Investigating Wastewater Generation and Wastewater Effluent Treatment in the South African Fruit & Vegetable Processing Industry

By

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DECLARATION

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ABSTRACT

During the mid-1980s, a series of national surveys was conducted by the Water Research Commission (WRC). These surveys (also known as NATSURV reports) investigated water and wastewater management within the industrial environment of South Africa. These original NATSURVs have, however, become outdated. The WRC has, therefore, commissioned updates for these reports. The aim of this study is to gather relevant information, pertaining to water and wastewater management in the fruit and vegetable processing industry, by means of a national survey. The quality and scope of the knowledge acquired should be suitable to be included in the second edition NATSURV 19 (Water and Wastewater Management in the Fruit and Vegetable Processing Industry).

As a means of comparison, an in-depth literature review was conducted before commencing with the surveying process. The literature review focussed on the various production processes found in the fruit and vegetable processing industry. Another key component of the literature review was detailing the various wastewater treatment methods available to the fruit and vegetable processing industry.

An industry database was built using a combination of internet sources, industry databases and referrals. Thereafter, all 78 facilities included in the database were telephonically contacted in order to verify their operational status. An internet-based survey was then made available to persons with executive authority within each facility. Site-visits of selected facilities were being conducted simultaneously. Each site visit included an interview with a person possessing in-depth knowledge of the processes involved. A walk-through audit of the facility was also conducted during these site-visits. The data acquired from the internet-based questionnaire and site-visits was subjected to Qualitative Data Analysis (QDA) using the ATLAS.ti 9 analytic software. Furthermore, water consumption, effluent generation and effluent quality parameters were also critically evaluated and compared to the available literature.

After analysis was completed it was found that some facilities reported SWI figures which were similar or better than their international counterparts. Furthermore, when considering the SWI determined for certain products in the 1987 NATSURV, it appears that some facilities were able to report improved SWI figures. This indicates at least anecdotally that the water-use efficiency of the South African FVPI has improved over the last 30 years. Analysis further revealed that raw material washing and facility cleaning were the most water intensive processes. The QDA revealed that the majority of facilities investigated do not utilise advanced wastewater treatment techniques. This may be due to lengthy pay-back period often associated with capital investments of this nature. Effluent disposal routes are largely influence by the nature of a facility's surroundings. Rural facilities often choose to irrigate their effluents, whilst facilities in an urban environment preferred to discharge directly into the municipal wastewater systems. It was found that in addition to environmental

concerns, financial incentives are often the reason for the improvement of water consumption and wastewater treatment within the South African FVPI.

This study's aim to provide suitable information and recommendations, to be included in the updated NATSURV 19, was achieved. Furthermore, this study has provided a sufficient sample of water and wastewater management practices observed in the industry, future research should, therefore, focus on individual facilities or processes and the optimisation thereof.

UITTREKSEL

Die Waternavorsingskommissie (WNK) het vanaf die laat 1980s ‘n reeks nasionale opnames uitgevoer. Hierdie opnames (bekend as die NATSURV verslae) het die bestuur van water en afvalwater in die Suid-Afrikaanse industriële omgewing ondersoek. Hierdie verslae is egter al verouderd en daarom het die WNK aangekondig dat hierdie verslae opdateer sal word. Die doel van hierdie ondersoek is dus om relevante inligting aangaande water- en afvalwaterbestuur in die vrugte- en groentverwerkingsbedryf (FVPI) in te samel, deur van ‘n nasionale opname gebruik te maak. Die kwaliteit en omvang van hierdie inligting moet sodanig wees dat dit deel kan vorm van die tweede uitgawe van die NATSURV 19 verslag (Water- en afvalwaterbestuur in die groente- en vrugteverwerkingsbedryf).

Voordat die opname kon begin, was ‘n gedetailleerde literatuurstudie gedoen sodat daar vergelykings getref kon word. Die literatuurstudie het klem gelê op die verkeie produksie-prosesse wat in die vrugte- en groenteverwerkings bedryf waargeneem word. ‘n Ander belangrike komponent was om die verskeie afvalwaterbehandelingsmetodes wat aan die vrugte- en groenteverwerkingsbedryf beskikbaar is, noukerig te dokumenteer.

‘n Bedryfsdatabasis is gebou met die hulp van internetnavorsing, verwysings as ook die verskillende bedryfsdatabasisse in die industrie. Daarna is al 78 fasiliteite telefonies gekontak om hul operasionele status te verifieer. ‘n Internet-gebaseerde opname is daarna beskikbaar gemaak aan persone met die nodige kennis, binne elke fasiliteit. Besoeke aan geselekteerde fasiliete was ook gedoen. Gedurende elke besoek was ‘n onderhoud gevoer met ‘n persoon wat oor die nodige kennis rakende die toegepaste prosesse beskik. Elke besoek het ook ‘n in diepte analise van die terrein behels. Die data wat via internet opnames en besoeke aan die fasiliteite verkry is, was onderworpe aan kwalitatiewe data-analise (QDA) deur gebruik te maak van die ATLAS.ti 9-ontledingsplatvorm. ‘n Kritiese evaluasie van die fasiliteite se waterverbruik, afvalwater generasie en afvalwaterkwaliteit was ook uitgevoer. Hierdie data parameters was daarna vergelyk met beskikbare literatuur.

Na ontleding skyn dit te blyk dat sommige van die fasiliteite SWI-syfers toon wat soortgelyk of selfs beter is as dié van hul internasionale eweknieë. Sommige fasiliteite toon ook beter spesifieke waterinnames (SWI’s) in verhouding met diéwat in die oorspronklike NATSURV vir soortgelyke produkte ingestel is. Dit dui anekdoties ‘n verbetering in die waterverbruiksdoeltreffendheid gedurende die afgelope dertig jaar aan. Na verdere ontleding was daar gevind dat die skoonmaak van rou materiale en die fasiliteite self, die grootste verbruikers van water was. QDA het aan die lig gebring dat meeste fasiliteite nie van gevorderde afvalwaterbehandeling tegnieke gebruik maak nie. ‘n Moontlike rede hiervoor kan die lang terugbetalingstydperk van die kapitaalbelegging wees. Die afvalwater verwyderings roetes word grootendeels deur die fasiliteit se onmiddelike omgewing bepaal. Fasiliteite in landelike omgewings gebruik gereeld hul afvalwater vir besproeingsdoeleindes,

terwyl fasiliteite in ontwikkelde omgewings gewoonlik kies om hul afvalwater na munisipale afvalwaterstelsels te stort. Daar is egter gevind die verbetering van waterverbruik en afvalwaterbehandeling binne die Suid-Afrikaanse FVPI nie net gemotiveer word deur omgewingsbewustheid nie, maar ook deur finansiële implikasies.

Die doel om inligting en aanbevelings te lewer wat geskik is om by die opgedateerde NATSURV ingesluit te word is deur hierdie studie bereik. Daar is lig gewerp oor die huidige water- en afvalwaterbestuurspraktyke in die vrugte- en groenteverwerkingsbedryf, en daarom moet toekomstige navorsingsprojekte fokus op die individuele fasiliteite asook die optimalisering van prosesse binne hierdie fasiliteite.

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The language, style and referencing format used in this study are in accordance with the requirements of the International Journal of Food Science and Technology. This thesis is a continuous document, where each section is not regarded as an individual entity and must, therefore, be read in conjunction with other sections for context.

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ABBREVIATIONS

BAFF	Biological aerated flooded filters
BAT	Best available techniques
BMP	Best management practice
BOD	Biological oxygen demand
BREF	Best available technique reference documents
CAQDAS	Computer-assisted qualitative data analysis software
CFM	Cross-flow microfiltration
CIP	Clean-in-place
CLFP	California League of Food Processors
COD	Chemical oxygen demand
DAF	Dissolved air flotation
DAFF	Department of Agriculture Forestry and Fisheries
DO	Dissolved oxygen
DTI	Department of Trade and Industry
DWS	Department of water and sanitation
EDC	Endocrine-disrupting chemicals
EGSB	Expanded granular sludge blanket (reactor)
FDM	Food, Drink and Milk
FOG	Fat, oil and grease
FVPI	Fruit and vegetable processing industry
HAD	Hot air dryer
HRT	Hydraulic retention time
HS	Harmonised system
HTST	High temperature short time
IC	Internal circulation (reactor)
IPPC	Integrate Pollution Prevention and Control (bureau)
IQF	Individually quick frozen
ML	Mixed liquor
NASWI	National average specific water intake
NATSURV	National surveys
NF	Nanofiltration
PAO	Polyphosphate-accumulating organisms
QDA	Qualitative data analysis
REC	Research Ethics Committee

RO	Reverse osmosis
SBAF	Submerged biological aerated filters
SBR	Sequencing batch reactor
SIC	Standard Industrial Classification
SS	Suspended solids
SWI	Specific water intake
TCA	Thematic content analysis
TOC	Total organic carbon
TSS	Total soluble solids
UASB	Up-flow anaerobic sludge bed (reactor)
UF	Ultrafiltration
UV	Ultra-violet
WRC	Water Research Commission
WWTP	Wastewater treatment plant

Chapter 1 Introduction

According to Lal (2015) the majority (97.5%) of Earth's water is classified as saline, with the remaining 2.5% being classified as freshwater. Of this freshwater, 69.6% is trapped in ice caps and other frozen forms, rendering it inaccessible. Thus, only 1.2 % of all freshwater, is accessible to living organisms (Lal, 2015). The overuse and an increasing dependence on unsustainable groundwater has been reported on a global scale (Wada & Bierkens, 2014). Wada & Bierkens (2014) go on to state that approximately 30% of the human water requirements are met through unsustainable sources, with this figure projected to increase to 40% by the end of the century. The South African water situation is equally concerning, as the country's daily water consumption per capita is considered high for a water scarce country (DWS, 2017). Furthermore, it is estimated that approximately 15% of the country's population still do not have access to basic drinking water (UNICEF & WHO, 2017).

Due to the global and local water scarcity, the environmental impact of the domestic industry has come under scrutiny. Urban development, industrial effluent, mining, and agriculture have been identified as the main polluting processes (Mekonnen & Hoekstra, 2011; Oberholster & Botha, 2014; DWS, 2017). For this reason, the Water Research Commission (WRC) has been updating a series of national surveys, which investigate water and wastewater management in industry, since 2013 (Swartz *et al*., 2017).

The Department of Water Affairs and Forestry (now the Department of Human Settlements, Water and Sanitation) commissioned the original national surveys (also known as NATSURVS) during the mid-1980's (Swartz et al., 2017). Through conducting these NATSURVs it was hoped that the minimum specific water intake requirements, amongst other things, could be determined. This would be used to ensure that unfair blanket restrictions would not be placed on certain facilities during periods of drought. These surveys also allowed regulators to manage the discharging of effluent streams to prevent damage to assets such as downstream infrastructure, treatment facilities and water sources. Subsequently, the original NATSURVs have been a valuable benchmarking tool for regulators, academia and industry stakeholders (Swartz *et al*., 2017).

The result of the original NATSURVs was the publication of various reports, one of which was titled: *Water and Wastewater Management in the Fruit and Vegetable Processing Industry* by Binnie & Partners (1987). Included in this publication were parameters pertaining to water consumption, effluent quality, as well as recommendations for the improvement of water efficiency within the respective processes (Binnie & Partners, 1987). The food industry is known to be extremely water and energy-intensive, thus the inclusion of fruit and vegetable processing in the updated NATSURVs is not surprising (IPPC, 2006; Compton et al., 2018). Fruit and vegetable processing effluent streams have been noted to have a high pollution potential due to their relatively high chemical oxygen demand (COD) and biological oxygen demand (BOD) (Qasim & Mane, 2013). Fairly recent studies (CLFP, 2015; Meneses *et al.*, 2017) have commented on the lack of data pertaining to the reuse/recycling of food processing water, as well as the management of wastewater streams.

It has been noted that individual sectors within the food processing industry, including the fruit and vegetable processing industry, have their own key environmental issues (IPPC, 2006). The Australian Department of Agriculture (2007) identified fruit and vegetable processing as one of the sub-sectors with the highest annual water consumption. This is concerning as the food processing industry, in general, is regarded to be water intensive (Australian Department of Agriculture, 2007).

When considering the treatment of wastewater within the FVPI, various treatment options exist. These treatment options can be divided into three broad categories namely: primary, secondary and tertiary treatments (IPPC, 2006). Primary treatments often involve the removal of organic and inorganic solids which are readily settled by means of gravity, or those which are able to float (FAO, 1992). Secondary treatments focus on the removal of biodegradable organic matter and suspended solids (SS) by means of biological methods (IPPC, 2006). Secondary treatments can further be divided into aerobic and anaerobic processes (IPPC, 2006). Tertiary treatments on the other hand largely focus on the removal of suspended, colloidal and dissolved materials which may remain after processing (IPPC, 2006). However, the implementation of these treatment methods differ. It has been observed that facilities within the FVPI often only apply a form of pre-treatment before discharging the effluent into the municipal systems (Paulsen, 2006).

It is further necessary to take the economic importance of the South African fruit and vegetable processing industry into consideration. Bekker (2018) states that fruit and vegetable processing has become an integral part of the South African manufacturing sector. It is further stated that the industry is becoming the leader in inclusive and labour-intensive growth. Whilst the FVPI is a highly concentrated industry, the majority of the industry's total income and employment can be attributed to a few key players (UNIDO, 2017; van Lin *et al*., 2018, Bekker, 2018). When considering the value of the individual sectors within the FVPI, fruit juices were found to be the most valuable produce. The fruit juice industry yields an annual turnover of approximately R 10 billion (van Lin *et al.*, 2018). Bekker (2018) reports that the majority (over 80%) of South African processed fruit products are destined for the export market, whilst only 10% of the processed vegetable products are exported.

In conclusion, the South African FVPI is of great economic importance; and its high water intensity and polluting effects have been noted. However, data pertaining to the generation of wastewater and the treatment thereof is outdated. It would be valuable and necessary to include the South African FVPI in the NATSURV document series. Therefore, the aim of this study is to provide meaningful data and recommendations which can be used to create a comprehensive guide and benchmarking tool. It is hoped that this information will inform the fruit and vegetable processing industry on how they can contribute towards the reduction of water usage; effluent generation; and the pollution prevention.

The objectives of this study were firstly, to critically evaluate the water and wastewater management techniques currently adopted by facilities within the South African fruit and vegetable processing industry. The second objective was to determine the volumes and typical pollutant loads of wastewater being generated. Determining the adoption of best practice technologies was also included in the second objective. The last objective was to provide appropriate recommendations to the South African FVPI with regards to water and wastewater management.

Chapter 2 Literature Review

2.1 Background

Water is regarded as being a crucial element in human survival and socio-economic development (Zhang *et al.*, 2019). Water is regarded as being a fundamental element in the Food Energy Water Nexus, as water is required to process fossil fuels such as coal in order to generate thermoelectric power. The energy generated is in turn used during the food production process as well was the treatment of wastewater (Oberholster & Botha, 2014). It is, therefore, concerning that the Integrated Pollution Prevention and Control (IPPC) bureau (2006) view water as a key environmental issue in the Food, Drink and Milk (FDM) industries. Compton *et al.* (2018) also reflected on the strenuous nature of food processing with regards to energy and water consumption. Polluted water can be detrimental to human health as well as the environment, food processing wastewater consequently has a high pollution potential due to its Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) (Qasim & Mane, 2013; Noukeu *et al.*, 2016). The COD and BOD levels of food processing wastewater can commonly be 10 – 100 fold higher than that of domestic wastewater (IPPC, 2006). More severe regulations on the treatment of wastewater have been imposed by environmental protection agencies in order to ensure the preservation of the environment (Qasim & Mane, 2013). This has ensured that the treatment of wastewater has become a financial burden for food processing facilities, whether they make use of an on-site Waste-Water Treatment Plant (WWTP) or be it levies placed on discharging into the public water course (Cooke, 2008; Qasim & Mane, 2013).

It has been noted that individual sectors within the food industry have their own key environmental issues. Key environmental issues related to fruit and vegetable processing include water use, the generation of wastewater, output of problematic solids and energy use (IPPC, 2006).

In order to successfully complete the benchmarking of facilities one would need reliable sources as a reference. However, it seems that publications dealing specifically with the metric evaluation of water usage and saving within the industry declined during the early 1980s, with information of this format only becoming more readily available in the late 1990s (CLFP, 2015; Meneses *et al.*, 2017).

While peer reviewed research publications investigating general techniques for water minimisation in industry are scarce, various publications submitted by industry or governmental entities exist. CLFP (2015) and IPPC (2006) are examples of such publications. In contrast to this, publications regarding the use of “Green Techniques” (processes which reduce the consumption of water and energy) during processing has become more readily available (Chemat *et al.*, 2017).

However, as with the publication of Khan *et al*. (2018) most of these “Green Processes” are still novel methods and are not commonly implemented in industry. Several publications do, however, clarify the adoption rate of these novel technologies in industry (Barba *et al.*, 2015; Jermann *et al.*, 2015; Huang *et al.*, 2017).

2.2 Defining Fruit and Vegetable processing

The Harmonized System (HS) of export classification states that there are currently 55 categories of products which fall under ‘Preparations of vegetables, fruit, nuts or other parts of plant’ (UN Trade Statistics, 2010). Each of these categories may, however, contain a wide variety of products. For instance, H20090 is used to describe any mixture of fruit juices which are unfermented and does not contain additional spirits (Department of Trade and Industry (DTI), 2018). Thus, it is seemingly difficult to classify products according to the process from which they originate. The situation is further complicated by the lack of a formal definition. As if to complicate matters further, the definitions used by different governmental statistical bodies differ. For example the South African definition specifically excludes dried soups, while this product is included in the U.S. definition (Bureau for Economic Analysis, 2017; StatsSA, 2019). Another example of this complication is the exclusion of fruit juice in the definition compiled by IBISWorld (2017). This definition would, however, not be applicable in the South African context as fruit juice is regarded as an extremely important product with regards to its value and quantity produced (StatsSA, 2019).

There is a necessity to provide a formal definition for fruit and vegetable processing. This will prevent any ambiguity in any future research procedures. In South Africa, fruit and vegetable processing is classified under the SIC (Standard Industrial Classification) code 3013. This describes the following:

- The manufacturing of food consisting primarily of fruit and vegetables
- Preserving cooked or uncooked fruit and vegetables by freezing
- Preservation methods such as dehydration, drying and immersion in oil or vinegar
- Processing of potatoes, including the manufacturing of potato flour and meal
- Manufacturing of prepared meals or vegetables
- Preservation of fruit and vegetables by canning
- Manufacturing of marmalades, jams and jellies

It is, however, important to note that some activities are specifically excluded in the definition. This includes the manufacturing of soups of vegetables and fruit (classified under group 3049) or the manufacturing of bean flour or meal (classified under group 3031) (StatsSA, 2019). Canned fruit and vegetable juices are also excluded from this definition as they are classified under group 3121 (StatsSA, 2019).

2.3 The Global Water Situation

It is estimated that Earth has a total amount of water of roughly 1.26×10^{21} litres. Of this total water reserve 97.5% is regarded as saline (Lal, 2015). The remaining 2.5% is classified as freshwater and is, therefore, usable by plants and other living organisms. To complicate matters even further about 69.6% of this freshwater reserve is found in ice caps, glaciers and permanent snow, rendering it inaccessible to living organisms (Lal, 2015). This means that only about 1.2% of all freshwater is found in a usable state, be it surface water or other forms of usable water (Lal, 2015). It is possible to further classify the available freshwater into blue, green and grey water (Mekonnen & Hoekstra, 2011). Blue water refers to liquid water which is accessible as surface or groundwater; green water refers to rainwater which is consumed whilst producing goods (Pahlow *et al.*, 2015). Grey water serves as an indicator for the degree of freshwater pollution, which is associated with the production of goods (Pahlow *et al*., 2015; Mekonnen & Hoekstra, 2011).

Blue water amounts to 85.9% of the total freshwater, with green water making up the remaining 14.1% (Lal, 2015). The overuse and an increasing dependence on unsustainable groundwater (i.e. blue water) resources has been reported on a global scale (Wada & Bierkens, 2014). It has been noted that there is an evident increase in the consumption of unsustainable water sources, with about 30% of the human water supply coming from unsustainable sources in 2010 (Wada & Bierkens, 2014). It is, furthermore, projected that the consumption of non-renewable water sources will increase to 40% before the end of the century is reached (Wada & Bierkens, 2014).

On a global scale, agriculture is responsible for the withdrawal of about 70% of the available freshwater, while in developing countries this figure can reach up to 95% (FAO, 2017). Industry is responsible for 19% withdrawal, while the remaining 11% is used for municipal purposes (Lal, 2015). It is estimated that agricultural activities are responsible for the withdrawal of 2500km^3 blue water per year. Of concern, therefore, is the notion that as the food demand increases so will the use of blue and green water (Lal, 2015).

Access to clean drinking water is a major problem in the world, the United Nation (UN) have reported that since 1990 about 2.6 billion people have been provided with an improved source of drinking water (Marcantonio, 2018). During the year 2015 it was estimated that around 6.5 billion people had access to at least a basic drinking water service. This implies that it would take individuals 30 minutes per trip to collect drinking water (UNICEF & WHO, 2017). It is stated that as of 2016 roughly 663 million people still do not readily have access to a water source of sufficient quality (Marcantonio, 2018; UNICEF & WHO, 2017).

2.4 The Water Situation in South Africa

2.4.1 Sources of water and rainfall

South Africa is a semi-arid, highly water stressed country and is ranked as the 30th driest country in the world (GreenCape, 2019). This is attributed to the extreme weather conditions and the fluctuations in rainfall (GreenCape, 2019). South Africa has an estimated mean annual precipitation of 500mm compared to a global average of 860mm (DWS, 2015). The nation is known to have a high variability of rainfall across the country, which further complicates its water scarce status. According to Kruger & Nxumalo (2017) the precipitation patterns in South Africa have changed between the years 1921 - 2015. It was further observed that the southern interior of the country seemed to be experiencing higher rainfall; whilst the north and north-eastern regions of the country were experiencing lower levels of rainfall (Kruger & Nxumalo, 2017). Due to climate change, South Africa is expected to be increasingly affected by variations in rainfall and water scarcity (GreenCape, 2019). Due to the current population and economic growth projections it is predicted that by the year 2030 South Africa will have a water demand of nearly 17.7 billion m^3, meaning that the water demand would exceed the supply by 17% (GreenCape, 2019). As if to validate this prediction during the years 2015 and 2017 South Africa experienced one of its worst drought periods in history (GreenCape, 2019).

South Africa has a dependable water yield of about 15 billion m^3 per year (DWS, 2017; GreenCape, 2019). As seen in Figure 1 this consists of 68% surface water, 13% return flows, 13% ground water and 6% other sources such as seawater.

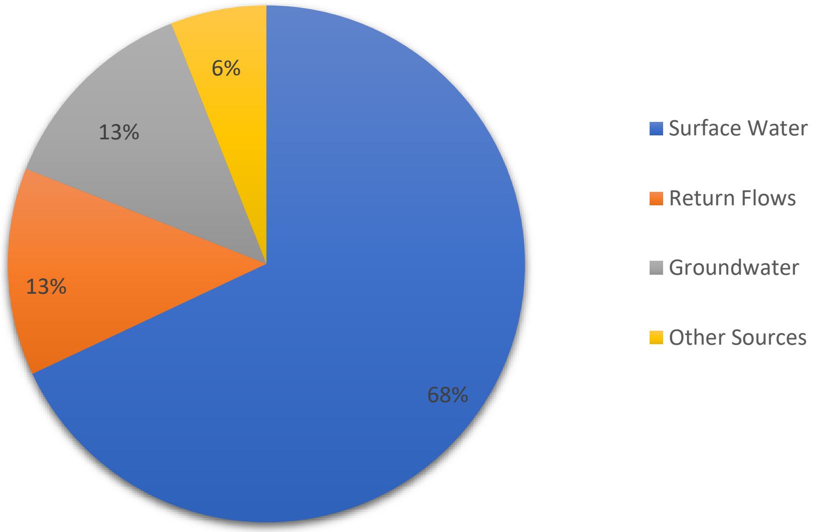

Figure 1 South African water sources (Adapted from GreenCape, 2019).

In order to manage the inconsistency observed in terms of surface water runoff, the South African government has provided an extensive water sources infrastructure. Furthermore, this ensures that economically active areas are provided with water (DWS, 2017). This includes 794 large storage dams, which have wall heights ranging from 5 to 15 meters as well as a holding capacity greater than 3 million m^3. In order to overcome the high variability of rainfall observed across South Africa, it is necessary to have a system in place which can re-route the water supply to areas which are experiencing water shortages. Therefore, there are 29 inter-basin and inter-river transfer systems currently being used in South Africa (DWS, 2017). The Lesotho Highlands Water Scheme is an example of such a system, it is responsible for diverting water from the Orange-river to the Vaal-river (Water Technology, 2019).

2.4.2 Water Availability per capita

According to the South African constitution each person has the right to at least basic water supply as well as sanitation services (DWS, 2017). However, approximately 15% of the population still do not have access to basic drinking water (UNICEF & WHO, 2017). The nation has a low water availability per capita in comparison to other countries, with an annual water availability of 843 m^3 water per person (WWF, 2017). Furthermore, the country displays a daily average water usage of 230 litres per capita, this is however, considered to be rather high for a country with low water availability (DWS, 2017).

2.4.3 South African water footprint

As of 2013 South Africa withdraws a total of 15.5 x 10^9 m^3 of water per annum (FAO, 2016). The agricultural sector is responsible for the withdrawal of 63% of the total water supply, 26% is withdrawn by the municipal sector and 11% by the industrial sector (WWF, 2017). While water withdrawal is a sufficient indicator, the water footprint of industries might be of interest as it provides a more holistic analysis of the water usage. The water footprint is a comprehensive measurement of fresh water consumption as it not only measures direct water usage but also indirect usage (Mekonnen & Hoekstra, 2011). A more formal definition was provided by Hoekstra *et al*. (2011) wherein they described the water footprint as being the total volume of freshwater consumed during the production process, which calculated by taking the entire supply chain into consideration. Thus by using this method Mekonnen & Hoekstra (2011) were able to quantify the effect of human activities on the South African fresh water supply. Their findings are displayed in Table 1 below.

Table 1 National water footprint per sector in South Africa (Mekonnen & Hoekstra, 2011; Pahlow et al., 2015)

Water Footprints (million m^3)						
Agricultural Sector			Industrial Sector		Municipal sector	
Green	Blue	Grey	Blue	Grey	Blue	Grey
45 928	6 694	3 126	38	309	390	2 368
55 748			347		2 758	

It was revealed that the agricultural sector yielded the largest water footprint, with a total of 55 748 million m^3 per annum. It is important to note that the agricultural sector includes the production of crops as well as the production of animals. The industrial and municipal sectors contributed considerably less to the national water footprint, yielding 347 million m^3 and 2 758 million m^3 respectively. Although, the total water footprint of the industrial and municipal sectors are much lower than that of the agricultural sector, they do however, produce a much larger proportion of grey water. As seen in Table 1, 89% (309 million m^3 p.a.) of the industrial water footprint is attributed to grey water production, while 86% (2 368 million m^3 p.a.) grey water production is observed in the municipal sector. The agricultural sector, however, only contributed 6% (3 126 million m^3 p.a.) towards grey water production. This implies that when considering strategies for the mitigation of the water footprint of the municipal and industrial sector, the focus should be on the minimisation of the effluent pollution.

When considering the anthropogenic issues that affect the South African water quality, the DWS (2015) identified four major contributors that are of concern, namely: mining, urban development, effluents produced by industries and agriculture. Acid mine drainage (AMD) is of specific concern in the mining industry, as it is characterised by low pH, high levels of heavy metals and sulphates and dissolved solids (Oberholster & Botha, 2014). Oberholster & Botha (2014) deemed AMD as the main source of water pollution in the mining industry. In an urban environment, untreated effluent originating from failing sewage systems is seen as an abundant source for pathogenic bacteria, such as *Escherichia coli*, which are associated with faecal contamination. Industrial effluents are viewed as a major source of toxic substances, such as endocrine-disrupting chemicals (EDC's) (Oberholster & Botha, 2014). Oberholster & Botha (2014) further stated that agricultural activities affect freshwater quality by means of eutrophication and the presence of contaminants such as agro-chemicals.

2.5 Previous studies regarding water usage and best practice adopted in fruit and vegetable processing

Businesses within the food industry are becoming more motivated to find alternative methods to efficiently produce food stuffs, with the determining factors being the scarcity of water, more stringent environmental regulations and an increase in levies placed on municipal water and wastewater treatment (Maguire, 2015). Although, Meneses *et al.* (2017) noted that information regarding water usage within specific operation processes are not openly accessible in the U.S. food industry. They further commented that the limited knowledge surrounding potential water recovery streams is a hindrance for the improvement of these operations. It seems that government led studies regarding best practice adoption and water usage has tapered off since the 1960s, at least within the context of the US, with these studies being replaced by reports and surveys generated by industries (CLFP, 2015). With little data publicly available, more recent studies have to rely on data obtained from earlier work as a benchmark (Ajiero & Campbell, 2018).

For the context of this study it is necessary to take studies addressing the processing of food in general into consideration. This is necessary partly due to the lack of studies focussing specifically on the processing of fruits and vegetables, but rather products forming part of the sub-industry which are mentioned in the study or report (Ajiero & Campbell, 2018; CLFP, 2015). Furthermore, many Best Management Practices (BMPs) are relevant for a variety of sub-industries within the food processing industry. The cleaning practices recommended by the IPPC (2006) does not only apply to the production of dairy products and edible oils, but also to the production of fruit and vegetable related products.

