Investigating Water and Wastewater Management in the South African Fruit and Vegetable Processing Industry

by

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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This study was approved by the Research Ethics Committee (REC) of Stellenbosch University as project 8641 on the 28th of January 2019

SUMMARY

The Water Research Commission (WRC) has commissioned updated versions of national surveys (known popularly as the NASTURV reports) dealing with water and wastewater management within various industries. The NATSURVS were originally completed in the late 1980s and early 1990s and were used to determine minimum specific water intake requirements; protect downstream infrastructure and water sources; as well as to provide benchmarking criteria for academia, industry and regulators. The second edition of NATSURV 19 (Water and wastewater management in the fruit and vegetable processing industry) is due to be published in 2021 and will draw heavily on this study and related work. The aim of this study, therefore, is to perform a national survey of water and wastewater management within the fruit and vegetable processing industry. The quality and scope of which should be suitable for inclusion in the updated version of NATSURV 19.

The research processes commenced with an in-depth literature review, with much attention being given to the economic structure of the fruit and vegetable processing industry. This was done to facilitate a more focused selection of key sub-sectors later in the study. Another key component of the literature review was careful documentation of all available methods of reducing water use in food processing, and more specifically, in the processing of fruits and vegetables.

The actual survey process began an application for ethical clearance with the Stellenbosch University research ethics committee (REC), with the actual approval being granted on the 28th of January 2019. The building of an industry database then commenced using a combination of internet research, industry databases and referrals. The operational status of all 78 facilities were thereafter telephonically verified. An internet-based survey was then made available to designated persons within each facility. During the period in which the internet-based survey was available, site-visits to selected facilities were performed. The site-visits included a walk-through audit as well an interview with persons having in-depth knowledge of the processes involved. The data obtained via the internet-based surveys and site-visits was subjected to Qualitative Data Analysis (QDA) using the ATLAS.ti 9 analytic platform. Water consumption and effluent quality parameters were also critically evaluated and compared to the available literature.

Analysis revealed that some of the facilities reported SWI figures comparable or better than that of their international counterparts. In addition to this, some facilities did perform well in relation to the specific water intakes (SWIs) established for certain products in the original 1987 NATSURV, indicating at least anecdotally an improvement in water-use efficiency over the last three decades. The QDA revealed, in general, that raw material washing and facility cleaning were the main consumers of water within surveyed facilities. It was also noted that improvements in water efficiency in the South African FVPI are not only motivated by desire for environmental protection or drought risk, but also for financial reasons. By improving the water efficiency of the processes, savings related to water consumption and effluent disposal could be achieved. With regards to wastewater management, it was discovered that advanced treatments are not generally practiced within the

industry, possibly due to the extended pay-back periods associated with the capital expenditure. Only three of the 19 facilities included in the final sample practiced advanced/tertiary treatment. The nature of the immediate surroundings was the primary factor in determining the effluent disposal technique. Rural settings most commonly saw irrigation as the preferred disposal route, whilst urban environments provided the means for discharge into municipal wastewater systems.

The study achieved the aim of providing information and recommendations suitable for the updated NATSURV 19. The investigation has provided a sample of current water and wastewater management practices in the industry, and therefore, future work should seek to focus on individual facilities and the optimisation of processes within them.

OPSOMMING

Die Waternavorsingskommissie (WRC) het dit bekend gemaak dat n reeks van nationale opnames rondom water- en afvalwaterbestuur in industrie (bekend as NATSURV-verslae) opgedateer gaan word. Die NATSURVS is oorspronklik in die laat 1980's en vroeë 1990's voltooi en is gebruik om minimum spesifieke waterinnamevereistes te bepaal; stroomaf infrastruktuur en waterbronne te beskerm; sowel as om kriteria vir die akademie, die industrie en reguleerders te bied. Die tweede uitgawe van NATSURV 19 (Water- en afvalwaterbestuur in die groente- en vrugteverwerkingsbedryf) sal in 2021 gepubliseer word en sal sterk steun op hierdie studie en verwante werk. Die doel van hierdie studie is dus om ondersoek in te stel op die nasionale bestuur van water en afvalwater in die groente- en vrugteverwerkingsbedryf. Die kwaliteit en omvang daarvan moet geskik wees sodat dit deel kan vorm van die opgedateerde weergawe van NATSURV 19.

Die navorsingsprosesse is begin met 'n in diepte literatuuroorsig, daar is baie aandag aan die ekonomiese struktuur van die groente- en vrugteverwerkingsbedryf gegee. Die doel hiervan was om later in die studie 'n meer gefokusde seleksie van belangrike subsektore te vergemaklik. ‘n Ander belangrike komponent van die literatuuroorsig was om alle beskikbare metodes hoe waterverbruik in voedselverwerking, en meer spesifiek, in die verwerking van vrugte en groente verminder kan word, noukeurig te dokumenteer.

Aansoek om etiese goedkeuring by die Universiteit Stellenbosch se navorsingsetiekkomitee (REC) is gedoen voor die werklike opnameproses kon begin. Die goedkeuring is op 28 Januarie 2019 toegestaan. Daarna is die bedryfsdatabasis gebou met behulp van internetnavorsing, die verskillende databasisse in die industrie en verwysings. Die operasionele status van elk van die 78 fasiliteite is daarna telefonies geverifieer. 'n Internet-gebaseerde opname is daarna beskikbaar gestel aan uitgesoekte persone binne elke fasiliteit. Gedurende die tydperk waarin die internet-gebaseerde opname beskikbaar was, is besoeke aan geselekteerde fasiliteite gedoen. Die besoeke het bestaan uit ‘n in diepte analise van die terrein asook ‘n onderhoude met van die meer ervare personeel. Die data wat via internet opnames en besoeke aan die fasaliteite verkry is, is onderwerp aan kwalitatiewe data-analise (QDA) met behulp van die ATLAS.ti 9-ontledingsplatform. Parameters vir waterverbruik en afvalwaterkwaliteit is ook krities geëvalueer en vergelyk met die beskikbare literatuur.

Na ontleding blyk dit dat sommige van die fasiliteite SWI-syfers vergelyk of selfs beter is as die van hul internasionale eweknieë. Sommige fasiliteite presteer ook goed in verhouding tot die spesifieke waterinnames (SWI's) wat in die oorspronklike NATSURV van 1987 vir sekere produkte ingestel is, wat anekdoties 'n verbetering in die watergebruiksdoeltreffendheid gedurende die afgelope drie dekades aandui. Die QDA het aan die lig gebring dat skoonmaak van rouinsette en die fasiliteite self, die belangrikste verbruikers van water was. Daar is ook opgemerk dat verbeterings in waterdoeltreffendheid in die Suid-Afrikaanse groente- en vrugteverwerkingsbedryf nie net gemotiveer word deur die begeerte na beskerming van die omgewing of droogterisiko nie, maar ook

om finansiële redes. Deur die waterdoeltreffendheid van die prosesse te verbeter, kan die hoeveelheid waterverbruik en die afvoer van afvalwater verminder word. Wat die afvalwaterbestuur betref, is dit bevind dat gevorderde behandelings gewoonlik nie in die bedryf toegepas word nie, moontlik as gevolg van die lang terugbetalingstydperk van die kapitaalbelegging. Slegs drie van die 19 fasiliteite wat in die finale monster ingesluit is, het gevorderde/tersiêre behandeling beoefen. Die afvalwater verwyderings tegniek bepalende faktor was die aard van die onmiddellike omgewing. Landelike omgewings beskou besproeiing meestal as die voorkeurroete, terwyl stedelike omgewings die middele bied om na munisipale afvalwaterstelsels te stort.

Die doel om inligting en aanbevelings te gee wat geskik is vir die opgedateerde NATSURV 19 is deur die studie bereik. Die lig is geplaas oor van die huidige water- en afvalwaterbestuurspraktyke in die bedryf, en daarom moet toekomstige projekte probeer fokus op individuele fasiliteite en die optimalisering van prosesse binne hulle.

This thesis is dedicated to

God my Father. May the words in these pages and the intent by which they were made be pleasing in your sight.

My dearest parents, Frans and Paula. Thank you for being there for me - no matter where, when or why.

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Language and style used in this thesis 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 an individual entity and must be read in conjunction with other sections for context.

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LIST OF ABBREVIATIONS

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
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
DIC (*French*)	Instant controlled pressure drop technology
DTI	Department of Trade and Industry
DWS	Department of water and sanitation
EC	Electrical conductivity
FAO	Food and Agriculture Organisation (of the United Nations)
FOG	Fat, oil and grease
FVPI	Fruit and vegetable processing industry
HAD	Hot air dryer
HPP	High pressure processing
HS	Harmonised system
HTST	High temperature short time
IQF	Individually quick frozen
IR	infra-red
MBR	Membrane bioreactor
MW	Microwave
NATSURV	National surveys
PEF	Pulsed electric fields
QDA	Qualitative data analysis
RBC	Rotating biological contactors
RO	Reverse osmosis
SAFCA	South African Fruit and Vegetable Canners Association
SAFJA	South African Fruit Juice Association
SCF	Super critical fluids
SG	Specific gravity

SS	Soluble solids
SWI	Specific water intake
TCA	Thematic content analysis
TDS	Total dissolved solids
TOC	Total organic carbon
TS	Total solids
TSS	Total suspended solids
UASB	Up-flow anaerobic sludge bed (reactor)
UF	Ultrafiltration
UV	Ultra-violet
WRC	Water Research Commission
WWTP	Wastewater treatment plant

GLOSSARY OF TERMS

Acid: Substance with a pH of less than 7.0.

Aerobe: Organism (most commonly in relation to bacteria) that requires oxygen to live.

Aerobic: Requires oxygen.

Alkaline: Substance that has a pH of more than 7.0

Ambient temperature: Temperature of the immediate environment. Ambient room temperature can range from 19 - 23°C.

Anaerobe: Organism, especially a bacterium, that does not require oxygen or free oxygen to live.

Antifoaming agent: Substance that prevents foam and bubble formation during the cooking and concentrating process.

Aseptic: Without contamination by microorganisms, i.e. sterile.

Bacteria: Large group of microorganisms which can be both harmful and helpful to food.

Blanching: Process of immersing fruit or vegetable material in hot water (or heating in steam at 95°C) for 1 - 5 minutes to reduce enzyme activity.

Blast chiller: Refrigeration unit that chills foods from 60° to 3°C in 90 - 120 minutes or less.

Canning: Process by which a food product is enclosed in a sterilised container and subjected to a thermal treatment until all microorganisms inside the container are killed.

Chlorination: Addition of chlorine to water to inactivate micro-organisms

Coliforms: Bacteria (primarily *Escherichia coli* and *Enterobacter*) used as an indicator of the sanitary quality of food or water. High coliform counts indicate the presence of faecal contamination in food and water.

Contamination: Process by which harmful or unpleasant substances (such as metal or plastic material, strong odours, microorganisms or poisons) become incorporated into the food product.

Disinfect: Clean something (mostly by a strong oxidant, high temperature or UV radiation) in order to destroy disease-carrying microorganisms and prevent infection.

Disinfectant: Chemical that destroys or inhibits the growth of microorganisms that may cause disease.

Effluent: Liquid industrial waste

Food processing: Changing a raw food material in some way to make a food product

Food safety: Protecting the food supply from microbial, chemical and physical hazards or contamination.

Heat processing: Treatment of jars/cans with sufficient heat to enable storing of food at normal ambient temperatures.

Monitoring: Tracking actual performance versus that which was planned.

Pathogen: Disease-causing agent, most commonly a living microorganism.

Pesticides: Chemical agents used to kill pests on plant material.

Pickling: Practice of adding enough vinegar/acetic acid or lemon juice to a low-acid food to lower its pH to 4.6 or lower.

Preservation: Process used to impede or halt the progress of spoilage.

Radiation: Rays of energy having both a wave and particle nature

Radiation dose: Quantity of radiation energy absorbed by the food product as it moves through the radiation field during processing.

Recycled: To use again.

Specific gravity: Measure of the density of a liquid relative to the amount of fermentable sugars it contains.

Spoilage: Significant food deterioration (usually caused by bacteria and enzymes) that produces a noticeable change in quality.

Sulphites: Used to preserve the colour of foods such as dried fruits and vegetables, and to inhibit the growth of microorganisms in fermented foods (e.g. wine).

Definitions adapted from Arrow Scientific (2013). *Definitions of words used in Food Processing*: Extensive glossary of food manufacturing, science and technology.

Chapter 1 INTRODUCTION

The vast majority (97.5%) of water on planet earth is classified as saline, with the remaining portion (2.5%) being classified as fresh water (Lal, 2015). Of this fresh water, 69.6% is contained in ice caps and other frozen forms, meaning that only a mere 1.2% is available for use by living organisms (Lal, 2015). Overuse of the surface and ground water has been reported worldwide, casting significant doubt on the ability of irrigated agriculture to sustain its contribution to the world food supply (Wada & Bierkens, 2014). A cause for further concern is that 30% of human water consumption is supplied by non-sustainable water sources, with this figure anticipated to rise to 40% by the end of the century (Wada & Bierkens, 2014). The South African water situation is no more favourable, with the estimated per capita consumption considered high for a water scarce country (DWS, 2015a). It is also worrying that an estimated 15% of the population still lack access to basic drinking water (UNICEF & WHO, 2017).

It is within the context of global and local water scarcity that the environmental impacts of the domestic industry come under the spotlight. Indeed, the polluting effects of local industry are well noted, with mining, industrial effluent, urban development and agriculture being pointed to as the main culprits (DWS, 2015b; Oberholster & Botha, 2014; Mekonnen & Hoekstra, 2011). It therefore seems rather appropriate that the Water Research Commission (WRC) has since 2013 been at work updating a series of national surveys pertaining to water and wastewater management in industry (Swartz *et al.,* 2017).

The original national surveys (or NATSURVS as they later became known) were commissioned during the middle 1980s with the support of Department of Water Affairs and Forestry (now the Department of Human Settlements, Water and Sanitation) (Swartz *et al.,* 2017). The purposes of these NATSURVs were to determine, amongst other objectives, minimum specific water intake requirements so that during times of drought, blanket restrictions would not impose an unfair burden on certain facilities. The surveys were also used by regulators to manage wastewater discharges in order to protect water sources, downstream infrastructure and treatment facilities. The original NATSURVs have been used by academia, industry and regulators as a valuable benchmarking platform for the last three decades (Swartz *et al.,* 2017).

The original series of NATSURVs resulted in the publication of, inter alia, a report entitled: *Water and Wastewater Management in the Fruit and Vegetable Processing Industry* by Binnie and Partners (1987). This publication included parameters for fresh water usage, wastewater quality, as well as recommendations for improving water efficiency within the respective processes (Binnie & Partners, 1987). The inclusion of fruit and vegetable processing in the updated NATSURVS finds its context in the highly water and energy-intensive nature of the food industry (Weng *et al.*, 2019; Compton *et al.*, 2018; IPPC, 2006), The polluting effects of the effluent, due to relatively high chemical oxygen demand (COD) has also been noted (Cooke, 2008). The updating of the NATSURV seems rather timely as even fairly recent publications (Meneses *et al.*, 2017; CLFP, 2015) lament the lack of information regarding reuse/re-conditioning of food processing water, as well as water-efficiency indicators.

Within the food industry, fruit and vegetable processing has also been noted to have its own key environmental issues (IPPC, 2006). In Australia, the Fruit and Vegetable Processing Industry (FVPI) has also been identified as one of the sub-industries within food processing with the highest annual water usage (Australian Department of Agriculture, 2007). This statement carries much weight, as the food industry is already, in general, defined as water intensive (Australian Department of Agriculture, 2007).

When it comes to mitigating water use in the FVPI, various options exist, and can be broadly categorised as i) design-based strategies, ii) water reuse/recycling; and iii) process changes (Kim & Smith, 2008). Food processing in general has its own unique characteristics that make it advisable to start with more simple water saving measures (e.g. good housekeeping based on efficient management principles) followed by progression onto more advanced strategies (Klemeš & Perry, 2007). The intermittency of production, as found in fruit and vegetable processing, influences the investment in water and waste minimisation technologies (Klemeš & Perry, 2008), and a thorough investigation into the economic feasibility would be necessary (Cooke, 2008). On the wastewater treatment side, suitable primary, secondary and tertiary options have been identified by the Integrated Pollution Prevention and Control (IPPC) (2006).

From an economic point of view, Fruit and vegetable processing has become increasingly important to the South African manufacturing sector, with the industry becoming a driver of inclusive and labour-intensive growth (Bekker, 2018). The FVPI is however highly concentrated, with a few major players contributing massively to total income and employment (Bekker, 2018; van Lin *et al.*, 2018; UNIDO, 2017). In terms of value, fruit juices are found to be the most valuable produce, with an estimated value of R 10.049 billion in 2014 (the latest disaggregated data available), followed by preserved vegetables at just over R 6 billion. South African processed fruits are mainly export orientated, with over 80% estimated to be destined for overseas markets according to the South African Fruit and Vegetable Canners Association (SAFVCA) in Bekker (2018). This is in stark contrast to processed vegetable products, where only 10% is exported, and mainly to regional African trade partners (Bekker, 2018).

The lack of concurrency when defining fruit and vegetable processing complicates the global analysis of the industry, with Statistics South Africa (2018); IBISWorld (2017a); and the Bureau for Economic Analysis (2017) all having their own criteria for the inclusion/exclusion of certain products. However, certain conclusions are drawn regardless of the differences in definition.

North America remains the global giant of fruit and vegetable processing, with this status driven largely by the increased demand for frozen products in the region itself (Bekker, 2018).

However, key growth areas are expected to shift towards the Asian and South American markets (Bekker, 2018).

In conclusion, the economic importance of the South African FVPI; as well as its documented water intensity and polluting effects make it a valuable and necessary inclusion in the NATSURV document series.

Chapter 2 AIMS AND OBJECTIVES

As part of their capacity building initiative, the Water Research Commission (WRC) has made funding available for postgraduate students to be a part of the NATSURV process. The greater aim of the current research, therefore, is to generate meaningful data and recommendations that can be included in *NATSURV 19: Water and wastewater management in the fruit and vegetable processing industry (2nd edition).* The greater aim of this NATSURV will be to encourage water saving and pollution prevention by serving as a comprehensive guide and benchmarking tool for various stakeholders, including local governments, industry, academia. The objectives of the research were therefore to:

- Provide a detailed economic analysis of the FVPI in South Africa and its changes since the publishing of the first edition NATSURV in 1987, as well as its projected changes in future
- Critically evaluate the generic industrial processes of fruit and vegetable processing in terms of main water use operations and current practice using case studies
- Determine the water consumption and specific water consumption of the processes under investigation at case-study level, using local and global benchmarks as a means of comparison; and
- Determine effluent volumes and typical pollutant loads as well as best practice wastewater treatment technology adoption, as well as recommend best practice guidelines for the industry as a whole.

Chapter 3 LITERATURE REVIEW

3.1 Background

Water is undeniably a vital resource for the development of any human activity (Mancosu *et al.*, 2015), and is seen as the central element in the Food Energy Water Nexus (Oberholster & Botha, 2014). Of concern, therefore, is that the Integrated Pollution Prevention and Control (IPPC) bureau (2006) views water consumption as one of the key environmental issues for the food industry, with Compton *et al.* (2018) and Weng et al. (2019) also commenting on the energy and water intensive nature of food processing. Whilst most emissions from the food and drink industry are biodegradable, some sectors use materials like salt or brine, which are resistant to conventional treatment methods (IPPC, 2006). Food processing wastewater, although not highly toxic, can also have a particularly high polluting potential due to the high chemical oxygen demand (COD) (Cooke, 2008). It has been found that wastewater from these industries is extremely high in both COD and Biological Oxygen Demand (BOD), with levels commonly 10-100 times higher than domestic wastewater (IPPC, 2006). The costs of removing this oxygen demand have risen, be it using an on-site Wastewater Treatment Plant (WWTP), or because of levies when discharging to a public water course (Cooke, 2008).

