLUENT COD$_{total}$ ANALYSES (g/L)					Effluent Flowrate (m^3/d)							
DAY	GRIND (tonnes/d)	Acid-syrup	Starch	CPV	Wetmill	Storm-water	Acid-syrup	Starch	CPV	Wetmill	Storm-water	pH Neutralisation Basin	Digester	Total
63	**184**	**59.7**	**1.7**	**1.2**	**1**	**3.9**	**4**	**45**	**228**	**107**	**779**	**518**	**61**	**1163**
64	**230**			**0.6**	**0.8**	**1.7**	**14**	**134**	**113**	**151**		**521**		**412**
65	**260**	**5.4**	**1.3**	**0.7**	**3.4**	**3.8**	**30**	**202**	**268**	**128**	**819**	**642**		**1447**
66	**241**	**6.2**	**3.2**	**0.7**	**2.6**	**2.9**	**8**	**146**	**261**	**130**	**84**	**732**	**346**	**629**
67	**112**	**15.6**	**1.9**	**0.5**	**0.7**	**1.8**	**6**	**130**	**269**	**1**	**15**	**637**	**366**	**421**
68	**170**	**26.4**	**1**	**0.6**	**2.3**	**2.5**	**15**	**188**	**262**	**93**	**58**	**655**	**385**	**616**
69	**143**	**140.4**	**2**	**0.5**	**1.1**	**2.7**	**14**	**75**	**265**	**86**	**37**	**678**	**404**	**477**
70	**167**	**61.7**		**0.3**	**0.4**		**34**	**87**	**281**	**91**	**45**	**721**	**405**	**538**
71	**240**	**42.3**	**1.1**	**0.6**	**1.4**	**1.5**	**12**	**69**	**171**	**135**	**49**	**460**	**233**	**436**
72	**191**	**93**	**0.7**	**0.4**	**1.3**	**1.2**	**3**	**146**	**267**	**144**	**50**	**689**	**386**	**610**
73		**1.2**	**0.7**	**0.5**	**1.5**	**0.7**	**8**	**213**	**189**	**15**	**19**	**719**	**401**	**444**
74	**112**	**0.9**	**0.7**	**1**	**1.1**	**1**	**11**	**162**	**202**	**96**	**43**	**707**	**382**	**514**
75	**104**	**1.9**	**6.9**	**0.6**	**1.6**	**0.9**	**5**	**111**	**298**	**100**	**77**	**673**	**406**	**591**
76	**165**	**8.3**	**13.7**	**0.4**	**8.7**	**0.5**	**41**	**136**	**261**	**83**	**189**	**592**	**359**	**710**
77	**239**									**135**	**61**	**293**		**196**
78	**128.9**	**128.9**		**0.3**	**4.4**	**4.7**	**26**	**50**	**49**	**135**	**33**	**488**		**293**
79	**245**	**192.2**		**3.4**	**3.7**	**4.6**	**1**	**14**	**84**	**131**	**160**	**409**		**390**
80	**258**	**65.4**	**0.9**	**2.6**	**5.4**	**1.2**	**7**	**86**	**195**	**135**	**44**	**152**	**72**	**467**
81	**255**	**14.4**	**1.7**	**1.3**		**0.8**	**4**	**133**	**266**	**14**	**49**	**637**	**282**	**488**
82	**253**	**7.9**	**0.6**	**0.6**	**2.2**	**1.1**	**19**	**122**	**280**	**97**	**186**	**664**	**365**	**704**
83	**170**	**6.5**	**1**	**0.5**	**1.6**	**1.6**	**44**	**100**	**185**	**95**	**46**	**600**	**409**	**470**
84	**145**	**5.4**	**0.5**	**0.5**	**2.6**	**25.4**	**22**	**104**	**102**	**97**	**55**	**468**	**415**	**380**
85	**39**	**18.6**	**57.1**	**0.6**		**46.2**	**8**	**118**	**218**	**60**	**69**	**349**	**362**	**473**
86	**27**	**100.8**	**1.1**	**0.5**		**0.7**	**11**	**193**	**210**	**117**	**164**	**536**	**572**	**695**
87	**189**	**19.4**	**3.5**	**0.9**	**1.9**	**0.9**	**13**	**184**	**322**	**117**	**112**	**968**	**198**	**748**
88	**145**	**2.8**	**1.3**	**0.5**	**1.1**	**1.2**	**10**	**111**	**212**	**133**	**48**	**820**	**350**	**514**
89	**185**	**3.5**	**1.5**	**0.4**	**1.8**	**3.9**	**13**	**125**	**419**	**96**	**114**	**660**	**413**	**767**
90	**232**	**21.1**	**1.5**	**0.5**	**1.2**	**2.1**	**29**	**158**	**90**	**137**	**64**	**657**	**414**	**478**
91	**232**	**26.2**	**1.4**	**0.7**	**1.4**	**0.5**	**4**	**95**	**327**	**96**	**229**	**638**	**367**	**751**
92	**91**	**5.7**	**1**	**0.5**	**1.1**	**1.3**	**4**	**140**	**210**	**80**	**61**	**869**	**301**	**495**
93	**280**	**5.8**	**1.2**	**0.5**	**10**	**5.7**	**5**	**162**	**162**	**129**	**48**	**574**	**284**	**506**
94	**184**	**33.4**	**2.4**	**0.6**	**1.7**	**9.6**	**26**	**151**	**224**	**107**	**45**	**543**	**209**	**553**
95	**230**	**23.7**	**4.6**	**1.7**	**1.2**	**10.1**	**18**	**129**	**253**	**151**	**113**	**749**	**394**	**664**