2.5.1 Foreign studies regarding water usage and best practice

In North America, the publicly available data containing metric values pertaining to water usage was rather abundant during the 1960s, but seemed to have tapered off approaching the new millennium (CLFP, 2015). Compton *et al*. (2018) also commented on the general lack of data pertaining to the consumption of water within this region. The latest metric data which is publicly available, is that found in a study conducted by the CLFP in 2015, while prior to that the most recent study was conducted in 1993 by Mannapperuma. The study conducted by the CLFP (2015) proved to be especially useful as it provides a complete list of the most relevant studies ranging from 1977 to 1993, which is used as a baseline for comparison. Both the CLFP (2015) and Mannapperuma (1993) focus on the region known as California, which is a limiting factor that needs to be taken into consideration as it might not be representative of the entire region of North America. A study conducted in 2015 by Amón *et al*. specifically focussed on water and energy recovery techniques utilised in the Californian tomato paste processing industry. Masanet *et al*. (2008) have, however, extensively investigated water and energy saving techniques applied within the fruit and vegetable processing industry as a whole.

With regards to Europe, the situation is slightly more illuminating. This is due to the measures taken by the European Union IPPC (The Integrated Pollution Prevention and Control) directive. The IPPC implemented an agenda which required all member states to dispense permits for industrial processes which perform polluting activities (Klemeš & Perry, 2007). These permits are required to contain conditions which take the best available technique (BAT) with regards to pollution control into account. It should also aim to prioritise the improvement of environmental protection measures (IPPC, 2006; Klemeš & Perry, 2007). The IPPC directive compiles Reference Documents on BAT's (BREF's) by gathering information regarding BAT's from member states. These Reference Documents contain metric comparisons for a variety of fruit and vegetable products, as well as procedures which can improve the efficiency of water usage (IPPC, 2006). As of 2019 a final draft of an updated version has been submitted for review (European IPPC Bureau, 2019). This draft has, however, not been approved yet and the 2006 version is, therefore, still used as a benchmark when determining the conditions for operating permits. Research studies pertaining to wastewater generation and treatment within the EU include that of Valta *et al*. (2017), who investigated the most prolific sources of wastewater generation and possible treatment options within the Greek FVPI. In the United Kingdom (UK) a study was conducted by Bromley-Challenor *et al*. (2013), investigating water usage as well as possible opportunities to minimise water usage within the UK food and drink industry.

Literature discussing the water usage or water efficiency of other international regions include a report compiled by the Australian Department of agriculture (2007), which addressed water minimisation and reuse within the food processing industry. Meneses *et al*. (2017) provided a holistic review relating to the reconditioning and reuse of water within the food processing industry.

2.5.2 South African studies investigating water usage and best practice within the fruit and vegetable processing industry

It is evident that literature containing metric values pertaining to water usage as well as information regarding best management practices adopted is limited on a global scale. The availability of such data in South Africa is even more concerning, as the only data available to the public is found in the form of a national survey (NATSURV) commissioned by the Water Research Commission (WRC) in 1987(Binnie & Partners, 1987). Included in this report are metric comparisons across a wide range of fruit and vegetable related products. This includes the National Average Specific Water Intake (NASWI) (Fig. 2); wastewater volumes; COD; BOD and suspended solids (SS). The report further includes targets for the previously mentioned metrics. In addition to these targets the report also contains recommendations which would allow facilities toreach said targets. In addition to the metric data the NATSURV also contained a guide on water usage and effluent treatment (Binne & Partners, 1987).

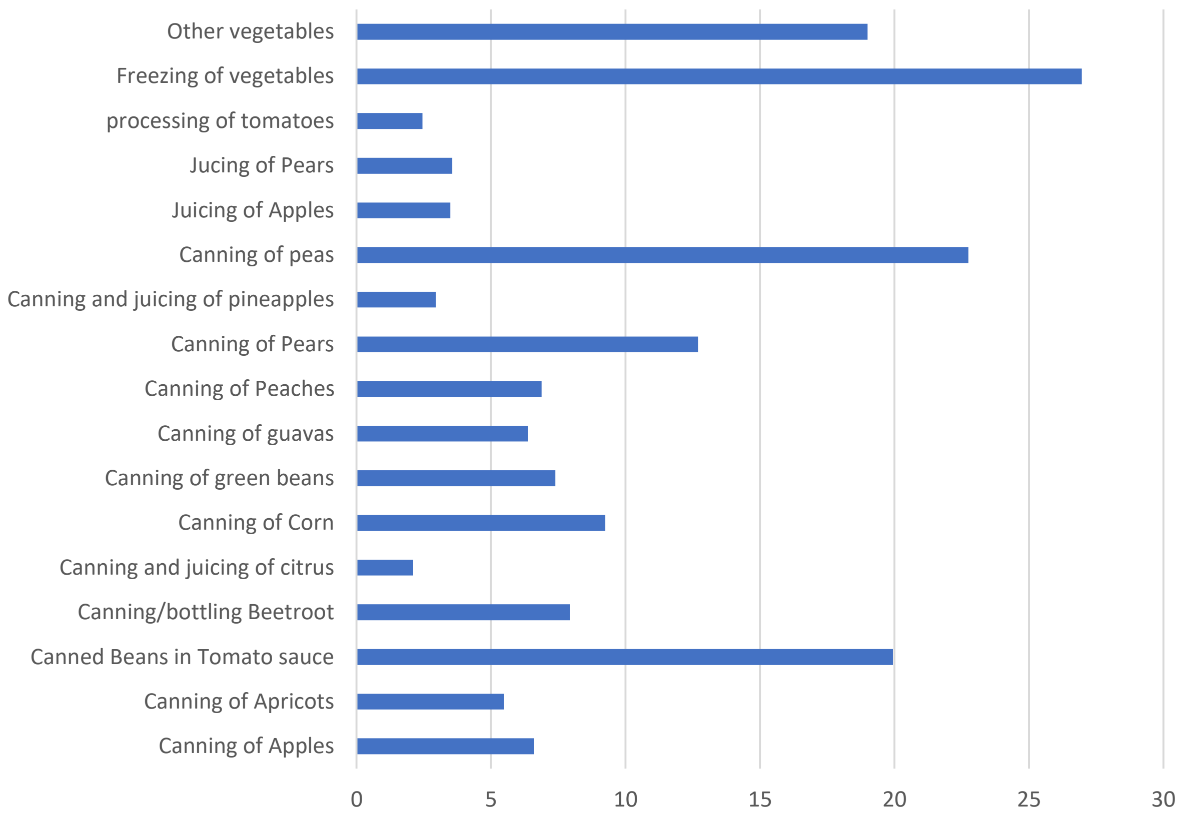

Figure 2 NASWI per category of products (m^3/ton raw material) during 1987 (Binnie & Partners, 1987).

Within their Guide to Water Use and Effluent Management, Binnie & Partners (1987) make specific mention of a facility which heavily distorted the NASWI of vegetable freezing processes. This distortion was due to the facility making use of a once-through cooling system. Both the NATSURV and the accompanying guide compiled by Binnie & Partners (1987) will serve as a comparative platform for the subsequent research chapters in order to determine the progress of the industry.

2.6 Water usage during generic fruit and vegetable processing practices

It has been found that with sufficient knowledge regarding the specific degradation properties of food products, it is possible to compile a list of various physical, biological and chemical methods which could be used in order to accomplish the preservation of the material in question (Table 2).

Table 2 Technical parameters for the preservation of food products (Dauthy, 1995).

Descriptor	**Technical Parameter**
Physical	Irradiation
	Sterilising filtration
	Drying/Dehydration
	Heating

	Cooling
	Vacuum
	High pressure
	Inert gases
Chemical	Artificial acidification
	Addition of ethyl alcohols
	Smoking
	Salting
	Addition of sugar
	Antiseptic substances
Biochemical	Alcoholic fermentation
	Lactic fermentation

The classification of processing procedures may, however, be difficult due to the fact that their effects are often accomplished by utilising a combination of biochemical, chemical, physical and physico-chemical phenomena (Dauthy, 1995). When dealing with fruit and vegetable products various aspects, such as changes to nutritional and sensory characteristics as well as the technical-economic requirements, are taken into consideration in order to determine the best suited processing method (Dauthy, 1995). Thus, not all of the processes listed in Table 2 are necessarily suitable for the processing of fruit and vegetables. Considering the various possible deterioration reducing techniques, some specific preservation techniques have been identified as suitable processing methods for fruit and vegetable products (Table 3) (Dauthy, 1995).

Table 3 Possible preservation procedures for fruit & vegetables (Dauthy, 1995)

Procedure	**Possible applications**
Fresh Storage	Fruit and vegetables
Cold Storage	Fruit and vegetables
Freezing	Fruit and vegetables
Drying/Dehydration	Fruit and vegetables
Concentration	Fruit and vegetable juices
Chemical Preservation	Semi-processed fruit
Preservation with sugar	Fruit products and preserves
Pasteurization	Fruit and vegetable juices
Sterilisation	Fruit and vegetables
Sterilising filtration	Fruit juices
Irradiation	Fruit and vegetables

For the purpose of this investigation it is necessary to view the processes mentioned in Table 3 in a more generic manner, in order to address the most common practices in the South African fruit and vegetable processing industry. This is required due to facilities often using a combination of these procedures. For instance, the juicing of fruit usually involves chemical preservation as well as pasteurization. Thus, specific principles would be addressed when looking at generic processes such as juicing. Furthermore, investigating the individual processes would not be within the scope of this study, as the study is mainly focused on water usage during the production processes and not necessarily which principles are applied.

2.6.1 Fruit and vegetable juices

Before processing is initiated, the fresh fruit undergo a preparation process, during which the fruit is graded, washed and the stems removed. The fruit is then exposed to a manual selection process which removes all unwanted components as well as fruit that has deteriorated (Horváth-Kerkai & Stéger-Máté, 2012). Following this the fruit is subjected to chopping and subsequent procedures, this may involve mechanical processing, heat treatment as well as enzymatic treatment (Horváth-Kerkai & Stéger-Máté, 2012). It is common practise for industries to make use of pectinases, cellulases and hemicellulases, collectively known as macerating enzymes (Sharma *et al.*, 2017). This combination of enzymes leads to increased juice yields, Total Soluble Solids (TSS) and assists in the clarification process; furthermore, it decreases turbidity as well as viscosity (Sharma *et al.*, 2017). Thereafter, follows the liquid extraction, with pressing being the most commonly used method (Horváth-Kerkai & Stéger-Máté, 2012). In cases where a cloudy juice is not desired the pressed juice undergoes a clarification process, which involves a physiochemical (generally a combination of enzymatic treatment and mineral clarification agents) and a mechanical process (generally membrane filtration or centrifugation) (Horváth-Kerkai & Stéger-Máté, 2012). However, due to the negative effect of heat on the quality of fruit juices the use of membrane technologies are becoming more common (Bhattacharjee *et al.*, 2017). A limitation experienced with membrane treatments, such as microfiltration or ultrafiltration, is fouling. Fouling is responsible for the reduction of permeate flux as well as a reduction in the lifespan of the membrane (Bhattacharjee *et al*., 2017).

The clarified or cloudy juice can be directly packaged, or it can be concentrated in order to improve the shelf life and the transportation properties of the product (Horváth-Kerkai & Stéger-Máté, 2012). Evaporation, membrane processes and freeze concentration can be used to produce juice concentrates; it is important to note that each of these methods has its own advantages and disadvantages (Fellows, 2009; Horváth-Kerkai & Stéger-Máté, 2012). Freeze concentration is often used for the production of high value juices, as it is able to preserve the sensory and nutritional properties of the product. However, this process often requires a higher capital investment as well as higher energy and operational requirements in comparison to the other concentration methods (Fellows, 2009). Once final packaging is performed, the juice is heated to temperatures of 82-85°C, after which the juice is filled into a suitable container. The most common pasteurisation technique in the juice industry is HTST (High Temperature, Short Time) pasteurisation (IPPC, 2006; Koutchma *et al*., 2016). When manufacturing vegetable juice it is important to consider the fact that the pH is often 4.5 or greater, thus a full sterilisation treatment is required (IPPC, 2006). It is possible to reduce the pH by treating the vegetable juice with mild organic or inorganic acids. A less intensive treatment might be possible should a sufficiently low pH be reached; similar effects might be accomplished when mixing the vegetable juice with high acidity juices (e.g. tomato or citrus) (IPPC, 2006).

The spray drying of fruit and vegetables seems to be another widely used method (Shishir & Chen, 2017). A reduction in transport, storage and packaging costs are some of the key advantages of this processing method. An improved shelf life is also accomplished due to the high stability of the powders being produced (Shishir & Chen, 2017).

With regards to the water usage within a typical fruit processing operation, such as apple juicing for instance, the water usage is divided between process water, boiler feed and washdown or domestic requirements (Binnie& Partners, 1987). Process water accounts for 20% of the water consumption, while the boiler feed utilises 4%. Another 20% is used during the washdown of the processing plant, while the remaining 56% is consumed during other general washing and domestic operations (Binnie& Partners, 1987).

2.6.2 Heat treated fruit and vegetables

During canning operations, it is standard procedure to use the fresh fruit as soon as possible after it has been delivered, however, there are cases when the fruit has to be stored under chilled conditions for an extended period of time (IPPC, 2006). Before the fruit is peeled it is subjected to a washing phase, after which it is sorted, graded and cored or pitted. A variety of peeling methods exist, with the most common techniques being abrasive, steam, caustic or mechanical peeling techniques. After the peeling process the fruit may be directed to tanks containing ascorbic acid or brine, which prevents colour loss and browning. Thereafter, the fruit may be sliced before being filled into a container along with a syrup or natural juice. Before the container can be sealed it often undergoes a procedure known as 'exhausting', during which the headspace of the container is subjected to a brief steam treatment, which creates a negative pressure gradient in the container (IPPC, 2006). When canning fruit such as apricots for example, the pasteurisation process should aim to reach a minimum temperature of at 90.5°C in the centre of the product (Siddiq *et al*., 2012).

A study was conducted by Valta *et al.* (2017) in order to identify the main sources of water usage within a facility which produces canned apricots and peaches. They found that 40% of the water supply is used during the cutting and pitting operations, while 35% is used pasteurisation purposes, with the remaining 25% being linked to peeling and transfer processes. Furthermore, a facility which produces canned peaches and apricot compote was also investigated, they recorded the major water uses within the production process. It was noted that 44% of the water supply was attributed to the pasteurisation of the canned goods, while the washing and transfer process consumed 38%, with the remaining 18% being utilised for steam production, cleaning and domestic needs.

2.6.3 Frozen fruits and vegetables

Freezing is generally regarded as a preservation method within its own right, however, it is often mainly used to preserve products intended for further processing (IPPC, 2006). Different freezing methods exist and are used based on the type of product (Fellows, 2009). Furthermore, they are categorized based on the medium used for heat transfer (Rahman & Velez-Ruiz, 2007; Fellows, 2009):

1. **Freezing by means of a cooled gas**: *Cabinet cooling* involves placing the product on a tray within an enclosed space and subsequently passing cooled air around the product. An alternative to this is *air blast freezing*, which involves the products being cooled by high speed cooled air.
2. **Freezing by means of a cooled liquid**: This process is also known as immersion freezing. The product is lowered into a low temperature brine, which ensures a rapid reduction of temperature due to direct heat exchange. This method is often used for products such as fruits, orange pieces and tomato slices.

3. **Freezing by means of a cooled surface**: Also known as plate freezing. The product is placed between two cooled plates. After freezing is accomplished, the ice seal is broken by circulating hot water around the edges.
4. **Cryogenic freezing**: This method allows the product to be frozen at an extremely high rate. This is accomplished by placing the product in direct contact with liquified gases, such as carbon dioxide or nitrogen. Gas compression if often associated with high operational costs, therefore, this method is generally only used when preserving products of high value

A facility included in the study conducted by Valta *et al*. (2017) is that of a Greek fruit freezing facility. They noted that 67% of the facility's water supply was used for the actual freezing process, while washing consumed 13%. Bleaching and slicing consumed 12% and 8% respectively.

2.6.4 Fruit preserves

Fruit preserves include the manufacturing of marmalades, jams and jellies. The standards set for jams, marmalades and jellies are generally similar. However, jams and marmalades make use of whole fruits rather than fruit juice. Typically, the minimum soluble solids (SS) for jams and marmalades is also higher than that of jellies (Vibhakara & Bawa, 2012). The selection of raw materials initiates the manufacturing process. When producing jams the fruit should have a suitable texture, be fully matured and rich in flavour, whilst jellies require fruit containing sufficient amounts of pectin and acids. Ingredients such as sweeteners (often cane sugar), acids (generally malic or citric acid), buffers such as trisodium citrate, gelling agents (typically pectin), and foaming agents as well as citrus peel; for marmalades (IPPC, 2006). Typically, the fruit is washed in order to ensure that dirt and other foreign objects are removed, after which the fruits are pitted and/or subjected to a peeling process. A pectin, acid and sugar union is produced by boiling the mixture of fruit and other ingredients. Boiling is possibly the most vital step of the process, however, it should be as short as possible. A short boiling period helps avoid colour and flavour loss; it furthermore, prevents pectin hydrolysis (Vibhakara & Bawa, 2012). The syrup that is created is then hot-filled into glass containers and hermetically sealed with metal lids, which includes a rubber gasket. The temperature of the container is then lowered to 21°C, which allows the pectin to set (Vibhakara & Bawa, 2012).

2.6.5 Dried fruit and vegetable products

The drying of food products aims to reduce the water activity (a_w), which inhibits the degradative activities of microorganisms and enzymes (Fellows, 2009). Whilst various drying methods exist, sun drying remains the most common technique (Fellows 2009). Generally the process of sun drying involves a sorting step, grading, washing, dipping, drying and lastly the product is packaged. Some fruits are, however, also exposed to sulphites before the drying process is initiated. This provides protection against mould, as well as decreasing the time required for drying by softening the tissue of the fruit (IPPC, 2006). In certain cases the harvested fruit may be covered with a solution consisting of potassium carbonate and a dipping oil; this is accomplished by means of spraying or dipping (IPPC, 2006). Naturally, sun drying does have some limitations, these include loss of product due to the presence of animals, spoilage due to adverse climatic effects, insect infestation as well as fungal growth (Vijayavenkataraman *et al*., 2012). Sun drying is a labour intensive and time consuming process and it often requires a large operating area as well (Vijayavenkataraman *et al*., 2012).

When considering the context of the food processing industry, it appears that conventional Hot Air Dryers (HAD) are still the key components of modern technologies, even though they have a high energy requirement (Michailidis & Krokida, 2015). Freeze drying seems to be the most versatile process, even though it is largely limited to products of high value, due to the high operating costs associated with the creation of a vacuum and the freezing of raw ingredients (Michailidis & Krokida, 2015).

Solar drying has been proposed as an alternative to sun and mechanical drying methods due to their limitations (Vijayavenkataraman *et al*., 2012). Solar drying seems to be a viable alternative due to its lower consumption of fossil fuels in comparison to purely mechanical processes. Furthermore, it provides a higher quality product, with less product loss in comparison to sun drying methods (Vijayakataraman *et a*l., 2012). Whilst investigating industrial dehydration facilities, the CLFP (2015) found that the washing of raw materials was attributed to half of the facility's water requirements, while the other half was consumed by sanitation procedures.

2.6.6 Processing of Tomatoes

Tomato processing involves the production of a wide range of products, this includes canned-whole tomatoes, tomato juice and canned-crushed tomatoes. The three main processing routes for tomatoes are displayed in Figure 3 below. Valta *et al*. (2017) noted that the water usage within a tomato paste production process is largely related to the cooling of condensers, washing and transport operations. They also found that a portion of the water supply is used for pasteurisation, cutting or pitting and domestic supply, however, their water requirements are minor in comparison to the cooling and washing procedures. The water requirements differ between the processing routes followed. For instance when canning tomatoes the main water requirements are material washing (approximately 40%) and the boiler feed water (32%) (CLFP, 2015).

Tomato processing facilities do, however, generally reuse the water obtained from raw materials as well as condensates for processes such as (Valta *et al*., 2017; CLFP, 2015):

- Use in flume systems
- The washing of raw ingredients; and
- Rotary screen cleaning sprays

2.6.7 Processing of Potatoes

In the context of South Africa the main products of potato processing are chips, also known as fries, and crisps (DAFF, 2017). The production of both these products involves similar manufacturing processes (IPPC, 2006).

Deep fat-frying is a processing method which allows for the simultaneous transfer of heat and mass, while the food sample is immersed in oil (Liberty *et al*., 2019). The immersion of food in the oil results in the swift transfer of heat into the product, this vaporises the intrinsic moisture and drives it to the surface of the product and finally into the surrounding oil (Ghaitaranpour *et al*., 2018; Liberty *et al*., 2019). During the frying

process some of the oil is absorbed by the product as well (Ghaitaranpour *et al*. 2018). The frying process leads to the initiation of the maillard reaction, which is a reaction between reducing sugars and amino acids within the product. This reaction leads to the browning of the product, textural changes and the softening of the product at the beginning of the process, with the surface hardening during the later stages of the process (Liberty *et al*., 2019). It is important to note that the frying process is often responsible for the formation of heat-induced toxins such as acrylamide and furan (Pedreschi & Enrione, 2015).
Sodium metabisulphite and frying pyrophosphate are often used during potato processing in order to prevent the discolouration of the products. Pyrophosphate was found to be prevalent in the effluent streams of potato processing facilities (IPPC, 2006).

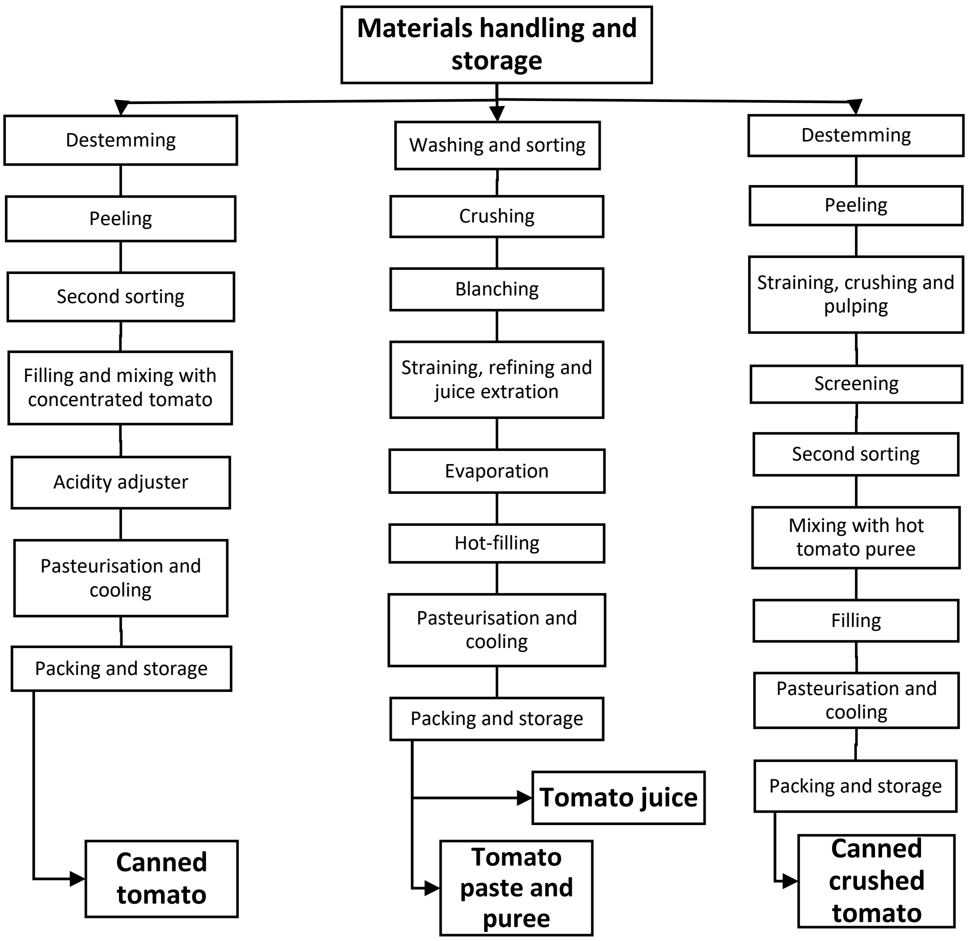

Figure 3 Possible routes available for the processing of tomatoes (adapted from IPPC, 2006).

2.6.8 Preservation by means of acidification

The acidification of food leads to the formation of an environment which prevents microbial growth (Dauthy, 1995). Acidification of food products can be accomplished naturally or artificially (Dauthy, 1995). Typically, the industrial process is initiated by the arrival of raw ingredients, this is followed by a washing and screening step, which is responsible for removing any superfluous materials. For some vegetables this process may include a steam cooking phase, which is followed by rapid cooling. After this the product is peeled and subjected to another inspection before being sliced or diced. Containers are then filled with the sliced fruit/vegetables, along with an acidifying liquor. The acidifying liquor generally consists of liquid sugar, acetic acid, spirit vinegar, malt vinegar and salt. This may, however, differ between production processes. Once the containers are sealed, the product is subjected to pasteurisation (IPPC, 2006).

2.7 Water Minimisation Techniques

Within the food processing industry, it is often found the water is used as either process water (i.e. for material cleaning, peeling etc.) or as utility water (e.g. steam, cooling, facility washing, etc.). Due to strict regulations regarding product quality, the food processing industry is responsible for the consumption of large volumes of high-quality water (Klemeš *et al*., 2009). As a result, the improvement of water minimisation techniques has received much attention. The IPPC (2006) provide a detailed discription of a systematic approach to minimise and prevent the wastage of water; it consists of the following steps:

1. Gaining approval from management, and completing the organisation and planning process
2. Analyse the entire production process
3. Assess the objectives
4. Identification of possible minimisation and prevention opportunities
5. Conduct an identification and feasibility study
6. Application; and
7. Continuous monitoring and inspection

The minimisation techniques identified during step four can be described under three broad categories, namely water minimisation; water-reuse/recycling and process changes (IPPC, 2006). Water minimisation and reuse/recycling mainly relate to design options of the facility's water networks, whilst process changes are generally concerned with this optimisation of unit operations (IPPC, 2006; Klemeš *et al*., 2009).

2.7.1 Design-based minimisation

Water pinch technology is a powerful tool which can be used to identify possible water-reuse, recycling and regeneration opportunities within a process. This is accomplished through the use of advanced algorithms (IPPC, 2006). Water pinch analysis is done by graphically manipulating the facility's limiting water profiles (IPPC, 2006; Klemeš & Perry, 2007). The practical application of this techniques has been explored by Thevendiraraj *et al*. (2003). Various water minimisation software packages are available and are capable of dealing with high complex optimisation problems (Kim & Smith, 2008).

2.7.2 Water reuse/recycling

Water regeneration may be economically feasible in cases where freshwater supply is limited and/or the recovery of process materials from wastewater is possible (Kim & Smith, 2008). However, due to perceived quality concerns it is not common practice to apply treatments for the purpose of water reuse (Bromley-

Challenor *et al*., 2013). Another deterrent is the fact that a highly robust and effective wastewater treatment systems is required to yield water of sufficient quality. The wastewater treatment would, therefore, need to include a primary, secondary and tertiary treatment (descriptions provided in Section 2.8).

According to Kim & Smith (2008) two design options can be considered when implementing optimisation strategies using treated wastewater, namely regeneration recycling and regeneration reuse.

- **Regeneration recycling**: water recovered from the WWTP can be fully or partially recycled to the same operation; and
- **Regeneration reuse**: water recovered from WWTP is not suitable for use in the same operation, due to contaminant levels, but may be utilised in different operations

Kim & Smith (2008) further describe how the use of regenerated water could reduce the freshwater requirements of the production process. If, hypothetically, the wastewater treatment system was able to achieve the same quality as freshwater, it would be possible to achieve a zero discharge of water (Kim & Smith, 2008). In reality, however, the WWTP would not be able to deliver water of the same quality as freshwater. Therefore, sub-processes which require higher quality water should only be supplied by a fresh source (Kim & Smith, 2008).

2.7.3 Process changes

In order to further improve a facility's water efficiency and minimisation efforts, it is possible to optimise an individual process (IPPC, 2006; Kim & Smith, 2008). Examples of possible methods are provided below.

2.7.3.1 Reduction of Driving Force used for the Transfer of Mass

Within the food industry, water is often used to supply the driving force required for the transfer of mass. It should be noted that the driving force of an operation is linked with said operation's flowrate. Whilst it is possible to reduce the driving force, it should be noted that a small driving force could result in additional capital expenditures (Kim & Smith, 2008).