Within the food industry, fruit and vegetable processing has also been noted to have its own key environmental issues, namely water use, wastewater generation, problematic solid output and high energy usage (for heating and cooling operations specifically) (IPPC, 2006). In Australia, the Fruit and Vegetable Processing Industry (FVPI) has also been identified as one of the sub-industries within food processing with the highest annual water usage (Australian Department of Agriculture, 2007). This statement carries much weight, as the food industry is already, in general, defined as 'wet' (i.e. water intensive) (Australian Department of Agriculture, 2007).

For benchmarking of facilities, it is obviously necessary to have a reliable source for comparison, but unfortunately publications that deal specifically with the metric evaluation of water usage and water saving in industry seem to have tapered off from around the early 1980s, with only a few industry reports forming the majority of available information in the new millennium (California League of Food Processors (CLFP), 2015; Meneses *et al.,* 2017). A major exception can be found within the South African context, where the Water Resource Commission (WRC) has been hard at work updating outdated reports on water management in industry, in the form of national surveys (Also known as NATSURVs).

Although peer reviewed publications on general water minimisation techniques used in industry seem to be scarce, there does exist a number of industry/governmental publications that deal with this. For example: CLFP (2015); IPPC (2006) and Masanet *et al.* (2008), and once again within the South African context, the NATSURV reports.

In stark contrast to this, publications on "Green Processing Techniques" ,such as water and energy friendly technologies, are readily available (Jermann *et al.*, 2015; Chemat *et al*., 2017). These publications, however, often deal with methods that are still in the initial stages of technological maturity, and therefore, have not yet found their way into commercial installations (locally or internationally) (Jermann *et al.*, 2015). Publications such as those by Leonelli & Mason (2010) and Jermann *et al.* (2015) do, however, shed light on the rate of adoption of these technologies on a global scale.

3.2 Definition of fruit and vegetable processing

According to the Harmonised System (HS) of export classification, there are presently 55 categories of products that fall under 'Preparations of vegetables, fruit, nuts or other parts of plants' (UN Trade Statistics, 2010). However, it must be noted that each of these categories could include a very broad variety of products within their own right. For example, code H20090 includes any mixture of fruit juices that is unfermented and contains no added spirits (Department of Trade and Industry (DTI), 2018). Therefore, an obvious question that arises from this seemingly wide array of goods is how to exactly categorise them according to the processes from which they originate. An issue even more central is that a lack of formal definition will complicate any investigative procedure, both in scope and execution. As if to cause further confusion, many governmental statistical bodies have different definitions of fruit and vegetable processing, with a point in case being the South African definition making specific exclusion of dried soups, whilst the U.S. definition includes this product (Bureau for Economic Analysis, 2017; StatsSA, 2018). Furthermore, IBISWorld (2017) also excludes fruit juices from its definition. This omission in the South African context, however, would be nonsensical, as fruit juices are the most important product both in terms of quantity and value (StatsSA, 2016). Wherever international statistics are quoted in this review, care will be taken to adjust them to represent the South African definition. Where this is not possible and/or practical, the differences will be clearly described.

In order to avoid ambiguity in any subsequent investigative procedure, it is necessary to first provide a formal definition for fruit and vegetable processing. Statistics South Africa (2018) classifies fruit and vegetable processing under the Standard Industrial Classification (SIC) code 3013, which describes the following activities:

- Manufacture of food consisting mainly of fruit and vegetables
- Preserving of fruit and vegetables by freezing
- Preserving by other means such as dehydration, drying, immersing in oil, or in vinegar
- Processing of potatoes, including potato flour and meal
- Manufacture of prepared meals or vegetables
- Preserving of fruit and vegetables by canning; and
- The manufacture of jams, marmalades and preserves

It must however be noted that the definition specifically excludes dried soup mixes (classified under group 3119) and canned fruit and vegetable juices (group 3121) (StatsSA, 2018).

3.3 The global water situation

The total amount of water on planet earth is estimated at 1.26 x 10^{21} L, with 97.5% being classified as saline (Lal, 2015). The remaining portion (2.5%) is classified as fresh water and falls as precipitation (Lal, 2015). Of this fresh water, 69.6% is contained in ice caps and other frozen forms, meaning that only 1.2% is available for use by living organisms (Lal, 2015). The available fresh water can be further classified into blue water, that is, liquid water available as surface and groundwater; and green water, which is rainwater consumed during the production of goods (Pahlow *et al.,* 2015). Blue water amounts to approximately 85.9% of all fresh water, with green water making up the balance (Lal, 2015). Overuse of the blue water supply (i.e. surface and groundwater) has been reported worldwide, casting significant doubt on the ability of irrigated agriculture to sustain its contribution to the world food supply (Wada & Bierkens, 2014). A cause for concern is that 30% of human water consumption is supplied by non-sustainable water sources, with this figure expected to rise to 40% by the end of the century (Wada & Bierkens, 2014).

The Food and Agriculture Organisation (FAO) of the United Nations estimated that renewable water resources amount to 42 000 km^3 per year, with 3 900 km^3 being withdrawn for human uses (FAO, 2011). Of this 3 900 km^3, 70% is used for irrigation, 19% for industry and 11% for municipal use (FAO, 2011). Withdrawals of water for irrigation have been rising globally, although be it with large geographical discrepancies. Europe withdraws only 6% of the available internal water sources and a mere 29% of this goes to agriculture (FAO, 2011). The agriculturally intensive economies of Asia extract 20% of their water resources, with 80% destined for irrigation (FAO, 2011). The water scarce regions of the Middle East, Central Asia and North Africa already exploit most available water, with 80 to 90% of this going to agriculture (FAO, 2011).

Availability of adequate drinking water still plagues many societies well into the new millennia. It is estimated that during the year 2015, 71% of the world's population (5.2 billion people) had access to an adequately managed drinking service, whilst 89% had access to at least a basic service (an improved source within 30 minutes round trip to collect water). However, this still left 844 million people without access to a basic water service (UNICEF & WHO, 2017).

3.4 The South African water situation

3.4.1 Rainfall and water sources

South Africa is a water stressed, semi-arid country (GreenCape, 2017) and is ranked as the 30th driest country in the world, with a mean annual precipitation of 495 mm (FAO, 2016). This is compared to a world average of 850 mm per annum (DWS, 2015a). Further complicating the country's water scarcity status is the high variability of rainfall across the country. Rainfall of less than 100 mm per annum (p.a.) is common in the western regions, and precipitation of more than 1 500 mm p.a. common in the extreme east (DWS, 2015a). To complicate matters further, Kruger and Nxumalo (2017) have concluded that precipitation patterns have changed during the years 1921-2015. In general, the southern interior seems to be experiencing higher rainfall, in contrast to the north and north eastern parts of the country, that appear to be receiving less precipitation. Due to the effects of climate change, the country is expected to increasingly be adversely affected by water scarcity and variability in rainfall (GreenCape, 2017). A testimony to the validity of this prediction are the years 2015 and 2016, where South Africa experienced its worst period of drought since 1904 (GreenCape, 2017). The drought itself has taken a direct toll on socioeconomic development in the country, with agriculture in particular shedding 37 000 jobs in response (WWF) (2017). The ongoing drought was noted to be especially challenging to the FVPI (Bekker, 2018).

South Africa has a reliable water yield of approximately 15 billion m^3 per annum (DWS, 2015a). This consists of 68% surface water, 13% groundwater, 13% return flows and 6% from other sources (DWS, 2015a). Government has provided a comprehensive water sources infrastructure to manage the high variability of surface water runoff, as well as to provide water to economically active locations (DWS, 2015a). This infrastructure includes 794 large storage dams (dams with a wall height of ≥15m, or a wall height of between 5 and 15 meters and a capacity greater than 3 million m^3) (DWS, 2015a). To overcome the problem of high rainfall variability across the country, a system is required to redirect water supply to where it is most needed. For this purpose, there are currently 29 inter-basin and inter-river transfer systems in South Africa, an example of which is the Lesotho Highlands Water Scheme, which supplies water to Gauteng's Vaal Water Management Area (DWS, 2015a).

3.4.2 Water available per capita

The South African constitution mandates that every person has the right to basic water supply and sanitation services (DWS, 2015b), but despite this imperative, it is estimated that 15% of the population still lacks access to basic drinking water (UNICEF & WHO, 2017). Of those who lack access to basic drinking water, 3% still rely on surface water and 2% make use of unimproved sources (UNICEF & WHO, 2017). In addition to these institutional challenges, the nation has a low per capita water availability when compared to other countries, with 843 m^3 per person per annum (WWF, 2017). Average per capita consumption is approximately 230 L/day, which is considered high for a water scarce country (DWS, 2015a).

3.4.3 National water footprint

A total of 15.5 x 10^9 m^3 of water is withdrawn in South Africa per annum (2013) (FAO, 2016). Of this, 62% is withdrawn for use by the agricultural sector, 11% by the industrial sector and 27% by the municipal sector (DWS, 2015a). Figure 1 provides an expanded view of total water use within the South African industry.

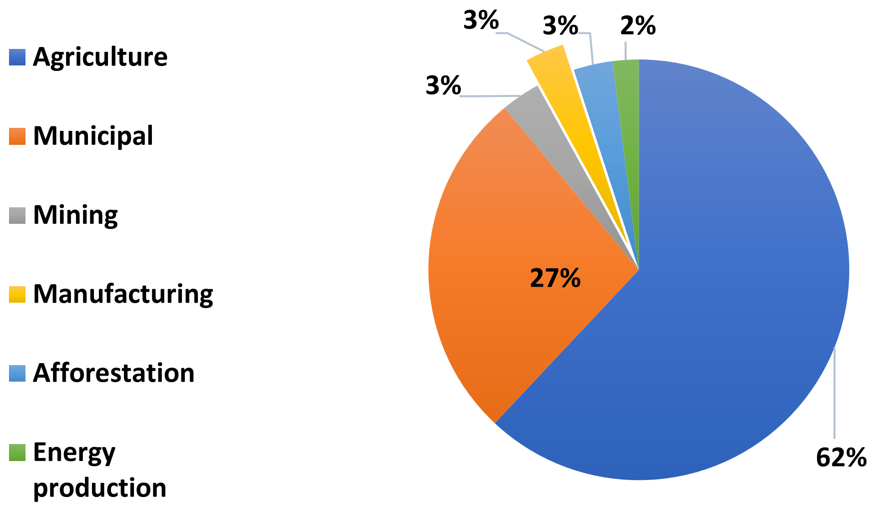

Figure 1 Water withdrawals per economic activity in South Africa (DWS, 2015).

Although water withdrawals are an adequate indicator, it may be in the interest of a more holistic analysis to consider the water footprint per industry. Water footprint is a comprehensive indicator of fresh water appropriation, as it looks not only at direct water usage by consumers and producers, but also indirect water usage (Hoekstra *et al.,* 2011). More formally defined, the water footprint is the volume of freshwater used to produce the product, and calculated for the entire supply chain (Hoekstra *et al*., 2011). Water footprint calculations require an understanding of blue, green and grey water consumption in the production process. Blue water footprint is the consumption of surface and ground water. Green water footprint is concerned with the rain consumed in production (particularly applicable to crops), whilst grey water footprint is the determination of the polluting effect of the activity on fresh water supply .Using the water footprint technique, Mekonnen & Hoekstra (2011) undertook to quantify the impact of human activities on fresh water supplies in South Africa. Their findings are presented in Table 1 below.

Table 1 National water footprint of different sectors in South Africa (Mekonnen & Hoekstra, 2011; Pahlow *et al*., 2015)

Water Footprints (million m^3)						
Agricultural Production			Industry		Domestic Supply	
Green	Blue	Grey	Blue	Grey	Blue	Blue
45 928	6694	3126	38	309	390	2368
55 748			**347**		**2758**	

The water footprint of agricultural production (which includes both animal and crop production) is revealed to be by far the greatest, with a total of 55 748 million m^3 per annum. Industry and domestic supply contribute considerably less, with a total of 347 million m^3, and 2 758 million m^3 respectively (Table 1). An important aspect to note when considering industry and domestic supply, is that although the overall water footprint is relatively low, they do produce proportionally more grey water (in terms of their own total water footprints) when compared to agricultural production. This is evident in that 89% (309 million m^3 p.a.) of the water footprint in industry, and 86% (2 368 million m^3 p.a.) in domestic supply is attributed to greywater, whereas in agricultural production, this figure is 6% (3 126 million m^3 p.a.) (Table 1). This seems to imply that when looking at a strategy for mitigating the water footprint of domestic supply and industry, the focus should be on the minimising the polluting effect of effluent, before reducing the supply of fresh water.

When it comes to looking at specific anthropogenic issues affecting water quality in South Africa, four main culprits have been identified by the DWS (2015b), namely: mining, industrial effluent, urban development, and agriculture. Oberholster & Botha (2014) have expanded on each of these sources and how specific sources affect water quality for the food industry. Acid mine drainage (AMD), characterised by low pH, elevated heavy metals and sulphates, is deemed a major contributor to degeneration of water quality (Oberholster & Botha, 2014), particularly in the Olifants River system (McCarthy, 2011). Effluent from failing/poor sewage systems in urban settings is seen as an ubiquitous source of pathogenic faecal bacteria in river systems, whilst industry is seen as a source of dangerous substances, most notably endocrine-disrupting chemicals (EDC's) (Oberholster & Botha, 2014). Finally, agricultural production is also seen to affect fresh water quality by contamination with agro-chemicals and eutrophication (Oberholster & Botha, 2014).

3.5 Previous studies on water use and best practice within fruit and vegetable processing

Meneses *et al.* (2017), in their review on water reconditioning and reuse in the global food processing industry, make note of the following:

> "Knowledge about potential streams for water recovery and water quality requirements for different operations is limited and therefore does not allow for improvements in the most significant water consuming operations".

This lack of knowledge, in their view, is a significant hindrance to water conservation studies. Indeed, government led surveys on best practice and water use, at least within the US context, appear to have tapered off after the 1960s and 70s, to be replaced mainly with industry generated reports and surveys (California League of Food Processors (CLFP), 2015). Since this data is not made publicly available, even recent studies make use of metrics from earlier work (Bromley-Challenor *et al.,* 2013; CLFP, 2015).

For the purposes of this literature review it is also necessary to consider studies addressing food processing in general. This is done for two reasons. Firstly, many Best Management Practices (BMPs) are applicable across a broad variety of food processing sub-industries. For example, IPPC (2006) recommended cleaning practices are not only applicable for dairy and edible oils, but also for fruit and vegetable processing. Secondly, few studies focus specifically on fruit and vegetable processing, but rather some products that form part of the sub-industry are mentioned in the results, or as a subsection in the report/study (Bromley-Challenor *et al*., 2013; CLFP, 2015).

3.5.1 Foreign studies investigating water use and best practice

Within the North American context, publicly available data on metric values related to water use are relatively abundant in the 1960s, but become scarcer in the new millennium (CLFP, 2015). Compton *et al.* (2018) also make note of the general lack of water consumption data within the region. The most recent metric data obtainable is that of the CLFP (2015), and prior to that a study by Mannapperuma (1993). The CLFP study is extremely useful in that it makes available a complete list of the most relevant literature (from 1977 to 1993) used as a baseline for comparison. A limiting factor to consider is that both these surveys find their focus within the California region, and therefore may not be representative of the entire Northern America region. Amón *et al.* (2015) have more specifically investigated techniques used for water and energy recovery in Californian tomato paste processing, whilst Masanet *et al.* (2008) have written extensively on different energy and water saving techniques for the fruit and vegetable processing industry in general.

The European context is slightly more enlightening due to the involvement of the European Union Integrated Pollution Prevention and Control (IPPC) directive, which introduced a framework requiring all member states to issue operating permits for industrial activities performing polluting activities (Klemeš & Perry, 2007). The permits must contain conditions that take into account the best available techniques (BAT) in terms of pollution control, and aim to provide a high level of environmental protection (IPPC, 2006; Klemeš & Perry, 2007). The IPPC Directive collects BAT's from member states and uses them to compile Reference Documents (REF's) on BAT's (referred to as BREF's). The BREF on the food, drink and milk industry (promulgated in 2006) contains metric comparisons across a wide variety of fruit and vegetable products, as well as techniques that can increase water efficiency (IPPC, 2006). As of August 2018, only a working draft of an updated version is available (European IPPC Bureau, 2018), and therefore, the 2006 version is still used to determine conditions relating to operating permits. Other studies to have emerged from the EU include one by Valta *et al*. (2017) who investigated typical wastewater sources and treatments within the Greek fruit and vegetable processing industry. Bromley-Challenor *et al.* (2013) have also reported on water use and water saving opportunities within the United Kingdom (UK) food and drink industry.

Literature relating to studies from other regions include a report by Australian Department of Agriculture (2007) relating to water saving and reuse opportunities in food processing. Meneses *et. al.* (2017) have written a review on water reconditioning and reuse in food processing at large.

Table 2 Specific water intakes (SWI) for various products

Product	SWI (m^3/tonne product)	Region	References
Canning/Bottling			
Canned oranges	30	China	Wang *et al.* (2006)
Canned oranges	35	China	Wu *et al.* (2016)
Canned fruit	5,8	USA	CLFP (2015)
Canned tomato	2,93		
Canned olives	16,93		
Canned fruit (not specified)	3,25	EU	IPPC (2006)
Canned vegetables (not specified)	4,75		
Jams	6		
Baby food	7,5		
Juicing			
Fruit juice (unspecified)	6,5	EU	IPPC (2006)
Fruit juice (unspecified)	3,5	UK	WRAP (2010)
Drying			
Tomato paste	1,33	USA	CLFP (2015)
Dehydrated onions	3,92		
Dehydrated fruit	0,3		
Freezing			
Frozen fruit and vegetables	9,42	USA	CLFP (2015)
Frozen vegetables (unspecified)	6,75	EU	IPPC (2006)

3.5.2 South African studies on water use and best practice in fruit and vegetable processing

The availability of metric data pertaining to water use and information on best management practices (or even current practices) in South Africa, is scant at best. The only publicly available data is that found in the national survey (NATSURV) conducted by Binnie & Partners (1987) on behalf of the Water Research Commission (WRC). This report contains metric data across a wide variety of fruit and vegetable products, including National Average Specific Water Intake (NASWI) (Fig. 2); effluent volumes; BOD; COD and soluble solids (SS). The report also sets targets for the metrics, that may be achieved by application of the accompanying recommendations. The NATSURV was also accompanied by a guide to water use and effluent treatment (Binnie and Partners, 1987).
Observations observed during the study by Binnie and Partners (1987), which promulgated the development of the guide, were as follows:

- Specific water intake varied widely amongst factories processing the same base commodities

- Similar individual processes at different facilities consumed varying amounts of water
- Production lines consumed water as related to full capacity, regardless of whether the facility was only producing at part load
- Lack of water meters/flow recorders on each process line at most facilities made record keeping and control of water usage nearly impossible
- Effluent quality varied greatly between facilities involved in processing the same commodity
- Unnecessary contact between water and product/water and solid waste lead to higher COD and SS in effluent
- Seasonal constraints imposed on industry affect water and wastewater management
- Low cost of water and wastewater disposal lead to overuse; and
- There was a lack of information enabling the identification of minimum quantities of water for each processing step.