		EFFLUENT COD$_{total}$ ANALYSES (g/L)					Effluent Flowrate (m^3/d)							
DAY	GRIND (tonnes/d)	Acid-syrup	Starch	CPV	Wetmill	Storm-water	Acid-syrup	Starch	CPV	Wetmill	Storm-water	pH Neutralisation Basin	Digester	Total
96	112	47	6.8	0.7	1.2	1.2	20	142	284	69	51	570	312	566
97	170	95.2		0.9	1.2	1.6	20	23	167	32	58	429	235	300
98	143	63.3	0.9	0.7	1.7	1	11	35	158	86	115	469	285	405
99	167	41.4	1.1	0.8	0.8	1.3	6	91	35	91	115	615	243	338
100	240	17	0.9	0.4	1.1	1.5	4	116	274	135	285	598	354	814
101	191	9.1	1.8	0.3	0.9	1.9	8	92	170	144	220	1093	412	634
102		10.8	2.2	0.4		1	1	110	321	15	123	700	160	570
103	112	1.8	1.2	0.5	1.5	1.2	11	196	262	96	110	680	131	675
104	104	106.7	2.4	0.8	0.6	1.2	12	143	269	100	86	643	501	610
105	165	37.2		0.6	0.7	1.5	11	46	109	83	87	525	367	336
106	239	37.4	3.5	0.6	0.7		15	59	294	135	114	800	406	617
107	252	49.9	1.6	0.6	1	8.4	14	146	314	135	135	782	421	744
108	245	64.4	1.1	0.4	1.2	2.3	8	143	282	131	54	748	48	618
109	258	115.3	0.8	0.4	2.3		8	138	255	135	59	818	347	595
110	255	75.9	0.7	0.4	6.1	1.6	1	143	359	95	60	795	402	658
111	253	41.6	1.2	0.5	2.2		6	126	268	97	62	766	406	559
112	170	9.1	1.5	0.8	6.2		3	99	248	95	78	755	395	523
113	145	12.7	2.1	0.4	0.6	2.1	55	79	143	97	59	621	284	433
114	39	90.3	4	1.7	5.1	3	4	18		60				82
115	27	46.7	1.6	1.5	2	1	94	49	104	117	181	751	224	545
116	189	42.9	1.6	1.6	3.3		54	49	249	117	181	631	141	650
117	145	47.6	1	1.1	2.7	8.8	46	226	186	133	109	767	398	700
118	185	20.8	1.1	0.6	2.7		49	79	215	96	36	550	228	475
119	232	2.9	1.1	0.5	1.9		36	79	285	137	70	694	313	607
120	232	2.7	1.8	0.7	2.8	4.7	32	106	32	96	47	437	202	313
121	91	31.1	0.8	0.8	3.3	3.7	4	69	144	80	92	539	266	389
122	280	86.5	1.8	0.7	1.3	1.7	13	141	208	129	130	636	400	621
123	184	73.2	1.1	0.5	1.6	14.5	11	192	216	107	92	612	310	618
124	230	37.5	0.8	0.4	1.6	3.9	8	156	123	151	144	913	353	582
125	260	7.3	0.5	0.7	1.8	2.3	4	52	220	128	152	630	362	556
126	241	22.5	3.9	1.4	2.1	2.7	11	159	256	130	125	508	330	681
127	21	24.6	1.3	0.6	1.4	2.8		122	142	70	41	472	10	375
128			1	0.6		1.9	1	115	244	46	35	505	351	441
129	70	11.2		0.5		1.4	5	59	238	145	64	273	121	511

		EFFLUENT COD$_{total}$ ANALYSES (g/L)					Effluent Flowrate (m^3/d)							
DAY	GRIND (tonnes/d)	Acid-syrup	Starch	CPV	Wetmill	Storm-water	Acid-syrup	Starch	CPV	Wetmill	Storm-water	pH Neutralisation Basin	Digester	Total
130	222	10.9		0.7		5.4	10	32	72	67	112	551	225	293
131	101	7.5	1.4	0.7	1.3	14.3		154	224	70	34	344	128	482
132	86		1.1	2.2	4.8	3.3	5	54	199	86	23	426	144	367
133	260		1.8	1.3	2.6	30.5	4	51	172	81	130	353	141	438
134	100	17		1.8	1.9	6.1	5	69	144	50	80	454	176	348
135	240	5.9	1.1	0.8	2.4	4.8	2	46	38	17	58	241	81	161
136	147	8.7	1.1	0.8	7.7	10.1	63	4	195	17	97	240	100	376
137		27.1	1.2	0.8	22.9	6.7	313	164	230	0	30	494	159	737
138	168	17.8	2.4	0.9	3.7	1.9	7	123	166	74	63	376	232	433
139	183			0.5	12.2	5.1	3	34	160	122	65	352	257	384
140	227	4.8	12.3	0.5	1.6	1.9	12	37	221	60	86	465	333	416
141	25	7.3	0.9	18.2	1.6	8	15	85	172	122	71	399	275	465
142	135	13.7		16.4	2	66.4	24	43	238	63	91	256	140	459
143	243	21.9	1.1	9.8	7.2	40	71		252	145	67	496	364	535
144	255	2.2	1.1	1.9	1.5	4.7	62	109	241	136	78	427	247	626
145	211	3.5	1.8	1.7	1.5		73	143	230	129	58	497	400	633
146		5.1		1.1	1.4	1.3	21	76	91	59	53	443	251	300
147	203	6.1	0.4	1.4	17.9	2.5	8	19	176	106	159	623	406	468
148	175	4.8	0.6	1.2	1.4	2.8	8	87	223	127	10	205	49	455
149		1.5	0.8	0.6			62	189	280	41		731		572
150	151	0.5	0.7	3.8	2.7		186	192	85	79		647		542
151	262	46.2	0.5	5.8	19.8		30	126	119	109		443		384
152	86	58.3	0.9	2.2	2.5		17	119	276	78	175	722	186	665
153	103	54.5	4.9	1.8		29.4	10	145	190	84	112	458	189	541
154	190	72.1	1.3	1.7	2.5	44.4	8	74	235	138	158	594	185	613
155	202	51	1.3	0.9	5.7	8.1		99	361	117	156	704	230	733
156	228	56.8	1.1	0.7	8.6	12.8	18	143	287	90	91	633	237	629
157	194	23.7	0.8	0.6	25.8	20.1	2	150	243	125	128	662	233	648
158	196		4.1	0.7	3.5	5.5	1	135	269	89	83	556	234	577
159	163	14.2	0.8	0.6	4.1	1.8	21	115	284	97	84	713	239	601
160	145	22.5	4	0.8	5.5	10.8	3	109	261		89	613	262	462
161	37	118.2		0.6		2.2	33	11	195	39	109	468	164	387
162	185	43.2	0.9	0.6	2.8	2.2	7	122	191	109	169	667	167	598
163	48	45	2.3	1.0	4.4	7.2	31	158	226	115	74	633	116	604