2.7.3.2 Water Free Operations

It is possible to replace water using processes with non-water using processes (Kim & Smith, 2008). Examples of these include:

- **Dry Conveyors**; which could replace flume systems (Masanet et al., 2008); and
- **Ohmic thawing**; in place of traditional heating methods such as water baths (IPPC, 2006)

2.7.3.3 Process Control and Optimisation

Through the implementation of process control measures it is possible to identify any existing spare capacity. Furthermore, these measures allow facilities to prevent any unnecessary water usage (Kim & Smith, 2008). In their reference document the IPPC (2006) provide a list of potential process control and optimisation methods. A few of these examples are listed below:

- **Use of Water nozzles**; water consumption can be lowered by correctly positioned and directed nozzles
- **Use of automated stop/start controls**; water is only supplied when sensors detect the presence of raw inputs
- **Analytical Measurements**; the use of acids and alkalis, and subsequently wastewater generation, can be reduced by using a pH probe
- **Use of Control devices**; valves are the most commonly used control device and their use often results in reduced consumption of water
- **Flow measurement and control**; by installing flow meters it becomes possible to optimise water usage; and
- **Dedicated monitoring and correction of temperature**; steam heating systems can also be optimised to reduce water consumption

2.7.3.4 Avoidance of once-through usage

Water is often used as conduit for cooling or heating processes within the food industry. Once-through systems are known to require large volumes of water to accomplish these processes (Kim & Smith, 2008). However, it has become an established practice for facilities to use recirculating cooling water systems, which are connected to a heat exchanger, for reuse and recycling purposes (Kim & Smith, 2008). The IPPC (2006) report that the use of a closed circuit cooling system could result in water savings of up to 80% in comparison to an open system. Of concern, however, is that bacterial and algal growth could occur within the closed system. This could, however, be mitigated through the addition of chemicals (IPPC, 2006).

2.7.3.5 Improve Production Schedules

By reducing the product changeover of multi-product batch systems, it is possible reduce the amount of water used for washing operations (Kim & Smith, 2008).

2.7.3.6 Provide Staff Training

Consumption and emission levels can be reduced by providing staff with adequate training (IPPC, 2006). The training should not only cover all operations which might be needed during the production process. This includes routine operations, start-up and shutdown operations, cleaning and maintenance practices as well as non-routine operations or abnormal situations (IPPC, 2006).

2.7.3.7 Proper Maintenance

An effective maintenance schedule could result in lower water consumption and wastage (IPPC, 2006). Equipment such as holding tanks, valves, compressor seals and pumping equipment are often the source of major leaks. Therefore, it is necessary to implement pre-emptive and timely maintenance (IPPC, 2006; CLFP, 2015).

2.7.3.8 Improved Cleaning Practices

It is often found that improper cleaning techniques result in the wastage of large volumes of water. It is, therefore, necessary to ensure that water-friendly cleaning techniques are being practiced. A brief description for various techniques can be found in Table 4 below.

Table 4 Brief description of Best Available Cleaning Practices (IPPC, 2006; Masanet *et al.*, 2008)

Cleaning Practice	Description
Pre-soaking of floor and equipment	Dirt can be loosened through pre-soaking; this could make subsequent cleaning easier.
Pressure Cleaning	High Pressure cleaning has been recommended as a BMP by the CLFP (2015). This method could result in greater cleaning efficacy, whilst consuming less water.
Proper use of CIP (Clean-in-place)	CIP systems are cleaning systems which are built into the equipment. These systems can be calibrated to use the optimal amount of water and detergents.
Equip floor drains with catchpots	In order to prevent solids from entering the drainage system, and subsequently the WWTP, a fine mesh basket can be placed over floor drains.
Equip hoses with hand operated triggers	Hoses can be equipped with automatic or trigger controlled shut-off valves
Immediate cleaning of equipment	A delay in cleaning operations could result in the product residues becoming dry and/or crusty. Thus, more water would be required to remove it.

2.8 Wastewater Treatment Options

The fruit and vegetable processing industry is responsible for generating large quantities of both liquid and solid waste (IPPC, 2006). Furthermore, fruit and vegetable processing wastewaters are often associated with high BOD, COD and TSS levels (Table 4). In comparison to other industries the effluents generated by the FVPI are generally less polluted. Treatment is, however, still required before the effluent can be discharged (Valta *et al.*, 2017). Various wastewater treatment techniques exits, all of which fall under three broad categories, namely Physical, Chemical and Biological treatments (Chynoweth *et al.*, 2001; IPPC, 2006). These treatments can further be separated into primary, secondary and tertiary treatments (IPPC, 2006). It has been observed that facilities within the FVPI often only apply a form of pre-treatment before discharging the effluent into the municipal systems (Paulsen, 2006; IPPC 2006).

Table 5 Physiochemical characteristics of various wastewater streams in the FVPI (El-Kamah *et al*., 2010; Amor *et al*., 2012; Valta *et al*., 2017)

Processing type	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	pH
Processing of tomatoes	500	1 500	400	6.5 – 8.0
Fresh and frozen peaches/apricots	1 100	2 300	900	-
Peach and apricot compote	1 300	1 800	460	-
Canned and pureed peaches/apricots	1 750	3 500	500	7.0 – 8.5
Canned and pureed peaches/apricots	1 200	4 000	800	6.0 – 8.0
Citrus juice	6 619	10 019	777	3.8
Fruit juice	1 289	5 157	323	-
Citrus concentrate	13 900	21 040	3 130	3.5
Potato processing	4 000 – 5 000	5250 - 5750	2000 - 2100	7.0 – 8.0

2.8.1 Primary Treatment Options

Primary treatments are mainly focused on the removal of organic and inorganic solids which are readily settled by means of gravity, or those which are able to float (FAO, 1992). Possible primary treatment options include:

2.8.1.1 Screening

Screening is responsible for removing solids such as foreign objects or organic materials. The screening unit generally consists of parallel rods, bars, wires or perforated plates (Spellman, 2016; IPPC, 2006). The spacing between the gratings may vary based on the type of screening desired. For example, when screening for coarse materials a spacing of 20 – 60 mm may be used, whilst for finer screening processes a spacing of no greater than 5 mm is utilised (IPPC, 2006). The main types of screening being utilised in industry include (Kutz, 2018; PPC, 2006):

- **Vibrating screens** are largely utilised for treatments, which mainly focus on the recovery of by-products. More specifically the recovery of solids with a low moisture content. In order for this screening method to be effective rapid motion is required. Vibrating screens are often operated between 900 and 1800 rpm. The screening surface generally consists of one or more decks, but the use of more than two decks is rarely observed. When selecting an appropriate fine vibrating screen it is important to consider the combination of wire strength and open area percentage being applied. The percentage of open area of the screening medium is the determining factor of the capacity of a vibrating screen. The efficiency of vibrating screens is influenced by various factors including: the composition of the solid waste, shape and size of particles, feed rate, stroke length and vibration frequency, ratio of length to width and the slope of the screen (Kutz, 2018). Vibrating screens are best suited for relatively dry and granular mixtures. The use of these systems is rarely seen in the fruit and vegetable processing industry as this method is susceptible to clogging and does not operate efficiently when separating wet materials (Kutz, 2018).
- **Rotary or drum screens** are specifically effective for effluent streams which contain a high solids content. Rotary screens are a popular form of screening devices due to their effectiveness, efficiency and clogging resistance, which can be attributed to their design and operation (Kutz, 2018). Wastewater passes through one end of the screen and solids are dispensed at the other end. Microscreens are utilised in order to accomplish the separation of solid particles from the wastewater. It has been reported that optimal separation is accomplished at operating pressure of 5 – 10 mbar.
- **Static screens** often comprise of vertical bars or a perforated plate. Static screening required manual or automatic cleaning processes.

2.8.1.2 Flow and Load Equalisation

Storage tanks also known as equalisation tanks are often used in order to manage the variability observed in the flow and composition of wastewater. Thus, these tanks may be used to ensure that a steady throughput is maintained and ultimately aim to improve the effectiveness of secondary or advanced wastewater treatment processes (Prabu *et al*., 2016; Chang & Li, 2006). Alternatively, it is used to provide corrective treatments, such as pH adjustment or chemical conditioning (Prabu *et al*., 2016). Load equalisers aim to provide secondary and advanced treatment processes with wastewater which has uniform properties. This is done to ensure that a uniform and effective treatment may be applied to the wastewater. Thus, flow and load equalisation processes aim to improve the efficiency of secondary wastewater treatment processes (IPPC, 2006).

2.8.1.3 Neutralisation

This process is often utilised in the FVPI. The main purpose of neutralisation is to prevent the discharge of strongly acidic or alkaline wastewater (Prabu *et al*., 2016). Neutralisation may be carried out in a holding tank, rapid mx tank or an equalisation tank, in order to maintain pH of between 6 and 9 (Prabu *et al*., 2016. This process further provides protection for downstream treatment operations. Naturally the treatments utilised differ based on the pH of the wastewater (IPPC, 2006).

Neutralisation of acidic wastewater:

- Addition of limestone, limestone slurry or milk of lime
- Addition of sodium carbonate (Na_2CO_3) or caustic soda (NaOH)
- Utilisation of cationic ion exchangers

Neutralisation of alkaline wastewater:

- Addition of CO_2, e.g. flue-gas and gas obtained from fermentation processes
- Addition of hydrochloric acid (HCl) or sulphuric acid (H_2SO_4)
- Utilisation of anionic ion exchangers

The utilisation of this treatment method prevents the negative effect associated with strongly acidic or alkaline wastewater, i.e. the reduction of biological treatment efficiency and/or corrosion (IPPC, 2006).

2.8.1.4 Sedimentation

Sedimentation is often used in operations which produce wastewater containing large amounts of SS. Therefore, it is often utilised in the fruit and vegetable industry (IPPC, 2006). Sedimentation involves the separation of SS from water, by allowing the SS to settle due to gravity (Prabu *et al*., 2016). The settled solids may then be removed in the form of sludge. The sludge produced during sedimentation is often recoverable as by-products for another product such as animal feed (IPPC, 2006).

While the sedimentation unit is simple to install and fairly reliable, the process does have some disadvantages. The sedimentation tanks require large surface areas, the process is not suitable for finely dispersed materials and the laminar separators are often prone to blockages with fat (IPPC, 2006).

2.8.1.5 Dissolved Air Flotation (DAF)

DAF introduces small air bubbles into wastewater containing suspended solids (Prabu *et al*., 2016). The air bubbles are able to attach to particles, which have been chemically conditioned; as the bubbles rise to the surface so do the solids (IPPC, 2006). The float is frequently removed from the surface of the tank (Prabu *et al*., 2016). The air is dissolved into the wastewater under pressures of 300 – 600 kPa. The process has various advantages in comparison to the conventional sedimentation processes. The use of DAF could be advantageous in the sense that it is compact, possesses low hydraulic detention times, high loading rates, smaller flocculation tanks and lastly it has lower construction costs (Lee *et al*. 2020). The process does, however, possess some technical limitations. The DAF process is not suited for the treatment of raw waters containing high-density suspended solids. Additionally, the process also needs to be protected from the environment; for example rain could cause the previously floated solids to settle once again (Lee *et al*. 2020). DAF allows for the reduction of free BOD, COD, SS, as well as the nitrogen and phosphorous levels. As with sedimentation, the sludge acquired during treatment may be recoverable as a by-product (IPPC, 2006).

2.8.1.6 Centrifugation

Centrifugation is often applied for thickening or dewatering purposes. The centrifugal forces created when the centrifuge rotates at high speeds ensure that the sedimentation process is accelerated (Strande *et al*., 2014). Four types of centrifuges are available in industry, namely **solid bowl**, **basket**, **disc-nozzle** and **decanter centrifuges**. Solid bowl centrifugation requires the supernatant liquors to be removed from the surface. Whilst the basket system makes use of a perforated mesh, which allows the liquids to pass through the screening medium during centrifugation. Disc-nozzle centrifugation is mostly used in processes where liquid/liquid separation is required. Decanter centrifuges are often used for the separation of activated sludge (IPPC, 2006).

2.8.1.7 Precipitation

Precipitation may be used in cases where suspended solids cannot be separated from wastewater by means of gravity. The primary targets of precipitations are SS and phosphorous. The process of precipitation consists of three stages. With coagulation being the first stage; it is carried out in order to disrupt the colloidal system by lowering the potential responsible for the stability of the system. This is usually accomplished by dosing the wastewater with inorganic chemicals such as ferric chloride, lime or aluminium sulphate (Prazeres *et al*., 2019; IPPC, 2006). This is followed by the flocculation of the smaller particles into larger particles, which are readily able to settle or float. Polyelectrolytes may be added in order to assist with bridge formation between particles to eventually produce large flocs. In some cases the precipitation of metal hydroxides may occur, these hydroxides are able to adsorb fat particles. Once precipitation has been completed, the sludge is removed by means of sedimentation or DAF (IPPC, 2006).

2.8.2 Secondary Treatment Options

The primary focus of secondary treatments are the removal of biodegradable organic matter as well as SS by means of biological methods (IPPC, 2006). The organic sludge produced during the treatments are also responsible for the adsorption of non-biodegradable compounds, such as heavy metals. It is possible to utilise a single secondary treatment or a combination of methods, based on the wastewater characteristics as well as the requirements before discharge (IPPC, 2006). Processes where secondary treatments are used in combination are often referred to as multistage systems (IPPC, 2006). The main types of metabolic processes utilised during secondary treatments are: aerobic and anaerobic processes.

2.8.2.1 Aerobic Processes

Aerobic processes are often only utilised when the wastewater in question is readily biodegradable (IPPC, 2006). During these processes digestion takes place in the presence of oxygen. A combination of autotrophic and heterotrophic microorganisms are often used to accomplish the aerobic digestion (Aziz *et al*., 2019). Microorganisms in suspension are provided with oxygen by means of submerged diffusers or a surface input. Oxygenation cages or surface aerators may be used to inject oxygen into the suspension from the surface (IPPC, 2006). The advantages and disadvantages of aerobic treatments are displayed in the Table 6.

Table 6 Advantages and Disadvantages of aerobic treatment processes (IPPC, 2006)

Advantages	Disadvantages
Degrades organic matter into harmless compounds	Produces large amounts of sludge Digestion results in fugitive releases which may cause odours Low temperatures lead to a decrease in bacterial activity FOG needs to be removed prior to initiation of aerobic biological treatment, as it could lower the efficiency of the WWTP since it is not readily degradable by bacteria

2.8.2.1.1 Activated sludge

The activated sludge process is characterised by its ability to produce an activated mass of microorganisms, which are able to stabilize waste in the presence of oxygen. The process allows operators to reduce the COD, BOD, nitrogen and phosphorus levels of the wastewater (IPPC, 2006). After the retention period the microbial biomass and treated liquid are separated (Sigge, 2005). The biomass is often kept in suspension in a reactor vessel, where it is further supplied with oxygen. This process is divided into two distinct phases, which are generally performed in separate basins, namely: aeration and settling (Paulsen, 2006; Sigge, 2005).

Aerobic oxidation takes place within the aeration basin. During this phase the organic matter is degraded to CO_2, H_2O, ammonium (NH_4) and new biomass (Paulsen, 2006; Sigge, 2005). The suspension within the aeration basin is known as the mixed liquor (ML). Aeration serves two functions within this process: firstly supplying the aerobic microorganisms with oxygen and, secondly ensuring the constant agitation of the activated sludge flocs (Paulsen, 2006). Agitation ensures that sufficient contact between the flocs and incoming wastewater takes place. Aeration is furthermore regarded as the main energy consumer of the activated sludge process, due to oxygen being supplied by mechanical means on a continuous or semi-continuous basis. Due to the aerobic conditions energy may be recovered in terms of biomass per unit substrate processed. This, however, results in a large amount of sludge production, which requires further processing and disposal. The sludge production is largely responsible for the major operating expenses of this procedure and is further regarded as its main disadvantage (Deepnarain *et al*., 2019; Paulsen, 2006).

The retention times of the biomass within the reactor vessels may vary from several hours to more than 10 days. Generally a loading rate or F/M ratio of 0.1 – 0.15 BOD/kg MLSS per day is used (von Sperling, 2007; IPPC, 2006). After this predetermined retention period, the mixed suspension of microorganisms is forwarded to a sedimentation facility. The F/M ratio and hydraulic retention time (also known as sludge age) may vary based on multiple factors. This includes the characteristics of the raw wastewater, such as its composition as well as the degradability of organic material; and the quality required for the final wastewater. For instance, nitrification only occurs at low loading rates (<0.1 BOD/kg MLSS per day) (von Sperling, 2007; IPPC, 2006). Upon reaching the sedimentation facility, the microbial flocs start to settle and the clear wastewater passes over a weir and on to a watercourse. The majority of the settled sludge is returned to the aeration tank.

However, in order to maintain the MLSS at an acceptable level, e.g. 3 000 mg/L, the excess sludge is wasted (von Sperling, 2007; IPPC, 2006).

Bulking is a problem commonly associated with the activated sludge process. More specifically it is often observed in processes treating high carbohydrate wastes, such as those found in fruit and vegetable canneries (Sigge, 2005). Bulking describes biological sludge which possesses meagre settling characteristics. It is generally observed due to excessive water binding within the biological flocs and/or the presence of filamentous bacteria (IPPC, 2006). It is important to note that when considering the bulking of sludge, prevention is better than curing the problem. This is due to the fact that various chemicals may be used as a cure for bulking. However, these curing methods are usually not highly selective and may lead to the destruction of the entire biological activity (IPPC, 2006). The prevention of bulking may be accomplished by various methods, these include: maintaining an optimal balance of added nutrients as well as minimising the overproduction of filamentous bacteria. Load reduction has been reported as an acceptable method to manage the effects of bulking once it has occurred. The operating temperatures, hydraulic retention time and sludge age are the most important factors to consider when dealing with the bulking of sludge (von Sperling, 2007; IPPC, 2006).

In addition to the above mentioned processes the use of a selector has been recognised as an acceptable method to restrict the growth of filamentous bacteria. This process involves the selective growth of floc-forming organisms; this is accomplished by supplying the wastewater with high F/M ratios at controlled dissolved oxygen levels. The contact time for this process is generally short, with a range of 10 – 30 minutes usually being utilised (von Sperling, 2007; IPPC, 2006).

It has been reported that the activated sludge process is capable of accomplishing phosphorus removal efficiencies of about 10 – 25% (IPPC, 2006). Furthermore, it has been found that this process is capable of treating wastewater with high or low BOD levels, but the treatment of low BOD water yields higher efficiencies and is more cost effective. The application of this method may however, be limited by its space requirements (IPPC, 2006).

2.8.2.1.2 Pure Oxygen Aeration

Ordinary oxygen supply technologies are usually sufficient in biological processes, which treat low intensity effluents. A problem often arises when treating high intensity wastewaters, as the supply of oxygen often becomes a bottleneck in the activated sludge process (Zhang *et al*., 2019). In order to solve this problem the pure oxygen aeration system was developed in 1970, this system aims to maintain a high concentration of dissolved oxygen (DO) in aerobic systems (Zhang *et al*., 2019). By maintaining a high DO concentration this system is able to enhance the efficiency of the activated sludge process (IPPC, 2006).

In their study Zhang et al. (2019) found that a pure oxygen activated sludge system was able to reduce the total organic carbon (TOC) from an initial concentration of 103 mg/L to 13 mg/L within 60 minutes. This was much more effective than the air aerated system which was only able to reduce the concentration from 103 mg/L to 66 mg/L. Thus, it is possible to increase the rate of degradation by implementing pure oxygen aeration. This improved rate of degradation may also result in lower tank volumes being required.

Furthermore, this technique also utilises less energy in comparison to conventional activated sludge processes. This is due to the fact that in conventional systems roughly 70% of the energy is wasted since the air utilised consists of 70% nitrogen (IPPC, 2006). The main driving force for the implementation of this technique is the fact that it may be retrofitted to already existing processes, thereby improving their efficiencies (IPPC, 2006). It is, however, important to note that the implementation of this technique often results in higher operational costs compared to conventional techniques.

2.8.2.1.3 Sequencing Batch Reactors

The Sequencing Batch Reactor (SBR) process is a variation of the activated sludge process. This process generally utilises two identical reaction tanks and its operations is based on the fill and draw principle. Multiple stages of the activated sludge process occur within the same reactor (WEF, 2018).
This process is regarded as being very flexible since it is possible to make various process changes within the operating cycles, such as improved denitrification during the stationary phase. Typically the cycle period lasts about six hours. However, the time utilised for each stage within the process may be adjusted in order to suit the requirements. Furthermore, the process is not dependant on the fluctuations in hydraulic input. This means that SBR possess a simpler and more robust operation in comparison to conventional activated sludge processes (WEF, 2018; IPPC, 2006).

SBR are capable of treating high and low BOD wastewaters, but a higher efficiency cost effectiveness is accomplished when treating low BOD wastewater. SBR are also suitable for industrial wastewaters which have a tendency towards the bulking of sludge. This is due to the fact that this process makes use of batch wise filling, which allows for the formation of readily settling activated sludge (IPPC, 2006). The SBR is typically utilised in small-flow operations, which produce around 4 000 m^3 wastewater per day. Thus, it is typically applied as an extended aeration system (WEF, 2018). Similar processes with larger capacities do, however, exist with capacities ranging from 150 000 – 700 000 m^3 wastewater per day (WEF, 2018). The SBR process requires lower capital but higher operational costs in comparison to conventional activated sludge processes (IPPC, 2006).

2*.8.2.1.4 Aerobic Lagoons*

Aerobic lagoons can be described as large shallow earthen basins which are used for treating wastewater by means of natural processes. They generally involve the use of bacteria, algae, the sun as well as the wind. The algae and bacteria are kept in suspension in the lagoon whilst aerobic conditions are maintained throughout the entire lagoon. Oxygen may enter the system by means of mechanical or atmospheric diffusion, however it may also be produced by algae (Paulsen, 2006; IPPC, 2006). Pumps or surface aerators are usually used to mix the contents of the lagoons (IPPC, 2006).

Aerobic lagoons can be divided into two basic types, differing in objective. The first operation is mainly focussed on maximising the production of algae, the design utilised during this process is generally limited to pond depths of 150 – 450 mm. The second type is aimed at maximum oxygen production, using pond depths up to 1.5 m (Paulsen, 2006).

Aerobic lagoons aim to reduce the nitrogen and BOD levels within the wastewater. This process may however lead to soil degradation, contamination of groundwater and the production of unwanted odours (IPPC, 2006). Due to the low solids maintained in the system aerobic lagoons are often operated at high organic loadings (Sigge, 2005).

When applying this technique to processes within the fruit and vegetable industry the lagoons should have sufficient capacities in order to prevent uncontrolled overflows. The lagoons should also allow for the controlled discharge of wastewater during periods where high flow is experienced (IPPC, 2006). Furthermore, it has been reported that the aerated lagoons were able to obtain 95 % BOD removal efficiencies (Manivasakam, 2013; Sigge, 2005).

2.8.2.1.5 Trickling Filters

Trickling filters, also referred to as biofilters or percolating filters, are an example of a fixed film aerobic process (Manivasakam, 2016). During this procedure wastewater, after being subjected to a primary treatment, is passed over a bed of broken rocks. The biomass formed on the surface of these stones oxidize the wastewater as it passes across the film (Manivasakam, 2016; IPPC, 2006). Trickling filters generally consist of a circular or rectangular tank containing the filter medium (stones, plastic media, treated wood or hard coal) with a bed depth of 1.0 – 3.0 m. This ensures that a large surface area is available for maximal microbial growth and film formation (Manivasakam, 2016; Sigge, 2005). Furthermore, it should also be sufficiently porous in order to allow air and sloughed microbial biofilm to pass through. The selection of filter media is generally based on various factors including: specific surface area, unit weight, void space as well as media configuration, size and cost. For example, smaller filter media provide a larger surface are for biofilm formation, but also results in a smaller void space (Sigge, 2005). Plastic media usually consists of polyvinylchloride (PVC) or polypropylene (PP) and are primarily applied in high rate trickling filters. They have a low bulk density and provide an optimum surface area (85 – 140 $m^2.m^{-3}$) as well as a higher void space (up to 95%) in comparison to other media (Manivasakam, 2016; Sigge, 2005). Therefore, this media reduces the occurrence of clogging. Since plastic is a lightweight material, it requires less heavily reinforced concrete tanks than observed when making use of stone media.

Generally, an underdrain system is included as a means to collect the treated wastewater and biomass that have been sloughed off the biofilm material. Finally, a separation tank, also known as a humus tank, is required to separate the solids from the treated wastewater (Manivasakam, 2016; Sigge 2005). A portion of the treated liquid is recycled within these settling tanks in order to dilute the incoming wastewater (IPPC, 2006).

Trickling filters are generally applied to reduce the BOD/COD, phosphorus and nitrogen levels of wastewater. Organic loading rates associated with this method may vary, with the typical loading rate being 0.5 $kgBOD.m^{-3}.d^{-1}$. Low rate filters may exhibit loading rates of 0.1 – 0.4 $kgBOD.m^{-3}.d^{-1}$, whilst high rate filters exhibit loading rates of 0.5 – 1.0 $kgBOD.m^{-3}.d^{-1}$ (Sigge, 2005). BOD removal by means of trickling filters is around 85% for low rate filters, while high rate filters show 65 – 75% BOD removal (Sigge, 2005). Trickling filters are, however, generally only utilised for wastewaters with relatively low BOD levels since high organic loads may cause filter blockages as a result of excessive biofilm formation (IPPC, 2006; Sigge, 2005). In order to ensure that the process operates at optimal efficiency it is important to minimise FOG levels before the wastewater is fed into the high rate filter. In certain cases where high effluent quality is required, a secondary sedimentation process may be applied after the high rate filtration (IPPC, 2006).

2.8.2.1.6 Biological Aerated Flooded Filters (BAFF) and Submerged Biological Aerated Filters (SBAF)

Biological Aerated Flooded Filters (BAFF) and Submerged Biological Aerated Filters (SBAF) are fixed-film systems, which entails submerging a biofilm support medium in wastewater in order to provide a large contact surface for aerobic biological treatment (Hodkinson *et al*., 1999). Media often utilised in BAFF's generally have a high specific surface area as well as a low voidage. The requirements of the surface-area is usually very low and organic loading rates may be greater than 10 kgCOD.m^{-3}.d^{-1}. Due to the high level of solid retention and the development of biomass a regular backwashing step is required in order to remove the accumulated solids. SBAF's are essentially BAFF's which make use of high-voidage media (typically < 400 m^2.m^{-3}). However, a backwashing step is not required as the solids accumulated in the reactor are regulated by biomass sloughing as well as air-scouring (Hodkinson *et al*., 1999). By removing the backwashing process the costs of construction and operation are reduced. SBAF's are generally suitable for small plants where robust, simple and compact treatment is desired. SBAF is usually used to treat settled wastewater and often requires secondary sedimentation (Hodkinson *et al*., 1999). Typically these systems are primarily used as a polishing phase in domestic wastewater treatment processes, however, the use of SBAF has increased in the FDM sector.

2.8.2.1.7 High Rate and Ultra-high rate Aerobic Filters

The use of high rate and ultra-high rate filters allow aerobic systems to accommodate higher loading rates than usual. With ultra-high rate filter systems providing the potential for loading aerobic systems 50 – 100 times greater than conventional aerobic processes (IPPC, 2006). This is due to the fact that these processes utilise media, such as PVC, which are able to minimize clogging issues and provide a large surface area for biofilm formation (Jeong *et al*., 2019; Manivasakam, 2013). These processes involve a high wastewater recycle rate, which is directed through a nozzle assembly. The nozzle provides the system with air, which provides a high shear force on the bacteria in the system. It also yields a high degree of oxygenation (IPPC, 2006).

High rate and ultra-high rate filters are mainly concerned with the reduction of BOD and COD levels within the wastewater effluent. However, due to their high throughput rates they generally do not yield a wastewater quality that is sufficient for river discharge. Thus, an additional aerobic phase, which is loaded more conservatively, is often required (Manivasakam, 2013; IPPC, 2006).

2.8.2.2 Anaerobic Processes

Anaerobic wastewater treatment processes entail the degradation of organic matter in the absence of oxygen, this often leads to the production of CO_2 and methane (CH_4) as a by-product (IPPC, 2006; Paulsen, 2006). Certain anaerobic processes produce methane as a by-product, which may be utilised as a source of fuel. Standard anaerobic reactors are generally unheated whilst high rate anaerobic processes make use of heated reactors. In both cases, the temperature of the reactors need to be maintained at approximately 30 - 35°C for standard processes or 45 – 50°C when using high rate processes (Manivasakam, 2013; IPPC, 2006).

Even though microbial growth is slower under anaerobic conditions, higher BOD loadings are achievable in comparison to aerobic techniques. Anaerobic processes are typically applied in industries which have a high level of soluble and readily biodegradable organic material as well as wastewater strength, when expressed in COD, greater than 1 500 – 2 000 mg/L (IPPC, 2006). In the Food, Drink and Milk industry anaerobic processes are generally only applied when treating wastewater with a COD of approximately 3 000 – 4 000 mg/L, commonly observed in the sugar, starch, fruit and vegetable industries.

2.8.2.2.1 Anaerobic Lagoons

Anaerobic lagoons serve as both a sedimentation basin and an anaerobic treatment device for high-strength organic wastewater which contains a high solid concentration (Paulsen, 2006). These lagoons are generally deep earthen basins with appropriate inlet and outlet piping. These lagoons may have a depth of 2.5 – 9.0 m in order to ensure that anaerobic conditions are maintained throughout the lagoon as well as to ensure the conservation of heat energy (Cheremisinoff, 2016; Paulsen, 2006; Sigge, 2005). In anaerobic lagoon systems organic matter is converted to CO_2, CH_4 and other gasses such as hydrogen sulphide (H_2S) as well as organic acids and cell biomass (Paulsen, 2006; Sigge, 2005). Conversion efficiencies ranging from 75 – 85% have been reported when operating at optimal conditions (Paulsen, 2006). The minimum organic loading level generally required to acquire totally anaerobic conditions in a lagoon is 100 g $BOD_5.m^{-3}.d^{-1}$. For optimal performance systems should be maintained at conditions which are favourable to the methanogenic bacteria present in the lagoons. It is necessary to maintain the temperature of the system between 25 - 40°C. A rapid decrease in anaerobic activity is observed at temperatures below 15°C, with activity being virtually halted once temperatures drop below 10°C (Cheremisinoff, 2016; Paulsen, 2006). Naturally this process comes with its own unique advantages and disadvantages, which are displayed in Table 7.