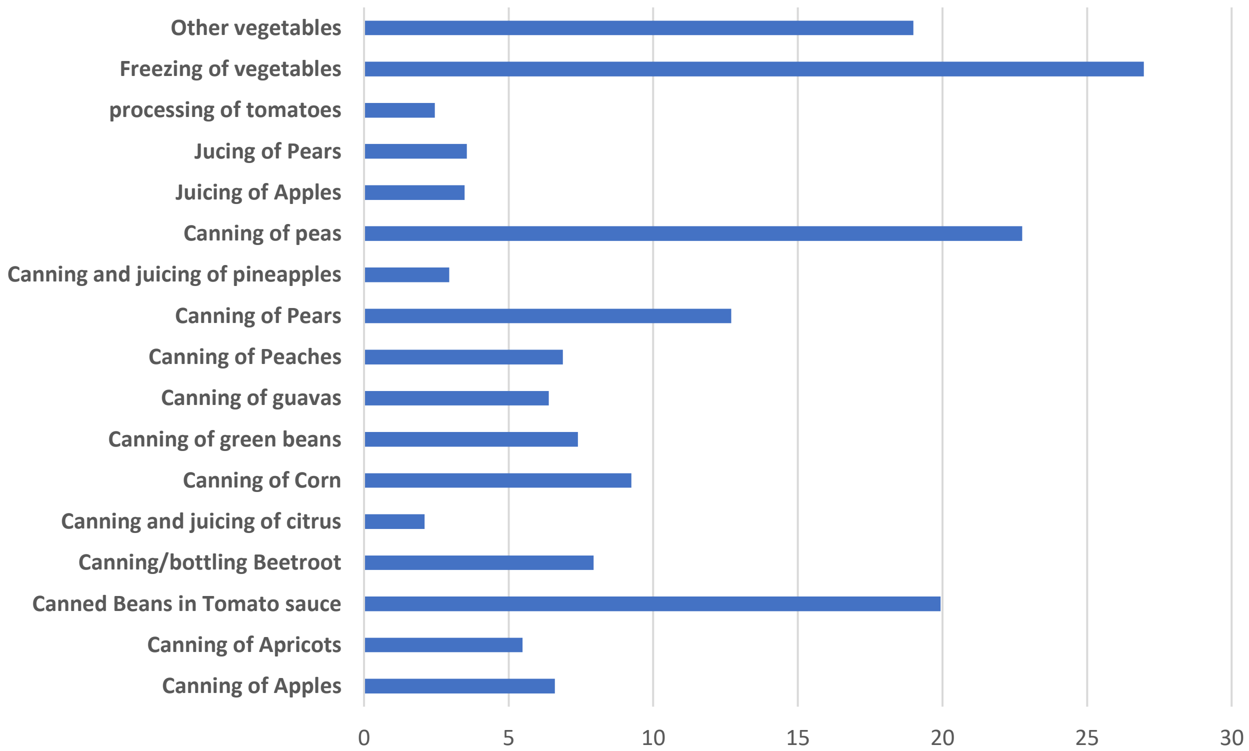

Figure 2 National average specific water intake per product category (m^3 per ton raw material) in 1987 (Binnie & Partners, 1987).

The Guide to Water Use and Effluent Treatment (Binnie & Partners, 1987) makes specific mention of how one particular facility heavily distorted the National Average Specific Water Intake (NASWI) for freezing of vegetables specifically. This was due to the facilities use of a once-through cooling system.

The steps to water and wastewater management as discussed by the guide are as follows:

1) *Preliminary measures*
    a) Measure all incoming water including private supply
    b) Fit water meters at every process step
    c) Fit effluent flow meters and conduct detailed effluent survey for each commodity
    d) Read all meters daily and plot graphs
    e) Compare water usage with targets
    f) Provide hosepipes from separate metered main supply
    g) Improve washdown procedure
2) *Segregation of effluents*
    a) Segregate effluents and remove solids from the following process steps:
        i) Washing
        ii) Pitting
        iii) Peeling; and
        iv) Scrubbing
    b) Fit juice trays beneath slicing, coring, dicing and filling machines
3) *Transportation within factory*
    a) Convert flumes to dry-belt systems where it is practical
    b) Fit constant head and overflow tanks to all pump circuits and flumes
4) *Utilise closed recycling loops*
    a) Apply counter current reuse of water along process lines, if practical
    b) Purify and recycle post blanch waters
    c) Reuse treated flume water
5) *Apply a revised washdown sequence using (in order):*
    a) Dry-brushing or squeegee
    b) Compressed air
    c) Secondary water
    d) Chemically assisted; and then lastly
    e) Potable water
6) *Draw up a water and effluent balance and compare with targets* (Specifics were not mentioned under this heading in the NATSURV)

3.6 The current structure of the fruit and vegetable processing industry

3.6.1 The global fruit and vegetable processing industry.

Demand for processed fruit and vegetables has remained relatively consistent for the five years preceding 2017, as most economies continue to consume the products, whilst consumer spending has simultaneously increased (IBISWorld, 2017a). This demand has been especially prevalent in developing countries where industrialisation has resulted in increasing urbanisation, an expanding middle class and rising incomes, with the desire for an increasingly more health-centred diet. These factors have largely driven the increased spending on processed fruit and vegetables (IBISWorld, 2017a).

Global revenue from fruit and vegetable processing (excluding juices) was approximately $292 billion in 2016, with this expected to grow to $335 billion by 2022 (IBISWorld, 2017a; Statista, 2018). Segmentation per product category (excluding juices) in terms of sales share is shown in Figure 3 below (IBISWorld, 2017b). The clear leader is found to be frozen fruit and vegetable products with a sales share of 48%, followed by canned vegetables, with a sales share of 30.3% (Fig. 3). 'Other' includes jellies, jams, dried fruits and vegetables, fruit preserves and other miscellaneous products.

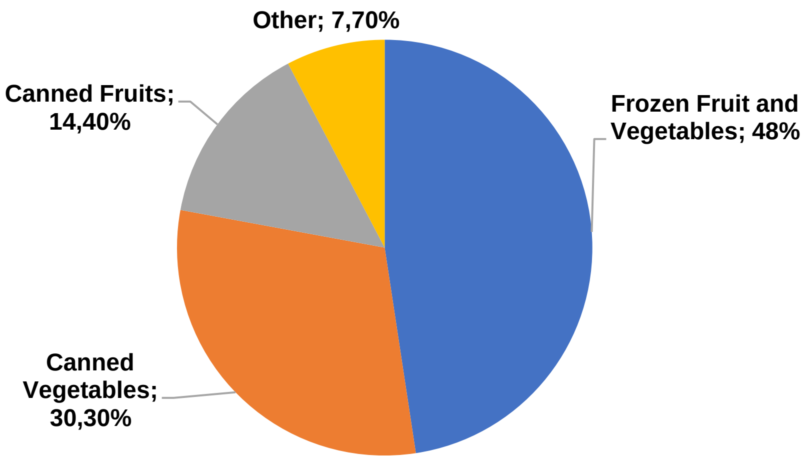

Figure 3 Global segmentation of fruit and vegetable processing (excluding fruit juices) in 2017 (IBISWorld, 2017).

North America remains the hub of fruit and vegetable processing, driven largely by the increased demand for frozen products in the USA and Canada (Bekker, 2018). However, international associations indicate that the key growth areas are expected to be the Asian and South American markets (Bekker, 2018).

3.6.2 The South African fruit and vegetable processing industry

3.6.2.1 Economic contribution and composition

The latest disaggregated data was published in 2016, but makes use of information collected in earlier years, most notably the 2014 National Census (StatsSA, 2016; Bekker, 2018). According to the 2014 National Census, the manufactured food and beverage industry recorded an income of R342 billion (StatsSA, 2016). This equated to 19% of the income from manufacturing (Fig. 4). The domestic food processing industry is also highly concentrated, with a few major players contributing a large percentage to both income and employment (UNIDO, 2017; Bekker, 2018; van Lin *et al.*, 2018). South African food processors are generally located in urban areas, far removed from the production areas (Harcourt, 2011), although this may differ with regards to fruit and vegetable processing (Dauthy, 1995) (Harcourt, 2011), where primary processing does often occur closer to the areas of production, especially with regards to fruit (Bekker, 2018). This may be due to the high waste content associated with the primary processing, shelf life of the raw ingredients (Harcourt, 2011), as well as the desire to allow sufficient ripening before processing, and the reduction of transport associated damages (Dauthy, 1995). Within the food and beverage industry Fig. 4), fruit and vegetable products contributed R24.07 billion, or 8% (Fig. 5). The leading contributors were alcoholic beverages with 20%, and grain products with 18%. When looking into the individual components of the fruit and vegetable processing industry (Fig. 6), the clear leader in both value and quantity of production are fruit juices. Over 999 000 litres where produced in 2014 with a nominal value of R10.049 billion. Prepared and preserved vegetable products followed in second place, with slightly over 279 000 tons.

Dekker (2018), using the relative contributions in earlier years, has estimated that sales of fruit and vegetable preparations (including exports) were between R21 and R23 Billion in 2017. Dekker (2018) does however makes note of the fact that this figure should be seen as a "ballpark" estimate, as the calculations do not consider inflation or relative shifts in production patterns.

3.6.2.2 Employment

The FVPI provides direct employment to approximately 15 000 factory workers, but due to close linkages with the primary agricultural industry, it may indirectly support many times more than that (Bekker, 2018). South African deciduous fruit farms alone provide over 107 000 permanent jobs, with approximately 429 485 dependants (Hortgro, 2017).

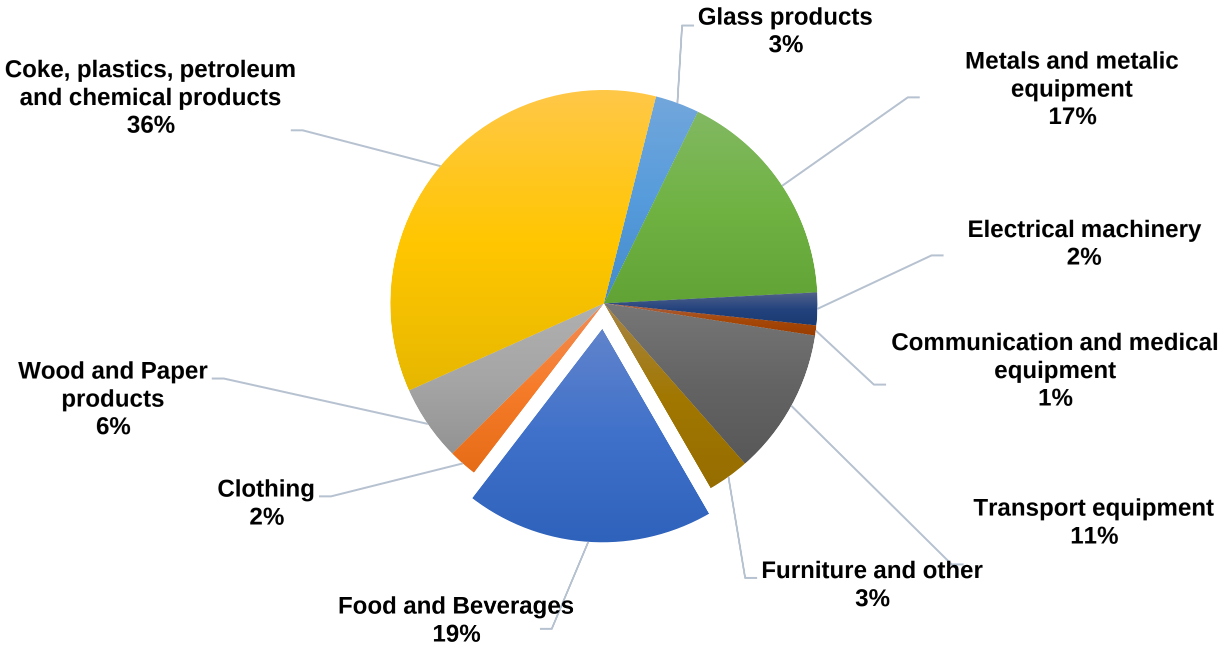

Figure 4 Food and beverage share of manufacturing income in South Africa (StatsSA, 2016).

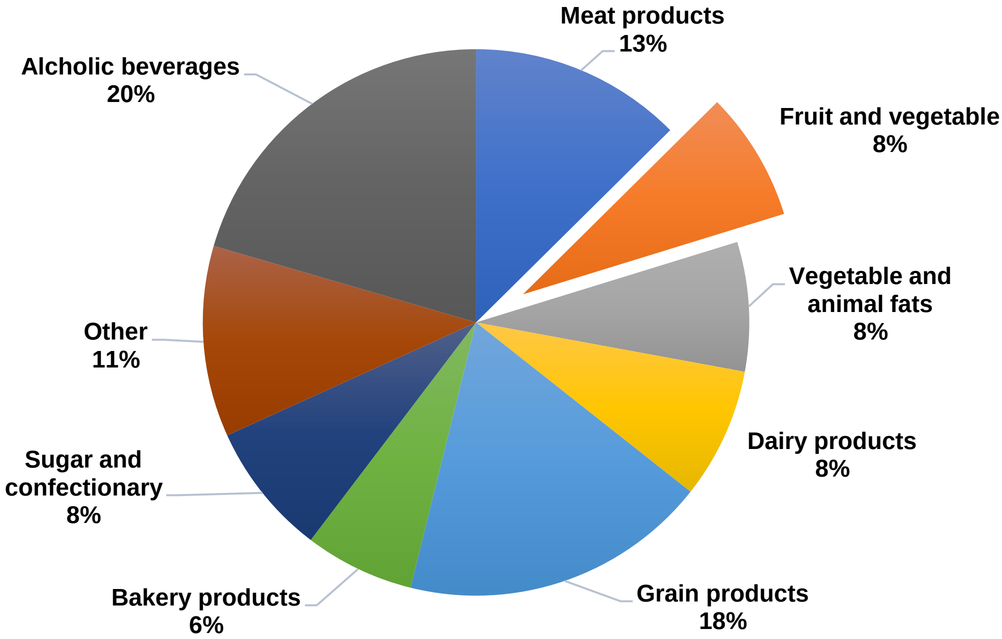

Figure 5 Relative contributions of the various components within the South African food processing industry (StatsSA, 2016).

3.6.2.3 Fruit inputs

Excluding grapes and berries, it is estimated that over 1.18 million tons of fresh fruit was purchased for processing in 2017 (Bekker, 2018). It must be noted, however, that fruits used in processing only account for an estimated 29% of national production. This makes fruit processing more of a "residual industry", which uses the fruit not suitable for the fresh market (van Lin *et al*., 2018)

Deciduous fruit inputs

Deciduous fruit production occurs mainly in the Western Cape (Bekker, 2018) and in certain areas in the Eastern Cape where warm dry summers and cold winters prevail (DAFF, 2017).

During the 2016/17 season, approximately 574 221 tons of deciduous fruit were utilised for processing. This amounted to a 1.5% decline from the 583 217 tons processed during 2015/16 (DAFF, 2017), possibly as a consequence of drought (Bekker, 2018). Most of the fruit in the 2016/17 season was used in the production of juice, with the exception of apricots and peaches, which were used mainly for canning (DAFF, 2017). The largest contributor within deciduous fruits were apples, with 318 448 tons purchased for processing in the 2016/17 season (DAFF, 2018). Of this, 98.9% was used in the production of juice, with the remaining 1.1% used for canning (DAFF, 2017). The next biggest contributor was pears, with 154 940 tons purchased for processing (DAFF, 2018). Figure 7 below shows the distribution of deciduous fruit used in processing.

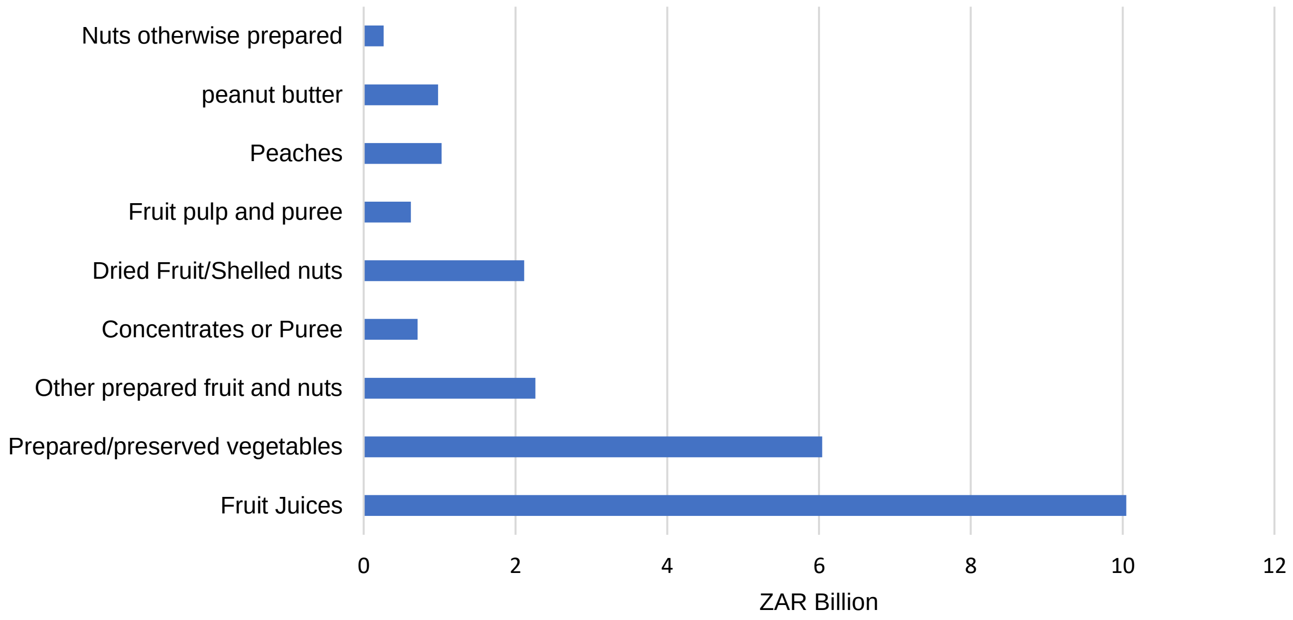

Figure 6 Value of processed fruit and vegetables in South Africa (2014) (StatsSA, 2016).

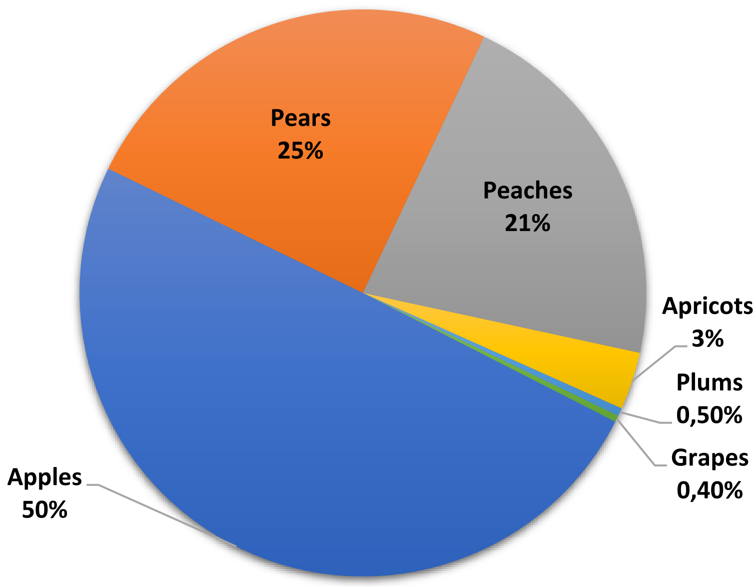

Figure 7 Relative contributions of deciduous fruit purchased for processing in South Africa (DAFF, 2017).

Subtropical fruit inputs

Subtropical fruits require warmer conditions than deciduous fruits, and are also sensitive to large temperature fluctuations and frost (DAFF, 2017). It is for this reason that cultivation of such fruit is only possible in certain regions of the country (DAFF, 2017). The most suitable regions are the northern provinces of Mpumalanga, Kwazulu-Natal and Limpopo, but certain subtropical fruits like granadillas and guavas are also found in the Western Cape (DAFF, 2017). Pineapple production is concentrated in the border region of the Eastern Cape, with Summerpride Foods in East London operating the only large pineapple processing facility in the country (Bekker, 2018). It must however be noted that Swazican (a Rhodes Food Group subsidiary) in Eswatini (Formerly Swaziland) manufactures and distributes canned pineapples to South Africa and abroad (Bekker, 2018). Figure 8 below shows the relative contributions to the 132 392 tons for subtropical fruits used in processing for the year 2016/17.