		EFFLUENT COD_{total} ANALYSES (g/L)					Effluent Flowrate (m^3/d)							
DAY	GRIND (tonnes/d)	Acid-syrup	Starch	CPV	Wetmill	Storm-water	Acid-syrup	Starch	CPV	Wetmill	Storm-water	pH Neutralisation Basin	Digester	Total
164	**162**	**6.9**	**1.3**	**0.7**	**10.4**	**2.9**	**104**	**199**	**265**	**24**	**112**	**653**	**144**	**704**
165	**258**	**34.2**	**1.1**	**0.8**	**12.5**	**14.1**	**9**	**172**	**268**	**86**	**79**	**637**	**126**	**614**
166	**202**	**16.8**	**0.8**	**0.8**	**7.9**	**3.1**	**11**	**79**	**256**	**61**	**112**	**556**	**136**	**519**
167	**195**	**36.3**		**0.5**	**2.3**	**1.6**	**12**	**98**	**173**	**106**	**168**	**695**	**204**	**557**
168	**27**	**19.5**	**3.2**	**0.5**	**2.2**	**0.9**	**3**	**130**	**102**	**78**	**74**	**459**	**175**	**387**
169	**90**	**30.8**	**0.6**	**0.6**	**1.9**	**2.2**	**3**	**95**	**84**	**76**	**71**	**383**	**16**	**329**
170	**245**		**1.6**	**0.4**	**1.6**	**2.8**		**124**	**107**	**159**	**188**	**691**	**138**	**578**
171				**0.7**	**3.9**	**1.9**	**15**	**163**	**129**	**43**	**137**	**595**	**140**	**487**
172		**55.7**	**1.4**	**0.6**		**0.6**	**9**	**112**	**235**	**1**	**43**	**575**	**111**	**400**
173	**163**	**78.3**	**7.8**	**0.6**	**0.4**	**1.9**	**14**	**168**	**233**	**118**	**91**	**596**	**117**	**624**
174	**243**		**0.6**	**0.4**	**1.4**	**1.4**	**2**	**159**	**146**	**114**	**103**	**620**	**140**	**524**
175	**219**	**11.6**	**3.5**	**0.7**	**2**	**2.2**	**1**	**110**	**273**	**114**	**62**	**598**	**87**	**560**
176	**225**	**2.6**	**0.9**	**0.4**	**3.9**	**3.7**	**26**	**94**	**270**	**105**	**44**	**579**	**140**	**539**
177	**223**	**0.4**	**1.1**	**0.5**	**3.3**	**2.3**	**137**	**124**	**290**	**108**	**44**	**796**	**143**	**703**
178	**138**	**0.3**	**0.9**	**0.2**	**46.4**	**2.5**	**208**	**181**	**294**	**65**	**61**	**862**	**181**	**809**
179	**186**	**1.1**	**0.7**	**0.2**	**4.9**	**5.6**	**235**	**170**	**238**	**101**	**60**	**886**	**189**	**804**
180	**81**	**65.5**	**2.8**	**0.4**	**1**	**1.8**	**91**	**151**	**169**	**73**	**43**	**502**	**185**	**527**
181			**1**	**0.4**		**1.7**	**5**	**134**	**143**	**23**	**52**	**497**	**191**	**357**
182	**229**	**45.8**	**0.6**	**1.1**	**1.8**	**1.6**	**20**	**124**	**162**	**102**	**17**	**483**	**149**	**425**
183	**214**	**38.1**	**1.4**	**2.2**	**1.4**	**12.9**	**5**	**105**	**236**	**140**	**36**	**561**	**220**	**522**
184		**24.5**	**1.1**	**1.7**	**1.1**	**13.1**	**12**	**134**	**267**	**24**		**572**	**151**	**437**
185	**162**	**32.7**	**1.1**	**1**	**1.8**	**2.8**	**2**	**88**	**240**	**92**	**60**	**599**	**189**	**482**
186	**260**	**50.2**	**0.8**	**0.4**	**5.9**	**2**	**4**	**197**	**277**	**139**		**657**	**187**	**617**
187	**198**	**6.5**	**0.6**	**0.3**	**4.5**	**1**	**14**	**191**	**256**	**66**	**112**	**674**	**187**	**639**
188	**265**	**54.9**	**1.1**	**0.4**	**4.3**	**1.3**	**7**	**164**	**235**	**100**		**464**	**160**	**506**
189	**257**		**1.6**	**0.5**	**18.7**	**0.5**	**4**	**85**	**252**	**103**		**439**	**152**	**444**
190	**90**	**6.3**	**0.7**	**0.3**	**1.7**	**7.2**	**3**	**141**	**95**	**118**	**146**	**582**	**185**	**503**
191		**10.1**	**1.9**	**0.4**		**5.1**	**3**	**168**	**324**	**14**	**54**	**522**	**191**	**563**
192	**195**	**11.8**	**2.7**	**0.5**	**0.3**	**6.1**	**2**	**120**	**248**	**81**	**89**	**548**	**183**	**540**
193	**260**	**76.7**	**0.7**	**0.3**	**1.5**	**29.1**	**5**	**140**	**232**	**89**	**62**	**543**	**189**	**528**
194	**220**	**96.5**	**1.9**	**1.2**	**4.5**	**2.1**	**3**	**124**	**156**	**90**	**50**	**488**	**186**	**423**
195	**131**	**51.5**	**3.1**	**2.2**	**1.8**	**2.3**	**6**	**71**	**71**	**85**	**48**	**423**	**163**	**281**
196	**200**	**19.6**	**1.3**	**0.8**	**23.8**	**1.7**	**3**	**149**	**45**	**97**	**70**	**500**	**186**	**364**
197	**204**		**1.9**	**1.2**	**1.6**	**0.5**	**4**	**203**	**2**	**87**	**93**	**544**	**190**	**389**