Table 7 Advantages and Disadvantages of Anaerobic Lagoons (Cheremisinoff, 2016)

Advantages	Disadvantages
More effective for rapid stabilization of strong organic wastes; allows for greater influent organic loading	Requires relatively large area of land
Produces CH_4 as by-product, which can be used to generate power for other processes within the facility	May produce undesirable odours (due to production of H_2S)
Produces less biomass per unit of organic material processed	Requires a long retention time for organic stabilization
Does not require additional energy, since systems are not aerated, heated or mixed	Wastewater may cause ground degradation or affect underground water quality
Lower construction and operation costs than other methods	Environmental conditions directly impact the operation of this system
Lagoons may be operated in series	

2.8.2.2.2 Anaerobic Contact Processes

Anaerobic contact processes are often associated with the activated sludge process, due to the design incorporating the separation and recirculation of biomass (IPPC, 2006). The influent waste passes through a contact reactor which contains a high concentration of active biomass. A downstream clarifier is responsible for removing the active biomass from the effluent stream in order to recycle the biomass back to the contact unit (Show, 2008). This method is generally applied when treating wastewater which contains high-strength soluble wastes. The fact that this technique is relatively simple to operate and does not experience high levels of clogging is arguably the main driving force for its implementation (IPPC, 2006). In comparison to other high performance processes, contact stabilisation processes usually do not produce such high biomass concentrations. Thus, this process can accommodate a relatively low organic loading of up to 5 kg COD/m^3 per day (IPPC, 2006).

2.8.2.2.3 Anaerobic Filters

In anaerobic filters, as with aerobic filters, microbial growth is established on a packaging material (Stanbury, 2017; IPPC, 2006). The packaging material is responsible for retaining the biomass within the reactor. It further assists with the separation of the gas from the liquid phase. This system may be adapted to operate in an upflow or downflow mode, with a wide variety of packaging materials available (Stanbury, 2017; IPPC, 2006). The average specific surface area of the packing utilised in this process is about 100 $m^2.m^{-3}$. Anaerobic filters are suitable for the treatment of wastewaters containing a COD level of 10 000 – 70 000 mg/L (IPPC, 2006). Stanbury (2017) reported that this technique has been applied for the treatment of effluents originating from various processes, including: citric acid fermentation wastes, molasses distillery slops, domestic effluents, food canning and soft drink wastes.

2.8.2.2.4 Upflow anaerobic sludge blanket (UASB)

In this system high levels of active biomass are retained through the formation of sludge granules, a process also known as flocculation (Stanbury, 2017; van Schalkwyk, 2004).The UASB reactor can be separated into three distinct parts (van Schalkwyk, 2004; Lettinga & Hulshoff Pol, 1991):

1. A sludge bed situated at the bottom of the reactor, where the heaviest portion of the biomass is located.
2. A sludge blanket is positioned slightly above the sludge bed and is a dispersed layer of fluidized sludge flocs and small granules.
3. The gas-solid separator is found at the top of the reactor, where the gas and sludge are separated by means of gas baffles. Once the gas and sludge have been separated, the sludge particles settle back to the sludge bed (Stanbury, 2017; van Schalkwyk, 2004).

Wastewater is directed towards the bottom of the reactor in order to ensure uniform distribution (IPPC, 2006). The organic compounds are then metabolized by the anaerobic biomass within the reactor. This leads to the conversion of organic matter into biogas and new biomass (van Schalkwyk, 2004). The biogas is then removed from the sludge, after which the clean effluent is pumped out of the top of the reactor. Typically the design of the UASB reactor favours the formation of heavy biomass/granules, but simultaneously it aims to maximize the hydrolysis of suspended solids. A schematic illustration of a UASB reactor design is shown in Fig. 4. It is possible to change the design of these reactors in order to suit hydraulic capacities. Furthermore, they exhibit excellent flexibility when it comes to treating wastewater with high COD levels (van Schalkwyk, 2004). The success of this system is largely based on two principles. The optimal contact between the sludge and wastewater is acquired by means of natural mixing within the reactor due to biogas production and a well-designed inlet system, which results in the wastewater being equally distributed within the reactor (Stanbury, 2017; van Schalkwyk, 2004). A typical loading rate for this system is about 10 kg COD.m^{-3} per day, with loading rates of up to 60 kg COD.m^{-3} have been reported (IPPC, 2006).

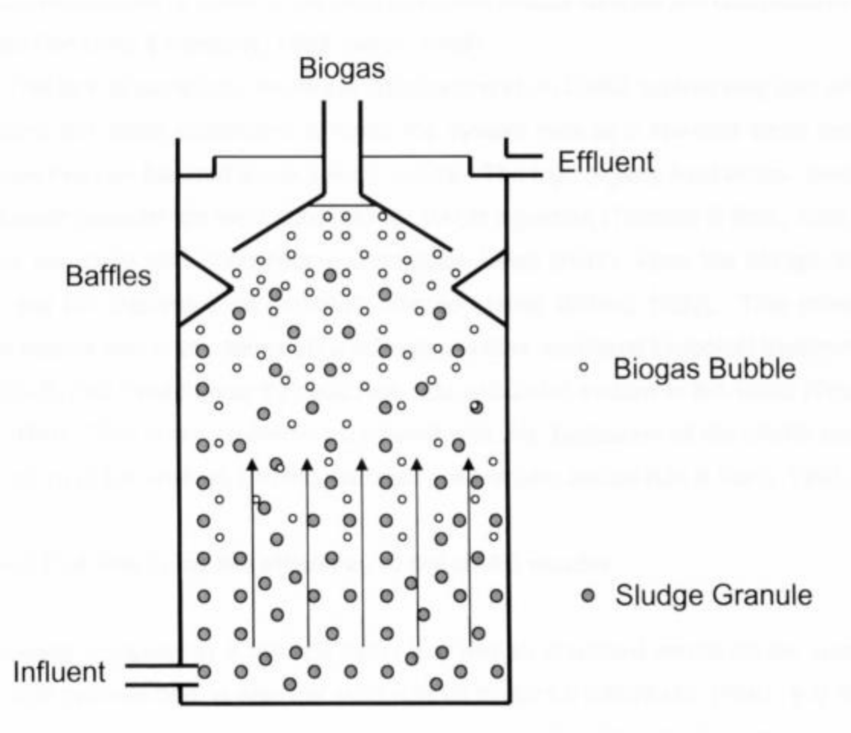

Figure 4 Typical Upflow Anaerobic Sludge Bed (UASB) reactor (van Schalkwyk, 2004).

It has been found that anaerobic sludge blankets are an efficient technique for treating various wastewaters, including sugar-beet wastes, domestic effluents, slaughterhouse wastes and agricultural effluents (Stanbury, 2017). With van Schalkwyk (2004) stating that the high organic load observed in food processing effluents provide an ideal substrate for UASB digestion. Since the sludge retention is not dependant on hydraulic retention times, the reactor is able to accommodate short hydraulic retention time (HRT). In comparison to other 'new' systems, the UASB reactor is fairly simple to operate. It, furthermore, does not require support media to operate (Stanbury, 2017). These characteristics provide the UASB reactor with various competitive advantages over other conventional biological treatments (van Schalkwyk, 2004).

2.8.2.2.5 EGSB

The Expanded Granular Sludge Blanket (EGSB) reactor is a variation of the UASB reactor. The EGSB reactor was developed in order to compensate for the suboptimal mixing observed in the UASB reactors (Nishio & Nakashimada, 2013). The EGSB reactor can simply be described as a vertically stretched variation of a UASB reactor. EGSB reactors are typically 12 – 16 meters in height, whilst conventional UASB reactors are typically 4.5 – 6.5 meters in height (Driesen & Vereijken, 2003). Due its high height/diameter ratio, the EGSB reactor is able to achieve greater upflow rates (ranging from 2 – 10 m/h) when compared to those achieved by the UASB reactor (Faria *et al*., 2019). The increased uplfow rates result in the partial expansion or fluidization of the granular sludge bed; which in turn ensures improved contact between the wastewater and the sludge. The EGSB system makes use of granules, which possess a high cell density as well as good settleability characteristics (Faria *et al*., 2019). The EGSB system is able to accommodate organic loading rates of up to 40 kg-COD/m^3/day. The system is, furthermore, suitable for the treatment of low-strength (<1-2 g-COD/L) as well as effluents containing inert suspended particles (Nishio & Nakashimada, 2013) . The advantages associated with the EGSB system include (Cruz-Salomón *et al*., 2019):

- Simple design
- Makes use of unsophisticated equipment
- Produces low levels of anaerobic granular sludge (AGS)
- Provides high treatment efficiency
- Inexpensive operating costs
- Potential to generate renewable energy

2.8.2.2.6 Internal Circulation (IC) Reactor

The internal circulation reactor is another version of the UASB reactor. An IC reactor consists of two UASB reactor compartments stacked on top of each other (Habets *et al.*, 1997; Li & Li, 2019). Similar to the EGSB system the IC reactor possesses a greater height to diameter ratio in comparison to the UASB reactor (Chen *et al.*, 2021). This results in improved biomass retention capabilities as well as an enhanced mixing intensity (Chen *et al.*, 2021).

The first compartment of the reactor contains an expanded granular sludge bed, which converts most of the COD, found in the effluent, into biogas. The produced biogas is then captured and redirected towards the bottom of the reactor; this creates a gas lift which carries the water and sludge upwards to the top compartment (Habets *et al.*, 1997; Wu *et al.*, 2012). Once the mixture reaches the top compartment, the biogas is separated from the effluent and discharged. The water and sludge mixture is then pumped back to the bottom compartment, resulting in the internal circulation flow (Habets *et al.*, 1997). The improved internal circulation ensures the greater transfer of biomass (Wu *et al.*, 2012). Consequently, the IC reactor is capable of accommodating organic loads of up to five times greater than those observed for UASB reactors (Chen *et al.*, 2021). Therefore, the IC reactor is suitable for the treatment of high strength wastewaters (Li & Li, 2019; Chen *et al.*, 2021).

2.8.3 Tertiary treatment options

Tertiary treatment typically refers to any method which is regarded as a 'polishing' step. Tertiary treatment is the further treatment of wastewater effluent from secondary processes in order to remove any suspended, colloidal and dissolved materials which may remain after processing (IPPC, 2006; Manivasakam, 2013; Stanbury, 2017). These elements may be simple inorganic compounds such as nitrates and metal ions or more complex organic molecules. Components of particular concern are ammonia, plant nutrients (i.e. nitrogen and phosphorus), dangerous and priority hazardous compounds or residual SS (IPPC, 2006; Stanbury, 2017). When selecting a suitable nutrient control strategy, it is important to consider the following factors (IPPC, 2006):

- The characteristics of the raw wastewater

- The type of WWTP to be utilised
- The level of nutrient control necessary
- The need for seasonal or year-round nutrient removal

2.8.3.1 Biological nitrification/denitrification

The IPPC (2006) describe four types of denitrification processes:

- In **preceding denitrification**, wastewater enters the denitrification basin. Nitrogen in the form of NH_4 does not experience any changes when passing through the basin, however, organic N is partially hydrolysed to NH_4. The hydrolysis is completed in the subsequent nitrification basin, and the ammonium gets nitrified to nitrate. The nitrate is then directed to the denitrification basin, where it is able to reduce the nitrogen concentration.
- In systems using **simultaneous denitrification**, anaerobic and aerobic zones are formed on a targeted basis by regulating the basin's oxygen input. These systems are commonly designed as circulation systems.
- **Intermittent denitrification systems** utilise activated sludge basins, which are continuously stirred and periodically aerated. In such a system aerobic and anaerobic processes take place sequentially within the same basin. It is possible to adjust the levels of nitrification and denitrification in order to suit the feed conditions. This can be accomplished by adjusting the operating times.
- In **cascaded denitrification** systems, multiple basin partitions consisting of aerobic and anaerobic regions are arranged in series. The raw wastewater is passed into the first cascade in order to ensure that substrate present in the wastewater is utilised to an optimal extent.

Generally these processes provide a high removal efficiency as well as high operating stability and reliability. Furthermore, the process is relatively easy to control and does not require a large area of space to be constructed (IPPC, 2006).

2.8.3.2 Ammonia stripping

In the Food, Drink and Milk sector it is a common occurrence for condensates to contain high concentrations of ammonium. A two-phase system, consisting of a desorption and an adsorption column may be used to accomplish the stripping of ammonia. Both columns contain packing material which increases the water-air interface (IPPC, 2006; Larsen *et al*., 2013).

The **desorption column** is loaded with an alkalised condensate from the top, which charges the column. This leads to the NH_4^+ - NH_3 equilibrium shifting in the favour of ammonia (NH_3). Subsequently, NH_3 moves towards the bottom of the column. Simultaneously, the column is aerated by injecting air into the base of the column. In this counter-current process NH_3 is transferred from the liquid state to the gaseous state (IPPC, 2006; Larsen *et al*., 2013).

Thereafter, the NH_3 enriched air is transferred to the **adsorption column**. Here the ammonia is removed from the stripping air by means of an acidic solution, which consists of approximately 40% ammonium sulphate, circulating through the desorption column. After the NH_3 has been removed from the air, the clean air may be re-used for further stripping (IPPC, 2006; Larsen *et al*., 2013).

Ammonia levels within wastewater are usually strongly regulated due to the toxic effect it has on the environment. When implementing this process, ammonium concentrations of less than 2 mg/L may be achieved in the outflow, which corresponds to removal efficiency of about 99% (IPPC, 2006). Furthermore, this procedure is a viable option for facilities who are aiming to be environmentally friendly since it results in reduced nitrogen level, creates less waste and allows for the re-use of water as service water (IPPC, 2006; Larsen *et al*., 2013).

2.8.3.3 Biological removal of phosphorus

If facilities within the Food, Drink and Milk sector make use of cleaning agents which contain phosphate, their wastewater may contain significant levels of phosphorus. Up to 25% of the phosphorus found in raw wastewater may be removed during primary and secondary treatments. However, should further removal be required, biological methods may be used to achieve this (IPPC, 2006). When applying biological methods the phosphorus is removed from the effluent incorporating it into the biomass and wasting the excess phosphorus-laden biomass (WEF, 2015). This process is dependent on specific groups of bacteria which are capable to metabolize phosphorus in excess of their growth requirements when exposed to anoxic conditions in the presence of volatile fatty acids (VFA), and then being subjected to aerobic conditions (WEF, 2015). These bacteria are commonly referred to as *polyphosphate-accumulating organisms* (PAOs).

When subjected to anoxic conditions, PAOs take up VFAs from the wastewater, and store this carbon within their cells. Once subjected to aerobic conditions, the PAOs are able to use this carbon reserve for vital functions such as: growth, cell maintenance as well as creating phosphorus reserves within the cells. The phosphorus acquired from the wastewater is stored within the cells as polyphosphates, which in turn results in the significant increase of phosphorus observed in the sludge (WEF, 2015). Sedimentation is used to separate the PAOs, with high phosphate content, along with the biomass from the clean water. Subsequently, these PAOs are removed from the system when the excess biomass is discarded. The phosphorus removal efficiencies of various wastewater treatment processes are summarised in Table 8.

Table 8 Phosphorus removal efficiencies of various wastewater treatment processes (IPPC, 2006)

Treatment Process	**Removal of phosphorus (%)**
Primary processes	10 – 20
Precipitation	70 – 90
Activated Sludge	10 – 25
Trickling filter	8 – 12
Biological phosphorus removal	70 – 90
Carbon adsorption	10 – 30
Filtration	20 – 50

Biological phosphorus removal is applicable in any process where wastewater containing phosphorus is produced. Therefore, it a suitable treatment process for facilities within the fruit and vegetable processing industry.

2.8.3.4 Dangerous and priority hazardous substances removal

It is not uncommon for organic solvents, pesticide residues and toxic organic and inorganic chemicals to appear in wastewater streams. The removal of many of these substances may be achieved by implementing treatment processes such as sedimentation, precipitation, filtration as well as membrane filtration. However, further removal may be accomplished by utilising processes such as carbon adsorption and chemical oxidation (IPPC, 2006; WEF, 2015).

The **carbon adsorption** process utilises a filtration bed, which contains granular activated carbon. The effluent passes through the filtration bed, where organic compounds are absorbed on the carbon surface (Cheremisinoff, 2016). Once the carbon is saturated it may be removed from the system and restored. Bituminous coal is the most widely used carbon source utilised for this process (Cheremisinoff, 2016). Some organic compounds found in the effluent exhibit resistance to degradation by means of biological techniques and are often responsible for the foul odour, taste or colour of the water. The activated carbon has an affinity for these organic constituents. The adsorption rate of this process generally influenced by the size of the carbon particles, whilst it is not influenced by the adsorptive capacity (Cheremisinoff, 2016).

Chemical oxidation may be used in order to remove ammonia, lower the residual organics concentration and reduce the bacterial and viral content of the wastewater. This is accomplished by utilising oxidative reagents such as chlorine, chlorine dioxide and ozone (IPPC, 2006; Jafarinejad, 2017).

2.8.3.5 Filtration

Filtration is often used as a wastewater polishing step, which ensures the removal of solids. However, unlike processes such as sedimentation or DAF, in filtration systems it is not necessary for the particles and the liquid to possess different densities (IPPC, 2006). The separation of the particles from the wastewater occurs due to the presence of a pressure gradient following the passage of water through the filter. Thus, the filter medium ensure that the particles are held back (IPPC, 2006).

The type of filter used may vary based on the nature of the solids within the wastewater. Standard sand filters are generally used for the removal of SS, since the soluble BOD levels are usually very low after aerobic treatments (IPPC, 2006). Simple sand filters are capable of removing particles down to 5 μm in size. More complex systems such as multi-media filter, which generally consist discrete layers of sand and anthracite, are able to efficiently remove particles down to 2 μm in size (Mobley, 2001; IPPC, 2006).

2.8.3.6 Membrane filtration

Membrane filtration systems make use of a pressure driven, semi-permeable membrane in order to accomplish selective separations (IPPC, 2006). The selectivity of these systems can be attributed to the pore sizes of the membranes. For example, if the aim of the process is to remove precipitates or suspended solids, relatively large pores may be used. Whilst, when the aim is to remove inorganic salts or other organic molecules, very small pores are generally utilised (Manivasakam, 2013; IPPC, 2006). These systems function by allowing the feed solution to flow over the surface of the membrane, the clean water then passes through the membrane whilst the contaminants and a portion of the feed remain in solution (IPPC, 2006). Various types of membrane filtration systems exist:

- **Cross-flow microfiltration (CFM)** is a filtration system which makes use of membranes with pore sizes of approximately 0.1 – 1.0 μ. This technology is, however, not regularly implemented in the food processing industry since it is not capable or removing suspended solids. Therefore, it is generally best utilised as a pre-treatment for other filtration methods such as nanofiltration (Manivasakam, 2013; IPPC, 2006).
- **Ultrafiltration (UF)** is a process similar to CFM, however, it makes use of smaller pores (0.001 – 0.02 μ) (IPPC, 2006). This smaller pore size allows these systems to prevent molecules with diameter larger than 1 nm or nominal molecular weights larger than 2 000 to pass through the filter. In order to combat the fouling of the membrane, primary treatment is generally required (IPPC, 2006).
- **Reverse osmosis filtration (RO)** may also be referred to as hyper filtration. This technique is capable of rejecting dissolved organic and inorganic molecules (Manivasakam, 2013; IPPC, 2006). Wastewater is filtered through a semi-permeable membrane at a pressure greater than the osmotic pressure experienced due to the presence of salts. This allows the clean water to be separated from the dissolved salts (IPPC, 2006). An advantage of RO filtration is the fact that dissolved organics are subjected to a less selective separation procedure than in other methods. RO filtration, furthermore, yields product stream of high quality, which usually allows the water to be re-used within the manufacturing processes (IPPC, 2006). While this method may be highly effective, the cost of the membrane remains a limiting factor. The membranes need to be replaced at regular intervals, since they are susceptible to clogging (Manivasakam, 2013).
- **Nanofilltration (NF)** is a technique which combines features of UF and RO with a high selectivity. This method is able to remove organic molecules with low molecular weights (200 – 1 000 g/mol). This may be achieved by utilising membranes which have specifically defined pore sizes, however, their retention is dependent on the electrostatic charges of the molecules which have to be separated (Manivasakam, 2013; IPPC, 2006). Furthermore, these systems have a selective permeability for minerals. NF generally operate at moderate pressures within the range of 1 – 5 MPa (IPPC, 2006). Due to the lower pressure requirements nanofiltration is considered to be a cost effective filtration method (Manivasakam, 2013).
- **Electrodialysis** is able to yield ionic separation by utilising an electric field as its driving force instead of hydraulic pressure (Manivasakam, 2013; IPPC, 2006). These systems make use of membranes which have been modified in order to be ion selective. A series of specifically modified anion and cation permeable membranes are arranged in an alternating order between an anode and a cathode. Membranes typically used for these purposes include cellophane and cellulose nitrate (Manivasakam, 2013). A major drawback of this technique is that the membranes are very susceptible to fouling. However, when subjecting the wastewater to a pretreatment with activated carbon or chemical precipitation, the clogging of membrane precipitated salts may be prevented (Manivasakam, 2013; IPPC, 2006)

2.8.3.7 Disinfection and Sterilisation

All techniques classified as disinfection or sterilisation operate on the same basic principle. Disinfection and sterilisation methods mainly target the cell structure of bacteria and aim to prevent their replication (IPPC, 2006). Various treatment methods are available for use. Biocides (e.g. chlorine, ozone etc.) and UV radiation are the methods most commonly used (IPPC, 2006; Valta *et al.*, 2017). In cases where thermo-resistant microorganisms are prevalent, steam may also be used as a disinfectant (IPPC, 2006).

2.9 Qualitative Data Analysis (QDA)

The aim of qualitative approaches is to gain an understanding of phenomena within their context by investigating their underlying themes and concepts (Bradley *et al.*, 2007). In contrast to quantitative approaches, QDA does not aim to identify occurrences (such as the frequency of phrases or word), but rather to identify common themes in the obtainable data (Bradley *et al.*, 2007; Koutiva *et al.*, 2017). Thematic content analysis (TCA), a popular technique used within QDA, aims to describe a specific phenomenon in a theoretical form. This is accomplished by lowering the quantity of text collected; identifying categories, and finally seeking to gain some level of understanding (Vaismoradi *et al.*, 2013; Friese *et al.*, 2018). Computer-assisted qualitative data analysis software (CAQDAS) can be used in order to simplify the content analysis process.

2.9.1 Computer Assisted Qualitative Data Analysis Software (CAQDAS)

The use of CAQDAS is advantageous in the sense that it allows one to efficiently handle and manage large quantities of data, thereby lessening the workload of the researcher (Sinkovics & Alfoldi, 2012). It should, however, be noted that the CAQDAS software packages currently available do not automatically analyse the data , but rather make the accumulated data easier to manage(Silver & Lewins, 2010; Sinkovics & Alfoldi, 2012). A user-friendly interface may then be used to access and view the data (Silver & Lewins, 2010). Alternative advantages of CAQDAS include (Cope, 2015):

- Clerical tasks such as transcribing, importing data and manual coding are less time-consuming for the researcher
- Allows the researcher to easily alternate between various analytical tasks such as memo-writing, coding, as well as the exploration of patterns
- Provides the researcher with flexibility when managing large transcripts; and allows for ease in changing codes, addition of notes, merging, deleting and moving data
- Text generated by the software can be copied directly into the final document, making the process of report writing more simplistic; and
- CAQDAS software permits multiple researchers to access and examine the data; whilst tracking alterations and systematic analysis

CAQDAS does, however, have some limitations. Various CAQDAS packages are currently available, with each one being unique. This means that not all software packages may be suitable for the purposes of any given qualitative study (Cope, 2015). For novice researchers CAQDAS has also been found to be more time-consuming in comparison to more traditional data coding and analysis methods, and does not necessarily yield higher-quality results (Silver & Lewins, 2010; Cope, 2015).

2.9.2 Using ATLAS.ti 9 as the CAQDAS platform

ATLAS.ti is an example of CAQDAS that has been utilised by researchers from various fields of study (Friese *et al.*, 2018). ATLAS.ti may be used for a variety of theoretical approaches as well as various data analysis processes. The ATLAS.ti software has been described as suitable for Thematic Content Analysis (TCA) purposes (Friese *et al.*, 2018). The ability to create networks for the purpose of analysis and eventual reporting is one of the key functionalities of ATLAS.ti.

Within the created ATLAS.ti networks, central ideas or themes can be linked to lower order codes by lines known as “linkages”. These linkages may be labelled according to the researcher’s needs. Codes may be connected to one-another by what is known as ‘Semantic’ linkages. ‘Hyperlinking’ may be used to connect two or more quotations. It is possible to assign labels to both semantic linkages and hyperlinks, this allows the researcher to explain relationships. As can be seen in Figure 5 below, Quotation 3 *criticises* Quotation 2. It is also possible to link codes to quotations in order to explain the code. The amount of times any particular code is applied in the network is referred to as the ‘Groundedness’ of said code and is represented by the symbol **G**. ‘Density’ refers to the amount of linkages associated with any particular code; the symbol **D** is used to represent density. Only in cases where the linkage between two codes has been pre-defined will density have a value other than 0.

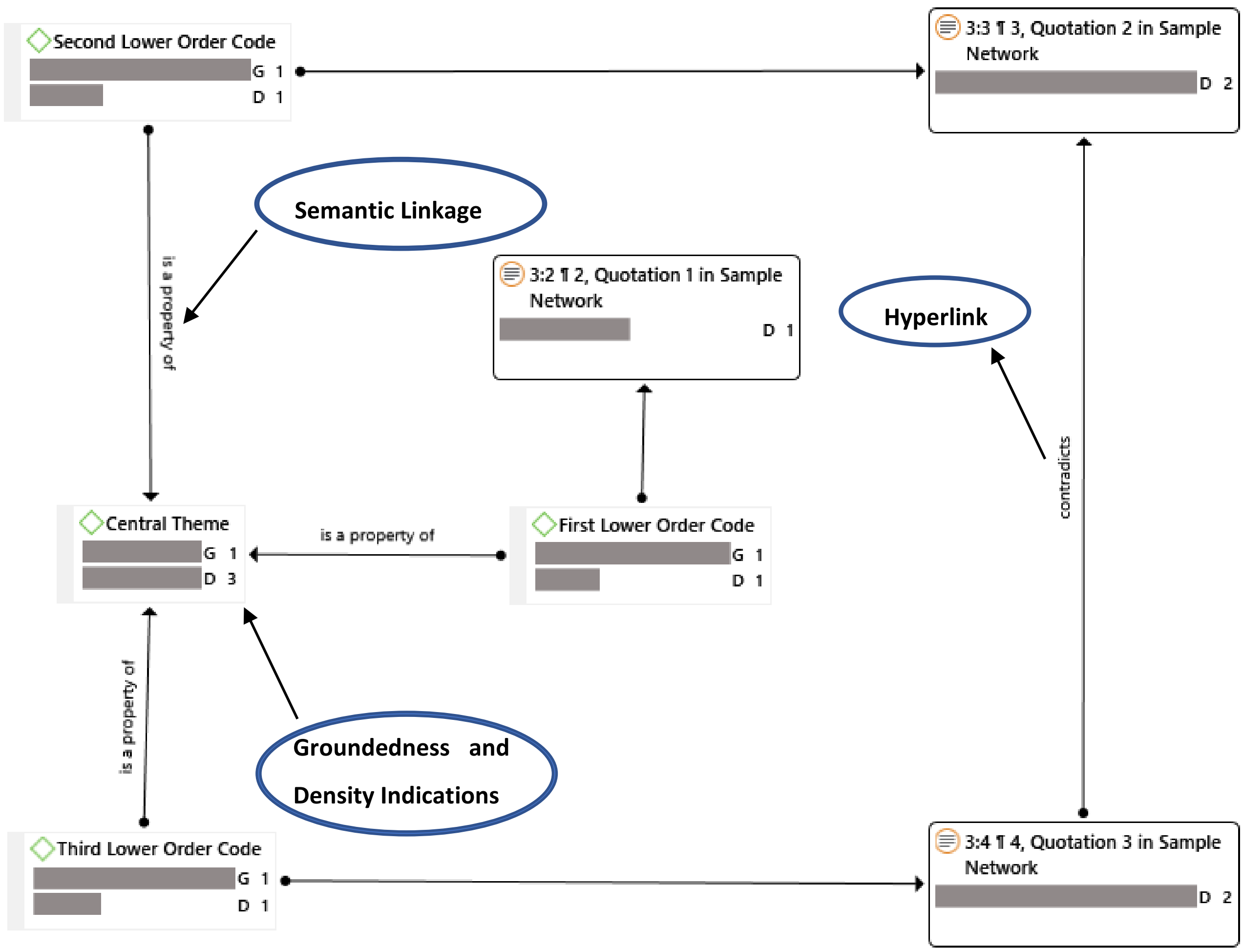

Figure 5 A Sample Network of the ATLAS.ti 9 output.