During the 2016/17 season, pineapples accounted for 48.4% of subtropical fruits used in processing , whilst mangoes contributed 25.2%, and guavas 20.4% (DAFF, 2017). The quantities of avocados and pineapples used for processing decreased during the 2016/17 season by 30% and 19%, respectively (DAFF, 2017).

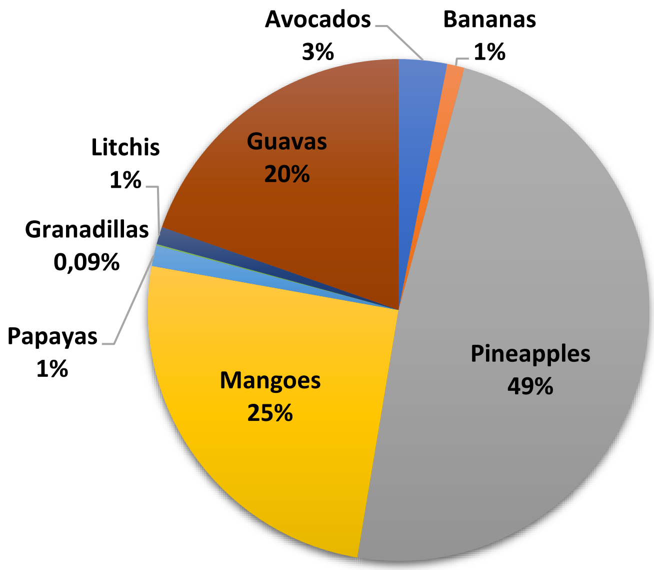

Figure 8 Relative contributions of subtropical fruits purchased for processing in South Africa (DAFF, 2017).

Citrus Inputs

Citrus fruit is grown mainly in the Mpumalanga, Limpopo, Eastern Cape and Kwazulu-Natal provinces, where subtropical conditions (warm summers and mild winters) prevail, although it can also be found in the Western Cape (Bekker, 2018; DAFF, 2017). Citrus fruit taken in for processing amounted to 16.8% of total production in the 2016/17 season. A decrease in fruit purchased for processing of 44.4%, (682 000 tons in 2015/16 to 379 437 tons in 2016/17) was experienced in relation to the previous season (DAFF, 2017). Oranges were the main citrus fruit used in processing, with a total of 195 436 tons (52%) (DAFF, 2018).

Dried Fruit

South Africa's dried fruit comes mainly from the Orange river region in the Northern Cape (vine fruit), and the western and southern areas of the Western Cape (tree fruit) (DAFF, 2017). In terms of volumes, the most important fruit varieties are Thomson's seedless grapes, unbleached sultanas, golden sultanas, currants, peaches, apricots, pears and prunes (DAFF, 2017).

The total production of dried vine fruit increased by 20% to 65 589 tons in 2017, compared to 54 629 tons in 2016 (DAFF, 2017). The reason for this drastic increase in production was an increase in demand for high quality fruit (Dried Fruit Technical Services in DAFF, 2017). Production of dried tree fruit was less impressive, with a decrease of 8.8%, from 6 779 tons in 2016, to 6 181 tons in 2017 (DAFF, 2017).

3.6.2.4 Vegetable Inputs

Vegetables are produced in most parts of the country, but certain areas tend to focus more on one specific type of vegetable. For example, green beans are found predominantly in Kaapmuiden, Marble Hall and Tzaneen, green peas mainly in George and Vaalharts, onions mainly in Pretoria, Brits and Caledon, whilst asparagus is mainly grown in Ficksburg and Krugersdorp (DAFF, 2017)

Vegetable production in South Africa, like fruit production, is also geared towards the fresh market (although this production is mainly focused on the national market). Limited processing is evident, although consumer trends do indicate an increase in demand for vegetable-based condiments and sauces (van Lin *et al*, 2018). Whilst specific data on quantities used for processing is not as readily available as for fruit, DAFF (2017) does estimate that 9% (265 860 tons) of the total vegetable crop (excluding potatoes) is used in processing (Fig. 9). This corresponds approximately to the SAFVCA estimate of 200 000 tons annually (SAFVCA (n.d.) in Bekker, 2018). Specific mention is made of onions, of which approximately 1% (or 5 524 tons) was used for processing in the 2016/17 season (DAFF, 2017). Approximately 80% was canned and the remaining 19% was frozen (DAFF, 2017).

Potatoes are South Africa's most economically important vegetable (UNIDO, 2017), accounting for 44% of total vegetable production in the 2016/17 season (DAFF, 2018). There are 18 distinct potato growing regions across South Africa, with the main production areas being found in Mpumalanga, Western Cape, Limpopo and the Free State provinces (DAFF, 2017). Fresh potatoes are available year round, as planting times differ between regions in response to climatic variation (DAFF, 2017). According to DAFF (2017), approximately 18% of the total potato crop was used in processing in the year 2016. Of this, 91% was used in the production of potato chips (both fresh and frozen), whilst the remaining 8% and 1% was used in freezing and canning, respectively (DAFF, 2017).

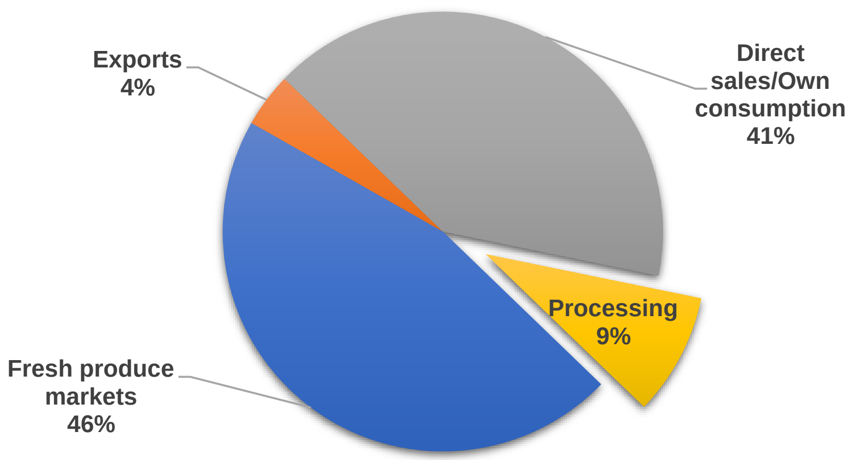

Figure 9 Distribution channels for vegetables (excluding potatoes) in South Africa (DAFF, 2017).

3.6.2.5 Locations of Processing facilities

It is advantageous that a processing facility be within close proximity to a fresh raw material supply (Dauthy, 1995b; IPPC, 2006) especially with regards to primary processing (Harcourt, 2011). This is to ensure reduced damage to the material during transport and to allow sufficient maturation time before processing (Dauthy, 1995). It is also desirable for processing facilities to have access to labour, adequate markets, and road or rail transport (Dauthy, 1995). In addition to this, it is especially advantageous for fruit and vegetable preservation installations to be close to receiving waters for the discharge of large amounts of treated wastewater (IPPC, 2006). In the South African context, fruit processing tends to be concentrated according to the areas of cultivation, where vegetable processing seems be more closely correlated to the primary markets (Bekker, 2018).

Establishing a fruit and vegetable processing facility only makes economic sense when production can be maintained for many months at a time (Dauthy, 1995). To make this a reality, many processing facilities are required to process a variety of different horticultural products (up to five), whilst accommodating a variety of different processing techniques (for example, juicing, pulping and canning) (Dauthy, 1995). For ease of reference, Figure 10 shows the locations of verified processing facilities (current as of April 2018). To simplify the classification of all these facilities, a distinction has not been made between vegetable or fruits, but rather the type of processing predominantly used (as per Binnie and Partners (1987)), these being i) Canning/bottling; ii) Juicing (concentrate, pulp and fresh juice); iii) Drying; and iv) Freezing.

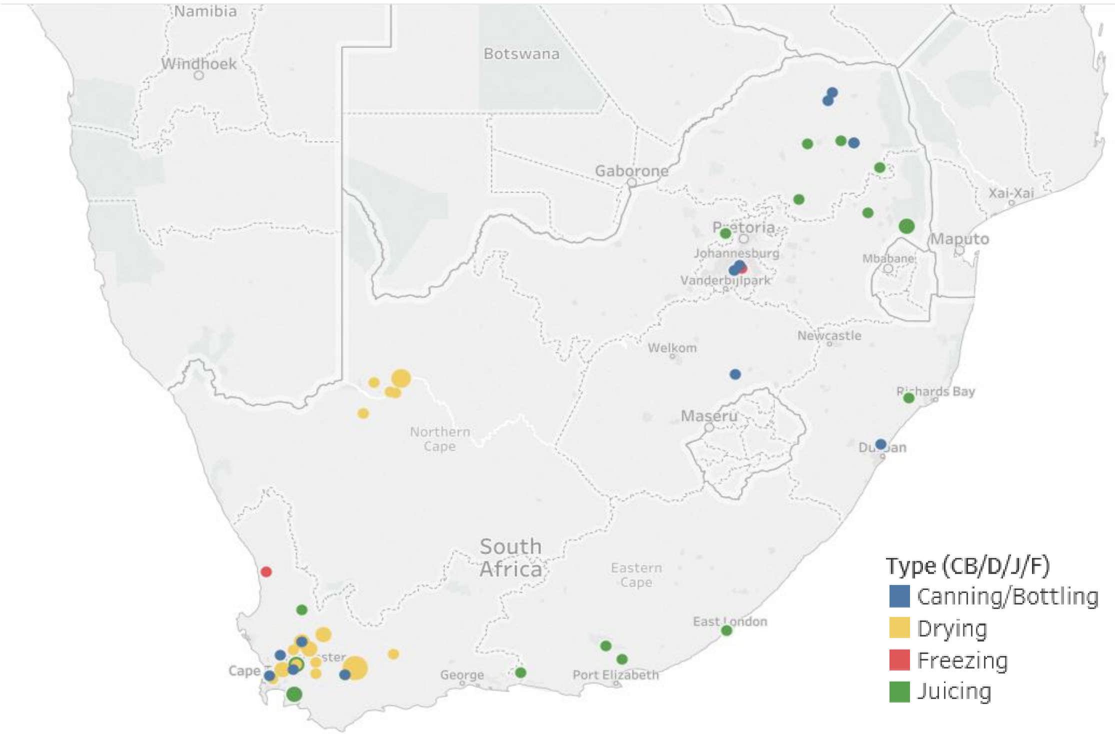

Figure 10 Locations of verified fruit and vegetable processing facilities in South Africa (Current as of May 2018).

3.6.2.6 Trade Statistics

The Department of Trade and Industry (DTI) maintains a very comprehensive database on exports and imports, and classifies all goods according to the Harmonised System (HS) (DTI, 2018). The purpose of this nomenclature is to allow for classification of traded goods on a common basis for customs purposes (UN Trade Statistics, 2010). Figure 11 below shows imports and exports of processed fruit and vegetables (code H20: preparations of vegetables, fruit, nuts or other parts of plants) for South Africa from 1992 to 2017, normalised according to a 2010 base year (DTI, 2018). Interesting to note is that from 1992 to the present, processed fruit and vegetables have maintained a positive trade balance, making the industry a net earner of foreign exchange for at least the past 25 years. Exports reached a maximum value of R5.803 billion in 2016 (2010 base year) (DTI, 2018). The slight drop in exports that can be seen at the terminal end of Figure 12 (2016) may be as a result of drought and various currency fluctuations (Bekker, 2018). According to SAFVCA in Bekker (2018), approximately 80% of South African canned and processed fruit is destined for export. This is in stark contrast to processed vegetable products, where only 10% is exported, and even that is mainly to regional African trade partners (Bekker, 2018). Data from the DTI (Fig.13 & Fig. 14) lends much support to this claim.

Figure 12 shows the contributions of the nine product categories within H20 (Processed fruit and vegetables), with Table 3 providing a detailed description of each HS code. The H2008 (fruit, nuts and other edible parts of plants, otherwise prepared or preserved) and H2009 (juices) category made up the majority (75%) of exports within processed fruit and vegetables in 2017, and therefore warrant further investigation. An expanded view of the change in value of the six most important items is provided in Figure 13 below. The two clear leaders were *mixed juices* and *processed peaches/nectarines*, with an export value of R1.06 billion (nominal) and R915 million (nominal), respectively in 2017 (DTI, 2018). Also of interest is that the prepared peaches/nectarine category enjoyed the leading position until 2009, when it was then overtaken by mixed juices (Fig. 13).

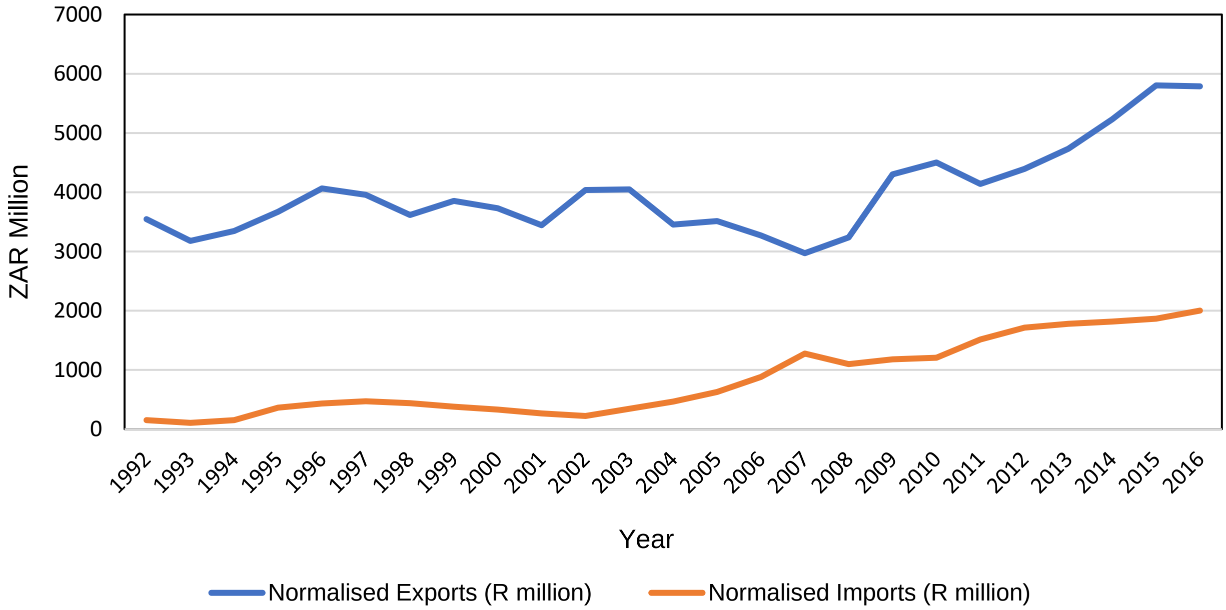

Figure 12 Value of trade in processed fruit and vegetables (2010 base year) (DTI, 2018).

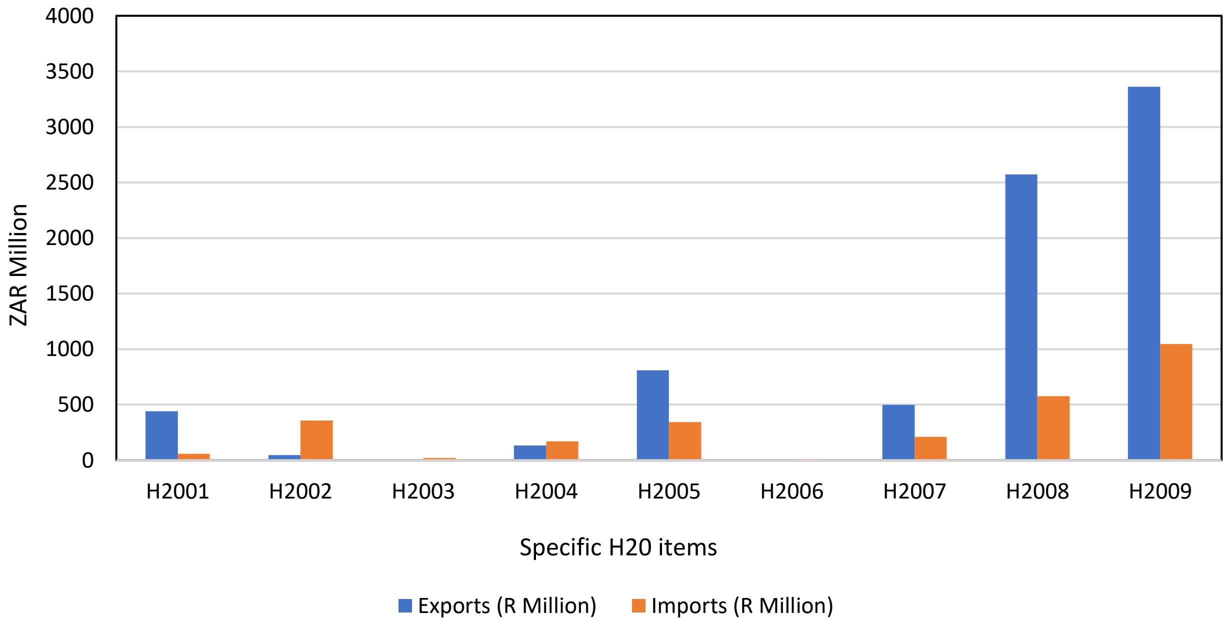

Figure 11 Imports and exports of processed fruit and vegetables (South Africa) in 2017 (DTI, 2018).

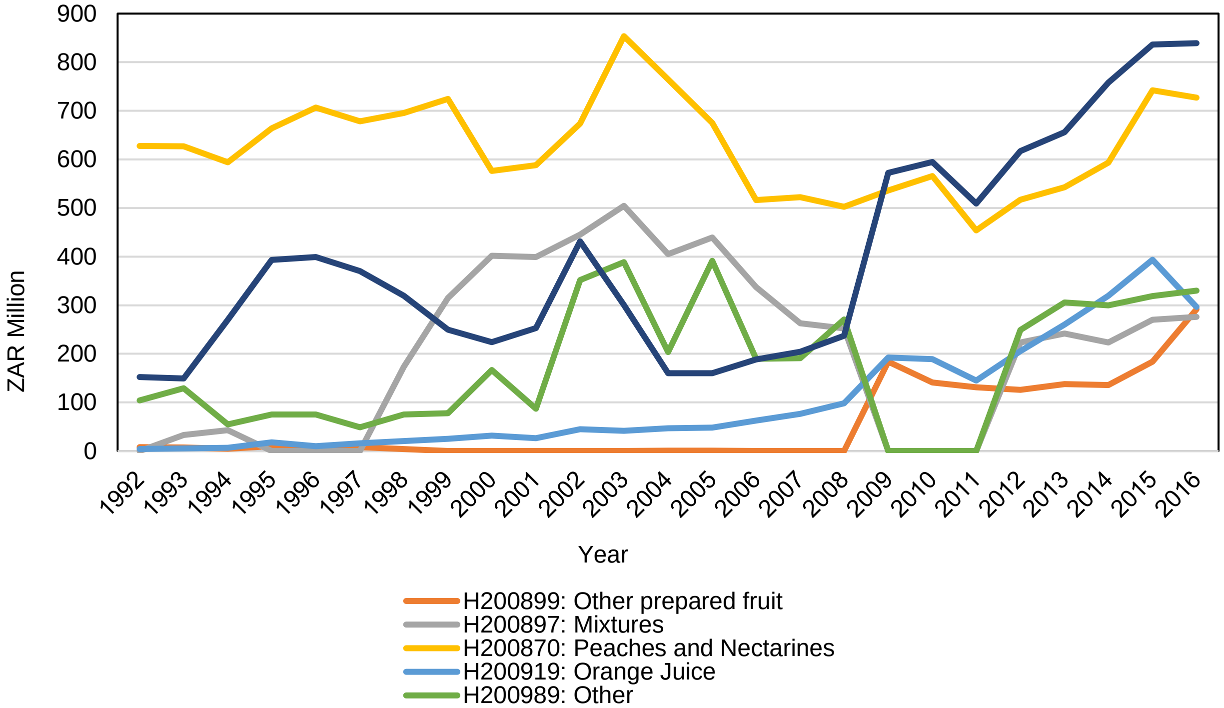

Figure 13 Change in total value of exports (2010 base year) (DTI, 2018).