		EFFLUENT COD$_{total}$ ANALYSES (g/L)					**Effluent Flowrate (m^3/d)**							
DAY	GRIND (tonnes/d)	Acid-syrup	Starch	CPV	Wetmill	Storm-water	Acid-syrup	Starch	CPV	Wetmill	Storm-water	pH Neutralisation Basin	Digester	Total
198	**27**	**53.1**	**3.1**	**1.2**	**2.3**		**14**	**213**	**1**	**121**		**504**	**194**	**349**
199	**150**	**31.9**	**0.8**	**0.7**	**1.5**		**7**	**159**		**117**	**254**	**588**	**176**	**537**
200	**180**	**30.2**	**1.3**	**2.1**	**0.9**	**2.2**	**5**	**130**		**103**	**218**	**519**	**174**	**456**
201	**217**	**47.2**	**1**	**1.5**	**1.1**	**1.4**	**12**	**119**		**57**	**214**	**498**	**188**	**402**
202	**134**	**51.5**	**4**	**0.8**	**1.8**	**1.8**	**5**	**173**	**55**		**71**	**531**	**190**	**304**
203	**182**	**13.5**	**1.9**	**0.9**	**2.1**	**1.4**		**145**	**61**	**94**		**562**	**195**	**300**
204	**108**	**0.95**	**0.2**	**0.97**	**1.25**	**0.5**	**17**	**161**	**158**	**36**	**149**	**540**	**168**	**521**
205	**211**	**2.9**	**1.1**	**0.86**	**1.13**	**1.94**	**18**	**291**	**148**	**130**	**96**	**475**	**246**	**683**
206	**247**		**1.68**	**1.24**	**1.81**	**2.7**		**88**	**256**	**126**	**74**	**639**	**274**	**544**
207	**254**	**48**	**2.6**	**0.6**	**1.7**		**7**	**71**	**51**	**125**	**48**	**491**	**294**	**302**
208	**180**	**42**	**2.6**	**0.5**	**1.9**	**1.3**	**84**	**177**	**110**	**95**	**50**	**626**	**188**	**516**
209	**201**	**8.3**	**2.5**	**0.5**	**2.4**	**3.4**	**84**	**116**	**186**	**55**	**110**	**584**	**163**	**551**
210	**123**	**5.3**	**2.9**	**0.6**	**2.7**	**5.8**	**61**	**165**	**202**	**96**	**132**	**691**	**191**	**656**
211	**60**	**15.7**	**1.1**	**0.4**		**3.8**	**6**	**218**	**220**	**23**	**128**	**683**	**184**	**595**
212	**193**	**13.6**	**1.6**	**0.4**	**8.9**	**5.8**	**9**	**96**	**184**		**128**	**587**	**201**	**417**
213	**274**	**12.1**	**1.9**	**0.5**	**2**	**2.2**	**10**	**136**	**90**		**47**	**470**	**119**	**283**
214	**211**	**21.3**	**6.9**	**1**	**3**	**1.3**	**2**	**164**	**125**		**60**	**604**	**149**	**351**
215	**215**	**10.9**	**3.7**	**0.6**	**4.3**	**2.7**	**7**	**117**	**128**		**42**	**512**	**116**	**294**
216	**249**	**14.2**	**1.6**	**5**	**6.8**	**3.1**	**30**	**123**	**162**		**99**	**625**	**207**	**414**
217	**214**	**57.1**	**1.1**	**0.8**	**6.7**	**1.2**	**67**	**149**	**207**		**61**	**560**	**166**	**484**
TOTAL	**36034**						**4489**	**25727**	**42426**	**19808**	**18952**	**127344**	**47958**	**111424**
MEAN	**180**	**34.7**	**2.3**	**1.3**	**4.2**	**5.3**	**25**	**123**	**205**	**98**	**95**	**598**	**232**	**513**
MAX	**280**	**222.2**	**57.1**	**18.2**	**46.4**	**66.4**	**313**	**292**	**419**	**159**	**819**	**1093**	**572**	**1447**
MIN	**21**	**0.3**	**0.2**	**0.2**	**0.3**	**0.5**	**1**	**4**	**1**	**0**	**2**	**40**	**10**	**82**
STDEV	**67**	**39.2**	**4.4**	**1.9**	**5.6**	**8.4**	**41**	**51**	**80**	**35**	**89**	**178**	**121**	**165**

TABLE F.2: MEYERTON PLANT EFFLUENT ANAEROBIC TREATABILITY DATA

Effluent Discharge to Sewer					Anaerobic Digester Feed			Digester Effluent		Digester Performance		
Day	COD (mg/L)	pH	Vol (m^3/d)	SS (mg/L)	COD (mg/L)	pH	Vol (m^3/d)	COD (mg/L)	pH	% COD Reduction	OLR ($kgCOD/m^3.d$)	HRT (d)
1	8250	7.9			8490	8.2	37	206	7.2	97.6%	0.34	25
2	7750	7.7			7930	8.5	40	233	7.3	97.1%	0.34	23
3	7240	7.6			7750	7.7	44	254	7.2	96.7%	0.37	21
4	6770	8.3			7240	8.3	51	260	7.2	96.4%	0.40	18
5	6710	7.9			6770	8.3	55	195	7.3	97.1%	0.40	17
6	5250	6.8			6690		64	219	7.3	96.7%	0.46	15
11	7710	6.9			6950	7.2	89	235	7.3	96.6%	0.67	10
12					7550	7.8	95	566	7.3	92.5%	0.77	10
13	7430	6.8			4900	8.3	94	221	7.3	95.5%	0.50	10
14	5150	6.0			5530	9.5	99	196	7.4	96.5%	0.59	9
15	4430	6.9			5790	6.9	105	198	7.3	96.6%	0.65	9
16	3450	7.0			5350	9.3	108	267	7.3	95.0%	0.62	9
17	2700	7.0			3180	10	108	192	7.3	94.0%	0.37	9
18	3830	6.7			3870	7.0	119	197	7.3	94.9%	0.50	8
19	4920	7.0			6450	7.1	129	296	7.3	95.4%	0.90	7
20	5210	6.5			7610	8.0	133	147	7.3	98.1%	1.09	7
21					9710	8.2	57	176	7.3	98.2%	0.60	16
24	4910	7.0			4630	7.3	163	187	7.3	96.0%	0.81	6
25	17790	5.5			5970	6.7	69	196	7.4	96.7%	0.44	13
26	16700	5.3			14040	5.4	49	180	7.2	98.7%	0.74	19
27	7080	6.3			16700	6.6	133	215	7.2	98.7%	2.39	7
28	5690	6.5			9080	6.0	181	223	7.2	97.5%	1.77	5
29	3270	6.6			6230	8.1	195	218	7.2	96.5%	1.31	5
30	5550	6.2		376	5010	6.5	99	212	7.2	95.8%	0.53	9
31	4840	6.7			3820	6.6	211	205	7.2	94.6%	0.87	4
32	5630	6.6			3420	6.3	219	200	7.2	94.2%	0.81	4
33	4600	6.6			4770	6.0	223	177	7.1	96.3%	1.15	4
34	4580	6.3	501		8390	6.2	238	201	7.0	97.6%	2.15	4
35	2510	6.4	754		7050	5.8	249	203	7.0	97.1%	1.89	4
36	1780	6.8	766		8390	6.2	302	201	7.0	97.6%	2.73	3
37	4610	5.5	900		7050	5.8	53	203	7.0	97.1%	0.40	18
38	2460	7.0	548		1590	8.1	220	202	7.0	87.3%	0.38	4
39	3160	6.9	609		3460	6.9	284	219	7.1	93.7%	1.06	3
40	1480	7.1	402		4200	6.6	254	231	7.1	94.5%	1.15	4
43	2240	7.4	670		4980	6.8	369	270	7.2	94.6%	1.98	3
44	1070	7.5	618		4990	6.9	430	274	7.2	94.5%	2.31	2
45	770	7.7	448		3980	6.9	384	179	7.3	95.5%	1.65	2
46	710	7.5	555		3970	7.2	448	176	7.2	95.6%	1.91	2
47	970	7.4	622		4210	7.2	419	180	7.2	95.7%	1.90	2
48	1470	7.7	712		3530	6.5	417	162	7.3	95.4%	1.58	2
49	2710	7.2	1019		3530	6.3	420	101	7.1	97.1%	1.60	2
50	840	7.2	661		3470	6.5	478	188	7.1	94.6%	1.79	2
51	870	7.3	601		4170	6.5	436	174	7.0	95.8%	1.96	2
52	1790	7.2	801		3090	6.6	440	173	7.0	94.4%	1.46	2
53	700	7.1	696		3200	7.1	480	124	7.2	96.1%	1.65	2
56	990	6.3	499		3970	8.4	314	142	7.1	96.4%	1.34	3
57	2490	6.2	982		4210	7.1	283	158	7.3	96.2%	1.28	3
58	600	7.6	546		4640	7.1	316	189	7.3	95.9%	1.58	3
59	830	7.2	691		5120	8.0	354	168	7.4	96.7%	1.95	3
60	910	7.1	939		3080	7.0	442	109	7.4	96.5%	1.47	2
61	511	7.1	518		4210	7.3	61	101	7.3	97.6%	0.28	15
62	315	7.4	521		6560	7.5		104	7.3	98.4%		
63	780	7.3	642		6630	7.4		142	7.4	97.9%		
64	980	7.3	732		5860	7.3	346	112	7.4	98.1%	2.18	3
94	10830	7.7	570		5820	7.6	312	133	7.3	97.7%	1.95	3
95	3950	6.1	429		5400	9.7	235	153	7.3	97.2%	1.37	4
96	2840	6.1	469		6380	7.0	285	119	7.4	98.1%	1.96	3
97	2510	7.0	615		5940	7.7	243	137	7.3	97.7%	1.55	4
98	2010	6.5	598		3780	8.6	354	82	7.3	97.8%	1.44	3
99	1360	6.2	1093		3450	6.9	412	100	7.3	97.1%	1.53	2
100	2820	6.6	700		3540	7.1	160	104	7.4	97.1%	0.61	6
101	2120	6.3	680		4250	7.2	131	101	7.4	97.6%	0.60	7
103	2010	6.6	525		3400	6.7	367	92	7.1	97.3%	1.34	3