2.9.2.1 Analytical methodology followed within ATLAS.ti 9

Deductive content analysis if often used when prior research on a phenomenon already exists and could benefit from further investigation and description. Whilst the inductive approach develops conclusions from collected data, by using the new information to form theories (Andersson *et al.*, 2015; Bengtsson, 2016). Qualitative content analysis may be approached in three phases, namely: Preparation, Organization and Reporting (Elo *et al.*, 2014).

The Preparation Phase

The preparation phase involves the collecting of suitable data, familiarising oneself with the data as well as selecting the unit of analysis (Elo *et al.*, 2014). Elo & Kyngäs (2008) suggest that when doing qualitative content analysis, a decision should be made regarding the inclusion of manifest or latent analysis in the approach. Manifest analysis (also referred to as semantic analysis) concentrates on what is being said and described, therefore, the coding is done at “face value” (Elo & Kyngäs, 2008; Friese *et al.*, 2018). The aim of latent analysis, however, is to examine the underlying meanings, assumptions and conceptualizations behind what is being stated or is apparent (such as body language, tone of voice, choice of words, silence etc.) (Elo & Kyngäs, 2008; Friese *et al.*, 2018).

An important phase in content analysis is selecting the unit of analysis. Definitions of the unit of analysis differ, however, its core principle is to describe what is being investigated (e.g. an individual, a group, an organization etc.) (Dohn, 2020).

The Organization Phase

Elo et al. (2014) recommend the development of a categorization matrix, which could be used to assign codes and categories. This is, however, meant for the more old-fashioned pen-and-paper approaches. CAQDAS, on the other hand, allows one to create provisional codes (Silver & Lewins, 2010), which subsequently replaces the necessity of a categorization matrix. The process of provisional coding begins by developing a list of codes, which were determined beforehand. These provisional codes are generated from sources such as literature reviews; previous research findings; pilot studies; the conceptual framework of the project as well as the investigators experience in the field (Saldaña, 2009; Silver & Lewins, 2010).

The Reporting Phase

Conceptual maps, conceptual systems, categories or model can be created by using the output gained during the organization phase (Elo & Kyngäs, 2008). More specifically, the purpose of the reporting phase is to describe the results by examining the content of the categories (Elo *et al.*, 2014) via the themes identified through the coding (Friese *et al.*, 2018). Friese et al. (2018) describe a theme as the result of coding, however, it is usually not depicted by a single code.

2.10 Concluding Remarks

South Africa is a semi-arid country, which experiences below average annual rainfall which is, furthermore, distributed unevenly across the country (GreenCape, 2019; Kruger & Nxumalo, 2017; DWS, 2017). In addition to this the country has experienced one of its worst draughts in history during the period of 2015 – 2017 (GreenCape, 2019). This lead to an increase in tariffs placed on water supplied and treated by governmental water schemes (DWS, 2017). The increase in tariffs has, therefore, become a financial burden to facilities within the fruit and vegetable processing industry. In order to counter these rising expenses two options which can be implemented in the industry have been identified: firstly water usage could be minimized and secondly implementing the re-use of wastewater (Masanet *et al*., 2008; IPPC, 2006).

The fruit and vegetable processing industry is, however, very diverse with a variety of different raw materials and processing methods being observed. This level of diversity poses a problem when attempting to classify processes. Classification is not only dependant on the wide range of raw ingredients, but also different processing methods. The large scale of diversity and complexity in classification may have been the deciding factor as to why researchers such as Akgüngör *et al*. (2002) and Valta *et al*. (2017) opted to either select random samples within the industry, or to focus on most prolific sub-sectors within their respective countries.

The complexity of the classification process once again poses a problem when attempting to identify specific water saving techniques and wastewater treatment options which may be applicable in specific processes. While specific mention of appropriate water saving techniques within the fruit and vegetable processing industry are made by Masanet *et al*. (2008) and the IPPC (2006). The IPPC (2006) further goes on to mention specific wastewater treatment options within the Food, Drink and Milk industries. However, not all processes mentioned are applicable to the fruit and vegetable processing industry. As discussed various treatment options exist, all differing in effectiveness and aim. Although, it seems that the most effective treatment processes are those which utilise a combination of primary, secondary and tertiary treatments. Yet it remains difficult to recommend a specific treatment option, as all processes have their own individual advantages and disadvantages. Recommendations would, therefore, have to be made on a facility-to-facility basis. Thus, it is crucial for facilities within the fruit and vegetable industry to, at the very least, apply some form of monitoring in order to correctly determine the facility's needs. However, it is recommended that facilities aiming to improve their water efficiency follow the systematic approach laid out by the IPPC (2006) and other researchers.

Chapter 3 MATERIAL AND METHODS

3.1 Research Design

The most appropriate research design was deemed to be a mixed methods triangulation approach. A mixed methods approach can be described as a research design in which both quantitative and qualitative methods and materials are integrated (Huan-Niemi *et al.*, 2016). The combination of quantitative and qualitative approaches allows one to generate a better and more comprehensive understanding of the phenomenon being investigated (Turner *et al.*, 2017). For the purposes of this study, the quantitative approach entailed the use of assessable parameters in the survey used for information gathering. The qualitative element consisted of open-ended questions which were included in the same questionnaire, and case studies serving as an additional data acquisition instrument. Triangulation simply refers to processes where multiple data sources (for the purposes of this study, the use of surveys and site visits) or multiple different analytical approaches, are utilised in order to improve the integrity of the research (Turner *et al.*, 2017). When discussing the importance of methodological triangulation McGrath *et al*. (1982) stated that "individually all research strategies and methods are seriously flawed", in combination however, the use of multiple approaches do not yield the same shortcomings and improve the understanding of the research question. Thus, the triangulation approach results in a better understanding of the phenomenon being investigated, due to its aim to align multiple perspectives (Turner *et al.*, 2017). An overview of the data acquisition and analysis process can be seen in Figure 6.

It is not a new phenomenon to survey the best and or/current practices regarding water and waste water management within the food processing industry, with various international studies (Mannapperuma, 1993; IPPC, 2006; CLFP, 2015; Valta *et al*., 2017) utilising questionnaires as an instrument during the data collection process. With regards to the South African context, the use of surveys and supplementing site-specific case studies has been observed to be a common feature in similar studies (Swartz *et al*., 2017; Welz *et al*., 2017).

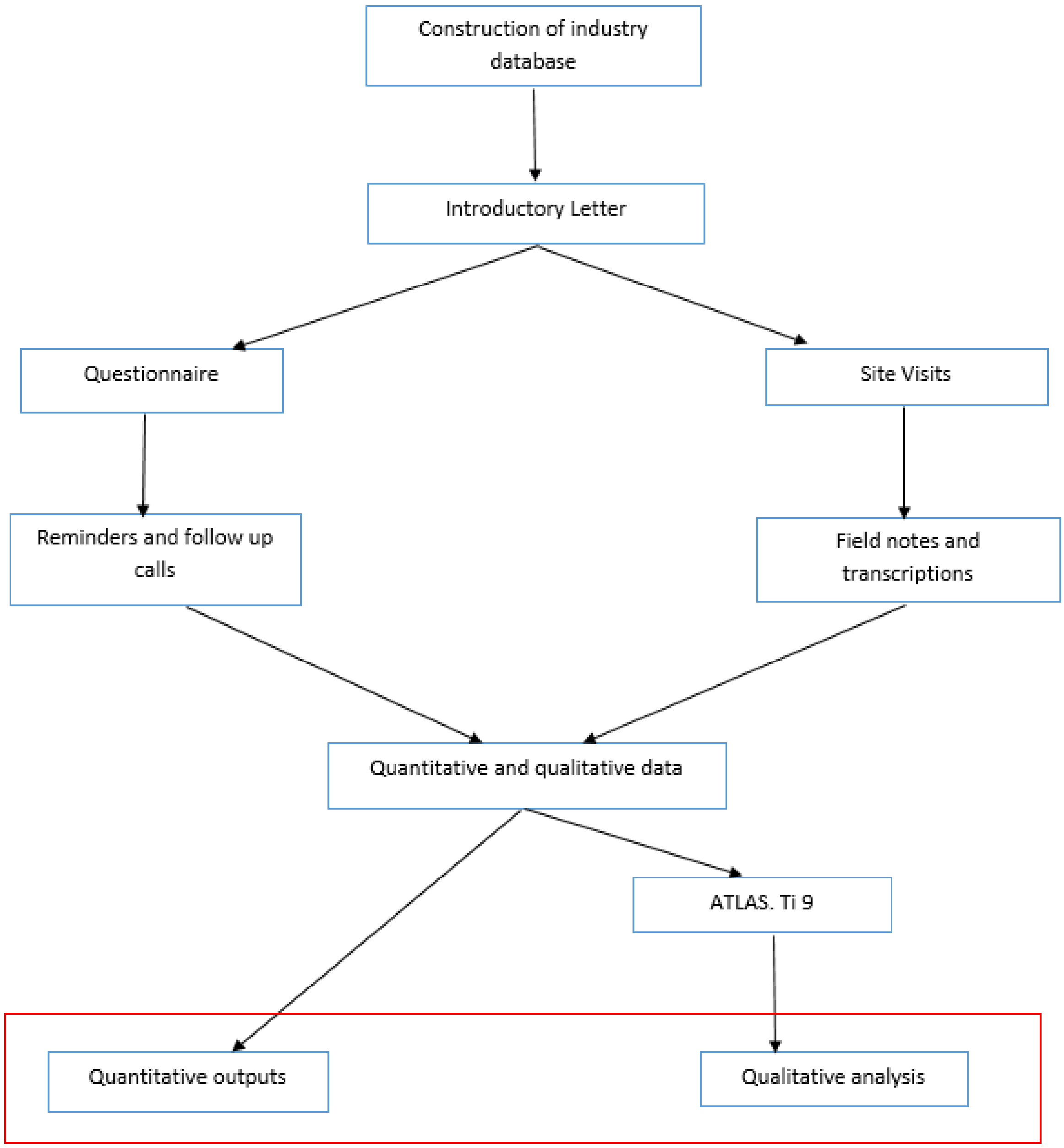

Figure 6 Summary of data-gathering and analysis strategies used during this study.

3.2 Research Methodology

3.2.1 The Sampling Process

3.2.1.1 Outlining the target population

For the purposes of this study the ideal target population would consist of facilities which can be grouped together by means of the Statistics South Africa SIC (Standard Industrial Classification) code 3013. Statistics South Africa possesses a database of all the facilities which operate under the code 3013, however, the research team was unable to establish contact with the organisation. Therefore, it was not possible to utilise this database and it was required to build a new database. In order to simplify the process of developing a database and to avoid uncertainty when identifying suitable facilities, the original definition had to be altered. Consequently, in order for facilities to be included in the target population they would need to meet the following description:

The processing of fruit and vegetables consists of activities during which raw fruit and vegetable inputs undergo significant physical and/or chemical alterations for the purposes of human ingestion. This definition does not include (Volschenk, 2020)*:*

- Processes where alcohol production is regarded as a key attribute of the final product (e.g. brandy, wine and ciders)
- Activities where the main product is the oils of fruit & vegetables (e.g. olive oil)
- Where intact fruit or vegetables are preserved by means of cooling/refrigeration or in a modified atmosphere (as the physical/chemical characteristics of the product are not significantly altered by these methods)
- Products consisting of less than 51% fruit and/or vegetables, without the preserving medium (such as baby foods consisting of fruit/veg portion less than the specified amount)
- Process where chopping/cutting and dicing are considered to be the only physical change (e.g. prepared salads)

A decision tree was developed in order to aid the process of determining whether a facility is suitable for inclusion in the database (Fig. 7).

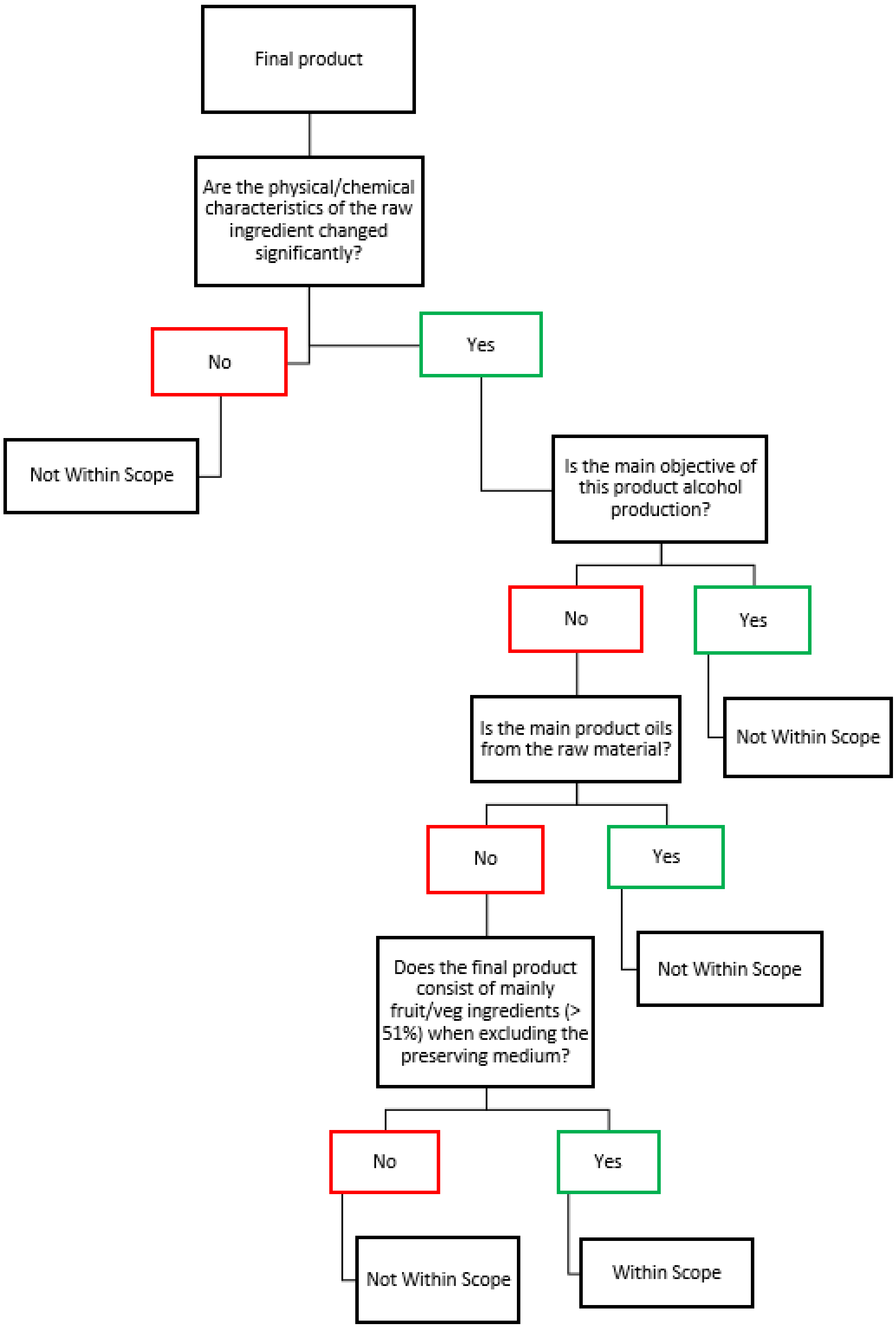

Figure 7 Decision tree for determining the appropriateness of facilities to be included in the database.

3.2.1.2 Determining Sampling Technique

Survey research is often associated with probability sampling. Probability sampling is a sampling method used to create a representative sample from a finite target population (Kim & Wang, 2019). However, it is often not possible for researchers to utilise probability sampling, due to time and financial constraints (Andres, 2017). The key reason for this is that a random sample is often not readily accessible. As mentioned earlier, a database of the facilities operating under Statistics South Africa's SIC code 3013 does exist. However, efforts to communicate with the establishment were unsuccessful, rendering the use of this database impossible.

Non-probability sampling is an alternative technique (ultimately used to create the industry database). Therefore, specific facilities, that best fit the modified definition, were selected. Non-probability by definition does not involve non-zero probability of selection (Kim & Wang, 2019). Suitable facilities were identified by means of contacting the relevant industry bodies as well as internet-based searches. After the verification process, the facilities were divided into categories according to the nature of the main type of processing being practiced. These categories included: juicing, canning/bottling, drying (both industrial and sun drying) and freezing. After the verification process, the database identified a total of 25 drying facilities, 19 canning/bottling processes, 28 juicing operations and six freezing operations. The designated sample (i.e. the number of sample units chosen for data gathering) (Lavrakas, 2008), therefore, consisted of 78 facilities.

Multiple problems arose during the development of the database. One such problem is with regards to the contact details of the facilities. The contact details provided by the relevant industry bodies were often dated, whilst many other facilities did not exist anymore. In an attempt to mitigate this problem, each representative on the lists provided by the industry bodies were telephonically verified. Another problem was also encountered when dealing with two of the largest corporates in South Africa, who refused to provide the research team with both the locations and contact information of their facilities.

The heterogeneity of the population also proved to be a problem. This is due the fact that whilst the definition of fruit and vegetable processing includes freezing, drying, juicing, canning and bottling, these processes still differ significantly. Thus, as a means to acquire a more profound understanding of the industry, it is crucial to ensure that each processing method is sufficiently represented in the final sample.

3.2.1.3 Final Sample Size

The final sample size refers to the quantity of completed interviews/questionnaires for which data was actually collected (Lavrakas, 2008). For the purposes of this investigation the final sample size takes into consideration factors that may lead to multiple components in the sampling pool being classified as non-completed responses. These factors include: non-contact, non-responses and other reasons such as ineligibility (Lavrakas, 2008). It has been a common occurrence that similar nation-wide investigations experience a meagre response rate, which leads to a small final sample size. In 2017, Swartz *et al*. published a NATSURV report investigating the water and wastewater management of the South African tanning and leather finishing industry. Whilst conducting this investigation they were only able to achieve a 5% response rate from participants. Pocock & Joubert (2017) also reported a low participation level whilst conducting another NATSURV titled: *NATSURV 9: Water and Wastewater Management in the Poultry Industry (Edition 2)*.

As mentioned previously, the high level of homogeneity observed within the industry could pose a potential problem. Thus, in order to generate meaningful results it is necessary that the final sample incorporates responses from each of the respective sub-industries.

3.2.1.4 The Sampling Process

In order to conduct the sampling process, the methodology reported in similar studies (Pocock & Joubert, 2017; Swartz *et al.*, 2017) was used as a guideline. Thus, the sampling process was initiated with the sending of an introductory letter to all the facilities included in the database. The contact information on the database was that of each facility's upper management in order to ensure that contact was established with an individual who possesses executive authority. The introductory letter included information regarding the details of the project, and information regarding the significance of the research. Three weeks after initial contact was established, a link to an internet-based survey was sent to each facility. Along with the link an electronic indemnity form (in accordance to the ethical clearance obtained) was sent. A notice was also sent to the participants in order to ensure the completion of the survey. Furthermore, it was deemed appropriate that two follow-up phone calls should be made when reminding facilities, deemed as extremely important to the investigation, to complete the survey (Singh & Wassenaar, 2016). In cases where the request to participate in the survey was clearly denied, the facilities were not contacted again. This was done in order to respect the facility's right to autonomy (Singh & Wassenaar, 2016). In order to allow for sufficient follow-up time, it was deemed appropriate to open the sampling window for a period of six months.

3.2.1.5 Dealing with coverage problems

Coverage error is a statistical bias that is observed when the target population does not correspond with the population actually sampled (Mulry, 2008). Mulry (2008) reports that establishment surveys (surveys of organisations and businesses) possess their own unique sources of coverage error. The miscoding of the industry, industry size, company structure or geographic location could result in coverage error (Mulry, 2008). Small businesses are particularly prone to coverage errors due to the fact that they lack the stability of the larger businesses. This often means that it is difficult to maintain an industry database, due to the continuous entry and exit of these small companies (Mulry, 2008). A list of reasons for coverage errors experienced during this investigation, as well as mitigating measures, can be seen in Table 9.

Table 9 Coverage errors experienced during the investigation and appropriate mitigating measures

Coverage Error	**Mitigating measures**
Inability to gain access to an already existing database of facilities within the South African FVPI	Building of own database with information acquired from industry bodies
Great processing heterogeneity observed in the FVPI	Include a wide range of different processing facilities in the industry database

Contact list acquired from industry bodies might be outdated	Telephonically confirm the validity of the contact details of each processing facility on the database

3.2.1.6 Attending to errors with non-response

As reported in investigations of a similar nature (Pocock & Joubert, 2017; Swartz *et al.*, 2017), it is not uncommon to experience poor industry participation both in terms of survey responses and the quality of the data provided. In order to limit the non-response error in this study, the following approaches were adopted:

- Contact information for individuals in executive positions were collected. It was anticipated that the willingness to respond would improve if the communication was addressed to a specific individual
- An introductory letter detailing the aim of the research was sent to the designated sample three weeks prior to the release of the questionnaire. It was hoped that this would help the potential participants to organize and/or collect the necessary data.
- In order to minimise the time burden to respondents the survey was kept as short as reasonably possible (approximate completion time of 15-20 minutes)
- All potential respondents received a *personalised* email containing the link of the online questionnaire
- All potential respondents received a follow up email; and
- Follow up phone calls were made to facilities who were considered to be the most significant

3.2.2 Ethical Considerations

Ever since the promulgation of the National Health Act in 2005 it has been required by law to seek ethical approval for research intentions, including behavioural and social sciences (Cleaton-Jones & Wassenaar, 2010). In most cases (including Stellenbosch University) the ethical approval is approved by a Research Ethics Committee (REC). Stellenbosch University ensures that all research studies, taking place at the institution, adhere to the core principles and responsibilities set out in the Singapore Statement on Research Integrity (Stellenbosch University Division for Research Development, 2013).

3.2.2.1 Steps taken to mitigate and avoid ethical issues

The Stellenbosch University REC requires the researcher to anticipate potential ethical problems that may be encountered during the investigation. It further requires that the researcher explains what steps were taken in order to mitigate these problems. In the context of this investigation the ethical considerations and relevant mitigating measures are as follows:

1. *Concern from the interviewee that they may be releasing classified company information*. To reduce this risk, only approved individuals in executive positions will be interviewed. It is also up to the discretion of the participants what data they feel comfortable releasing.

2. *Confidential company data may be released to the public*. In order to overcome this risk, just the project team will be able to view individual company information. All results will be published as a provincial or nationwide aggregate for each relevant process .The facility names and contact information will not be released to the public under any circumstances. All data collected will be kept in digital format on devices which are protected by passwords
3. *Encountering of illegal/and or environmentally damaging activities.* All survey participants have a right to confidentiality and this will be respected. Should any illegal/environmentally harmful practices be uncovered during the investigation, the researcher might be required to contemplate the confidentiality of the participant as well as the moral instinct to report such activities. Thus, for the purposes of this investigation the only cases that will be reported are polluting activities which could directly lead to the harming of individuals. In cases where polluting activities are deemed to be of a minor nature, the concern will reported to the management, who will be encouraged to resolve the issue.

The study was granted ethical clearance without additional conditions by the REC on the 28th of January 2019. The consent further required that gate-keeper permission would be obtained prior to the use of any data collection instruments.

3.2.2.2 Gate-keeper permission

Singh & Wassenaar (2016) state that in instances where the research is to be conducted in an institutional environment and not in the public domain, it is required to gain permission from appropriate authorities in order to adhere to the principle of respect for autonomy. It is necessary to acquire this permission as all parties reserve the right to either grant or refuse access to their clients, personnel, working spaces and data (Singh and Wassenaar, 2016). RECs often call for written consent from the appropriate authorities (the gatekeeper) in an organisation before approval may be granted. This is often referred to as gatekeeper’s permission (Singh and Wassenaar, 2016). There are, however, cases where REC’s grant approval with the provision that gatekeeper permission is acquired before the actual data collection, with this investigation being one such case (Singh and Wassenaar, 2016).

Initial contact was made with the gatekeepers by means of an introductory letter containing details regarding the purpose of the study, as well as the potential positive impact this research could have on the understanding of water and wastewater management within the South African fruit and vegetable processing industry. In their paper Singh & Wassenaar (2016) suggest that the chances of being granted authorisation might be improved by explaining the social value behind the research. Typically, an official letter from the facility being investigated serves as the institutional consent, however, obtaining an official letter from 74 different facilities would have been impractical. Therefore, it was judged that obtaining gatekeeper permission by means of an electronic consent form would be suitable.

3.2.3 Questionnaire Design

3.2.3.1 Rationale for the use of an online survey

Due to its enhanced capabilities (online interactive capabilities; possibilities of audio and visual stimulation; as well as the potential of enhanced skip patterns), the use of internet-based surveys has grown in popularity. These enhanced capabilities allow the online surveys to overcome the limitations of email surveys (Nathan, 2008). Various advantages are associated with the use of online surveys, these include: the low cost per respondent, the improved visual and auditory features of the collection instruments as well as the simplicity of data processing (Nathan, 2008).

Considering the above mentioned information, research data was captured and managed by means of the REDCap electronic data capture tools which are hosted at Stellenbosch University. REDCap (Research Electronic Data Capture) is a high security, web-based platform that was created to assist the process of capturing of data for research purposes. The decision to utilise an online/internet-based platform was based on the following reasons:

- The participants work under very stressful and time-consuming conditions. Thus, they would likely prefer using a platform that allows them to complete the questionnaire in their own time.
- Face-to-face interviews would not be practical, due to the national scale of the investigation.
- Whilst telephonic interviews would be possible, the participants would not necessarily have enough time available to complete the survey. Thus, as previously mentioned, they would likely prefer a survey that they could complete in their own time.

REDCap makes use of a logical project development process that systematically checks tasks off as they are completed. Data collection instruments are created by means of an ‘online builder’. The system allows one to format these instruments according to the type of information desired from a specific question. Drop-down list; slider scales; multiple-choice and radio buttons are amongst the most popular formats available. The REDCap system further allows the researcher to test the project and data collection instruments in what is known as the ‘development mode’. After the project has been thoroughly tested it is moved into the ‘production mode’, which subsequently activates additional data protection precautions.

3.2.3.2 Disadvantages associated with online questionnaires

The major disadvantages related to the use of internet questionnaires include a lack of suitable sample frameworks, non-response as well as coverage issues (refer to 3.2.1.5 & 3.2.1.6) ((Nathan, 2008).

3.2.3.3 Question selection and design

The questions used in the questionnaire were created with the aid of the NATSURV 19 project team. The surveys designed by Swartz et al. (2017) and Welz et al. (2017) served as templates in order to maintain comparability with other NATSURV reports. The questions included in the final online questionnaire were as follows:

General Information

I. Name of person completing survey
II. Position in Company

III. What is the main nature of the facility? (e.g., Juicing, canning, etc.)
IV. Please provide the name of the municipality responsible for monitoring your facility.

Seasonality

I. Is the production process seasonal? If so, over which months does the season extend? (Y/N)

Production

I. What are your main raw product inputs, and how many tons of each fruit or vegetable are produced annually?

Water Usage

I. Please provide your total annual and daily water consumption, and indicate the primary source of the water? (Municipal, borehole, river, dam)
II. What is the unit cost (R/kL) of water input?
III. Is any additional treatment applied to incoming water before use? If so please describe.
IV. If known, please provide specific water volumes per kg or per ton of final product produced.
V. Where is water used in your production process? Please describe and give approximate percentage consumption for each of the production processes in relation to total usage. If possible, please provide a process flow diagram indicating consumption percentages.

Wastewater generation and management

I. What is your total estimated annual and daily effluent volume? Please provide estimated percentages of the origin of effluent streams that make up the total effluent volume. If possible, please provide a flow diagram with relevant percentages.
II. What treatment does the effluent undergo before discharge?
(a) Primary treatment (Please Describe)
(b) Secondary Treatment (Please Describe)
(c) Tertiary Treatment (Please Describe)
(d) Other (Please Describe)
III. What happens to the discharged water? (e.g., irrigation, reuse, municipal sewage treatment plants, etc.)
IV. If discharge is sent to municipal sewage treatment plants, please provide formula used in the municipality's by-laws to determine tariffs.
V. Which wastewater quality parameters are routinely monitored? Please differentiate which parameters are monitored by the municipality and which are monitored by the industry.
VI. Are wastewater quality and quantity targets in place? If so, to what extent are these targets being met? If not, which water quality parameters are exceeding the discharge limits?
VII. Are wastewater monitoring routines in place? If so, please provide details.

VIII. Are any of the wastewater or effluent streams reused? Please provide details of reuse and volumes.

IX. Do you think that there is scope for further beneficiation using any effluent streams? Please elaborate.

Solid waste/ slurry generation

I. What is the type and quantity of solid waste or slurry generated per unit final product produced?

II. Does the fruit & vegetable processing process produce any potentially toxic by-products?

III. How is the solid waste currently disposed of?

IV. Do you think that there is scope for further beneficiation using any of the solid waste? Please elaborate.

Energy Usage

I. What are your energy sources? Please select
   (a) Boiler
   (b) Grid (Municipal electric supply)
   (c) Solar
   (d) Biogas from wastewater

II. What is your total energy use (kWh) in your production processes per day and per annum? Please indicate per product if available.