From an export destination point of view (Fig. 14) it is interesting to note, although not surprising, that exports to the African content lead with almost 49%. SAFVCA and the South African Fruit Juicers Association (SAFJA) also continue to identify the continent as an important export region (Bekker, 2018). Europe follows with 26%, more than double that of North America, Oceania and South America at 10.45% collectively (CID, 2018). Within the main export region (Africa), it is found that the immediate geographical neighbours of Namibia, Botswana and Mozambique lead with 9.76%, 9.75% and 4.95%, respectively (CID, 2018). This is not surprising, as Namibia and Botswana form part of the Southern African Customs Union (SACU), which together with the other member states (South Africa, Lesotho and Swaziland) aim to facilitate the cross-border movement of goods between the member countries (SACU, 2013). The main European export destinations are found to be the Netherlands (8.6%), and Germany (6.1%) (CID), 2018).

3.6.2.7 Economic outlook

Bekker (2018) has detailed the various challenges and outlooks facing the industry at present, with commentary well summarised in the form of a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis. The details of this SWOT analysis are presented in Table 4 below.

Table 3 HS codes defined (DTI, 2018)

HS	Description
H2001	Vegetables, fruit, nuts and other edible parts of plants, prepared or preserved by vinegar or acetic acid
H2002	Tomatoes prepared or preserved otherwise than by vinegar or acetic acid
H2003	Mushrooms and truffles prepared or preserved otherwise than by vinegar or acetic acid
H2004	Other vegetables prepared or preserved otherwise than by vinegar or acetic acid, frozen
H2005	Other vegetables prepared or preserved otherwise than by vinegar or acetic acid, not frozen
H2006	Vegetables, fruit, nuts, fruit-peel and other parts of plants, preserved by sugar (drained, glacé or crystallised):
H2007	Jams, fruit jellies, marmalades, fruit or nut purée and fruit or nut pastes, obtained by cooking
H2008	Fruit, nuts and other edible parts of plants, otherwise prepared or preserved
H2009	Fruit juices (including grape must) and vegetable juices, unfermented and not containing added spirit

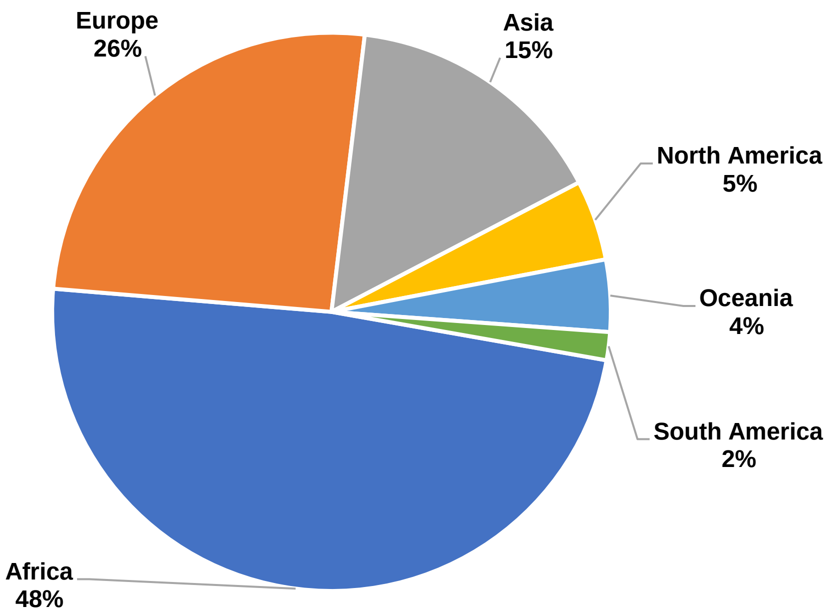

Figure 14 Export destinations for South African processed fruit and vegetables (CID, 2018)

Table 4 SWOT analysis of the South African FVPI (Bekker, 2018)

Strengths	Weaknesses
• Well established international trade network • Increasing processing capacity • Counter seasonality to export destinations • Proximity to African export markets • Industry has been targeted for governmental support	• Substantial barriers to entry • Susceptible to drought and fluctuations in horticultural yield • Profitability very dependent on exchange rate • Consumer spending constraints may lead to substitution with fresh produce • Increasingly concentrated and mature sector
Opportunities	**Threats**
• Increasing export opportunities, especially Asia • Increased regional demand for processed fruits and juices • Potential support from government in the form of funding and linkage schemes	• Slow economic growth and high unemployment will pressure consumer spending • Drought and water shortages • Rising input costs (including labour, energy and fuel) • Sugar Beverages Levy (SBL) • Carbon tax • Concerns over expropriation without compensation

3.7 Water use in context of generic processing practices for fruit and vegetables

Dauthy (1995) has found that with a knowledge of the specific deterioration properties of foods, it is possible to list a variety of biological, physical and chemical methods that may be used in the preservation of the material in question (Table 5).

Table 5 Technical means of preservation in foods (Dauthy, 1995)

Descriptor	Parameter
Physical	Heating
	Cooling
	Lowering of water content
	Sterilising filtration
	Irradiation
	Other (Inert gases, vacuum, high pressure)
Chemical	Salting
	Addition of sugar
	Artificial acidification
	Ethyl alcohol addition
	Antiseptic substances
Biochemical	Lactic fermentation
	Alcoholic fermentation

It must however be noted that the classification of processing procedures may be difficult as their effects are often a combination of physical, chemical or biochemical phenomena (Dauthy, 1995). Due to technical-economic considerations, as well as changes to nutritional and organoleptic properties, not all of the technical processes listed in Table 5 would be suitable for fruit and vegetable processing (Dauthy, 1995). From the many possible ways of preventing deterioration, specific techniques have been found appropriate for fruit and vegetables (Table 6).

Table 6 Practical processing applications for fruit and vegetables (Dauthy, 1995)

Process	Practical applications
Fresh Storage	Fruits & vegetables
Cold Storage	Fruits & vegetables
Freezing	Fruits & vegetables
Drying/dehydration	Fruits & vegetables

Concentration	Fruits & vegetable juices
Chemical preservation	Semi-processed fruit
Addition of sugar	Fruit products & preserves
Pasteurisation	Fruit and vegetable juices
Sterilisation	Fruits & vegetables
Sterilising filtration	Fruit juices
Irradiation	Fruits & vegetables

For the purposes of further discussion, it is necessary to condense the preservation techniques described in Table 6 into generic processing practices most commonly encountered in the South African situation. This is necessary for two reasons: Firstly, many of the procedures work in tandem when looking at a generic processing technique. For example, juicing often involves pasteurisation and chemical preservation (by addition of preservatives like sulphur dioxide). Therefore, looking at a more generic process such as juicing will by its very nature deal with more specific principles. Secondly, to investigate individual procedures would be beyond the scope of this study, as the investigation is primarily concerned with water use in the processes, not necessarily the principles themselves.

3.7.1 Fruit and vegetable juice

Firstly, fresh fruit is subjected to a preparation procedure where the fruit is graded, washed and stems are eliminated. The fruit is also subjected to a manual selection procedure where rotten fruit and other undesirable components are removed (Horvath-Kerkai, 2006). The next step is the chopping and subsequent preparation of the fruit, which may involve further mechanical manipulation, heating and addition of enzymes (Horvath-Kerkai, 2006). A common practice in industry is the use of cellulases and pectinases (Dauthy, 1995; Sharma *et al.*, 2017). Using enzymes in combination increases the juice yield, clarity and total soluble solids (TSS); whilst also decreasing viscosity and turbidity (Sharma *et al*., 2017). The next step involves the actual liquid extraction, with the most common method being pressing (Horvath-Kerkai, 2006). The pressed juice is then subjected to a clarification step (if a cloudy juice is not desired) which involves a physiochemical (usually a combination of mineral clarifying agents and enzymatic treatments) and/or mechanical procedure (centrifugation or membrane filtration) (Horvath-Kerkai, 2006). A movement towards membrane technology is currently underway, due to the negative effects of temperature on fruit juice quality, as well as savings in operating costs and man-power (Bhattacharjee *et al.,* 2017) A problem with membrane treatment (especially with microfiltration and ultrafiltration) however, is that of fouling, which reduces permeate flux and membrane lifespan (Bhattacharjee *et al.*, 2017). The cloudy or clarified juice can now be packaged directly, or be concentrated to extend shelf-life and improve storage and/or transport properties (Horvath-Kerkai, 2006). Concentration can be accomplished by three methods, namely evaporation, freeze concentration and membrane processes, each with their own particular advantages and disadvantages (Horvath-Kerkai, 2006; Fellows, 2009b). Freeze concentration is used mainly for high quality fruit juice due to its ability to preserve the organoleptic properties of the product, despite the fact that capital, energy and operating requirements are generally higher (Fellows, 2009b). When final packaging occurs, the juice (or reconstituted concentrate) is heated to a temperature of 82-85°C, after which it is filled into a suitable container (typically glass or plastic). High temperature, short time (HTST) pasteurisation is the most commonly used industrial technique for juice products (Koutchma *et al.*, 2016). An important factor to consider when manufacturing vegetable juice is that the pH is often greater than 4.5, therefore a full sterilisation treatment is necessary (IPPC, 2006). A treatment with mild organic or inorganic acids may lower the pH enough to allow for a less intense treatment, such as pasteurisation, although blending with high acidity juices (e.g. tomato, citrus or pineapple) may also provide a similar effect (IPPC, 2006).

Another widely used approach is spray drying of fruit and vegetable juices (Shishir & Chen, 2017). The key driver for this processing technique is the reduction in transport, storage and packaging costs, as well as the improvements in shelf life (made possible by the high stability of the powder) (Shishir & Chen, 2017).

When considering the water use within a typical operation, apple and pear juicing as an example, water use is split between process water, boiler feed and washdown/domestic requirements (Binnie & Partners, 1987). Process water consumes 20%, with boiler feed/steam raising utilising 4%. Washdown of the pressing plant uses 20%, whilst other general washing and domestic operations use the remaining 56%.

3.7.2 Heat treated fruit and vegetables

Fruit for canning should ideally be used as soon as possible after delivery, although at times it may have to be stored for extended periods under chilled conditions (IPPC, 2006). The fruit is first washed then sorted, after which it is then cored or pitted before peeling. There are a variety of peeling techniques, of which caustic, mechanical, steam and abrasive peeling are the most common. Peeled fruit may then be transferred to tanks containing either brine or ascorbic acid to prevent browning. The fruit may then be sliced before being filled into a container, with either a syrup or natural juice. Before being sealed, the container may be slightly heated, or subjected to a brief steam treatment in the headspace in a procedure known as ‘exhausting’, which is done to create a negative pressure gradient within the container (IPPC, 2006). Taking apricots as an example, pasteurisation should then seek to raise the temperature of the centres of the product to a minimum of 90.5 °C. (Lopez (1981) in Siddiq, 2006).

Valta *et al.* (2017) have recorded the main water using operations in a plant producing canned peaches and apricots. Forty percent is related to cutting and pitting, 35% for pasteurisation and the balance being attributed to peeling and transfer. For one plant involved in the canning of peach and apricot compote, they record that the main water usage in the manufacturing of canned peaches and apricots is pasteurisation (44%), washing and transfer (38%), steam production, cleaning and staff needs (18%).

3.7.3 Frozen fruits and vegetables

The freezing of fruits is commonly used when further processing (e.g. manufacturing of preserves) is likely (IPPC, 2006). Different freezing techniques are used for different products (De Ancos *et al.*, 2006) and are categorized according to the heat transmission medium used (Rahman & Velez-Ruiz, 2007):

1. **Freezing by contact with a cooled solid (Plate freezing)**: The product to be frozen is sandwiched between two cooled plates. When freezing is completed, hot water is circulated around the edges to break the ice seal. This technique is only suitable for regularly shaped products.
2. **Contact with a cooled liquid (Immersion freezing)**: Food is submerged in a low temperature brine to ensure a rapid temperature reduction by means of direct heat exchange. Fruits, tomato slices and orange pieces are examples of products that can be frozen in this way.
3. **Freezing by contact with a cooled gas**: Cold air can be circulated around a product placed on a tray within an enclosed space (*Cabinet cooling*). Another method is *air blast freezing*, where the product is cooled by high speed cooled air (2.5 - 5 $m.s^{-2}$ for most economical freezing).
4. **Cryogenic freezing:** An extremely rapid method where products are placed in direct contact with liquified gases, usually nitrogen or carbon dioxide. Due to the high costs associated with gas compression, this technique is typically used for high value products. It is also not recommended for large whole fruits (e.g. prunes, peaches) due to the risk of crushing (De Ancos *et al.*, 2006)

A Greek fruit freezing facility studied by Valta *et al*. (2017) used most of (67%) of its water in the actual freezing operation, followed by washing (13%), bleaching (12%) and slicing (8%) respectively.

3.7.4 Fruit preserves

Preserving is the manufacturing of jams, jellies and marmalades. Standards for jams and marmalades are similar to those for jellies, except that instead of fruit juice, whole fruits are added and the minimum Soluble Solids (SS) contents are slightly higher (68% for some and 65% for others) (Vibhakara & Bawa, 2006). The manufacturing process commences with the selection of the raw ingredients. Fruit used in the manufacturing of jams should be fully mature, rich in flavour and of suitable texture, whilst those used for jellies should contain sufficient pectin and acid. Other typical ingredients of the preserving processes are sweetening agents (typically cane or beet sugar) (Dauthy, 1995), an acid (typically citric or malic acid), buffers like trisodium citrate, gelling agents (usually pectin) and anti-foaming agents, and citrus peel; for marmalade (IPPC, 2006). Fruits are then generally washed to remove all dirt and foreign debris and are then pitted and/or peeled as required. The combination of fruit and other ingredients is then boiled to create a pectin, acid and sugar union. Although arguably one of the most important steps in the process, boiling should be as short as possible to avoid loss of flavour and/or colour and prevent hydrolysis of the pectin (which could lead to jelly failure) (Vibhakara & Bawa, 2006). The syrup is then hot-filled in jars and hermetically sealed with metal caps featuring a rubber gasket. The container is then cooled to 21ºC to allow setting of the pectin (Vibhakara & Bawa, 2006).

3.7.5 Dried fruit and vegetables

The aim of drying is reducing the water activity (a_w) to inhibit the deteriorative actions of microorganisms and enzymes associated with the food product (Dauthy, 1995; Fellows, 2009b). To achieve this, various techniques may be utilised, although the most common method still remains sun drying (Fellows, 2009a). The basic sun drying process involves sorting, grading, washing and dipping, drying and finally, packing. Some fruits are also sulphited before drying, in order to protect the fruit against mould, as well as to soften the tissue which in turn leads to faster drying (IPPC, 2006). In some cases after harvesting, the fruit is dipped in, or sprayed with a solution of potassium carbonate solution which also contains dipping oil (IPPC, 2006). Sun drying has its limitations, which include spoilage due to adverse climatic conditions; loss of product due to animals; insect infestation and fungal growth (Vijayavenkataraman *et al.,* 2012). The process is also labour intensive, time consuming and requires a large area (Vijayavenkataraman *et al*., 2012).

Within the industrial food processing environment, conventional hot air dryers (HAD) are the mainstay technology, despite their high energy requirements (Michailidis & Krokida, 2015). Freeze-drying is the most versatile operation, although its application is limited to high value products, as a result of the high cost associated with high vacuum creation and freezing of raw materials (Michailidis & Krokida, 2015).

Therefore, taking the drawbacks of sun and mechanical (industrial) techniques into account, solar drying has been proposed as a compromise (Vijayavenkataraman *et al*., 2012). The technique offers lower fossil fuel consumption when compared to purely mechanical processes, and a higher quality product, with fewer losses, when compared to sun drying (Vijayavenkataraman *et al*., 2012).

The CLFP (2015), in their study of industrial dehydration facilities, found that half the water requirements were for washing of raw product, whilst the other half was attributed to sanitation.

3.7.6 Tomato processing

Tomato processing can produce many different products, including canned-crushed tomato, juice and canned-whole tomatoes. Figure 15 below shows the 3 main processing routes for tomatoes, as well as the final products. Water usage in tomato paste processing can be mainly attributed to the cooling of condensers (greater than 50%), washing and transport operations (Valta et al., 2017). Other minor users of water include pasteurisation, cutting/pitting and use by personnel (Valta *et al.*, 2017). Other processing routes for tomatoes (e.g. canned) find their main water usages being in the washing stage (up to 40%), and boiler feed water (up to 32%) (CLFP, 2015). It is important, however, to note that tomato processors do reuse water obtained from the raw product and recovered condensate, for the following processes (Valta *et al*., 2017; CLFP, 2015):

- Washing of raw materials
- Rotary screen (a device for removing solids from wastewater) **cleaning sprays**; and
- For use in **flume system** (i.e. transfer systems)

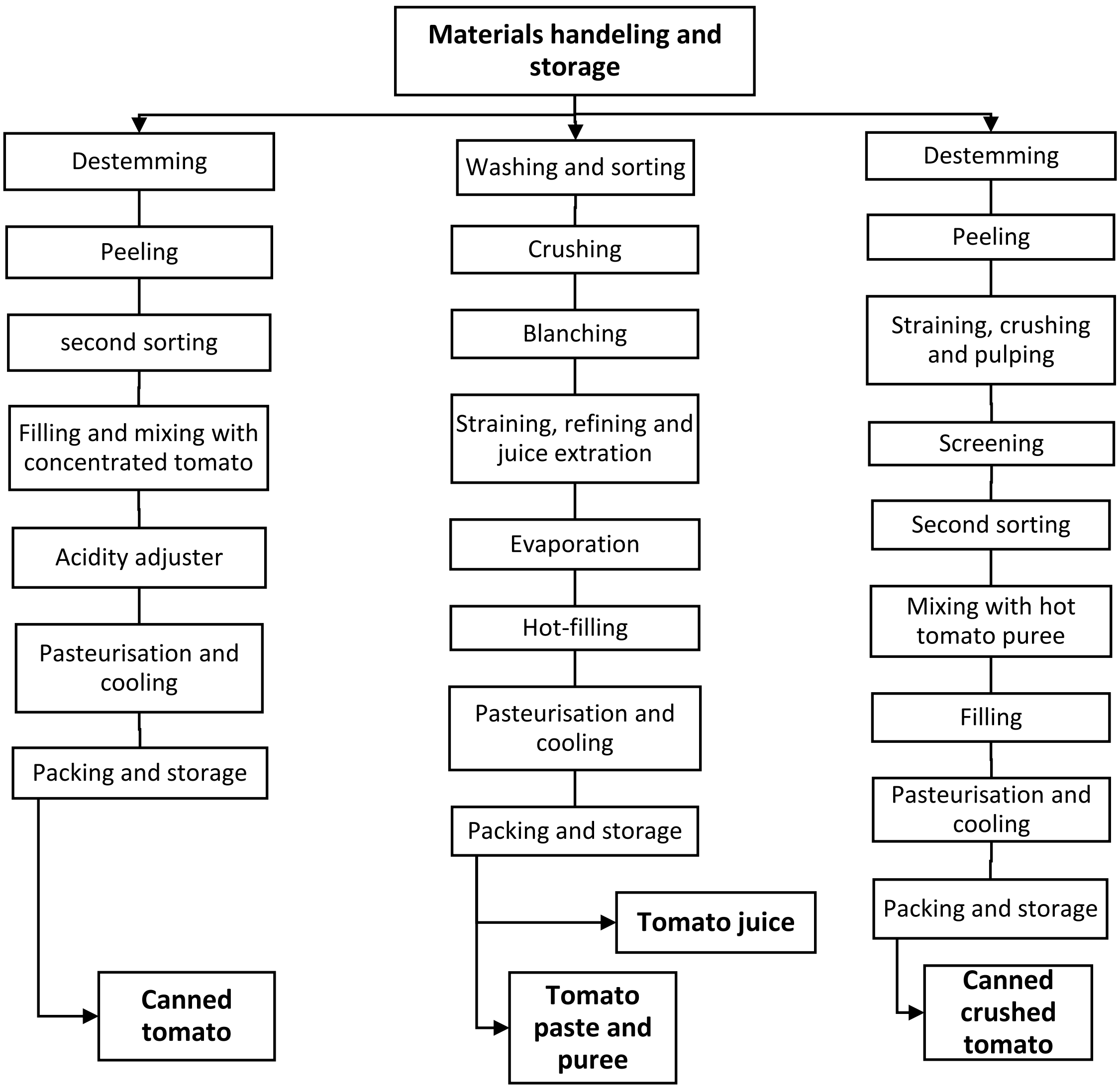

Figure 15 Processing options for tomatoes (adapted from Italian Contribution in IPPC, 2006).