Effluent Discharge to Sewer					Anaerobic Digester Feed			Digester		Digester Performance		
Day	COD (mg/L)	pH	Vol (m^3/d)	SS (mg/L)	COD (mg/L)	pH	Vol (m^3/d)	COD (mg/L)	pH	% COD Reduction	OLR (kgCOD/m^3.d)	HRT (d)
111	1520	6.5	621		2420	6.8	284	90	7.2	96.3%	0.74	3
114	4310	5.65	631	150	5250	7.5	141	85	7.2	98.4%	0.80	7
115	4020	5.97	767	10	6110	5.2	398	118	7.1	98.1%	2.62	2
116	10160	6	550		6250	6.5	228	110	7.2	98.2%	1.53	4
117	4030	6.2	694	5	5820	7.1	313	177	7.2	97.0%	1.96	3
120	2200	6.63	636	5	7380	7.4	400	181	7.3	97.5%	3.18	2
121	1890	6.59	612	5	4550	7.9	310	159	7.4	96.5%	1.52	3
122	7410	7.04	913	5	4200	7.5	353	156	7.4	96.3%	1.60	3
123	2100	6.86	630	2	3070	7.9	362	148	7.4	95.2%	1.20	3
141	1820	7.35	496	5	5590	7.2	364	159	7.3	97.2%	2.19	3
142	2100	7.52	427	10	6290	7.5	247	243	7.3	96.1%	1.67	4
143	1712	7.52	497	2	9170	7.0	400	324	7.4	96.5%	3.95	2
144	890	7.5	443	15	5490	7.5	251	183	7.4	96.7%	1.48	4
145	1850	6.84	623	15	5240	7.0	406	164	7.4	96.9%	2.29	2
146	2200	6.9	205	30	4680	7.5	49	220	7.4	95.3%	0.25	19
160	8920	6.8	667		11360	9.9	167	237	7.1	97.9%	2.04	6
161	27290	9.63	633		19520	7.5	116	217	7.2	98.9%	2.44	8
162	8740	6.54	653		15930	9.8	144	169	7.0	98.9%	2.47	6
163	8520	6.5	637		7010	7.1	126	107	7.1	98.5%	0.95	7
164	7880	6.65	556		10250	7.2	136	100	7.1	99.0%	1.50	7
165	9800	7.68	695		12540	7.1	204	172	7.2	98.6%	2.75	5
166	9980	7.5	459		13280	9.6	175	107	7.3	99.2%	2.50	5
167	5820	7.2	383		16500	8.3		129	7.3	99.2%		
168	3940	7.31	691		12500	8.1	138	135	7.2	98.9%	1.86	7
169	4520	6.85	595		6960	9.4	140	192	7.2	97.2%	1.05	7
170	4460	6.9	575		7530	8.3	111	155	7.2	97.9%	0.90	8
171	4230	7.68	596		8720	8.2	117	145	7.1	98.3%	1.10	8
172	4940	6.5	620		7960	4.4	140	137	7.0	98.3%	1.20	7
173	4430	6.5	598		8620	7.3	87	139	7.0	98.4%	0.81	11
174	4250	6.55	579		7990	7.4	140	140	7.1	98.2%	1.20	7
175	1720	9.6	796		8420	7.4	143	180	7.3	97.9%	1.30	6
176	2250	7.9	862		8580	12.2	181	148	7.3	98.3%	1.67	5
177	1980	7.2	886		16400	9.7	189	153	7.3	99.1%	3.34	5
178	8020	7.26	502		6890	7.8	185	144	7.3	97.9%	1.37	5
179	5120	7.2	497		6070	7.2	191	139	7.2	97.7%	1.25	5
180	5770	6.15	483		7240	7.3	149	144	7.2	98.0%	1.16	6
181	4240	6.5	561		7880	12.1	220	161	7.1	98.0%	1.87	4
182	2980	6.75	572		7240	9.2	151	132	7.2	98.2%	1.18	6
183	3230	7.2	599		8820	8.5	189	141	7.2	98.4%	1.79	5
184	3260	7.3	657		7540	11.2	187	110	7.2	98.5%	1.52	5
185	4200	6.74	674		7640	10.2	187	123	7.2	98.4%	1.54	5
186	5200	6.6	464		9220	7.5	160	101	6.9	98.9%	1.59	6
187	2730	6.71	439		8520	7.6	152	120	7.1	98.6%	1.39	6
188	740	6.9	582		2350	11.5	185	101	7.2	95.7%	0.47	5
189	3730	6.5	522		2510	7.7	191	59	7.1	97.6%	0.52	5
190	3250	6.61	548		1930	8.2	183	74	7.1	96.2%	0.38	5
191	3550	6.8	543		4500	8.9	189	95	7.0	97.9%	0.92	5
192	4210	10.1	488		7250	8.8	186	106	6.7	98.5%	1.45	5
193	4080	7.6	423		5300	11.4	163	201	7.0	96.2%	0.93	6
194			500		11610	9.6	186	44	7.1	99.6%	2.32	5
195	6360	7.67	544		8590	11.6	190	56	7.1	99.3%	1.76	5
196	13110	6.03	504		3870	11.1	194	44	6.9	98.9%	0.81	5
197	3310	6.99	588		13470	11.4	176	38	6.8	99.7%	2.55	5
TOTAL			81560				36021	27801				
MEAN	3864	6.2	595	41	6211	6.4	222	149	7.2	97.2%	1.36	5.90
MAX	27290	10.1	1093	376	19520	12.3	501	566	7.4	99.7%	3.9	25.1
MIN	145	4.5	205	2	1590	4.4	37	25	6.7	87.3%	0.25	1.85
V	3490	0.7	159	88	3008	1.4	115	63	0.1	1.5%	0.70	4.33