III. What is the unit cost (R/kWh) of energy used?

IV. What gaseous emissions are prevalent in your facility? Do you have measures in place to combat these emissions?

3.2.3.4 Pilot-testing the Online Survey

In order to conduct a pilot-test, three members of the NASURV 19 project team were requested to complete the online survey. Two of the project team members have extensive knowledge with water and wastewater management and were subsequently able to verify the validity and suitability of the questions. The members were instructed to comment on facets of the questionnaire such as completion time; wording and structure of questions as well as the clarity of the instructions. Thereafter, the author verified the exportability of the data, as well as ensuring that the computer-based systems being utilised were compatible with one-another. All members concluded that the electronic survey was simple to understand and complete, and that it was not too time consuming to complete (15 – 20 min). It was recommended that minor changes be made to the questionnaire in order to avoid ambiguous questions.

3.2.4 Case Studies as a data acquisition instrument

3.2.4.1 Suitability of the case study methodology

A case study can be described as a detailed examination and account of an individual, group or organisation based on various different sources. Sources include interviews, observations, documents as well as archival records and observations of participants (Kalaian, 2008). The aim of a case study is to create a comprehensive and detailed description of the case in question, in a narrative form (Kalaian, 2008).

As a means to add to the data collected from the survey, it was deemed necessary to contact particular facilities on the database and acquire authorization to conduct a walk-through audit. The walk-through audit is advantageous as it is a low-cost and time efficient method, which allows one to immediately identify savings opportunities that do not require significant alterations or expenditures (Navarri and Bédard, 2008). This auditing method further allows one to identify processes and equipment which require a more detailed examination (Navarri & Bédard, 2008).

The following methodology was followed whilst performing the walk-through audits:

1) Upon arrival the host of each facility was asked to fill out a site-visit consent form, as required by the REC
2) The questions used for the online survey were used to conduct an interview with the plant managers of each facility.
3) Thereafter, a walk-through of the primary operations and wastewater treatment facilities was conducted. Emphasis was placed on understanding the processes utilised as well as identifying potential areas for improvement.
4) Field notes were compiled for each facility where site-visits were conducted. The interviews were performed in a semi-structured approach, using the online survey as a foundation.

3.2.5 Analysing case studies by means of Qualitative Data Analysis (QDA)

The aim of qualitative approaches is the gain an understanding of phenomena within their context by investigating their underlying themes and concepts (Bradley *et al.*, 2007). In contrast to quantitative approaches, QDA does not aim to identify occurrences (such as the frequency of phrases or word), but rather to identify common themes in the obtainable data (Bradley *et al.*, 2007; Koutiva *et al.*, 2017). Thematic content analysis (TCA), a popular technique used within QDA, aims to describe a specific phenomenon in a theoretical form. This is accomplished by lowering the quantity of text collected; identifying categories, and finally seeking to gain some level of understanding (Vaismoradi *et al.*, 2013; Friese *et al.*, 2018). Computer-assisted qualitative data analysis software (CAQDAS) can be used in order to simplify the content analysis process.

3.2.5.1 CAQDAS

The use of CAQDAS is advantageous in the sense that it allows one to efficiently handle and manage large quantities of data, thereby lessening the workload of the researcher (Sinkovics & Alfoldi, 2012). It should, however, be noted that the CAQDAS software packages currently available do not automatically analyse the data, but make the accumulated data easier to manage instead (Silver & Lewins, 2010; Sinkovics & Alfoldi, 2012).

Various CAQDAS packages are currently available, with each one being unique. This means that not all software packages may be suitable to the purposes of any given qualitative study (Cope, 2015). ATLAS.ti 9 was identified as the software platform to be used for qualitative analysis during this investigation.

3.2.5.2 Analytical methodology followed within ATLAS.ti 9

Deductive content analysis if often used when prior research on a phenomenon already exists and could benefit from further investigation and description. Whilst the inductive approach develops conclusions from collected data, by using the new information to form theories (Andersson *et al.*, 2015; Bengtsson, 2016). Thus, deductive content analysis was deemed appropriate for the purposes of this study. Qualitative content analysis may be approached in three phases, namely: Preparation, Organization and Reporting (Elo *et al.*, 2014).

The Preparation Phase

For the purposes of this study it was deemed appropriate to use the manifest analysis approach. As mentioned in Chapter 2, manifest analysis focusses on what is being said and described. This means that the coding is done at “face value”(Elo & Kyngäs, 2008; Friese *et al.*, 2018). An important phase in content analysis is selecting the unit of analysis. Definitions of the unit of analysis differ, however, its core principle is to describe what is being investigated (e.g. an individual, a group, an organization etc.) (Dohn, 2020). For the context of this investigation, whole interviews and field notes from individual facilities were chosen as the unit of analysis.

The Organization Phase

The organization phase entails the development of a provisional code list. The process of provisional coding begins by developing a list of codes, which were determined beforehand. These provisional codes are generated from sources such as literature reviews; previous research findings; pilot studies; the conceptual framework of the project as well as the investigator’s experience in the field (Saldaña, 2009; Silver & Lewins, 2010).

For the purposes of this study a combination of literature and observational inputs were used as sources to create a provisional code list, as recommended by Saldaña (2009). As the investigation progressed, more potentially applicable concepts and themes were identified, which in turn lead to the provisional code list being continuously expanded and added to. After the surveys and facility visits were conducted the interviews and field notes were uploaded to the ATLAS.ti 9 platform. This allowed the author to commence with the formal coding process. Codes from the provisional code list were assigned to the relevant pieces of text. This process was repeated three times in order to ensure that the coding was done correctly. After the coding process was completed the author was able to continue to the reporting phase.

The Reporting Phase

As mentioned in the previous chapter the purpose of the reporting phase is to describe the results by examining the content of the categories (Elo *et al.*, 2014) via the themes identified through the coding (Friese *et al.*, 2018). Subsequently, the outputs gained from the coding process were used to generate networks or conceptual maps, in order to provide a visual representation of the data.

3.2.5.3 Trustworthiness in qualitative analysis

In qualitative research, the term '*trustworthiness*' is used to refer to the degree of confidence in the measures (e.g. data, interpretation and method) taken to ensure that the study in question is of high quality (Connelly, 2016). Trustworthiness is also often referred to as *authenticity*; *confirmability*; *transferability*; *dependability* and most importantly *credibility* (Elo *et al.*, 2014; Connelly, 2016). Elo & Kyngäs (2008) suggest that in order to ensure trustworthiness, the researcher must scrutinize and dissect the analysis process, and the validity of the results must be confirmed (Elo *et al.*, 2014). A checklist for researchers was developed by Elo *et al*. (2014) in an attemp to assit researchers in improving the trustworthiness of their content analysis. Table 10 below shows an adaption of this checklist, the author thought it wise to continuously refer to this checklist in order to monitor the trustworthiness of the analysis process.

Table 10 Checklist to ensure trustworthiness during content analysis (adapted from Elo et al., 2014)

Phase of content analysis	**Questions to ask**
Preparation phase	*Method of data collection*
	How do I collect the most relevant data?
	Is this the most suitable method to answer the research question?
	Are descriptive or semi-structured questions best suited?
	How will I pre-test my data collection method?
	Sampling Strategy
	What sampling method would suit my study best?
	Who are the best qualified informants for this study?
	What criteria will be used to select participants?
	Do I have an appropriate sample?
	How saturated is my data?
	Choosing unit of analysis
	What will be the unit of analysis?

		Is the unit of analysis appropriate?
Organization phase	*Categorization*	
		How should the categories or concepts be generated?
		Is the amount of categories suitable, and do they overlap?
	Interpretation	
		What is the level of interpretation?
		How will the accurate representation of the collected information be ensured?
	Representativeness	
		How will the trustworthiness of the analysis process be validated?
Reporting phase	*Reporting the results*	
		Are the results reported in a systematic and logical manner?
		How are the relationships between the data and results reported?
		Are the concepts reported in a clear and understandable manner?
		Can the transferability of the results be evaluated?
		Are references used in a systematic fashion?
		Is the data adequately covered by the categories?
		Are there resemblances within categories, as well as distinctions between them?
		Are the results conveyed with the proper scientific language?
	Reporting the analysis process	
		Has the analytic process been described in full?

Is the trustworthiness of the content discussed according to the criteria?

Chapter 4 Results & Discussion

A summary of the survey responses (Section 4.1) and case studies (Section 4.2) can be found below. These sections aim to provide context for the content analysis of water and wastewater management (Section 4.3) observed in the South African FVPI. In order to ensure the confidentiality of the participants, each facility was codified and referred to as 3013.1; 3013.2 *etc*. Fruit and vegetable processing is classified under the Standard Industrial (SIC) code 3013 (StatsSA, 2018). For this reason, it was deemed appropriate to use 3013 to codify the participating facilities.

4.1 Survey responses

The online survey was distributed to all the potential participants included on the database. As can be seen in Figure 8, only 16 of the original 74 facilities responded to the questionnaire. Seven of these responses were, however, incomplete or did not contain data of sufficient quality. It was, therefore, deemed appropriate to exclude these responses from the investigation. The exclusion of these seven responses meant that a final sample size of nine facilities was attained. This equated to a response rate of 12.16%, which is an improvement in comparison to the response rate of 5% achieved by Swartz *et al*. (2017) whilst conducting a similar study. It is important to note that a follow-up survey, focussing on wastewater management, was also distributed to all the facilities listed on the database (74 facilities). No responses were, however, acquired from this follow-up questionnaire. Statistical analysis of the questionnaire responses was not feasible due to the influence of various factors such as the small sample size and the high levels of homogeneity observed in the products and raw input materials. The final sample included four facilities which were visited by the project team at a later date; the results for these facilities will be discussed in section 4.2. The questionnaire survey results for the remaining five facilities are displayed in Table 11 and 12 below.

Table 11 Survey responses regarding production and water consumption of five facilities that completed the survey but were not visited.

Industrial unit	Production type	Raw inputs	Production season	Freshwater source	Annual freshwater consumption (m3)
3013.1	Juicing	15 000 tons grapes	Jan - Dec		3 000

		(produces 12 000 m^3 juice per annum)		Municipal Supply	
3013.2	Juicing	60 000 tons apples 10 000 tons pears	Jan - May	River/Dam	277 000
3013.3	Drying	10 000 tons grapes	Feb - Nov	Municipal Supply	13 173
3013.4	Drying	6 000 tons grapes	Feb - Sep	Municipal Supply River/Dam	No records maintained
3013.5	Juicing	50 466 tons citrus 4461 tons guava	Feb - Sep	Municipal Supply	123 870

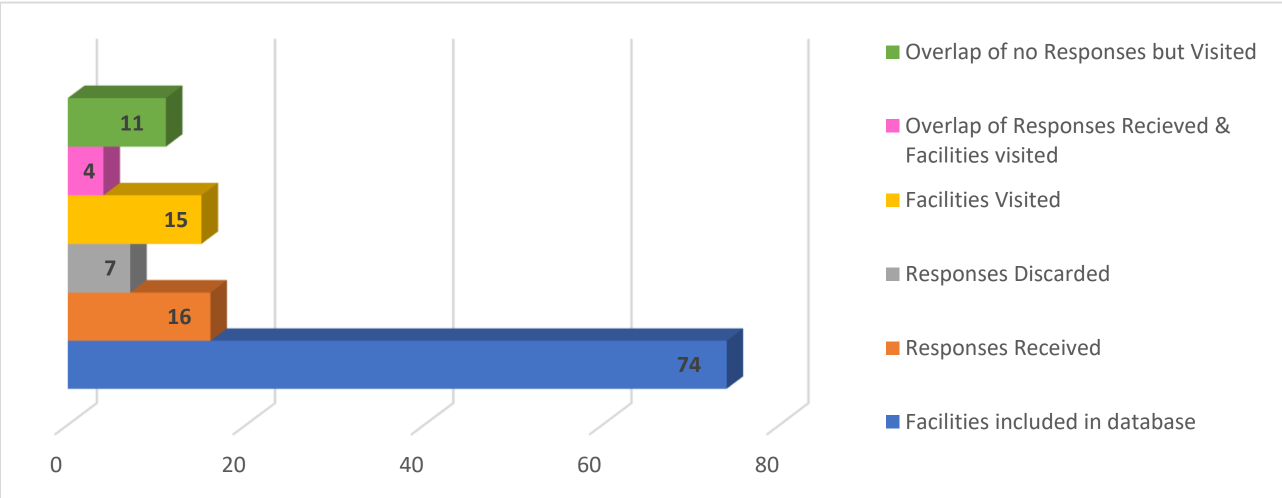

Figure 8 Overview of the number of facilities included in the database; responses received; responses discarded; facilities visited; and cases where overlaps are observed.

Table 12 Survey responses regarding wastewater treatment techniques that completed the survey but, were not visited

Industrial unit	Effluent volume (m^3 per annum)	Wastewater treatment
3013.1	130 000	***Primary treatments***
		Eco-Tabs™ are added to effluent*
		Secondary treatments
		None
		Tertiary treatments
		None
3013.2	415 000	***Primary treatments***
		Filtration to remove solids
		Secondary treatments
		Undefined aerobic and anaerobic bacterial reaction
		Tertiary treatments
		Chlorination and addition of Aluminium sulphate [$Al_2(SO_4)_3$]
3013.3	96 000	***Primary treatments***
		Filtration to remove solids
		Neutralisation
		Secondary treatments
		Undefined aerobic treatment
		Tertiary treatments

		None
3013.4	Not Provided	***Primary treatments***
		Filtration to remove solids
		Neutralisation
		Secondary treatments
		Undefined Biological treatment
		Tertiary treatments
		None
3013.5	14 040	***Primary treatments***
		Filtration to remove solids
		Neutralisation
		Secondary treatments
		None
		Tertiary treatments
		None

*Eco-Tabs™ are dissolvable tablets, which are added to the effluents in order to oxygenate the effluent, neutralize odours, remove organic and chemical pollutants through bioaugmentation, prevent corrosion as well as initiate the aerobic biological breakdown of organic sludge.

4.2 Case studies of water and wastewater management in the FVPI

The fruit and vegetable processing industry is an extremely competitive industry. Subsequently, facilities are often protective of their data. Nevertheless, the project team was able to visit 15 facilities on a case-study basis. Interviews were conducted during these visits. The interviews were recorded and transcribed where possible. The field notes made during the visits were, however, still of high enough quality to be used for qualitative analysis.

Industrial unit 3013.6 is a facility situated in the Limpopo province. They are a citrus juicing facility, with oranges and grapefruits being the main varieties. The facility only focusses on the production of juice concentrate, which is mainly intended for the export market. The facility employs 102 permanent staff, as well as 84 seasonal staff (February to middle October). The local dam is their main source of freshwater. The region recently experienced a drought and has, therefore, sunk a borehole on the premises. Raw material washing; the cooling towers for the freezers; and the pasteurisers were found to be the most water intensive processes. Another area of concern was the water utilised during the oil extraction process. As a means to save water the facility has implemented two recycling strategies, namely the reuse of evaporator water for the purposes of cleaning the facility equipment; the defrost water is collected from the freezers as well and then used to fill up the cooling tower water). The facility reported that high pressure hoses were used for cleaning. It was, however, observed that not all of the hosepipes used in the facility were suitable for this purpose. It was also reported that the facility implements dedicated leak repair as another mitigation technique. The facility's wastewater is treated by passing the effluent through screen filters as a means to remove solids and finally neutralising the pH. After treatment the effluent is used to irrigate pastures surrounding the facility. The facility was, however, unwilling to provide any data regarding their water consumption, effluent volumes or wastewater quality parameters (Tables 13, 14, 15).

Table 13 Production and freshwater consumption figures observed in South African FVPI facilities

Industrial unit	Production type	Raw input quantities	Freshwater intake Volume (m^3)	SWI (m^3/ton product)	SWI (m^3/ton product) found in literature
3013.6	Juicing	Not provided	Not provided	Not provided	Fruit Juice (UK): 3.5 Fruit Juice (EU): 6.5
3013.7	Juicing Canning Freezing	Not provided	Not provided	Not provided	Fruit Juice (EU): 6.5 Canned Fruit (USA): 5.8 Canned Fruit (EU): 3.25 Frozen fruit/vegetables (USA): 9.4
3013.8	Bottling (preserves)	100 -120 tons p/a Deciduous Fruit	1.58 p/d (576.7 p/a)	5.24	Jams (EU): 6.0

3013.9	Freezing	23 000 tons p/a Potatoes	143 018 p/a	6.2	Frozen vegetables (EU): 6.75 Frozen fruit/vegetables (USA): 9.4
3013.10	Canning	11 350 tons p/a Unspecified Vegetables	14 400 p/a	1.6	Canned tomato (USA): 2.93 Canned vegetables (EU): 4.75
3013.11	Freezing	92 701 tons p/a Vegetables	188 976 p/a	3.3	Frozen vegetables (EU): 6.75 Frozen fruit/vegetables (USA): 9.4
3013.12	Canning	6 212.2 tons p/a Picante Peppers 696.3 tons p/a Other vegetables	78 545 p/a	19.2	Canned vegetables (EU): 4.75 Canned tomato (USA): 2,93
3013.13	Canning	Not provided	553 824 p/a	6.16	Canned Fruit (EU): 3.25 Canned Oranges (China): 30 Canned Fruit (USA): 5.8 Canned vegetables (EU): 4.75
3013.14	Drying	1 000 tons p/a Tree fruits	60 p/d	21.9	Dehydrated fruit (USA): 0.3
3013.15	Freezing Canning	7 000 tons p/a Unspecified fruit	6000 - 13 000 p/m	Not available	Frozen fruit/vegetables (USA): 9.4 Canned vegetables (EU): 4.75
3013.16	Juicing	65 000 tons p/a Apples	200 000 p/a	3.08	Fruit Juice (UK): 3.5 Fruit Juice (EU): 6.5

3013.17	Juicing	79 349 tons p/a Pineapples	101 164 p/a	10.15	Fruit Juice (UK): 3.5 Fruit Juice (EU): 6.5
3013.18	Canning	4 762 tons p/a Peppers & Vegetables	17 700 p/a	5.9	Canned vegetables (EU): 4.75
3013.19	Juicing	90 000 tons p/a Citrus	90 918 p/a	Not provided	Fruit Juice (UK): 3.5 Fruit Juice (EU): 6.5
3013.20	Juicing Packaging	7 000 tons p/a Concentrate and Pressed Juice	2000 p/a	Not provided	Fruit Juice (UK): 3.5 Fruit Juice (EU): 6.5

Table 14 Wastewater volumes and characterisation for South African FVPI facilities

Industrial unit	Effluent volume (m^3)	COD (mg/L)	TSS (mg/L)	pH
3013.6	Not provided	-	-	-
3013.7	Not provided	-	-	-
3013.8	500 p/a	23 350	78	6.1
3013.9	177 710 p/a	4 155 – 6 350	533 - 20 168	4.7 – 6.2
3013.10	10 000 (tons per year)	-	1 740	7
3013.11	381 779 p/a	410 – 5 810	330 – 1 844	4.4 - 8
3013.12	800 p/a*	3 429 - 10 059	813 -1 500	4.1
3013.13	332 294 p/a	7 000 - 15 000	-	6.0
3013.14	30 p/d	< 100	-	-

3013.15	Not provided	-	-	-
3013.16	60 p/d (18 000 p/a)	6 000 – 8 000	-	6.3
3013.17	589 p/d	5 976	1 552	3.6
3013.18	10 380 p/a	No records kept	No records kept	No records kept
3013.19	Not provided	-	-	-
3013.20	3 000 – 4 000 p/m	5 000	-	-

*The low effluent volume (in comparison water intake of 78 545 m^3p/a) reported by 3013.12, is claimed to be due to evaporative losses experienced during production. This does however seem unlikely; leading to suspicions regarding the accuracy of the facility's water meter

Table 15 Wastewater treatment methods implemented by various South African FVPI facilities

Industrial unit	Effluent Treatment	Destination of discharged effluent
3013.6	***Primary treatment***	Irrigation
	Screen filter (solid removal)	
	Neutralisation	
3013.7	***Primary treatment***	Irrigation
	Screen filter (solid removal)	
	Neutralisation	
	Sedimentation	
	Secondary treatment	
	Anaerobic lagoons	
	Aerobic lagoons	
3013.8	***Primary treatment***	Irrigation

	None	
	Secondary treatment	
	Septic tank with French drain	
3013.9	***Primary treatment***	Discharged into ocean
	Sedimentation	
	Screening for large solids	
3013.10	***Primary treatment***	Irrigation
	Settling dams	
	Screen filter (solid removal)	
3013.11	***Primary treatment***	Municipal system
	Screen filter (solid removal)	
	Neutralisation	
	Flocculation	
	Sedimentation	
3013.12	***Primary treatment***	Municipal system
	Screen filter (solid removal)	
3013.13	***Primary treatment***	Irrigation
	Screen filter (solid removal)	
	Secondary treatment	
	Aerobic lagoons	

3013.14	***Primary treatment***	Irrigation/Municipal system
	Bag filter	
	Secondary treatment	
	3-stage aerobic bioreactor	
	Tertiary treatment	
	Filtration through peat bed	
3013.15	***Primary treatment***	Municipal system
	Screen filter (solid removal)	
3013.16	***Primary treatment***	Irrigation
	Screen filter (solid removal)	
	Neutralisation	
	Secondary treatment	
	UASB reactor and settling dam	
	Anaerobic digester	
3013.17	***Primary treatment***	Municipal system
	Screen filter (solid removal)	
	Neutralisation	
3013.18	***No treatment applied***	Municipal system
3013.19	***Primary treatment***	Irrigation
	Static screen	

	Neutralisation	
	Sedimentation	
	Secondary treatment	
	Anaerobic & aerobic batch process arranged in series	
	Tertiary treatment	
	Membrane filtration process	
3013.20	***Primary treatment***	Municipal system
	Screen filter (solid removal)	
	Neutralisation	
	Addition of BioTabs™*	

*BioTabs™ are slow-release fat solid and organic sludge treatment tablets. This product further assists in the reduction of bad odours

Industrial unit 3013.7 focusses on the processing of fruits, with the main inputs being fruit of the tropical varieties. Juice concentrates/blends/purees, fruit cubes, individually quick frozen (IQF) fruit pieces and canned products are manufactured in three different facilities, which are located on the same premises. Juicing operations take place between November and January, whilst the IQF and canned products, which rely on the availability of grapefruit, are produced between the months of March to early July. Freshwater is supplied by municipal sources and an on-site borehole, which is temporarily stored in a small reservoir. Although the facility did not provide any details, they stated that the physiochemical characteristics of the incoming freshwater is tested every day. The main water using operations of the IQF and canned products facility were found to be the washing of raw materials followed by floor cleaning (a near continuous operation to prevent slipping). Cleaning operations were found to be the main water using processes in both the juicing and sweets facilities. Various water minimisation techniques are implemented by this facility, these include

1. The water used during the IQF washing processes are reused (After the first and second rinses the water is chlorinated; mixed with fresh potable water; and used again in the same operations); and
2. Recirculating the water used to operate the conveyor responsible for delivering washed fruit into the IQF facility.

The effluent treatment implemented by this facility includes primary treatments as well as a secondary treatment. The primary treatments applied include a pH neutralisation step, followed by physical screening. After the screening the effluent is pumped to a holding tank; the tank also has a tap which allows for the treated water to be utilised for outside cleaning purposes. Thereafter, the wastewater is directed into sedimentation tanks, and finally to a dam, which further separates the floating solids from the liquid effluent. Secondary treatment involves subjecting the effluent to anaerobic and aerobic digestion; this is accomplished by pumping the effluent into anaerobic lagoons (covered with sails) followed by aerobic lagoons. Once the secondary treatment has been accomplished the effluent is pumped to a holding dam, from which it may then be used to irrigate pastures. The facility refused to provide figures pertaining to water intake, effluent volumes or wastewater quality parameters.

Industrial unit 3013.8 is situated in the Cederberg region. This facility is rather small, employing 17 permanent staff and six seasonal staff. Their production processes involve the bottling of jams and other preserves. These products are mainly destined for the domestic market. The raw inputs mainly consist of the deciduous fruits such as apples, apricots, blueberries and pears to name a few. The facility acquires its freshwater by means of a borehole. The incoming water is treated by a filter, a brominator and UV light before being used for production purposes. Pasteurising and cooking processes were identified as the major water using processes. Due to the severe drought recently experienced in the Western Cape, the facility implemented various water minimisation techniques. These include:

- Using less water for the washing of raw materials (from 200 L/day - 60 L/day) as well as for cooking processes
- The reuse of the pasteuriser water; and
- Reducing the frequency at which coats are washed (from three times per week, to once per week)

The wastewater treatment utilised by this facility is rather simplistic and consists of a septic tank, with a French drain system leading into a holding tank. After the water passes through a peat filtration system it is transferred to a smaller tank, from which it is used to irrigate the garden.

Industrial unit 3013.9 is located on the west coast of South Africa and specialises in the processing of potatoes. The facility does utilise other vegetables in secondary or tertiary processes. These are, however, usually bought pre-processed. The facility processes 90 tons of potatoes per day, for four days a week. The facility operates for most of the year except during the month of December. They mainly focus on providing products to the local market; they do however export internationally (Namibia, Botswana and Zambia). Facility 3013.9 utilises a combination of water sources such as: seawater (for initial washing and transportation); borehole water (for cleaning and secondary washing of potatoes); as well municipal water (for direct contact after peeling). The facility reports a SWI of 6.2 m^3/ton. It is, however, important to note that when the volume of seawater and borehole water used during the process is taken into consideration, this figure rises to 10 m^3/ton. These figures are higher than those reported in literature for both EU and American potato processing facilities (SWI figures of 6.75 and 9.4 m^3/ton respectively). The main water users were found to be facility cleaning; process water (from processes such as peeling and blanching). Freezer defrosting was also identified as a water intensive process. The following water saving measures have been put in place:

- As a means to assist in the identification of water saving opportunities 10 electronic flow meters have been installed
- Outdated and incorrectly sized nozzles in the peel remover are replaced
- After machinery shuts down the water flow is stopped by means of automatic switches; and
- In order to prevent wastage during cleaning operations the hosepipes have been equipped with triggers

The facility applies a rather basic treatment to its effluent streams. The effluent is merely pumped into sedimentation tanks in order to remove the majority of the solids from the process water. After passing through the sedimentation tanks the process water is mixed with seawater, which was used for conveying and washing, and finally discharged into the ocean. The effluent quality reported by the facility is very similar to that found in literature (Table 5).

Industrial unit 3013.10 is situated in the province of Limpopo and focusses on the processing of vegetables. The facility possesses four active processing lines, which produce tomato puree; canned tomatoes; atchar (mango and vegetable varieties); and gherkins. Products are mostly intended for the local market. They do, however, export cherry peppers in small quantities. The facility employs 146 permanent staff as well 300 – 500 seasonal staff. The facility's daily freshwater requirements of 80 000 – 160 000 L are supplied by boreholes. Washing of raw materials and cleaning operations were found to be the main water using operations. In order to save water the facility has implemented the following active water saving measures:

- Hosepipes have been equipped with triggers
- Staff training
- Water dispensing points as well as dispensing units for cleaning chemicals have been installed; and
- A condensate recovery system collects the water from the pasteurisers and double jacketed vessels to be re-heated by the boiler

The facility treats its wastewater by passing the effluent streams through settling dams. These settling dams also contain moving screen filters which further ensure that the solids are separated from the wastewater. After wastewater treatment has been completed the effluent is used to irrigate the surrounding fields. Figures regarding COD levels were not provided; the project team was however, able to acquire the facility's TSS figures (1740 mg/L on aggregate). According to literature this figure is larger than those reported by other facilities of similar nature (Table 5).

Industrial unit 3013.11 is located in southern Gauteng and manufactures frozen vegetables products. The facility employs 426 permanent staff, with seasonal staff contingent consisting of roughly 100 individuals per 12-hour shift. An annual water consumption of 188 976 m^3 is reported by the facility. This incoming freshwater is distributed as follows:

- 1 089 m^3 used by employees

- 41 525 m^3 required for cooling tower evaporation

- 33 975 m^3 required to operate the boiler
- 112 387 m^3 for other facility operations such as material washing and facility cleaning

Material washing and facility cleaning were identified as the most water intensive operations. Water saving measures such as design-based optimisation (the only facility to have employed this); dedicated maintenance; recirculation of water in the slither remover; water-wise cleaning (nozzles on hosepipes); as well as staff training have been implemented. Extensive wastewater treatment is not required due to the fact that the facility discharges its wastewater into the municipal system. Thus, they apply primary treatments in the form of screening for solids, the addition of lye, a flocculation process and finally a decanting step (Table 15). The effluent quality depends on the type of raw material being processed, with the facility reporting the following figures: pH (4.4 – 8.0); COD levels (410 – 5 810 mg/L); and TSS (330 – 1 840 mg/L). No comparable figures were found in literature.

Industrial unit 3013.12 is located in the province of Limpopo. Their main production focus is the bottling of picante peppers, although they do also produce other value-added vegetable products such as atchar, salsas, pickles and sauces. The facility is operational year-round, but experiences a peak season between the months of January and June (due to the picante season). The majority (80%) of their products are aimed at the export market. North America and Europe were reported to be the main export destinations. A total of 230 permanent staff are employed at this facility, along with 2 500 seasonal workers (who work on a day/night shift basis). The facility's daily water requirements of approximately 300 m^3 per day are met through municipal supply. The water saving techniques implemented at 3013.12 include the reuse of pasteuriser water (which is replaced every 2 weeks) and reuse of wash-water (replaced every day). The staff is further provided with water awareness training; water-wise cleaning techniques (dry cleaning of certain areas and nozzles on hosepipes) are also practiced. The facility is checked for leaks on a weekly basis. Facility 3013.12 does not do much in terms of wastewater treatment and merely passes the effluent through a screen filter before discharging it into the municipal sewerage system (Table 15). As was the case with facility 3013.11 the wastewater quality parameters (Table 14) differ according to the type of raw input being processed. COD levels range from 3 429 – 10 059 mg/L, whilst TSS reportedly ranges from 813 – 1 500 mg/L. The facility also reported that they are able to maintain an average pH value of 5.98 (Table 14). No comparable effluent quality data was readily available in literature.