3.7.7 Potato processing

The main potato processing products in South Africa are chips (fries) and crisps (91%) (DAFF, 2017), with both using similar processes in their manufacture (IPPC, 2006). The basic procedure consists of peeling, slicing to desired size, blanching, followed by frying to achieve the desired sensory properties (IPPC, 2006).

Deep fat-frying is a processes that involves simultaneous mass and heat transfer whilst the food sample is submerged in oil (Pedreschi & Enrione, 2014). The oil allows the rapid transfer of heat into the food, which vaporises the inherent moisture and drives it to the surface, and later into the surrounding oil (Pedreschi & Enrione, 2014). A certain amount of oil is also absorbed by the sample itself (Pedreschi *et al.,* 2012). The frying process also allows for the reaction between reducing sugars and amino acids which leads to browning, textural changes as well as softening at the beginning of the process, with surface hardening towards the end (Pedreschi & Enrione, 2014). However, the frying process is also known to form heat-induced toxins (e.g. acrylamide and furan) (Pedreschi & Enrione, 2014). Frying pyrophosphate and sodium metabisulphite are common ingredients used to prevent discolouring of the potato products, with pyrophosphate in particular being prevalent in waste streams from the processing facilities (IPPC, 2006).

3.7.8 Preservation by acidification

Acidification of the food environment creates a habitat that is unsuitable for further microbial growth (Dauthy, 1995). The process of acidification can be by natural or artificial means (Dauthy, 1995). Natural acidification, more specifically, may represent the easiest way of increasing the daily intake of fresh-like fruit and vegetables (Di Cagno *et al.*, 2013). The typical industrial process commences with delivery of the raw material, washing and screening to remove any extraneous material. Steam cooking followed by rapid cooling may be applicable for some vegetable varieties. The product is then peeled (typically by steam) and re-inspected before then being sliced/diced or shredded. The sliced fruit/vegetables are then filled into containers with an acidifying liquor. The formulation of the acidifying liquor is typically prepared using liquid sugar acetic acid, malt vinegar, spirit vinegar and salt, but may vary. After sealing, the container is pasteurised (IPPC, 2006).

3.8 Methods to minimise water use in food processing

Since the 1980s, the design of systematic methods to reduce water requirements has received much attention (Kim & Smith, 2008). A systematic approach to the minimisation and prevention of water wastage has been described in detail by the IPPC (2006) and consists of the following steps:

1. Obtaining management approval, and executing organisation and planning
2. Analysis of the entire production process
3. Assessment of objectives

4. Identification of prevention and minimisation options
5. Carrying out an identification and feasibility study
6. Implementation; and
7. Continued monitoring and visual inspection

The types of minimisation options under point 4 (Identification of prevention and minimisation options) can be broadly described under three complementary schemes, namely **water minimisation**; **water-reuse/recycling** and **process changes** (Kim & Smith, 2008). Water minimisation and reuse/recycling are primarily concerned with design options of the *water networks* present within facilities (Kim & Smith, 2008), whilst the process changes are primarily concerned with the optimisation of unit operations (Kim & Smith, 2008; IPPC, 2006).

Food processing has its own unique characteristics that make it advisable to start with more simple water saving measures (e.g. good housekeeping based on efficient management) followed by progression onto more complex methodologies (Klemeš & Perry, 2007). The intermittency of production, as found in fruit and vegetable processing, influences the investment in water and waste minimisation technologies (Klemeš & Perry, 2008) and a thorough investigation into the economic feasibility would be necessary (Cooke, 2008).

3.8.1 Design-based minimisation

Water pinch is a powerful systematic approach that uses advanced algorithms to identify water saving opportunities (IPPC, 2006). The technique was developed by Wang & Smith, (1994) and is based upon the graphical manipulation of limiting water profiles (Klemeš & Perry, 2007). A more detailed description of the concept and its application can be found in Wang & Smith (1994); Klemeš & Perry (2007) and Kim and Smith (2008).The technique has been applied practically by Thevendiraraj *et al.* (2003). There are a variety of software packages available for water minimisation, and can deal with extremely complex optimisation problems (Smith & Kim, 2008).

Panjeshahi *et al.* (2009) have taken the concept of water pinch further, in what they describe as Advanced Pinch design (APD), which amalgamates combined pinch technology and mathematical programming for a minimum cost outcome. They also consider the inclusion of ozone treatment in cooling towers for improved recirculated water quality.

3.8.2 Water reuse and recycling

When fresh water is in limited supply and/or process materials can be recovered from the wastewater, then water regeneration is likely to be economically feasible (Smith & Kim, 2008), although treatment for the purposes of water reuse are often not utilised due to perceived quality concerns (Bromley-Challenor *et al*., 2013). Also, the fact that water treatment facilities need to be both robust and significant for the achievement of sufficient quality also acts as a deterrent to their implementation. Wastewater treatment would have to include primary, secondary and tertiary steps, a description of which can be found in Section 2.9

Smith & Kim (2008) defined optimisation strategies using treated wastewater under two broad headings, namely regeneration reuse and regeneration recycling.

- **Regeneration reuse**: regenerated water from a WWTP is not supplied to the same operation, due to contaminant levels, but may be suitable for use in other operations; and
- **Regeneration recycling**: water from the WWTP can be fully or partly recycled to the same operation

Smith and Kim (2008) further describe a targeting method for regeneration reuse but go further as to describe how freshwater requirements can be reduced by using the regenerated water in the same operations. If, theoretically, the WWTP was able to supply the same quality of fresh water, a zero discharge of water is possible (Smith & Kim, 2008). The reality, however, is that the treated water is very likely more contaminated than the fresh water. In that case, sub-systems requiring better quality water should only be supplied by fresh sources (Smith & Kim, 2008).

A method for treating minimally contaminated water for the purpose of reuse has been investigated by Mavrov & Bélières (2000), who successfully demonstrated at pilot-scale the ability of a three-phase process (pre-treatment; membrane filtration and UV disinfection) to treat low contaminant wastewater in an economically feasible manner. The treated water was also found to be suitable for drinking as well as boiler make-up (which has requirements even more stringent than that of drinking water). Wu *et al*. (2016) have also demonstrated the ability of a relatively inexpensive process (chlorination, bag filtration and activated charcoal filtration) to reclaim water during the washing/sorting process in an orange canning plant.

In a survey of 18 companies across the food processing industry, the Australian Department of Agriculture (2007) found that the majority of water was used in non-contact processes, and therefore concluded that considerable scope exists for the adoption of recycling strategies. Possibilities for water recycling within food processing facilities have also been documented by the California League of Food Processors (CLFP, 2015) in their 2014 survey of food processing facilities. Masanet *et al.* (2008) also make mention of specific water recycling opportunities available to the fruit and vegetable processing industry. Recycling/Reuse Best Management Practices identified by CLFP (2015), Masanet *et al.* (2008) and others include:

- Recycling/re-circulation to reduce fresh water requirements (Casani *et al*., 2005; Panjeshahi *et al*., 2009). Bromley-Challenor *et al*. (2013) make specific mention of boiler water reuse
- Reuse cooling tower overflows for site sanitation

- Reusing process condensate (Sethu & Viramuthu, 2008; Bromley-Challenor *et al*., 2013; Amón *et al.*, 2015; Valta *et al*., 2017)
- Recirculating seal water
- Phasing out the use of once-through cooling (see also Bromley-Challenor *et al*. (2013))
- Evaluation of Clean In Place (CIP) chemicals, timing and required water
- Reusing process water for irrigation
- Re-circulation of water between clustered cooling towers
- Using lye concentrators for lye recovery from process water. This may also assist in the efficiency of Up-flow Anaerobic Sludge Blanket (UASB) during wastewater treatment, due to improved methanogenesis (Sigge & Britz, 2007)
- Using recaptured wash water as a 'first rinse' for raw fruit entering the washing area. Counter current washing (washing with progressively cleaner water) is also recommended
- Sourcing water from incoming raw materials (e.g. tomatoes)
- Segregation of wastewater streams for optimal reuse/recycling; and
- The use of hydrocyclones for wastewater streams with a high solids content. This allows for increases water reclamation, decreased WWTP costs and the use of recovered solids as animal feed, mulch or agricultural additives

3.8.3 Process changes

It is possible to optimise individual processes to further increase water efficiency and minimisation (IPPC, 2006; Smith & Kim, 2008), examples of which are discussed below. It is also possible to change product recipes and preservation techniques in order to use less water (Sethu & Viramuthu, 2008).

3.8.3.1 Reducing driving force for mass transfer

Extraction, absorption and stripping operations require a driving force for their respective mass transfers, and this is very often supplied by water. The driving force, which is obviously linked to the flowrate, can be reduced. It must be noted however, that a small driving force may result in additional capital requirements and/or the number of stages in the operation (Smith & Kim, 2008).

3.8.3.2 Water free operations

Non-water using operations can replace those using water (Smith & Kim, 2008). Examples of these would include:

- **Microwave heating and ohmic thawing**; in the place of conventional heating techniques (e.g. water bath or steam ovens) (IPPC, 2006; Varghese *et al.*, 2014)

- **Alternative separation techniques** such as crystallisation or microwave assisted extraction, that can replace water driven extraction (Smith & Kim, 2008; Cheng *et al.*, 2011); and
- **Dry Conveyors**; in place of flume systems (Masanet *et al.*, 2008)

3.8.3.3 Process control and optimisation

Process control measures can identify any existing spare capacity and avoid any unnecessary water usage (Smith & Kim, 2008). The IPPC (2006) gives an extensive list of process control and optimisation techniques, a summary of which can be found in Table 7 below.

Table 7 Process control for optimal water use (IPPC, 2006)

Technique	**Description**
Dedicated monitoring and correction of temperature	Reduced water use can also be achieved if the system uses steam for heating
Controlling flow or level using pressure monitoring	Pressure control can be applied using sensors for indirect control of other parameters (e.g. degree of filter clogging). Bromley-Challenor *et al.* (2013) have identified that water pressure optimisation may contribute to 4.5% of total saving opportunities in the UK food and drink manufacturing sector.
Level Measurement	An example of this would be a facility which installed level controls on the supply tanks supplying the flume system for transportation of the material). Previously, an operator would adjust the water supply controls manually which would allow excessive overflow from the tanks.). Bromley-Challenor *et al.* (2013) have noted that prevention of overflow can contribute 5.5% to identified savings opportunities in manufacturing.
Flow measurement and control	To optimise the use of water, the actual flow rates must be known in the first instance. Many different types of flow meters exist, (e.g. rotameters, electromagnetic flow meters and vortex shedding meters)
Analytical Measurement	The use of pH probes can lead to reduced use of acids and alkalis, and consequently reduced wastewater generation. Turbidity measurement can be used in the monitoring of process water quality and in the monitoring of CIP systems (to optimise the re-use of cleaning water)
Use automated stop/start controls	Sensors can detect the presence of raw materials and only supply water when it is required. Water supplies can be turned off automatically during production stoppages and product change-overs. Bromley-Challenor *et al.* (2013) have reported that savings from automatic stop controls in the food manufacturing sector may contribute 5.9% to identified saving opportunities.
Use of control devices	Valves are the most common control devices and their implementation can reduce water consumption and associated energy requirements
Use of water nozzles	Water consumption and wastewater generation can be reduced by correctly positioning and directing nozzles. Presence-activated sensors, and only installing nozzles where required can also ensure that water is only used when and where necessary
Improved Peeling Technology	Various peeling techniques for improved water use/effluent quality can be investigated (e.g. Dry peeling in place of conventional practices) (Masanet *et al*., 2008).

3.8.3.4 Avoidance of once-through use

Water is widely used in the food industry as a conduit for cooling or heating, and the use of once-through systems require especially large volumes (Smith and Kim, 2008). The CLFP (2015) makes specific mention of the fact that 'one pass' cooling should be avoided. In fact, Binnie & Partners (1987) make specific mention of a freezing facility, where the use of a once-through cooling system drastically altered the National Average Specific Water Intake (NASWI) for freezing in general. It is now common industrial practice to use recirculating cooling water systems, coupled to a heat exchanger (for energy recovery), for reuse and recycling (Smith & Kim, 2008; Panjeshahi *et al.,* 2009). As an example, closed circuit cooling may result in water savings of up to 80% when compared to an open system (IPPC, 2006). Bromley-Challenor *et al.* (2013) have also noted that 25% of identified savings opportunities may come from the elimination of once-through cooling systems in the UK food and drink industry. A problem however, that must be addressed, is that of bacterial or algal growth in the closed system (IPPC, 2006). Chemical addition may suffice for the most part, although special attention must be paid to the avoidance of conditions suitable for the proliferation of *Legionella* (Castor *et al*., 2005; IPPC, 2006; Cooke, 2008).

3.8.3.5 Improved production scheduling

Product changeover can be reduced in multi-product batch systems, to ensure that less water is used for washing (Smith & Kim, 2008)

3.8.3.6 Improving equipment design

The careful design of equipment can lead to a reduction in solid, liquid and gas emissions (IPPC, 2006), as well as a reduction in total inherent water use (Smith & Kim, 2008). Examples include (IPPC, 2006):

1. Identifying and marking all valves and settings for equipment. This may reduce the risk of staff incorrectly adjusting them
2. Optimising pipework systems and equipment capacity; and
3. Designing equipment that is easy to clean

3.8.3.7 Improving energy efficiency

Within food processing, energy and water systems are closely interrelated (Savulescu & Kim, 2008) and improving energy efficiency will very likely also lead to reduced water consumption (Savulescu & Kim, 2008; Smith & Kim, 2008). Masanet *et al.* (2008) provide a complete description of various energy saving techniques applicable to the fruit and vegetable processing industry, a summary of which is given in Table 7 below. The processes covered represent those which are determined to be amongst the most energy intensive within the FVPI (Masanet *et al*., 2008).

Table 8 General energy saving techniques applicable to the fruit and vegetable processing industry (Masanet *et al*., 2008)

Process	Energy saving technique
Blanching	Heat recovery from blancher water or condensate via a heat exchanger
	Upgrading of steam blanchers to modern units with energy efficient features (e.g. steam seals)
	Heat and hold techniques instead of continuous subjection to heating medium
	Steam recirculation
Dehydration/drying	Use of direct fired dryers
	Proper and timely maintenance
	Insulation of any hot surfaces on dryer that are exposed to outside air
	Mechanical dewatering of fruit and vegetables prior to drying
	Process control for optimisation of energy inputs
	Exhaust air heat recovery
	Using dry air to reduce the amount of energy required to heat and vaporise any incoming moisture
	Heat recovery from product where it is deliberately cooled after drying
Evaporation	Proper and timely maintenance of evaporator
	Use of multiple effect evaporators
	Mechanical or thermal vapour recompression (potentially more effective than multiple effect evaporators)
	Freeze or membrane concentration
Frying	Heat recovery via adsorption cooling
	Heat recovery via exhaust gas combustion
	Using spent fryer oil as fuel
	Heat recovery from fryer exhaust gases
	Heat recovery via adsorption cooling
Pasteurisation and sterilisation	Insulation of all hot surfaces in contact with external air
	Use of helical heat exchangers
	Induction heating of liquids
	Compact immersion tube heat exchangers
Peeling	Heat recovery from discharge steam
	Multi-stage abrasive peeling
	Dry caustic peeling

3.8.3.8 Provide training

Providing staff (at all levels of the company hierarchy) with the necessary training in their duties can minimise consumption and emission levels (IPPC, 2006; CLFP, 2015). The training can be in-house or externally, and should cover routine operations, start-up, shutdown, cleaning, maintenance , abnormal conditions and non-routine work (IPPC, 2006). The Australian Department of Agriculture (2007) also makes note of the fact that ‘behavioural change’ may result in water savings of up to 25% depending on the type of processing facility.

3.8.3.9 Ensure proper maintenance

Effective planned maintenance can minimise water use and liquid emissions (IPPC, 2006). An example would be that of tanks, pumping equipment, compressor seals, valves and process drains that can be a major source of leaks, and therefore require pre-emptive and timely maintenance (IPPC, 2006; CLFP, 2015). Bromley-Challenor *et al*. (2013) have identified that fixing supply leaks (in combination with water balance monitoring) may contribute to 12% of water saving opportunities in the UK food and beverage manufacturing sector.

3.8.3.10 Improved cleaning techniques

The IPPC (2006) and Masanet *et al*. (2008) describe a wide variety of water-friendly cleaning methods. A brief description of these techniques can be found in Table 9 below.

Table 9 Description of Best Available Techniques (BAT) for cleaning (IPPC, 2006; Masanet *et al*., 2008)

Type of cleaning practice	Description
Catchpots over floor drains	Fine mesh baskets placed over floor drains, to prevent solids from entering the drainage system, and consequently the WWTP
Floor and equipment pre-soaking	Pre-soaking the floors to loosen dirt can make subsequent cleaning easier. Depending on the situation, the consumption of water and chemicals may be reduced
Pigging	'Pigging' is a practice where a food grade rubber 'pigs'/projectiles are forced through piping by compressed air, to remove excess product between batches. Pigging increases product recovery, decreases water use and wastewater generation, and results in a less contaminated wastewater stream.
Flushing of pipework with compressed air	Gas flushing is effective at removing residual materials from piping, and can reduce water consumption in cleaning
Management of energy, water and detergents	By conducting trials and recording daily hygiene measurements, it is possible to ascertain a minimum combination of water, energy and detergents that do not compromise on food safety
Hand operated triggers on hoses	Hoses can be fitted with trigger control shut-offs, or with automatic shut-off valves
Pressure cleaning	High Pressure cleaning can be achieved in a variety of ways and achieves greater cleaning efficacy with the use of less water. It has also been recommended as BMP by the CLFP (2015). Care must be taken however during this operation, especially in confined spaces due to possible risk of *Legionella* contraction (Castor *et al.*, 2005)
Optimal use of CIP (Cleaning-in-place)	CIP systems are cleaning systems incorporated into the equipment (usually during the design stage) and are calibrated in such a way as to optimise the use of water and detergents. The CLFP (2015) also recommends investigating optimal CIP timing and chemical use
HPLV sprays for cleaning of vehicles	HPLV (High Pressure, Low Volume) sprays can be applied to all facilities where materials are delivered by truck.
Clean equipment immediately after use	Postponing cleaning can result in product residues becoming dry and crusty, meaning more water is needed to remove it.