TABLE F-3: MEYERTON PLANT WATER USAGE DATA

Day	Plant Sections				Total Process Use	Total Domestic Use	Total Usage
	Wetmill	Starch Plant	Acid Glucose	Steam Generation			
1	0.0	203	4	258	466	5.0	471
2	413.0	263	0	289	965	3.0	968
3	344.0	0	0	26	370	1.0	371
4	417.0	0	0	10	427	2.0	429
5	472.0	0	0	2	474	1.0	475
6	372.0	66	15	12	464	2.0	466
7	117.0	214	39	192	563	3.0	566
8	284.0	247	183	383	1097	2.0	1099
9	301.0	252	171	502	1226	3.0	1229
10	411.0	52	63	127	653	3.0	656
11	394.0	0	0	13	407	3.0	410
12	496.0	33	5	21	555	1.0	556
13	439.0	184	122	394	1139	4.0	1143
14	441.0	168	97	303	1009	3.0	1012
15	509.0	215	138	399	1261	5.0	1266
16	524.0	379	130	459	1492	7.0	1499
17	456.0	364	167	495	1482	9.0	1491
18	370.0	280	162	500	1312	3.0	1315
19	325.0	291	125	411	1153	4.0	1157
20	289.0	299	85	363	1036	7.0	1043
21	387.0	388	202	321	1298	4.0	1302
22	423.0	249	172	353	1197	5.0	1202
23	350.0	372	215	473	1410	4.0	1414
24	457.0	248	194	438	1337	3.0	1340
25	472.0	288	188	486	1434	4.0	1438
26	301.0	272	158	355	1086	5.0	1091
27	502.0	336	138	423	1399	9.0	1408
28	420.0	247	181	404	1252	8.0	1260
29	569.0	329	187	472	1556	5.0	1561
30	542.0	330	148	360	1379	6.0	1385
31	587.0	342	127	420	1476	2.0	1478
32	0.0	264	173	542	979	3.0	982
33	0.0	342	182	430	954	5.0	959
34	0.0	325	224	430	979	10.0	989
35	0.0	266	151	375	792	5.0	797
36		411	238	342	991	5.0	996
37	413.0	312	276	321	1322	4.0	1326
38	344.0	281	398	382	1405	4.0	1409
39	417.0	286	293		996	4.0	1000
40	472.0	243	148	310	1172	5.0	1177
41	372.0	176	184	348	1080	6.0	1086
42	117.0	278	159	350	904	3.0	907
43	284.0	301	232	300	1117	4.0	1121
44	301.0	280	248	416	1245	12.0	1257
45	411.0	281	178	427	1297	4.0	1301
46	463.0	172	210	442	1287	36.0	1323
47	414.0	239	171	373	1197	5.0	1202
48	439.0	242	231	443	1354	7.0	1361
49	441.0	271	223	391	1327	5.0	1332
50	509.0	348	258	351	1466	7.0	1473

Day	Plant Sections				Total Process Use	Total Domestic Use	Total Usage
	Wetmill	Starch Plant	Acid Glucose	Steam Generation			
51	524.0	288	259	450	1521	6.0	1527
52	456.0	329	219	445	1449	2.0	1451
53	370.0	470	224	410	1474	1.0	1475
54	325.0	287	234	413	1259	5.0	1264
55	289.0	290	141	421	1141	0.0	1141
56	387.0	251	224	457	1318	12.0	1330
57	423.0	247	217	258	1145	12.0	1157
58	350.0	281	169	272	1072	4.0	1076
59	457.0	204	188	465	1314	2.0	1316
60	472.0	275	204	487	1437	3.0	1440
61	301.0	239	192	481	1213	7.0	1220
62	502.0	266	182	409	1359	6.5	1366
63	420.0	210	198	338	1166	2.5	1169
64	569.0	265	199	407	1440	3.0	1443
65	542.0	339	237	460	1578	3.0	1581
66	587.0	225	195	452	1459	2.0	1461
67	515.0	224	165	485	1388		1388
68	494.0	396	185	468	1543	5.0	1548
69	199.0	177	182	354	912	11.0	923
70	394.0	321	213	428	1356	11.0	1367
71	401.0	335	180	360	1276	5.0	1281
72	497.0	373	228	441	1539	5.0	1544
73	227.0	335	180	397	1139	3.0	1142
74	280.0	333	192	426	1231	4.0	1235
75	339.0	282	252	408	1281	5.0	1286
76	9.0	265	258	235	766	3.0	769
77	26.0	129	8	73	236	14.0	250
78	411.0	256	108	268	1043	5.0	1048
79	481.0	164	176	324	1145	4.0	1149
80	181.0	140	222	272	815		815
81	107.0	199	221	345	872	554.0	1426
82	471.0	148	198	451	1268		1268
83	409.0	262	206	415	1292		1292
84	442.0	195	177	347	1161	316.0	1477
85	90.0	221	195	326	832		832
86	237.0	264	181	777	1459	3.0	1462
87	504.0	241	232	264	1241	4.0	1245
88	423.0	269	227	265	1184	7.0	1191
89	483.0	270	214	400	1367	4.0	1371
90	487.0	266	145	400	1298	4.0	1302
91	464.0	227	215	509	1415	5.0	1420
92	440.0	301	191	464	1395	6.0	1401
93	377.0	303	190	404	1274	4.0	1278
94	291.0	273	167	492	1223	3.0	1226
95	444.0	303	246	503	1497	3.0	1500
96	631.0	259	250	402	1542	3.0	1545
97	693.0	210	106	309	1318	4.0	1322
98	569.0	248	158	351	1326	4.0	1330
99	694.0	214	103	323	1334	53.0	1387
100	869.0	239	196	480	1784	4.0	1788
101	693.0	256	173	450	1572	5.0	1577
102	117.0	247	202	391	957	3.0	960
103	473.0	442	212	491	1618	5.0	1623
104	478.0	391	251	411	1530	6.0	1536
105	674.0	340	120	288	1422	2.0	1424