Industrial unit 3013.13 is a large facility which is situated in the Western Cape Province; it consists of two separate facilities (Namely an East and West facility). The western facility manufactures canned vegetables, whilst the eastern facility is responsible for the manufacturing of canned deciduous fruits. The two sites employ approximately 5 000 individuals (500 permanent staff; and 4 500 seasonal staff). The facility reports that the washing of raw materials accounts for roughly one third of their water requirements, whilst the remaining two thirds are assigned to material washing and the cleaning of the facility. Due to the threats of drought, water minimisation has been a high priority since 2016. Their water minimisation strategy involved the implementation of the following projects:

- Installation of Central Shut-off valves. This allows the facility to isolate the water supply to a specific part of the plant, once the work in that section has been completed

- Urinals have been upgraded to be water efficient
- Utilising mountain/stream water rather than municipal water supply
- Water pumps function as a closed system
- The pressure of the handwashing stations has been reduced; and
- Lye-peeling heat exchangers with higher efficiency have been installed

The above mentioned measures were found to be very effective, as can be seen in Figure 9 below. The facility managed to reduce their total water consumption by 54% over a period of two years. In 2016 they reported a total water consumption of 1 014 668 kL; this was reduced to 465 458 kL in 2018.

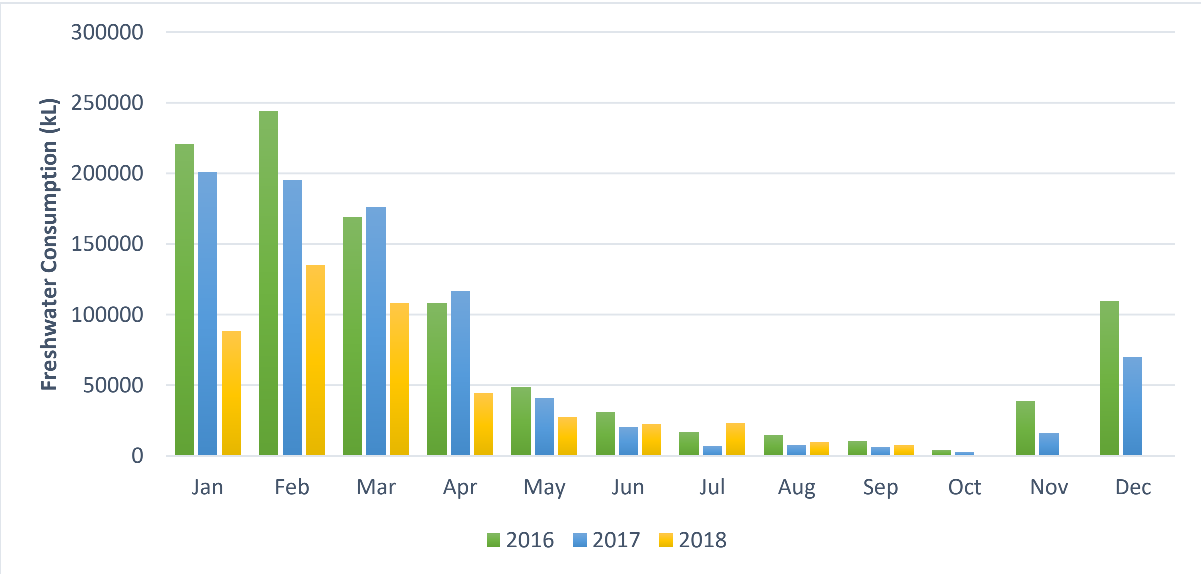

Figure 9 Comparison of water consumption at industrial unit 3013.13 during the period of 2016 – 2018 (Adapted from Volschenck, 2020).

Facility 3013.13 was found to have a SWI figure of 6.16 m^3/ton, which is greater than the figures reported for both American and European facilities of a similar nature (Table 13). It is possible to divide the facility's wastewater effluent stream into two separate streams; namely the lye-peeling wastewater and other water. These streams have COD ranges of 10 000 – 15 000 mg/L and 7 000 – 9 000 mg/L respectively. Their wastewater treatment strategy consists of screening for solids, after which the effluent is aerated and pumped into dams. Here the wastewater is continuously pumped between dams until a sufficiently low COD level is reached. Once a sufficient COD level is obtained the water may be used to irrigate the company farm's fields.

Industrial unit 3013.14 is located in the Western Cape and manufactures dried fruit products. The facility has a year-round supply of raw materials (various dried tree fruits) and is subsequently able to operate year-round. It is for this reason that the company's workforce only consist of 130 permanent staff. The facility reports that it manufactures roughly 1 000 tons of dried fruit per annum. They plant has a daily water requirement of 60 m^3 which is met by a 60 m^3/hour borehole. The incoming water is treated for high iron and manganese content before being used in the facility. The main water users were identified as the washing of raw materials and the cleaning of equipment. Facility 3013.14 states that they attempt to minimise their water consumption by training their staff sufficiently, practicing water-wise cleaning techniques as well as ensuring timely maintenance and leak repair. After the worn-out nozzles utilised during the initial fruit cleaning processes were replaced, the facility was able to reduce the water requirements by 75%. Facility 3013.14 is one the few facilities visited, which applies a primary, secondary and tertiary treatment to its wastewater effluents. Initially the effluent undergoes a filtration step by being passed through a bag filter. Thereafter, the effluent and the facility's sewage is mixed and discharged into a 3-stage aerobic bioreactor. Lastly the effluent is filtered through a peat bed filtration system. After treatment the water is pumped into a reservoir, from which it is either used to water the facility's lawn or discharged into the municipal system (Table 15). The facility reported that the municipality monitors their wastewater quality on a monthly basis. They routinely check parameters such as pH; Biomass; conductivity; TSS; Ca; Cl; Potassium and COD. Specific readings were however, not provided. The facility does not have any wastewater quality targets in place, other than achieving a COD level of less than 100 mg/L. Their wastewater treatment process is reportedly able to reduce their COD levels from above 4 000 mg/L to below 100 mg/L (Table 14), with typical effluent COD levels before treatment ranging from 2 165 to 3 110 mg/L. This means that their treatment process is highly effective. It should, however, be noted that drying facilities rarely produce high volumes of effluent; and their effluents generally also do not possess high organic loads.

When questioned about the possibility of further beneficiation of the effluent streams, the facility manager reported that the water could be used for irrigation, but their effluent volumes are too low to fully supply the orchards.

Industrial unit 3013.15 is situated in the Eastern Cape. Its main production focus is the freezing of fruit products, which are supplied to niche international markets. Piquante Peppers are also canned in limited quantities on the premises. About 500 individuals are permanently employed by the company. During peak seasons approximately 1 000 seasonal staff are hired to assist with the production processes. The facility processes 7 000 tons of raw fruit per annum. Deciduous fruits are mainly processed from January till April, whilst citrus is mainly processed during the winter months (May – August). Facility 3013.15 is also responsible for the production of sorbet, with the fruit juice ingredients being obtained from various suppliers. The production of sorbet is measured in units; 15 million units (100 grams each) have reportedly been produced in the past year. The facility has a freshwater consumption of between 6 000 - 13 000 kL per month. The incoming water is supplied by the Fish River Transfer system; this ensures that the facility has a constant water supply, even through periods of drought. The chlorine limits and microbial loadings of the incoming water are consistently monitored, with UV filters being utilised to treat the incoming water. The facility was unable to provide the project team with data pertaining to the water consumption of specific operations. Cleaning and washing operations were, however, identified as the most water intensive operations. Data pertaining to specific water intakes for various products were also unavailable. It was, however, admitted that water minimisation is not currently seen as a high priority by the company. This is due to the constant water supply provided by the Fish River Transfer System. They are instead focussing on reducing the high energy requirements of their operations (approximately 1 200 kWh/month). The effluent volume is estimated to be roughly 80% of the incoming water (between 4 800 – 10 400 kL per month). Facilitty 3013.15 does not implement much in terms of wastewater treatment, with screen filtering being the only treatment applied. After the solids have been separated from the wastewater, the water is discharged into the municipal sewerage system (Table 15). The facility was unwilling to provide information pertaining to wastewater quality.

Industrial unit 3013.16 is an apple juicing facility located in the Western Cape. The facility's employee contingent consist of 100 permanent staff, whilst seasonal staff are not required. This is due to the highly mechanised nature of the facility. Various different cultivars are juiced by the facility, with production taking place between January and July. The facility consumes a total of 65 000 tons raw materials in order to produce approximately 8 000 000 L of concentrate. By improving their production process, the facility was able to lower their water consumption of 300 000 m^3 (2018) to 200 000 m^3 (2019). This is now also supplied by a borehole instead of municipal supply. This change was made due to the unit cost of water increasing from R11/kL to R56/kL. The incoming water is treated for Iron and *E.coli*. The facility's main water using operations are material washing and facility cleaning. For the majority of the season Facility 3013.16 is self-sufficient in terms of process water, with the condensate being reused for most of the processing requirements. It was stated that water minimisation was a priority for the facility, substantiated by the planned installation of a UV filtration system in the initial washing area. It is hoped that by subjecting the incoming water to UV filtration, the facility could reduce the frequency at with wash water needs to be replaced. The concentration process is advantageous in the sense that the condensate can be collected and reused as process water. The facility also practices timely maintenance of leaks, and separates the cleaning chemicals from wastewater for reuse.

As stated earlier the facility made various changes to their production process. One of their main focusses was reducing their water consumption as well as improving their water recovery processes. The facility no longer uses any cooling systems as this was found to be too water intensive, they also no longer use activated carbon to clean their juice. Instead an absorber is used to clean their juice. They are now able to achieve 80% condensate recovery. The facility further reports that all process water is recovered and that they experience minimal water loss. The effluent is subjected to a 10 000 L/h caustic recovery system, which could be improved to 20 000 L/h. The implementation of the caustic recovery system has resulted in a 50% reduction in water use. The caustic that is recovered is reused in the production process. Retentate was initially used to clean their membrane filters, however once it gets into the effluent streams it significantly lowers the effectiveness of the treatment process. For this reason, they have stopped using retentate.

The facility generates a daily effluent volume of 60 m^3 of water. The effluent is passed through screens in order to remove solids, after which lye is added. The effluent is also subjected to a caustic recovery process. Thereafter, the water is pumped to a UASB reactor which is situated about two km from the factory. From there the water is pumped to a settling dam, from which it is used to irrigate the orchards. In 2020 the facility installed an Anaerobic Digester as a means to treat their solid organic waste. This was installed due to the fact that a regulation change is expected for 2024 which would mean that landfills would no longer be able to accept organic waste. This Anaerobic digester requires water to operate, thus the facility uses the effluent generated after the caustic recovery process. Thus, the effluent is passed through the digester before being pumped to the UASB reactor. This treatment process is able to yield COD levels of between 6 000 and 8 000 mg/L and a pH level of 6.31. These figures are slightly higher than those found in literature for fruit juicing facilities (Table 5). It is, however, important to note that the UASB reactor has barely been operational over the past two years. This is due to various reasons including high maintenance costs; it requires personnel to supervise the operation. This facility also attempted to install a nano-bubbler as a treatment process, however, this was ultimately deemed unsuccessful. The facility also considered shutting down the UASB reactor due to the high costs related to its operations. Taking this into account it can be concluded that the Anaerobic Digester is currently the main secondary treatment applied to the effluent. The facility also reported that the digester was able to yield far better COD levels than they were able to accomplish while using the UASB reactor, which is a much more advanced process. Their pH, COD, TSS, Na-absorbance is monitored by CSIR on a monthly basis.

The facility's annual energy requirement of 3 500 000 kWh is supplied by means of a 16 ton Coal boiler, a 8 ton coal boiler, a 1.4 ton biogas boiler, the municipal grid as well as a 350kW solar system (provides 1/3 of the daily requirement).

No further beneficiation for the wastewater effluent was reported. They do, however, view their solid waste as a source of income. After the waste is passed through the digester it can be sold off as a soil enhancer or animal feed (depending on the type of material digested).

Industrial unit 3013.17 used to be a pineapple canning facility. The canning industry was, however, found to be unprofitable. Thus during 2007/2008 the facility decided to change their operational focus to that of pineapple juicing. Subsequently, the factory now manufactures pineapple concentrate, as well as small quantities of 100% fresh juice. Approximately 120 individuals are employed by the company. The company reported that roughly 81 000 tons of raw fruit were processed during 2018; this figure was expected to increase to 87 000 tons for 2019. Production takes place from late February till December, this is due to potential year-round availability of pineapples. Facility 3013.17 is mainly geared towards the export, with about 85% of their products being exported to destinations such as Europe, Russia and South America. The company has stated that minimising water consumption is a priority for the facility. As a means to accomplish this they have improved the water consumption of their initial rinsing process. This was done by dumping the fruit directly onto conveyer belts rather than using 'Dumper Baths'. By implementing this change they were able to reduce their water consumption by approximately 20%. It is estimated this reduction in water consumption has resulted in R 1 million savings per annum. Other water saving measures include CIP (Clean-In-Place) of specific equipment such as the concentrate holding tanks. Furthermore, the condensate from the evaporation process is collected and reused to clean the facility and stainless-steel surfaces (the use of the condensate for other surfaces is restricted due to its low pH). Primary treatments are applied to the facility's wastewater in the form of screen filtering for solids as well as pH buffering (usually through lye addition). The COD (5 976 mg/L) and TSS (1 552 mg/L) levels were higher than the figures found in literature (5 157 mg/l and 323 mg/L, respectively) (Tables 5 & 14). The solid waste generated during the production is sold to local farmers as animal feed.

Industrial unit 3013.18 is a bottling and canning facility based in the Eastern Cape Province. They focus on the processing of various members of the *Capsicum* (Pepper) family. Red cherry peppers, sweetheart peppers and Jalapeño are typically produced. The company is mainly geared towards the export market and produces around 3 000 tons of packed product from December through March. Twenty three individuals are permanently employed by the company, whilst 1 280 seasonal staff work at the facility for about 8 months of the year. Due to drought and mismanagement Facility 3013.18 has found itself in a situation where the local municipality has been unable to meet the facility's water requirements over the past two seasons. In order to overcome this problem the facility fulfils its daily water requirements of 148 m^3 by trucking in the water from a nearby borehole. The facility states that it actively tries to minimise water consumption through implementing the following measures:

- Facility and equipment cleaning is accomplished by applying sanitiser and water using compressed air rather than with a traditional hosepipe
- Basic cleaning is done using a broom and squeegee sponge
- The change-over of washing tank water has been reduced
- Water efficient toilets have been installed; and
- Staff are provided with water-wise training

Facility 3013.18 does not apply any wastewater treatments to its effluent stream. The effluent streams do, however, pass through catch pots (for removal of large solids) before being discharged into the municipal system. No records regarding wastewater quality are kept by the facility.

Industrial unit 3013.19 is a citrus juicing facility situated in the Eastern Cape. They are mainly focussed on the production of concentrates. It is reported that facility processes approximately 90 000 tons of citrus per annum. Production takes place between March and end of October. The facility's staff can be divided into 160 seasonal staff and 37 permanent staff members. The plant's incoming water is provided by a local irrigation canal system. The evaporators and boilers were identified as the most water intensive operations. Active water saving measures include:

- Improving the water efficiency of the piping
- Condensate water is captured and reused
- It is planned to reuse the water captured from the vacuum pump
- Water consumption is monitored
- Boiler water is recirculated
- Redesigning the boiler layout and insulation of steam piping in order to improve the energy efficiency of the steam-based systems
- Practicing water-wise cleaning

The primary treatments applied to the wastewater includes static screen filtering and pH buffering by adding lime to the wastewater. After the effluent is pumped through a decanter, it is divided into two separate streams. An oxidation ditch is used to treat 50% of the effluent; after additional solids are separated from the water by means of a clarifier. The remaining 50% of the effluent is guided through a trial system, which consists of an aerobic and anaerobic reactor arranged in series. It is hoped that all organic matter will be dissolved by the aerobic reactor; whilst the anaerobic reactor will be responsible for the removal of biological nutrients. Additional solids are removed by means of a membrane system. After treatment is completed both of the effluent streams are used to irrigate the facility's fields (Table 15). No information regarding effluent quality was provided by Facility 3013.19.

Industrial unit 3013.20 is a juicing and packaging facility located in the Boland region of the Western Cape. Their production period runs from October through to April. The facility handles 7 000 000 kg of concentrate and pressed juice per year. Their annual water consumption requirement of 2 000 000 L is supplied by the municipal system, two boreholes and a water recovery system. The incoming water is passed through a sand filter, after which chlorine is added. The incoming water is also subjected to UV treatment. The main water using processes are washing of equipment followed by production processes. The facility produces 3 000 – 4 000 kL effluent per month. All the effluent is collected in a pit, from which it is passed through a screen in order to remove solids. Then the effluent is pumped to a 60 000 L tank where the effluent is mixed, to ensure a consistent flow. The effluent is also treated with caustic in order to neutralise the pH. BioTabs are added to the effluent as a means to lower the COD levels. After these primary treatments the effluent is discharged into the municipal system. The facility reports that they aim to keep their COD levels below 5 000 mg/L (with varying success). These figures are similar to those found in literature for fruit juicing facilities. The company has a total energy requirement of 400 000 kWh per annum, which is supplied by two steam boilers, solar panels and the municipal grid.

The facility reports that in their view there is no further beneficiation of their effluent streams or solid waste outputs. This is mainly due to the fact that the facility does not have orchards close by, thus irrigation is not an option. Furthermore, the tariffs placed on incoming and outgoing water are relatively cheap, thus there is no need for the facility to spend large amounts of money in order to build an advanced wastewater treatment plant.

4.2.1 Critical comparison of specific water intake findings of the current study versus those in the 1987 NATSURV

A few obstacles were encountered when attempting to compare the performance of the surveyed facilities with those included in the 1987 NATSURV. The first problem is the fact that the 1987 NATSURV calculated specific water consumption in terms of raw material intake. This is unfortunately contrasted by the international norm of calculating SWI in terms of production. Another obstacle encountered was the fact that the facilities investigated during this study did not necessarily fall under the categories included in the original NATSURV project. For example, the original NATSURV did not include ‘drying’ as a production category, whilst three drying facilities were included in the current study. Thus, in order to compare the SWI’s reported in the original NATSURV and the current study, the SWI’s were recalculated for facilities with sufficient data pertaining to raw materials. Unfortunately, not all the surveyed facilities provided sufficient data pertaining to raw material consumption. A comparison of the recalculated SWI’s and those reported in the 1987 NATSURV can be seen in Table 16 below.

Table 16 Comparison of SWI’s (m3/ton raw material) from the 1987 NATSURV versus the recalculated SWI’s of the current study

SWI’s of 1987 NATSURV		SWI’s of Current study	
Canning & juicing of citrus	2.1	Juicing of citrus	1.14
Freezing	26.97	Freezing of potato products	6.22
Canning & juicing of pineapples	2.94	Juicing of pineapples	1.27
Juicing of apples	3.48	Juicing of apples	1.14

Although this study produced very limited comparable data, it appears that the water consumption efficiency of the South African FVPI has improved. From Table 16 it can be seen that the process of freezing potato products has improved its water consumption efficiency by a factor of four in comparison to freezing process found in the 1987 NATSURV. Another significant improvement is observed in the apple juicing industry. Considering the information above, it can be stated that the water consumption efficiency has improved since the previous NATSURV was published.

4.2.2 Critical comparison of SWI's found in international literature and those found in the current study

According to international literature specific water intake is commonly determined in terms of production (i.e. m^3/ton final product). This data was more readily available, with 10 surveyed facilities yielding comparable SWI's. Table 13 provides a comparison of the calculated SWI's from the current study and those found in international literature. It was found that five facilities (3013.8; 3013.9; 3013.10; 3013.11; and 3013.16) were able to yield better SWI's than those reported for facilities of a similar nature in literature. Four facilities (3013.12; 3013.14; 3013.17; and 3013.18) had SWI's worse than those reported for their international counterparts. Therefore, whilst the performances of facilities within the South African FVPI may have improved over the last three decades, they still vary in comparison to their international counterparts.

4.2.3 Critical comparison of wastewater characteristics from current study versus those from the 1987 NATSURV

It appears that the wastewater treatment techniques applied in the 1980s were rather simplistic in both aim and in technologies utilised. According to the 1987 NATSURV report the main aim of the methods were merely to remove solids from the effluents streams. Unfortunately, the report does not explore the effectiveness of the methods implemented. This makes it impossible to draw a meaningful comparison between the current study and the previous NATSURV. Due to the technological advancements observed over the last three decades, one would expect that facilities included in the current study are able to achieve better effluent parameters than those from the original NATSURV.

4.3 Content analysis of water and wastewater management using ATLAS.ti 9

By utilising a deductive approach three major themes (Production information; water management and wastewater management) were identified. The content analysis for these themes can be found in the following section.

4.3.1 Production information

Qualitative data analysis (QDA) has revealed that the majority of the facilities investigated in this study function under a single processing category, this being either Canning/Bottling; Juicing; Freezing; or Drying. Of the 20 facilities surveyed, only two (Facility 3013.7 & 3013.15) were involved in multiple processing categories (Table 17). It was further found that 10 of the 15 facilities visited on a case-study basis were dependent on raw inputs of a seasonal nature. Consequently, they rely on seasonal staff for most of the production season. The facilities that do not rely on seasonal staff include 3013.9, 3013.14, 3013.16; as well as 3013.17 and 3013.20. Facility 3013.9 is responsible for the processing of potatoes and has access to raw inputs for most of the year, thus they are able to employ all their staff on a permanent basis. Facility 3013.14 is a drying facility which processes multiple varieties of tree fruit and consequently has year-round access to raw inputs. Thus, similar to 3013.9 a permanent staff contingent is a viable option. Facilities 3013.16 and 3013.17 are both single variety juicing facilities. Despite the seasonality of raw inputs, 3013.16 (Apple Juicing Facility) has stated that it does not require seasonal staff. This is due to the high level of automation observed in the production process. Facility 3013.17, a pineapple juicing facility, has also stated that their production process is highly automated and therefore seasonal staff are not required. Facility 3013.17 does, however, also have access to an almost year round supply of raw inputs. Facility 3013.20 is responsible for the packaging of various juices. They have access to a year-round supply of raw materials. Furthermore, their production process is also highly mechanised. Therefore, Facility 3013.20 does not require any seasonal staff.

Table 17 Production focus of surveyed facilities

Facility	Drying	Juicing	Canning/Bottling	Freezing	Totals
3013.1	-	1	-	-	1
3013.2	-	1	-	-	1
3013.3	1	-	-	-	1
3013.4	1	-	-	-	1
3013.5	-	1	-	-	1
3013.6	-	1	-	-	1
3013.7	-	1	1	1	3
3013.8	-	-	1	-	1
3013.9	-	-	-	1	1
3013.10	-	-	1	-	1
3013.11	-	-	-	1	1

3013.12	-	-	1	-	1
3013.13	-	-	1	-	1
3013.14	1	-	-	-	1
3013.15	-	-	1	1	2
3013.16	-	1	-	-	1
3013.17	-	1	-	-	1
3013.18	-	-	1	-	1
3013.19	-	1	-	-	1
3013.20	-	1	-	-	1
Totals	3	9	7	4	23

4.3.2 Water management

4.3.2.1 Priority of water saving strategies

Analysis has revealed that most facilities either view water saving as either an intermediate or high priority (Fig. 10). One facility did, however, state that water saving was not a priority and that they are instead focussing on improving the energy efficiency of the freezing process. Water saving is not a concern for this facility (Facility 3013.15) due to the constant water supply provided by the local canal system. It appears that environmental concerns or drought are not the only incentives which lead facilities to improve their water consumption. As can be seen by the following quotations, financial reasons also drive the implementation of water minimisation measures:

"Interviewer: So, you mentioned that the facility made changes in terms of freshwater sources and water recovery systems, what was the reason for this?

Interviewee: Well, the municipality increased the water fees from R11/kL to R56/kL so it just didn't make sense to keep using their water. The borehole and water recovery systems are able to meet our requirements and effectively cost us nothing..."

One facility mentioned that an increase in the unit cost placed on freshwater supplied by the municipality lead them to re-evaluate their water consumption:

"Interviewer: Why were these water saving measures implemented?
Interviewee: Cost saving and a precaution for drought since we experienced a serious drought a few years ago. The stakeholders also want us to report green or eco-friendly measures in the end of year reports. Some of our clients also want facilities to use green techniques."

Facility 3013.17 specifically highlighted the financial benefits of improving their water saving measures. They improved the water consumption of their raw material reception process by installing a dry conveying system, as a replacement for their water intensive "dumper baths". By doing so, the facility was able to reduce their water consumption by 20%, which is estimated to relate to more than R1 million in annual savings (2019).

The implementation of green or environmentally friendly technologies in food processing often entails the reduction of both water and energy costs (Jermann *et al*., 2015). Thus, it can be expected that the implementation of water-saving and wastewater treatment techniques, observed in this study, will largely be driven by financial incentives.

4.3.2.2 Water using processes

An overview of the code occurrence for water using operations across the four different processing categories can be found in Table 18 below. The main water using operations were found to be *material washing* and *facility cleaning*.

Considering the code occurrence observed in *canning/bottling* facilities, it is noted that only one facility list *process water* (code 1.5.3) as a major water user. It is important to note that this facility is a rather small facility. The facility's small scale, in comparison to other facilities, could be the reason for this outlier (i.e. the process water often becomes proportionately less, as the size of the facility increases). The occurrence of the *product make-up* (code 1.5.4) code is also only observed within canning/bottling facilities.

The code for *process water* (code 1.5.3) further occurs twice for facilities within the *juicing* category. In both cases the facilities are involved in citrus juicing and have identified *boilers* and *evaporators* as water intensive machinery.

Table 18 Code occurrence for major water using processes per processing category

Code	Drying	Juicing	Canning/Bottling	Freezing	Total
1.5.1 Material Washing	1	2	5	2	8
1.5.2 Facility Cleaning	1	1	4	2	10

1.5.3 Process Water	0	2	1	1	4
1.5.4 Product Make-up	0	0	2	0	2
Total	2	5	12	5	24

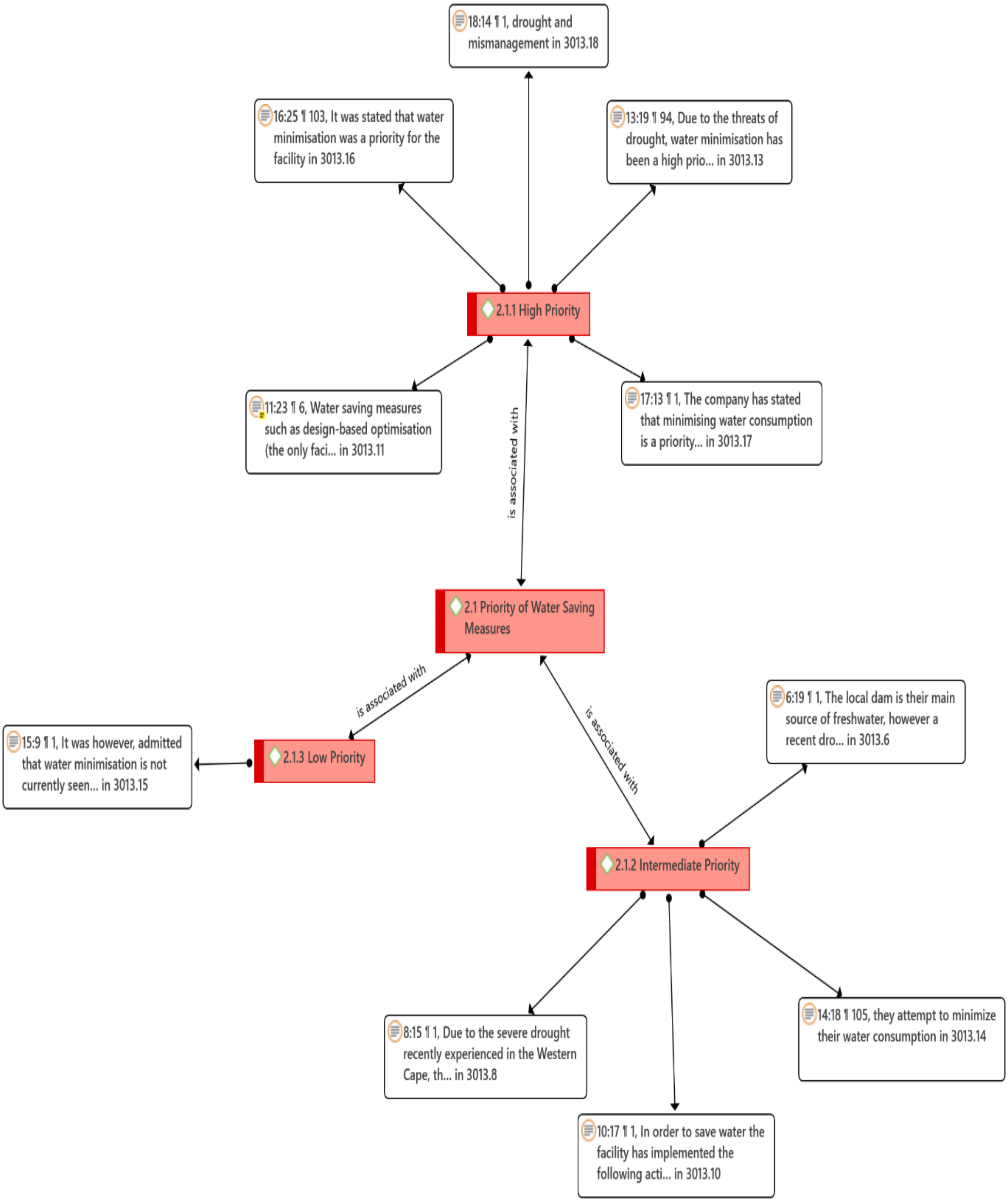

Figure 10 Network exploring the level of priority of water saving at surveyed facilities.