3.8.3.11 Use of novel technologies

There has been a great amount of interest, (propagated by consumer demand and regulatory pressures) in the use of novel processing techniques that could overcome the water and energy deficiencies of conventional practices (Toepfl *et al.*, 2006; Pan *et al*., 2015; Thirumdas *et al.,* 2015). In a survey by Jermann *et al.* (2015) 61% of respondents indicated that "solving environmental or waste issues" was one of the key drivers in the commercialisation of new food processing technologies, whilst 79% of respondents indicated that cost saving in terms of water and energy was also a driver. Alternatives to conventional processing may result in less water use, reduced wastewater output, less reliance on fossil fuels and reduced production of hazardous substances (Chemat *et al*., 2017). Ultrasound-assisted processing (UAP), ohmic heating (OH), supercritical fluids (SCF), microwave processing, controlled pressure drop process (DIC), cold plasma, high pressure processing (HPP) and pulsed electric fields (PEF) are examples of such processes (Bermúdez-Aguirre & Barbosa-Cánovas, 2011; Chemat *et al.*, 2017; Thirumdas *et al*., 2015). Despite large advances in these novel techniques, more research is required to prove their pragmatic feasibility in commercial operations. (Jermann *et al.,* 2015). Indeed within the South African context, Ronquest-Ross *et al.* (2018) makes specific mention of the need for both research and application of novel technologies within the country. Some limitations experienced by these technologies include high investment costs, lack of regulatory approval and incomplete control of variables associated with the operations (Jermann *et al.,* 2015).

Instant controlled pressure drop technology

'Détente Instantanée Contrôlée' (DIC), which is French for instant controlled pressure drop, is based mainly upon the thermodynamics of instantaneity and auto-vaporisation and has been discussed by Chemat *et al*., (2017) as a 'green' technology. The process has been found to be effective in the microbial sanitisation of foodstuffs (even when the microorganisms are in spore form), and has also demonstrated its abilities in vegetable-based extraction processes (Chemat *et al*., 2017). As a drying technique, it has been found to be useful in the texturing of dried fruit, vegetables and seaweeds; as well as in the creation of large granule powders, with quality attributes higher than those of traditionally dried or spray dried powders (Michailidis & Krokida, 2015). The advantages include reduced energy requirements and production costs, as well as improved quality and safety attributes (Michailidis & Krokida, 2015).

Ultrasound assisted processing

Power ultrasound (20-100 kHz) finds its mechanism around the cavitation phenomenon in liquid systems. Ultrasound is propagated by a series rarefaction and compression waves in the medium, which at sufficiently high power may be able to overcome the liquid-liquid intermolecular forces. At this point, cavitation bubbles will form from gas nuclei in the liquid (Soria & Villamiel, 2010). After a few cycles the gas bubbles will grow in size and then collapse violently. The collapsing bubbles will result in accumulated energy hotspots, with high pressure (5000 K) and pressure (1000 bar) (Herceg & Jambrak, 2015). The chemical effect of cavitation is still uncertain, although two theories have been proposed. Namely, the *hotspot theory* and *electrical theory.* (Herceg & Jambrak, 2015).

Gao *et al*. (2018) have described a novel ultrasound-assisted lye peeling regime for tomatoes, that reduced the use of lye, and favoured yield and lycopene retention. This novel technique improved the environmental friendliness of the lye-peeling process, whilst still offering 100% peelability. The use of ultrasonic cleaning for potential water recycling has been investigated by Anese *et al.* (2015) in the fresh cut industry. They concluded that the use of ultrasound *in situ* was effective in achieving a 5-log reduction in *Listeria monocytogenes*, *Escherichia coli*, and *Salmonella enterica* after 5 minutes. The application of the technology was also seen as cost effective and able to meet existing safety criteria.

Microwave processing

Microwave (MW) heating results from the dissipation of electromagnetic waves in the target medium (Perino-Issartier *et al.,* 2011). Unlike conventional practices, the heating is not restricted to thermal conduction or convective currents, which means that more rapid temperature increases can be obtained. (Perino-Issartier *et al.*, 2011).

MW processing has already found its way into commercial operations, being the second most widely applied novel/'green' technology (after HPP) (Jermann *et al*., 2015; Leonelli & Mason, 2010) The technique allows the effects of many processing techniques to be fully reproduced with numerous added advantages (Chemat *et al*., 2017). Amongst these advantages are the shorter processing times involved, reduced processing costs and energy requirements, higher final product purity and negation of wastewater treatment (Perino-Issartier *et al.*, 2011; Chemat *et al.*, 2017). However, Perino-Issartier *et al.* (2011) have made note of the fact that continuous MW pasteurisation may come at the expense of increased energy consumption and operating costs.

Typical water using operations such as sterilisation, extraction, pasteurisation and blanching have been shown to be reproducible by means of microwave processing (Viña *et al*., 2007; Cheng *et al*., 2011; Benlloch-Tinoco *et al.*, 2014; Chemat *et al*., 2017).

Cold Plasma

Plasma can be described as an ionised gas with a wide array of active species and exists as the so-called fourth state of matter. Furthermore, it is present in either a grounded or excited state, possessing a net-neutral charge (Chizoba Ekezie *et al.,* 2017). Within the food industry, non-thermal plasma generated by electrical discharges is of particular interest due to its processing ability at low temperatures (Chizoba Ekezie *et al*., 2017).

Cold plasma is an eco-friendly technique (Chizoba Ekezie *et al.*, 2017) with many advantages apart from its water free application. These include, but are not limited to high efficiency at low temperatures; 'just in time' production of acting agent; low impact on internal product matrix; no residual compounds and improved resource efficiency (Thirumdas *et al*., 2015). Montenegro *et al.* (2002) have proven the ability of non-thermal plasma treatment to achieve up to a 7-log reduction in apple juice inoculated with *E. coli* 0157:H7. Benghanem (2016) has demonstrated the ability of cold plasma to decontaminate wastewater from date palm and tomato processing facilities, after exposure of 130 and 150 seconds, respectively. The atmospheric pressure plasma jet also showed its ability in improving the COD of the wastewater by between 58% and 93%, whilst also reducing endotoxin loads by up to 90%.

Pulsed electric field processing

Pulsed electric field (PEF) processing is a non-thermal technique that exposes biological cells to an electric field of sufficient strength to induce electroporation (Toepfl *et al.,* 2006). PEF has been successfully utilised in tomato peeling (Arnal *et al*., 2018); pasteurisation of fruit juices; has been shown to improve the efficiency of drying operations, and has also demonstrated the ability to disintegrate excess sludge produced during wastewater treatment (Toepfl *et al*., 2006). Arnal *et al*. (2018) used Life Cycle Analysis (LCA) in a case study to determine the environmental advantages of PEF in tomato peeling. They concluded that the incorporation of the technology reduced steam requirements in the thermophysical peeling stage by 20%.

PEF was found to be the 3rd most commercially adopted novel technique according to a global survey by Jermann *et al.* (2015).

Infra-red

To negate the typically high water and energy requirements of lye and steam peeling in the processed tomato industry, Vidyarthi *et al.* (2018) have suggested infra-red (IR) peeling as an alternative. Their study revealed that IR dry peeling offered lower peeling losses (up to 12%) and a firmer peeled product (up to 38%) when compared to conventional lye peeling. Improved peelability and colour was also apparent. Likewise, Pan *et al.* (2015) have also demonstrated the viability of IR dry peeling in tomatoes to negate the typically high water and chemical use associated with the conventional process.

Ohmic heating

Ohmic heating, also known as joule heating, is the process whereby an electrical current is passed through a food medium for the purposes of heat generation (Chen, 2015). The rate of heating is dependent on the voltage gradient, as well as the electroconductivity of the food (thus making non-ionic mediums like oil unsuitable) (Chen, 2015).

Gupta & Sastry (2018) have demonstrated the desirable synergistic effects of ohmic heating and a 2% lye solution during pear peeling, when compared to the traditional 18% solution used in industry. The technique was able to significantly improve peel yields whilst reducing the negative environmental impacts associated with the conventional process (namely, the presence of large amounts of NaOH in the effluent). Likewise, Wongsa-Ngasri & Sastry (2015) have shown the potential of ohmic heating for tomato peeling. Sensoy & Sastry (2004) have also reported on the effectiveness of OH when used to blanch mushrooms. The technique was able to avoid the high consumption of water associated with conventional blanching, whilst still offering a high solids content during the process.

High Pressure Processing

High pressure processing (HPP), also known as high hydrostatic processing (HHP) is considered to be a waste free, environmentally friendly process (Pereira & Vicente, 2010; Bermúdez-Aguirre & Barbosa-Cánovas, 2011). The technology is especially prevalent in food industries where traditional heat treatments pose a threat to organoleptic and nutritional characteristics (Bermúdez-Aguirre & Barbosa-Cánovas, 2011; Perrut, 2012). HPP was found to be the most widely adopted novel/'green' technology in a global survey by Jermann *et al*. (2015). The basic process involves loading food products into a high-pressure vessel, which is then in turn filled with a pressure transmitting fluid (usually water). Additional fluid is then pumped into the chamber for pressurisation. The pressure is then maintained for a specified period of time, after which the vessel is depressurised and the food product removed (Karwe *et al.*, 2015). However, it must be noted that complete spore inactivation is usually not possible without a combination of high pressure *and* high temperature, accomplished by a process known as PATS (Pressure Assisted Thermal Sterilisation) (Bermúdez-Aguirre & Barbosa-Cánovas, 2011; Karwe *et al*., 2015).

Supercritical fluids

A supercritical fluid (SCF) can be defined as having a temperature and pressure higher than those at the critical point (Thereza *et al.*, 2015) Supercritical fluids have been suggested as a 'green' technological alternative to the conventional (also water and energy intensive) pasteurisation and sterilisation techniques (Perrut, 2012; Chemat *et al*., 2017). The previously described high pressure processes have a drawback in that extremely high pressures (and associated high costs) are required for effective sterilisation of the food product in question (between 4 000 and 8 000 bar) (Perrut, 2012). It is in light of this, that supercritical fluid exposure at lower pressures has emerged as an alternative sterilisation technique (Perrut, 2012). For example, complete sterilisation of *Alicyclobacillus acidoterrestris* spores in commercial apple juice was accomplished by Bae *et al.* (2009) at 100 bar for 40 minutes with a temperatures of 65 ºC; and 70 °C for 30 minutes at 80 bar.

Ultraviolet pasteurisation and sterilisation

Ultraviolet (UV) radiation describes a wide range of wavelengths in the non-ionising region of the spectrum, with wavelengths between 200 nm (x-rays) and 400 nm (visible light) (Ibarz *et al.*, 2015). In the food industry, UV-C (wavelengths between 200 – 280 nm) has been used to decrease the microbial load in the following products and processes (Ibarz *et al.*, 2015):

- Air in meat or vegetable processing
- Water to be used in later processing (thus, also has a use in internal reuse/recycling)
- Disinfection of the surfaces of fresh products; and
- Liquid foods such as milk, juice and cider

As an example, Tremarin *et al.* (2017) have demonstrated the ability of UV-C to achieve a 5-log reduction of *A. acidoterrestris* in apple juice, which was found to be more effective that a 95°C thermal treatment for the same amount of time (8 minutes).

3.9 Wastewater treatment in the FVPI

Fruit and vegetable processing effluent can be characterised by organic pollution, with high BOD, COD and TSS levels (Table 10). Although the wastewater is generally less polluted than that of other industries it does usually require treatment before discharge is possible (Valta *et al.*, 2017)
The wastewater streams are typically separated before treatment is applied (IPPC, 2006), with these treatments being categorised as primary, secondary or tertiary treatments. Table 11 below gives a brief description of wastewater treatment options found suitable for the FVPI by the IPPC (2006).

Table 10 Physiochemical characteristics of different effluent streams in the FVPI (El-Kamah *et al.*, 2010; Şentürk *et al.*, 2010; Amor *et al.,* 2012; Guzmán *et al*., 2016; Valta *et al*., 2017)

Processing type	**BOD (mg/L)**	**COD (mg/L)**	**TSS (mg/L)**	**pH**
Tomato processing	500	1500	400	6.5-8
Fresh and frozen peaches/apricots	1100	2300	900	-
Peach and apricot compote	1300	1800	460	-
Canned and pureed peaches/apricots.	1750	3500	500	7-8.5
Canned and pureed peaches/apricots	1200	4000	800	6-8
Citrus juice	6619	10019	777	3.8
Fruit juice	1289	5157	323	-
Citrus concentrate	13900	21040	3130	3.45
Potato processing	4000-5000	5250-5750	2000-2100	7-8

3.9.1 Primary treatment

Primary treatments include those processes that reduce floating or suspended solids in wastewater by mechanical or gravitational methods (Patel & Vashi, 2015). During this treatment phase, approximately 25-50% of the preliminary BOD, 50-70% of the TSS, and 65% of the oil and greases are removed (Sonune & Ghate, 2004). Primary treatments identified as suitable for the FVPI can be found in Table 11 below.

3.9.2 Secondary treatment

Secondary treatment, also termed as biological treatment, seeks to remove suspended solids by microorganisms under either aerobic or anaerobic conditions (Samer, 2015). During the biological processes the organic matter is either oxidised or incorporated into cells, which can later be removed by sedimentation (Samer, 2015). Secondary treatments found to be suitable for the FVPI can be seen in Table 11 below.

Aerobic processes use a culture of mostly bacteria, protozoa, rotifers and fungi to accomplish the oxidation of organic material (Taricska *et al.,* 2008). Suspended growth processes; attached growth process or a combination of both can be used to accomplish the treatment (Taricska *et al.,* 2008). The aerobic processes may however contribute to odour problems, and can be energy consuming and costly (Liu *et al*., 2009). A potential solution to this may be anaerobic digestion processes, with the added benefit of energy production. Three separate chemical/biochemical reactions are needed for the complete anaerobic oxygenation of organic waste, these being (Hung *et al.,* 2008):

- **Hydrolysis**: Decomposition of large organic molecules by bacteria into monomers such as sugars, fatty acids and sugars
- **Fermentation**: The biochemical conversion of carbohydrates into alcohols or organic acids; and
- **Methanogenesis**: The conversion of organic acids to methane by methanogenic bacteria

Aerobic and anaerobic treatments can also be combined in the form of membrane bioreactors (MBR), which can operate in either aerobic or anaerobic mode (IPPC, 2006).

3.9.3 Tertiary treatment

Secondary treatment has often proven to be insufficient in protecting the receiving waters or in providing water for recycling purposes (Sonune & Ghate, 2004). Tertiary treatment can thus be used and is considered a “polishing” step (IPPC, 2006).

Table 11 Suitable wastewater treatment options for the FVPI (IPPC, 2006)

Treatment options	Description	Additional References
Primary treatment options		
Screening	Static, vibrating or rotary screens are devices with small openings that remove coarse solids from wastewater	Valta *et al.* (2017)
Flow and load equalisation	Equalisation/buffer tanks are used to cope with variability in flow and composition	
Neutralisation	Addition of chemicals, or mixing of separate wastewater streams to avoid highly acidic or alkaline discharge, and to protect downstream treatments	
Sedimentation	Separation of suspended particles heavier than water by gravity, followed by subsequent removal of the sediment from the bottom of the tank	Pfitzmann (1983) in Casani *et al.* (2005); Lehto *et al*. (2014); Valta *et al.* (2017)
Dissolved Air Flotation (DAF)	Fine air bubbles attach themselves to chemically conditioned particles, which then assist the particles in rising to the surface	Valta *et al.* (2017)
Centrifugation	Solid bowl, decanter, disk-nozzle and basket centrifuges result in reduced FOG, COD/BOD and SS	Galanakis (2012)
Precipitation/coagulation	Dissolved substances are chemically treated to allow conversion into insoluble particles, following which they are removed by sedimentation or DAF	Amor *et al.* (2012); Valta *et al.* (2017); Weng *et al.* (2019)
Secondary aerobic treatment options		
Activated sludge	Activated mass of microorganisms aerated and maintained in suspension within a reactor vessel	Ozbas *et al.* (2006); Amor *et al.* (2012); Koppar & Pullammanappallil (2013); Valta *et al.* (2017)
Pure oxygen system	Essentially an intensified activated sludge process (i.e. injection of pure O_2 into the reactor vessel)	Sterritt,& Lester (1982)

Sequencing batch reactors (SBR)	Another variant of the activated sludge process that operates according to fill-and-draw principle	Ozbas *et al.* (2006); Tawfik & El-Kamah (2012)
Aerobic lagoons	Large, shallow dams used for the natural aerobic treatment of wastewater	Koppar & Pullammanappallil (2013);
Trickling filters	Biomass is grown as a film on the surface of packaging media, with the wastewater allowed to flow evenly across it	Chowdhury *et al.* (2010); Koppar & Pullammanappallil (2013)
Bio-towers	Specially designed trickling filters operated at high organic loading rates	
Rotating biological contactors (RBC)	The unit consists of a series of closely spaced, submerged, plastic discs covered with biomass	Najafpour *et al*. (2006)
Biological aerated flooded filters (BAFF) and submerged biological aerated filters (SBAF)	Activated sludge systems with high voidage media that encourages biological growth and a degree of physical filtration	
High rate and ultra-high rate aerobic filters	The system uses a high wastewater recycling rate directed through an integral nozzle. The nozzle provides intensive oxygenation, and high shear force on bacterial cultures	
Secondary anaerobic treatment options		
Anaerobic lagoons	Similar in construction to aerobic lagoons, with exception of mixing/aeration to allow for an anaerobic environment	Koppar & Pullammanappallil (2013)
Anaerobic contact processes	Analogous to the aerobic activated sludge process, with difference being that the reactor is sealed off from the entry of air	
Anaerobic filters	The growth of anaerobic biomass is established on a packaging material, with wastewater allowed to flow over it	Rajinikanth *et al.* (2009)

Up-flow anaerobic sludge blanket (UASB)	Wastewater is directed to the bottom of a reactor, where it passes through a blanket of bacterial granules. Natural convection raises a mixture of gas, treated water and sludge granules to the top of the reactor, where a three-phase separator is used to separate the final effluent from the solids	Ozbas *et al.* (2006); Sigge & Britz (2007); Koppar & Pullammanappallil (2013);
Hybrid UASB reactors	A variation of the conventional UASB that incorporates a packed media zone above the main open zone. The packed zone assists in the collection of non-granulated bacteria which, in a conventional UASB reactor would be washed out	
Fluidised and expanded bed reactors	A fluidised bed reactor the carrier material is constantly in motion and kept in suspension by using high circulation rates. An expanded bed reactor uses light materials to minimise the up-flow velocities required to fluidise the beds	
Internal circulation (IC) reactors	An adjusted configuration of the UASB, in which two UASB compartments are placed on top of each other (One with a high loading, the other with a low loading). Biogas collected in the first stage drives a gas-lift, resulting in internal recirculation of wastewater and sludge	
Expanded granular sludge bed reactors (EGSB)	EGSB reactors use the type of granular sludge found in in UASB reactors, but operate at a much greater depth of granular sludge, with a higher water rise rate	
Tertiary treatment options		
Biological nitrification/denitrification	A variation of the activated sludge process	
Ammonia stripping	Biological as well as physio-chemical processes are available for the purification of highly nitrogenous wastewater streams	
Biological phosphate removal	Microorganisms in the sludge are stressed in order to induce more phosphorous absorption for biological growth	
Hazardous substance removal	Removal of many hazardous substances is usually achieved through appropriate use of treatments like sedimentation, precipitation, filtration and membrane filtration. Further treatments such as **carbon adsorption** and **chemical oxidation** can also be applied	Wu *et al.* (2016)

Filtration	Filters may be of the gravity or pressure driven type, with **standard sand** or **dual media** filters (sand/anthracite) being common	
Membrane filtration	Membrane filtration is based on using a pressure driven, semi-permeable membrane in order to achieve selective separation based primarily on pore-size	Weng *et al*. (2019)
Biological Nitrifying filters	Although ammonia usually removed during secondary biological treatment, it also common to install separate tertiary biological nitrifying filters. Variations of the standard percolating or high rate aerobic filters are commonly used	
Disinfection and sterilisation	Biocides (e.g. chlorine, ozone etc.) and UV radiation are commonly used methods for sterilisation/disinfection	Wu *et al.* (2016); Valta *et al.* (2017)

3.10 Conclusions

The fruit and vegetable processing industry is very diverse, with many different raw ingredients and possible processing avenues being apparent. This diversity, however, presents a problem in that classification for the purposes of any further investigation is dependant not only on the huge variety of raw materials, but also different processes. This complexity in scope may be the reason why researchers such as Akgüngör *et al.* (2002) and Valta *et al*. (2017) have either selected a random sample within the industry, or decided to focus on the sub-sectors found to be the most prolific in their respective countries. The selection procedure is important when considering the economic analysis of the South African FVPI, as cognisance of the most prevalent raw inputs, products, and trade volumes should be useful in identifying certain industries that could form the focus of future research. For example, within subtropical fruit processing, pineapple was found to be the most prolific (48%), thereby warranting specific attention in future investigation where this sub-industry is considered.