Day	Plant Sections				Total Process Use	Total Domestic Use	Total Usage
	Wetmill	Starch Plant	Acid Glucose	Steam Generation			
106	834.0	369	202	480	1885	4.0	1889
107	882.0	333	203	511	1929	4.0	1933
108	830.0	383	236	509	1958	3.0	1961
109	851.0	374	149	516	1890	2.0	1892
110	951.0	398	252	517	2118	4.0	2122
111	962.0	342	210	488	2002	3.0	2005
112	744.0	279	192	446	1661	6.0	1667
113	601.0	201	204	401	1407	5.0	1412
114	437.0	100	43	15	595	3.0	598
115	348.0	154	154	458	1114	3.0	1117
116	643.0	178	236	424	1481	7.0	1488
117	692.0	394	180	413	1679	4.0	1683
118	627.0	197	201	447	1472	5.0	1477
119	841.0	216	246	512	1815	6.0	1821
120	852.0	222	147	421	1642	6.0	1648
121	481.0	209	160	450	1300	13.0	1313
122	896.0	276	186	500	1857	4.0	1861
123	707.0	306	174	488	1675	6.0	1681
124	984.0	280	153	476	1893	17.0	1910
125	961.0	252	182	473	1868	4.0	1872
126	960.0	327	251	543	2081	5.0	2086
127	234.0	322	146	289	991	3.0	994
128	326.0	292	285	425	1328	306.0	1634
129	812.0	218	217	341	1588	2.0	1590
130	452.0	216	136	393	1197	0.0	1197
131	455.0	405	204	436	1500	5.0	1505
132	847.0	273	206	380	1707	2.0	1709
133	585.0	197	196	457	1435	6.0	1441
134	874.0	207	174	280	1535	4.0	1539
135	567.0	240	112	319	1238	5.0	1243
136	47.0	145	278	333	803	2.0	805
137	0.0	238	265	286	789	4.0	793
138	566.0	180	198	322	1266	6.0	1272
139	681.0	108	195	333	1317	8.0	1325
140	887.0	193	206	424	1710	7.0	1717
141	246.0	265	183	301	995	6.0	1001
142	538.0	172	217	384	1311	5.0	1316
143	875.0	260	204	486	1825	6.0	1831
144	899.0	322	213	522	1956	5.0	1961
145	970.0	348	208	491	2017	5.0	2022
146	158.0	224	132	264	778	8.0	786
147	802.0	222	174	402	1600	6.0	1606
148	780.0	303	193	366	1642	6.0	1648
149	691.0	311	275	394	1671	30.0	1701
150	416.0	347	295	361	1419	3.0	1422
151	590.0	227	305	416	1538	2.0	1540
152	535.0	310	198	409	1452	5.0	1457
153	464.0	260	102	289	1115	8.0	1123
154	843.0	173	162	403	1581	4.0	1585
155	709.0	213	257	464	1643	5.0	1648
156	890.0	253	234	479	1856	4.0	1860
157	817.0	191	187	425	1620	2.0	1622
158	801.0	398	186	372	1757	7.0	1764

Day	Plant Sections				Total Process Use	Total Domestic Use	Total Usage
	Wetmill	Starch Plant	Acid Glucose	Steam Generation			
159	671.0	289	215	413	1587	9.0	1596
160	693.0	299	87	368	1446	9.0	1455
161	276.0	107	265	198	846	9.0	855
162	673.0	234	119	369	1395	6.0	1401
163	340.0	263	173	321	1097	4.0	1101
164	514.0	315	203	426	1458	3.0	1461
165	790.0	392	165	477	1824	2.0	1826
166	799.0	331	210	448	1788	4.0	1792
167	840.0	242	175	382	1639	-8.0	1631
168	235.0	228	37	235	735	14.0	749
169	491.0	252	15	268	1026	3.0	1029
170	986.0	226	42	451	1705	10.0	1715
171	169.0	294	149	319	930	4.0	934
172	17.0	259	148	418	842	6.0	848
173	633.0	351	140	482	1606	7.0	1613
174	908.0	315	102	458	1783	5.0	1788
175	942.0	282	256	497	1977	6.0	1983
176	834.0	216	140	461	1651	5.0	1656
177	895.0	308	330	552	2085	4.0	2089
178	520.0	336	378	452	1686	5.0	1691
179	686.0	315	405	454	1859	12.0	1871
180	441.0	262	205	311	1219	5.0	1224
181	116.0	292	128	333	869	3.0	872
182	701.0	301	124	457	1583	4.0	1587
183	831.0	273	109	437	1650	8.0	1658
184	58.0	273	205	350	885	6.0	891
185	582.0	245	201	517	1546	2.0	1548
186	919.0	341	200	560	2020	3.0	2023
187	773.0	277	199	533	1782	12.0	1794
188	883.0	267	203	547	1900	5.0	1905
189	840.0	230	182	553	1805	9.0	1814
190	460.0	232	187	440	1319	4.0	1323
191	44.0	304	242	416	1006	4.0	1010
192	614.0	283	207	516	1619	3.0	1622
193	800.0	281	199	508	1789	7.0	1796
194	868.0	271	197	491	1827	5.0	1832
195	560.0	169	150	388	1267	4.0	1271
196	710.0	274	173	499	1657	4.0	1661
197	820.0	278	105	418	1621	7.0	1628
198	731.0	284	150	384	1549	3.0	1552
199	767.0	150	157	492	1566	1.0	1567
200	774.0	250	190	468	1682	4.0	1686
201	498.0	156	209	504	1367	15.0	1382
202	0.0	202	227	487	916	7.0	923
203	742.0	270	200	537	1749	11.0	1760
204	436.0	300	205	529	1471	7.0	1478
205	798.0	301	193	348	1640	2.0	1642
206	878.0	306	247	464	1895	2.0	1897
207	859.0	207	167	435	1668	3.0	1671
208	787.0	334	220	425	1766	9.0	1775
209	738.0	121	248	447	1554	4.0	1558
210	641.0	293	241	445	1621	4.0	1625
211	241.0	341	234	376	1192	5.0	1197
212	695.0	249	239	451	1634	5.0	1639
213	796.0	243	212	491	1742	3.0	1745
214	791.0	229	241	485	1746	8.0	1754
215	831.0	252	216	482	1781	14.0	1795
216	876.0	273	235	463	1847	507.0	2354
217	761.0	290	293	508	1852	2.0	1854
TOTAL	113782	56588	39994	86137	296501	2829	299330