4.3.2.3 Implementation of water saving measures

As is the case with most processes or operations within the South African FVPI, there is no universal strategy when attempting to reduce a facility's water consumption. This is mainly due to the high process heterogeneity observed within the industry. As can be seen in Figure 11 below, it was found that the majority of the water minimisation strategies implemented involved process changes (e.g. 'Waterless Operations'; 'Improved Equipment Design'; and 'Proper Maintenance') and water reuse/recycling. Design-based improvements were however observed at five facilities. Whilst the implementation of novel technologies such as UV technology was not observed at any facility, Facility 3013.16 stated that they plan to install a UV filtration system in the initial washing phase. It is hoped that by doing so the wash water change over time could be extended. It is also important to note that in some cases the water saving measures mentioned during the interviews, were not necessarily implemented at factory level.

4.3.3 Management of wastewater

As can be seen in Table 19 it appears that most facilities within the South African FVPI do not implement complex multistage effluent treatments. It was, however, found that the majority of facilities at least implement some form of primary treatment, with secondary and tertiary treatments being utilised to a lesser extent. Only three facilities reported the use of a primary, secondary and tertiary treatment. Facility visits revealed that the effluent treatments implemented by many of the facilities were rather simplistic, and were not viewed as a priority by management. Interesting anecdotal information was also acquired through interviews with the production managers of the surveyed facilities. Of particular note was a manager which admitted that the quality of the wastewater, used for irrigation purposes, was above the legal limits. They further stated that the unwillingness of many other facilities to share information regarding effluent quality would likely be due to a similar reason.

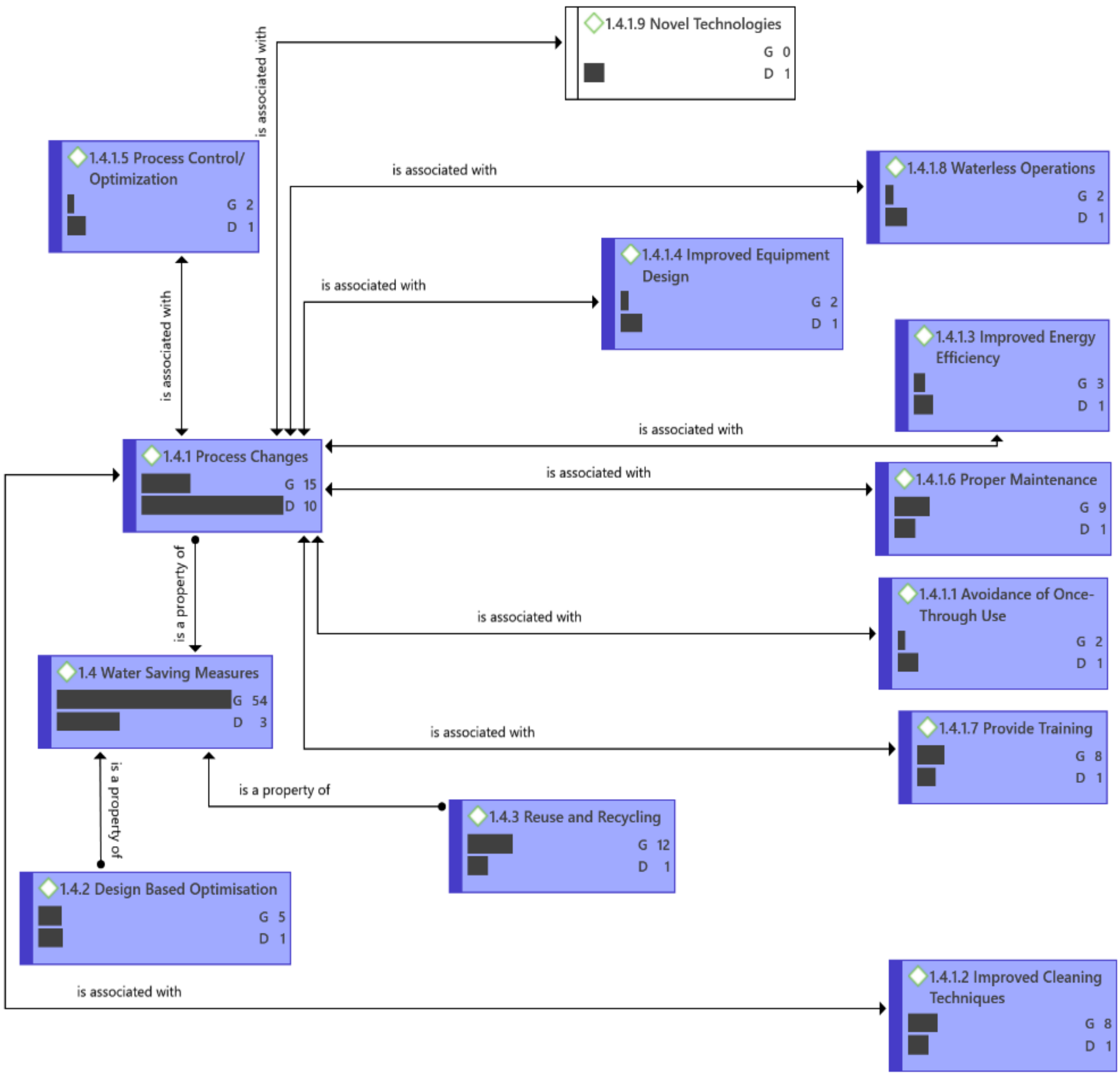

Figure 11 Network describing the water saving measures implemented by surveyed facilities

Table 19 Types of wastewater treatments implemented by surveyed facilities

Facility	Primary Treatment	Secondary Treatment	Tertiary Treatment	Totals
3013.1	1	0	0	1
3013.2	1	1	1	3
3013.3	1	1	0	2

3013.4	1	1	0	2
3013.5	1	0	0	1
3013.6	1	0	0	1
3013.7	1	1	0	2
3013.8	0	1	1	2
3013.9	1	0	0	1
3013.10	1	0	0	1
3013.11	1	0	0	1
3013.12	1	0	0	1
3013.13	1	1	0	2
3013.14	1	1	1	3
3013.15	1	0	0	1
3013.16	1	1	0	2
3013.17	1	0	0	1
3013.18	0	0	0	0
3013.19	1	1	1	3
3013.20	1	0	0	1
Totals	18	9	4	31

4.3.3.1 Primary Treatments

After analysis was completed it was found that various primary treatments were employed by the surveyed facilities. Table 20 below contains the code occurrence for these treatments. It appears that the most commonly used technique is screening, as it is implemented by almost all facilities. It is, however, important to note that most facilities stated that the screening is mainly intended for the removal of large solids. After screening, the next most commonly applied treatments were neutralisation and sedimentation, respectively. Flow and load equalisation was found at two facilities, whilst precipitation was only used by one facility. Literature stated Dissolved Air Flotation (DAF) and Centrifugation as possible primary treatments, these were however, not utilised at any of the surveyed facilities. As can be seen in Table 20, three treatments were allocated to the 'other' primary treatment code (code 2.1.8). These include subjecting the effluent to a caustic recovery process, the addition of 'BioTabs™', as well as the addition of 'Eco-Tabs™'. 'BioTabs™' are dissolvable tablets which are added to the effluent as a means to lower the COD levels. 'Eco-Tabs™' are another form of dissolvable tablets, which are added to the effluents in order to oxygenate the effluent, neutralise odours, remove organic and chemical pollutants through bioaugmentation; and prevent corrosion as well as initiate the aerobic biological breakdown of organic sludge.

Table 20 Code occurrence for primary treatments reported by surveyed facilities

Treatment Method	Totals
2.1.1 Screening	17
2.1.2 Flow and Load Equalisation	2
2.1.3 Neutralisation	10
2.1.4 Sedimentation	5
2.1.5 DAF	0
2.1.6 Centrifugation	0
2.1.7 Precipitation	1
2.1.8 Other	3

4.3.3.2 Secondary Treatments

It was found that within the South African FVPI, secondary treatments are implemented to a lesser extent in comparison to primary treatments. Of the 20 facilities surveyed, only nine utilise some form of secondary treatment (Table 19). As reported by literature, secondary treatments can be categorised as aerobic treatments and anaerobic treatments. Figures 12 and 13 below explore the treatment methods implemented at the surveyed facilities. Facility 3013.16's UASB reactor was found to be the most advanced form of biological treatment implemented. It is however, important to note that Facility 3013.16 effectively uses two secondary treatments, as they treat their solid waste with an anaerobic digester which requires water to operate. Subsequently they pass their effluent through the digester before pumping it to the UASB reactor. The use of the UASB reactor may therefore be redundant. Facility 3013.19 utilised a trial system, consisting of an aerobic and anaerobic reactor arranged in series, to treat 50% of their effluent. The description of their trial system is similar to that of a Sequencing Batch Reactor (SBR). The use of lagoons was also observed at two facilities. The descriptions acquired from the online surveys were unfortunately rather vague, as they only described the treatments as being either aerobic or anaerobic. For this reason, these responses were coded as *Other Aerobic Processes* (Fig. 12) or *Other Anaerobic Processes* (Fig. 13), respectively. In cases where facilities utilised custom units, which could not be included in any traditional classification, they were also coded as 'Other Treatments'. One such case is the '3-Stage Bioreactor' utilised by Facility 3013.14. As can be seen in Figures 12 and 13 many of the recommended treatments found in literature were in fact not utilised within the South African FVPI.

Considering Figure 12, which describes the secondary aerobic treatment options available to facilities within the FVPI, we can see that only the codes for 'SBR' (code2.2.1.3), 'aerobic lagoons' (code 2.2.1.4) and 'other aerobic treatments' (code 2.2.1.8) received 'groundedness' indications (i.e. frequency of code occurrence) other than zero. The implementation of all the other possible treatment methods recommended by literature was not apparent.

A similar pattern can be seen in Figure 13 which describes the secondary anaerobic treatment methods available for use. The only code which received 'groundedness' indications other than zero were 'UASB Reactors' (code 2.2.2.4), 'anaerobic lagoons' (code 2.2.2.1) and 'other anaerobic processes' (code 2.2.2.7). None of the other possible treatment options found in literature were implemented in the industry.

4.3.3.3 Tertiary Treatments

The possible tertiary treatment options available to the FVPI, and the application thereof is shown in Figure 14. As mentioned previously, it is not a common occurrence for facilities within the FVPI to apply tertiary wastewater treatments to their effluents. Of the 20 facilities surveyed, only four made use of a tertiary treatment. The treatments observed included: membrane filtration; chlorination and addition of aluminium sulphate [$Al_2(SO_4)_3$]; whilst two facilities made use of a peat-bed type filtration system. As can be seen in Figure 6 the quotation "Chlorination and addition of Aluminium sulphate" is linked to two codes namely: *Other Treatments* (code 2.3.8) and *Disinfection/Sterilisation* (code 2.3.7). None of the other possible treatment recommended by literature were observed in the industry.

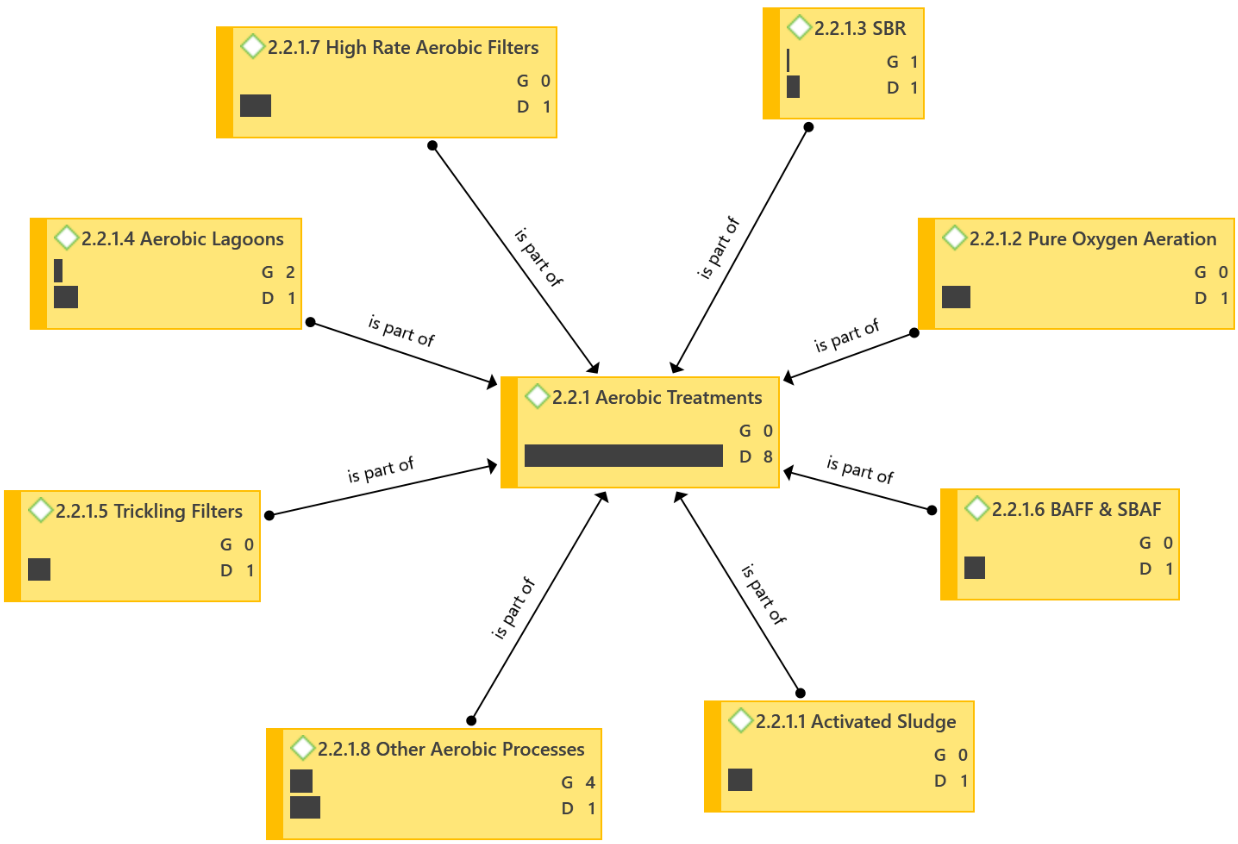

Figure 12 Network describing the possible and discovered aerobic treatments in the South African FVPI.

4.3.3.4 Destination of discharged effluents

The wastewater disposal routes in the FVPI were found to be very dependant, on the location of the facility in question. As was expected, facilities situated in urban environments often discharge their effluents into the municipal sewerage system. Facilities located in rural/agricultural areas often used their effluent streams to irrigate pastures or orchards. As mentioned earlier, the legality of the wastewater quality was, however, questionable at times. Facility 3013.9 deviated from the traditional effluent disposal routes, as they are permitted to discharge their effluent into the ocean.

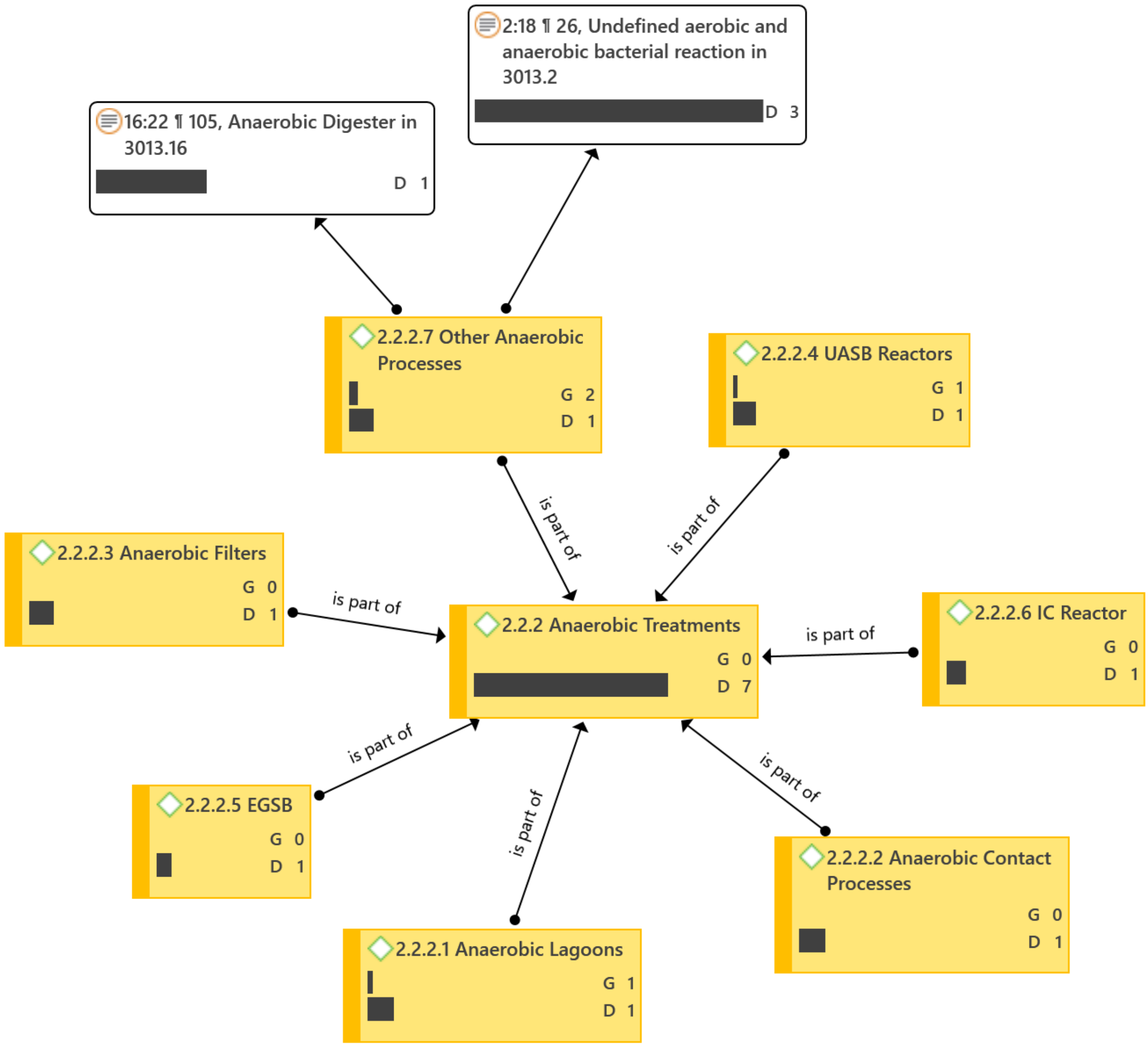

Figure 13 Network describing the available and discovered anaerobic treatments in the South African FVPI.

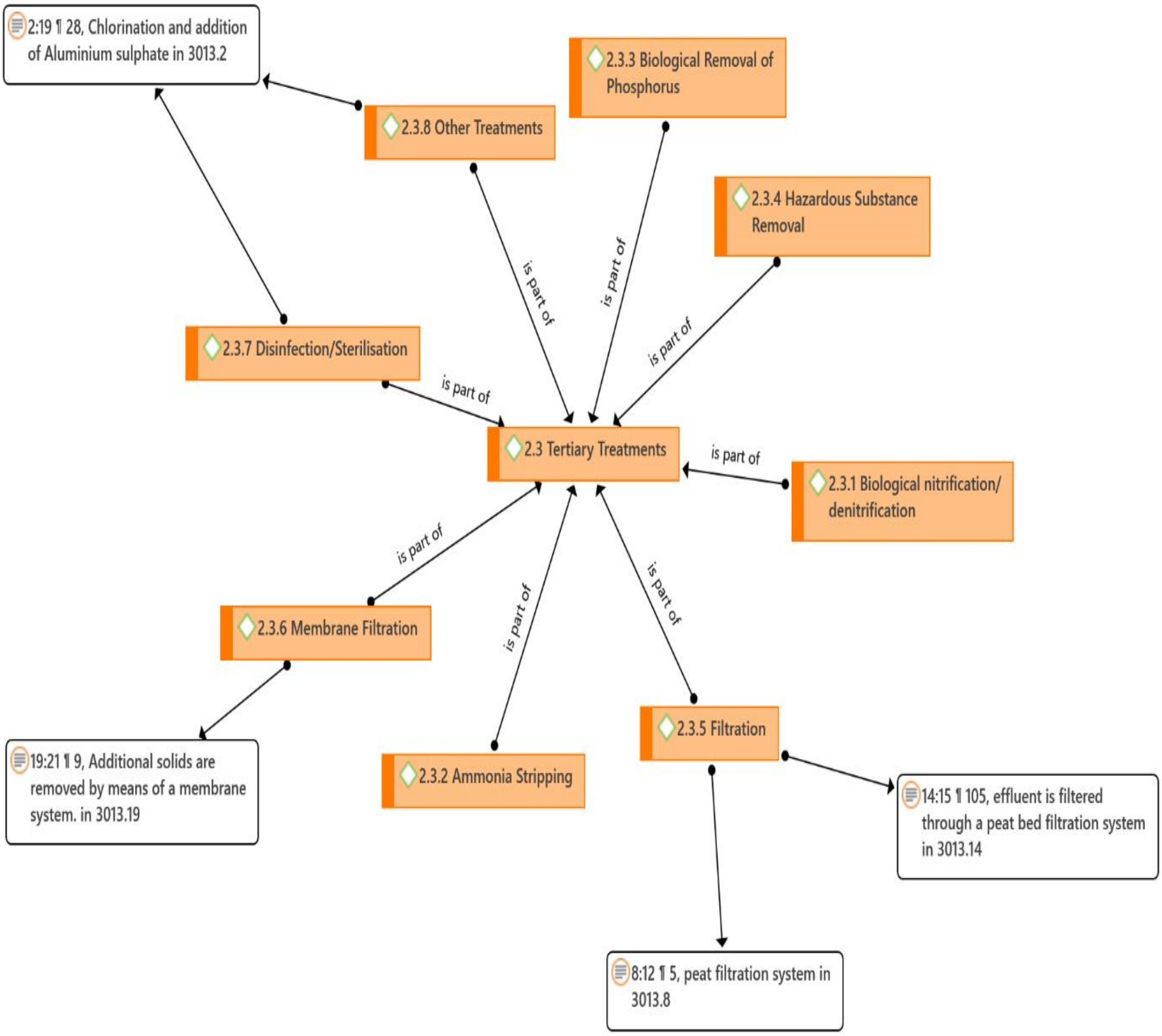

Figure 14 Network of available and implemented tertiary treatments in the South African FVPI.

Chapter 5 CONCLUSIONS AND RECOMMENDATIONS

In the context of South Africa, knowledge pertaining to water and wastewater management within the country's industrial environment was attained from the first edition NATSURV documents which were published between the late 1980s and early 1990s. The fruit and vegetable processing industry was also included in the first edition of NATSURVs. Specific mention is made regarding the industry's water intensive nature as well as its polluting effects. These documents also included recommendations for the improvement of water efficiency and wastewater management.

Only a limited amount of peer-reviewed articles discussing water efficiency and wastewater management in the fruit and vegetable processing industry were readily accessible. However, reports generated by industry bodies or governments do exist. A Reference Document on the European Food, Drink and Milk Industry (IPPC, 2006) was found to be one of the most useful sources of information. The document contained metric comparisons for a wide range of fruit and vegetable products; as well as recommended techniques to improve water consumption and wastewater management. Another document which proved useful was a report generated by the CLFP (2015), which contains metric comparisons as well as water minimisation and wastewater treatment techniques implemented by Californian fruit and vegetable processors. The literature review section of this study will provide interested parties with sufficient information regarding the various wastewater treatment options available.

The preliminary phase of this study entailed creating an industry database. This was accomplished by utilising a combination of sources such as: internet searches, referrals as well as contacting the relevant industry bodies. Once contact was made with the relevant industry bodies, they were notified of the purposes of this study and were requested to encourage study participation to their members. Once the industry database was finalised, an introductory letter was distributed to all the potential participants, detailing the aims, objectives and scope of the study. Shortly after initial contact was made, an electronic survey was made available. A follow-up survey was made available roughly 6 months after the initial survey. The electronic survey was created by making use of a secure online platform called REDCap. The initial survey achieved a response rate of 12.2%, whilst the follow-up questionnaire did not receive any responses. The initial response rate of 12.2% was seen as favourable due to the general lack of industry participation observed in earlier NATSURV projects. Additionally, site-visits were conducted at all facilities willing to accommodate the NATSURV 19 project team. The South African FVPI is known to be a highly competitive industry and facilities are often very protective of company data. Even so the NATSURV team was able to visit a total of 15 facilities on a case-study basis. All site-visits included a brief interview, with the interviews being recorded and transcribed when possible. In cases where recordings were not possible, field notes were made. Fortunately, these field notes were of high enough quality to be included in the same qualitative analysis process as the recorded interviews. Qualitative analysis was done using the thematic content analysis (TCA) technique (Vaismoradi *et al.*, 2013; Friese *et al.*, 2018). Content analysis, in-turn, was conducted following the deductive approach (Elo & Kyngäs, 2008; Andersson *et al.*, 2015; Bengtsson, 2016) using a CAQDAS platform called ATLAS.ti 9.

The surveying process shed light on the current practices and rate of technology adoption observed in the South African FVPI, which related to the first objective of this study. In terms of water efficiency it was revealed that at least some facilities reported SWI figures which were similar or better than their international counterparts. Furthermore, when considering the SWI determined for certain products in the 1987 NATSURV, it appears that some facilities were able to report improved SWI figures. This indicates at least anecdotally that the water-use efficiency of the South African FVPI has improved over the last 30 years.

The second objective was to determine effluent volumes, pollutant loads and best practice technology adoption. In terms of wastewater management it can be concluded that advanced technologies found in literature are generally not implemented within the industry. Furthermore, almost all facilities implement at least some form of primary wastewater treatment. It does however, appear that facilities are less motivated to invest in more advanced secondary treatments. Of the 20 facilities included in the final sample, only nine facilities make use of a secondary wastewater treatment, whilst only four facilities implement a tertiary treatment. A possible reason for the lack of advanced treatments could be the lengthy pay-back period often associated with such capital expenditures. However, as was demonstrated by Facility 3013.14, an effective wastewater treatment system does not necessarily need to be highly complex and expensive. On the other hand, facilities such as Facility 3013.20 stated that they do not need to invest in advanced technologies, as the levies placed on their outgoing effluents are relatively cheap. The destination of the discharged effluents is often largely determined by the nature of the facility's surroundings. It was observed that facilities in rural areas often utilise their wastewater effluents for irrigation purposes, whilst facilities in urban environments often choose to discharge their effluents into the municipal wastewater system. It is however, concerning that the managers of two facilities in the Eastern Cape questioned the operational integrity of municipal wastewater treatment plants to which their effluents were being sent. The quality of effluents observed throughout the study varied between facilities, with some reporting figures similar to those found in literature. In some cases the figures reported were higher than those reported in literature for facilities of a similar nature. Unfortunately, not all facilities were willing to provide figures pertaining to their effluent quality. Anecdotal evidence suggests that this may be because their irrigation levels exceed the parameters permitted by the General Authorisation in Terms of Section 13 of the National Water Act, 1998 (Act no 36 of 1998) (DWA, 2015).

It is important to note that the improvements in water efficiency and wastewater treatment observed in the South African FVPI are not merely driven by a desire to mitigate droughts or to be environmentally friendly, but also by financial reasons. Improved water efficiency and effluent disposal routes often result in reduced operational costs.

In conclusion, the overall aim of this study to provide a comprehensive guide as well as a benchmarking tool was achieved. This investigation has shed light on the status and technologies currently implemented in the South African FVPI. Future research should therefore, focus on individual processes as well as their optimisation. It appears that facilities are generally more inclined to invest in water saving measures rather than advanced wastewater treatment systems. This is likely due to a shorter pay-back period associated with water minimisation techniques. However, an argument can be made that it would be in a facility's best interest to invest in greener technologies due to consumers being more concerned about their environmental impact. In a review on "Competitive Environmental Strategies", Orsato (2006) explains that it could be financially advantageous to set oneself apart from the norm when it comes to the implementation of "green" technologies. Managers must, however, find a way to align these investments with the general strategy of the company. Therefore, future studies could potentially aim to improve the economic feasibility of advanced wastewater treatment technologies. Whilst this investigation made use of walk-through audits to gather information, it is recommended that individual facilities should be subjected to a more in-depth water audit (Navarri & Bédard, 2008). Another area of concern is the apparent lack of interest shown by the regulatory authorities with regards to water and wastewater management in the FVPI. This is substantiated by anecdotal evidence that some facilities are able to use wastewater of insufficient quality for irrigation purposes.

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