APPENDIX G

ANAEROBIC EFFLUENT DIGESTION CALCULATIONS

G-1: Organic Mass Loading Rate Calculation (kgCOD/d)

Influent COD concentration (mg/L) and influent volumetric flowrate (m^3/d) were determined from sample analyses. From this calculation, a mass flow rate of COD or TOC into a system was determined using the following equation:

$$\textbf{Organic Mass Load}\ (\frac{\mathbf{kg}}{\mathbf{d}}) = \frac{\mathbf{C\times Q}}{\mathbf{1000}} \quad \textbf{(G.1)}$$

Where

C is the organic content concentration of the wastewater stream in terms of COD or TOC, in mg/L, and

Q is the volumetric flow rate of that stream into the same system in m^3/d.

G-2: Organic Volumetric Loading Rate Calculation (kgCOD/m^3.d)

To calculate the organic volumetric loading rate (OLR), the above determined mass flow rate in G-1 was divided by the volume of the reactor into which the wastewater stream was being fed. The equation below was used.

$$\mathbf{OLR} = \frac{\mathbf{CODin\times Q}}{\mathbf{1000\times V}} \quad \textbf{(G.2)}$$

Where

OLR is the amount of organics (COD or TOC or BOD) applied to the reactor volume per day, in kg/d.m^3, and

V is the effective reactor volume, in m^3.

The mean hydraulic retention time (HRT) was also calculated based on the volumetric flow (Q) and the effective digester volume (V). This is a measure of the time a volumetric unit of effluent was retained within the digestion volume, and was calculated using the following equation:

$$\mathbf{HRT}\ (\mathbf{days}) = \frac{\mathbf{V}}{\mathbf{Q}} \quad \textbf{(G.2.1)}$$

G-3: Percentage Organics Reduction Calculation

This was a used as a measure of the degree of treatability of the treated effluent at specific operating conditions in terms of temperature, pH and feed flowrate (Q). The organic content as a measure of concentration that was used for this study was COD in mg/L. Digester influent (CODin) and effluent COD (CODout) concentrations were determined, from which percentage COD reduction was evaluated using the equation below.

$$\%\mathbf{COD\ Removal} = \frac{\mathbf{CODin - CODout}}{\mathbf{CODin}} \times \mathbf{100\%} \qquad \textbf{(G.3)}$$

G-4: Estimation of Theoretical Biogas Generation (m^3/d)

At standard conditions (0^oC and 1 atmosphere), the amount of CH_4 produced per unit of COD biodegraded under anaerobic conditions, is estimated at 0.35 m^3/kg COD converted (Tchobanoglous et al. 2003). At other different temperature and pressure conditions, the volume of CH_4 produced is determined through the universal gas law, using the following equation:

$$\mathbf{V} = \frac{\mathbf{nRT}}{\mathbf{P}} \qquad \textbf{(G.4)}$$

Where

V is the volume occupied by the gas in L,

n is the number of moles of the gas in moles,

R is the universal gas law constant, equal to 0.082057 atm.L/mole.K,

T is the prevailing temperature in K, and

P is the absolute pressure in atmospheres.

During the course of this anaerobic treatability study, the digester temperature was maintained between 27 and 37 ^oC. This equated to an average digester temperature of 32^oC which was used in the calculations. Using the above equation (G.4), the CH_4 generation at 32 ^oC and 1 atmosphere pressure was estimated at 25.04L/mol.

By stoichiometry, the equivalent COD of CH_4 is defined as the amount of O_2 needed to oxidise CH_4 to CO_2 and H_2O (Tchobanoglous et al. 2003). This is illustrated in Equation G.5.

$$\mathbf{CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O} \qquad \textbf{(G.5)}$$

Based on equation G.5, Tchobanoglous et al (2003) determined that the equivalent COD of CH_4 is 64g COD/mole CH_4. At 32^oC, 0.85 atm and under anaerobic conditions, the CH_4 generation was therefore estimated at 0.46 m^3 CH_4/kg COD converted as follows:

$$\textbf{Expected CH}_4\textbf{ Generation Rate} = \frac{29.5\ \mathrm{L}\frac{\mathrm{CH_4}}{\mathrm{mole}}}{64\mathrm{gCOD/moleCH_4}} = \frac{0.46\ \mathrm{m^3}}{\mathrm{kgCOD}} \qquad \textbf{(G.6)}$$

To estimate the theoretical amount of CH_4 generated at prevailing conditions, equation 3.14 was used to calculate the portion of influent COD that is converted to methane (COD methane in kg/d):

$$\textbf{CH}_4\textbf{ Generation } \left(\frac{\mathrm{m^3}}{\mathrm{d}}\right) = \frac{0.46\ \mathrm{m^3}}{\mathrm{kg\ COD}} \times \textbf{COD methane } \left(\frac{\mathrm{kg}}{\mathrm{d}}\right)) \qquad \textbf{(G.6.1)}$$

Equation 3.12 was rearranged for the calculation of CH_4 density (kg/m^3) at prevailing conditions of pressure (atm) and temperature (K).

$$\rho = \frac{\mathrm{Mr\ x\ P}}{\mathrm{R\ x\ T}} \qquad \textbf{(G.6.2)}$$

Where

ρ is the CH_4 density, kg/m^3

Mr is the molar mass of CH_4, g/mol

P is the prevailing pressure, atm

T is the prevailing temperature, K

R is the universal gas constant, 0.082057 atm.L/mole.K

At 35°C, Tchobanoglous et al. (2003) estimated the typical biogas concentration to be about 65 % CH_4 and CH_4 energy content to be 50.1 kJ/g. Based on these typical values, the amount of biogas and energy generated were calculated.