In terms of distribution, the Western Cape is unmatched in both the number and variety of fruit and vegetable processing. The province plays host to all forms of general processing (Canning, juicing, freezing and drying) although the products are seen to be mostly deciduous in nature (Fig 10; Fig 11). The North West and Free State provinces show the least number of verified processing facilities with one each (Fig. 10).

Bekker (2018) has detailed the various challenges and outlooks facing the industry at present, with commentary well summarised in the form of SWOT analysis. The ongoing drought, uncertainty surrounding expropriation without compensation, the Sugar Beverages Levy (i.e. Sugar Tax), slow economic growth and rising input costs have been listed as threats in the analysis.

The diversity in the FVPI once again presents a problem in identifying specific water saving techniques that may find application in specific processes. The IPPC (2006) & Masanet *et al.* (2008) make specific mention of water saving measures applicable to fruit and vegetable processing, although they hardly go into any specific detail in terms of individual processes. These general guidelines may however provide a solid grounding upon which to apply process-specific water saving measures. In this context, water saving measures may be grouped into either design-based minimisation techniques; reuse/recycling measures; or process changes. The process changes could include the adoption of so called ‘green’ processing technologies, which have the possibility of drastically minimising (if not eliminating) water requirements. Under process changes it is important to note that the energy requirements and water use of a processing facility are often closely linked. Therefore, improving the energy efficiency of a process may inherently also improve the water use efficiency. Investigating case studies may help the operator/production manager institute more process specific water saving measures (for example, the water minimisation study of a citrus plant by Thevendiraraj *et al*. (2003)). At all times it is advisable that facilities wishing to improve water use performance adhere to the systematic approach as described by IPPC (2006) and other authors.

The lack of up to date information concerning water and wastewater management within the South African FVPI (and indeed, at an international level as well) supports the need for the current study. It is hoped, therefore, that the investigation at hand will contribute to an improved understanding of water saving measures currently employed; how freshwater use has changed since the 1981 NATSURV, as well as provide appropriate recommendations for individual facilities used as case studies.

Chapter 4 MATERIALS AND METHODS

4.1 Research design

A mixed methods triangulation approach was deemed as the most appropriate research design. Mixed methods, at its core, entails the simultaneous use of both quantitative and qualitative methods in order to achieve a more enhanced and complete picture of the phenomenon under investigation (Lavrakas, 2008). The quantitative approach incorporated the inclusion of measurable parameters in the questionnaire used for data collection, whilst the qualitative component included the use of open-ended questions in the same survey, as well as case studies as a supplementary data collection instrument. Triangulation refers to the use of more than one source of data (in this study, the use of questionnaires and site visits) or multiple analytical approaches to enhance the credibility of an investigation (Salkind, 2010). The triangulation approach seeks to align various perspectives, and thus leads to a better understanding of the phenomenon under investigation (Salkind, 2010). See Figure 16 for an overview of the data collection and analysis procedure.

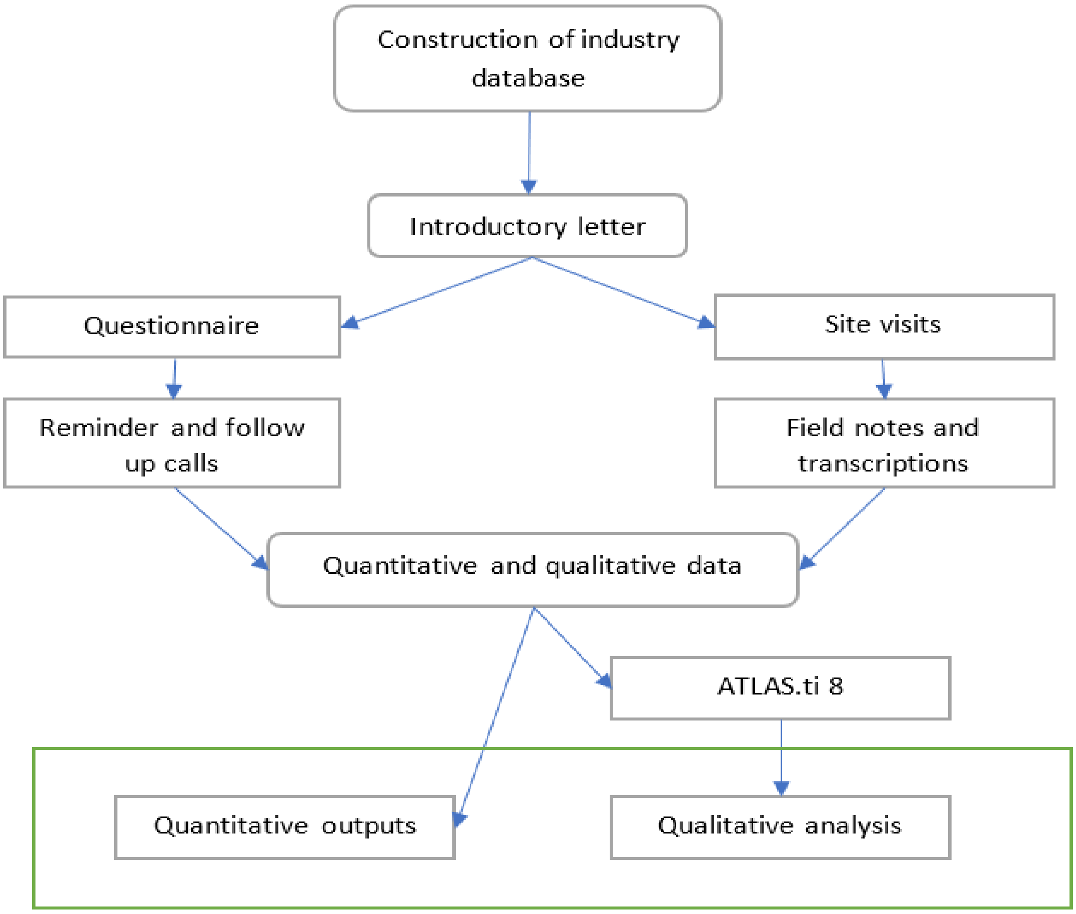

Figure 16 Overview of data collection and analysis procedure.

The surveying of best and or/current practice surrounding water management within the food processing industry is not a new phenomenon, with multiple international studies (Mannapperuma, 1993; Northcutt & Jones, 2004; CLFP, 2015; Jermann *et al.,* 2015; Valta *et al.*, 2017) making use of questionnaires as a data collection instrument. Specifically, within the South African context, the use of questionnaires supplemented with site-specific case studies (i.e. triangulation approach) has been a common feature of similar studies to the one undertaken (Swartz *et al.,* 2017; Welz *et al.,* 2017).

4.2 Research methodology

4.2.1 Sampling process

4.2.1.1 Defining the target population

The ideal target population in this investigation would include all facilities which operate under the Statistics South Africa SIC (Standard Industrial Classification) code 3013. Although Statistics South Africa maintains a database of facilities which fall under code 3013, repeated attempts to establish contact with the organisation were unsuccessful. Thus, the use of this database was not possible. To make the building a project specific database easier and to avoid ambiguity when searching for appropriate facilities, the original definition was modified. Therefore, facilities which would fall into the target population would have to meet the following definition:

Fruit and vegetable processing includes activities through which raw fruit and vegetable inputs are significantly altered physically and/or chemically for the purposes of human consumption. This definition, however, excludes:

- *Activities where co-production of alcohol is seen as a key characteristic of the final product (e.g. wine, brandy and cider)*
- *Where oils of the fruit and vegetables are seen as the dominant product (e.g. olive oil)*
- *When intact fruits/vegetables are preserved by cooling/refrigeration or preserved in a modified atmosphere (as these methods do not dramatically alter the physical or chemical make-up of the product).*
- *Products that are less than 51% fruit and/or vegetable based when excluding the preserving medium (e.g. mixed baby foods where the fruit/veg portion makes up less than the specified amount).*
- *Products where the physical change involves only chopping/dicing/cutting (e.g. prepared salads)*

A flow diagram (Fig. 17) was developed to assist in determining the suitability of a potential facility for inclusion in the database.

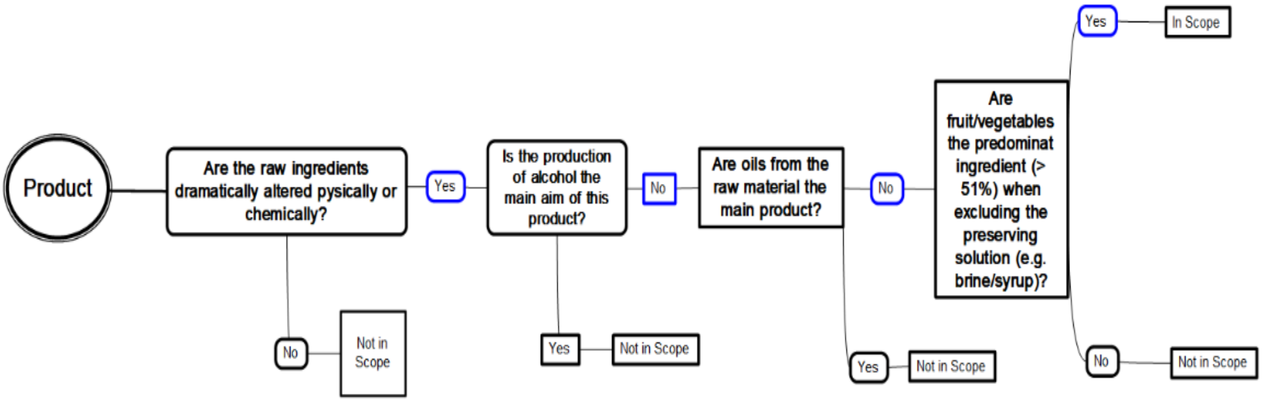

Figure 17 Flow diagram for determining suitability of facilities for inclusion in database.

4.2.1.2 Determining the sampling technique

Few researchers have the luxury, both in terms of time and finances, to be able to utilise probability sampling (Andres, 2017). The main reason being that access to a random sample of is often not as straight forward as one would hope – with the current investigation being no exception. As previously mentioned, Statistics South Africa maintains a database of facilities which fall under its fruit and vegetable processing SIC (Standard Industrial Classification) code 3013, although repeated attempts to establish contact with the organisation were unsuccessful. Thus, the use of this database was not possible.

The second approach (which was finally used to build the industry database) would be classified as non-probability, or more specifically, purposive sampling. Specific facilities were therefore selected which seemed to best fit the modified definition. Purposive sampling, as described by Lavrakas (2008), is a type of non-probability sampling (i.e. does not involve non-zero chances of selection) whereby subjective methods are used to determine which elements are included in the sample. Facilities were identified by a combination of internet-based searches and by contacting the relevant industry bodies. The verified facilities were categorised according to the main type of processing they were subjected to, these being divided into canning/bottling operations, juicing, freezing and drying (both sun and industrial drying). The database revealed a total of 19 verified canning/bottling facilities; 25 drying operations; 28 juicing facilities and 6 freezing facilities. Thus, a total of 78 facilities was included as the *designated sample* (i.e. the sample units selected for data collection in the study) (Lavrakas, 2008).

A problem observed with the contact details provided by the industry bodies was that many of the facilities were no longer in operation, whilst others had outdated contact information. In order to remedy this, each contact on the lists provided were verified by telephonic contact. An additional problem encountered was that two of the larger corporates in South Africa were unwilling to provide locations/contact details for their facilities despite repeated attempts to gain access to this information.

An additional problem is the extreme heterogeneity of the population in general. Juicing, canning/bottling, freezing and drying, although all included in the definition of fruit and vegetable processing, are all very different processes. In order to gain meaningful insight into the industry, it is important that the sample includes a representative portion of each different processing method.

4.2.1.3 Final sample size

The final sample size takes into consideration non-response, non-contacts, and other reasons (e.g. ineligibility) that may cause many elements in a sampling pool to end as non-completed responses (Lavrakas, 2008). It has been a common feature of similar national investigations that a poor response rate may lead to a small final sample size. Swartz *et al*. (2017) achieved a mere 5% response rate (2 facilities out 40), whilst other authors (Ramukhwatho *et al*., 2016; Pocock & Joubert, 2017) also make note of a poor level of participation in their respective industries.
Once again, a potential problem occurs due to the lack of process homogeneity within the industry. Therefore, to gain meaningful insight to the industry, is important that the final sample includes responses from all the different sub-industries (Canning/bottling, juicing, drying and freezing).

4.2.1.4 The sampling process

Following the methodology used by similar studies (Ramukhwatho *et al*., 2016; Pocock & Joubert, 2017; Swartz *et al*., 2017), the sampling process commenced with an introductory letter (Appendix A) being sent to all facilities on the database. The contact details on the database were those of upper management in each facility (CEOs; production managers, etc.) to ensure that the communication was established with individuals with executive authority. The introductory letter contained details of the project, as well as explanation as to the importance of the research (In line with recommendations by Singh & Wassenaar (2016)). Three weeks later a link to an internet-based questionnaire was sent to the same individuals at each facility. The link was accompanied by an electronic indemnity form (in compliance with the ethical clearance obtained – See Appendix B). A reminder to complete the survey was also sent. A maximum of 2 follow-up phone calls were also made to facilities deemed to be of extreme importance to the study in order to remind them to complete the survey. If the request to complete the survey was explicitly denied, the facilities were not contacted again to ensure respect of autonomy as emphasized in Singh & Wassenaar (2016). The sampling window was open for a period of 6 months, to allow for sufficient follow-up time.

4.2.1.5 Addressing coverage problems

Coverage error is an element of non-sampling error, where there is not one-on-one correspondence between the target population and the population actually sampled (Mulry, 2008). Establishment surveys (surveys of businesses and organisations) have their own unique source of coverage error, in that industry size and geographic locations may be miscoded (Mulry, 2008). Small businesses are especially prone to coverage errors due to them being less stable than larger entities. This results in an industry data base being difficult to maintain, due to the constant entry and exit of these small enterprises (Mulry, 2008). Reasons for coverage errors and the measures used to reduce them can be found in Table 12 below.

Table 12 Coverage errors in the investigation and appropriate mitigation measures

Coverage error	**Mitigation measure**
Access to the Statistics South Africa SIC database was not possible	Compilation of own database using information provided by industry bodies
Extreme processing heterogeneity within the FVPI	Including a variety of processing facilities in the industry database
Contact lists provided by industry bodies were outdated, with many facilities no longer in operation, or having been consolidated into larger corporate groups	Each processing facility on the database was contacted telephonically to confirm the validity of the contact details provided

4.2.1.6 Addressing errors with non-response

As seen in similar studies (Ramukhwatho *et al*., 2016; Pocock & Joubert, 2017; Swartz *et al*. 2017), poor participation from industry in terms of questionnaire responses and quality of data provided has been a recurring issue. To minimise the non-response error in the investigation, the following strategies were adopted:

- Contact details for individuals with executive authority were collected. It was hoped that by addressing all communication to a specific individual, the willingness to respond would improve
- An introductory letter explaining the purposes of the investigation was sent to potential respondents (the designated sample) a month before the questionnaire was made available. It was hoped that stating when the questionnaire could be expected and what type of information would be required, would help the respondents prepare/collect the required data. The introductory letter was also useful in securing gate-keeper permission (see 4.2.2.2)
- The questionnaire was kept as short as practically possible to minimise the time burden to respondents (estimated time of completion being 20 minutes)
- A *personalised* email containing the questionnaire link was sent to each potential respondent
- A follow up email was sent to the potential respondents; and
- Follow up phone calls were made to what were deemed the most important facilities

4.2.2 Ethical considerations

Ethical approval for research purposes, including behavioural and social sciences, became law with the inception of the National Health Act (2005) (Cleaton-Jones & Wassenaar, 2010), and is most often (as is the case with Stellenbosch University) authorised by a Research Ethics Committee (REC). Stellenbosch University adheres to the Singapore Statement on Research Integrity and applies a rigorous ethical standard to all research taking place at the institution (Stellenbosch University Division for Research Development, 2013).

4.2.2.1 Mitigation and avoidance of ethical issues

A requirement from the REC is that the researcher has anticipated potential ethical dilemmas that may arise from the investigation, and that he/she has taken steps to mitigate the occurrence/severity of these problems. The ethical considerations and mitigation procedures relevant to the investigation are as follows:

1) *Concern from the person being interviewed that he/she is releasing confidential company information*. To mitigate this risk, only approved persons (individuals with executive discretion) were asked to complete the questionnaires. Participants also had ultimate discretion when it comes to what data they felt comfortable releasing.
2) *Sensitive company data being made public*. To mitigate this risk, it was decided that only the project team would have access to individual company information. In addition to this, results would only be published as a regional or national aggregate and/or average for each process in question. No company names and/or contact details would be made public by any means. All data collected was stored in digital form on password protected devices. The RedCap system used for data collection also has a 2-factor login verification to ensure that no unauthorised parties can gain access to the online system.
3) *Discovery of illegal/and or environmentally damaging practices.* The survey participant's right to confidentiality is highly important. If any illegal/environmentally damaging activities were discovered during the investigation, the researcher might be placed in the ethical dilemma where he must weigh the confidentiality of the interviewee against the moral impulse to report such activity. For the purposes of this study, only polluting activities which place individuals in direct harm would be reported. Polluting activities found to be of a minor nature would be communicated to the management, who would be encouraged to rectify the problem.

Ethical approval for the investigation was granted without supplementary conditions by the REC on the 28th January 2019. The approval made provision for the fact that gate-keeper permission would be sought before the data collection instruments were used.

4.2.2.2 Gate-keeper permission

If the research is be undertaken in an institutional setting and not in the public domain, permission from the appropriate authority must be obtained in compliance with the respect for organisational autonomy (Singh & Wassenaar, 2016). This permission is necessary in that all organisations have the right to approve or deny access to personnel, clients, working spaces and information (Singh & Wassenaar, 2016). Most RECs (Research Ethics Committees) require that written permission from the relevant authority in an organisation (the gatekeeper) must be obtained before ethics approval can be obtained. However, a few may grant permission with the condition that gatekeeper permission is granted prior to the actual data collection (as was the case with the investigation at hand) (Singh & Wassenaar, 2016).

Initial contact with gatekeepers was established using an introductory letter (Appendix A) explaining the purposes of the project at hand, and how the research may contribute positively towards understanding water and wastewater management in South African fruit and vegetable processing. This agrees with Singh & Wassenaar (2016), who suggest that explaining the social context behind the reason for which permission is sought, may improve the chances of authorisation being granted. An important point to make, and which was communicated to the REC, is that the typical institutional permission (which comes in the form of an official letter from the company in question) may have been impractical to obtain from 74 different facilities. It was therefore deemed appropriate to rather obtain gatekeeper permission via a suitable electronic platform, which was accomplished by simply using an electronic consent form (Appendix B) mailed to the identified gatekeepers.

4.2.3 Questionnaire design

4.2.3.1 Rationale for an internet-based questionnaire

The use of online/internet-based surveys has become increasingly popular over the last 3 decades, with the enhanced capabilities (opportunities for visual and audio stimulation; online interactive capabilities; and the use enhanced skip patterns or branching logic) making it far superior to the email survey (Lavrakas, 2008). The main advantages of internet-based surveys include the low cost per respondent, enhanced visual and aural aspects of the instruments being used, and the ease of data processing (Lavrakas, 2008).

With the aforementioned in mind, study data was collected and managed using the REDCap electronic data capture tools hosted at Stellenbosch University. REDCap (Research Electronic Data Capture) was developed as a highly secure, web-based platform designed to support data capture for research purposes. The system provides a user-friendly interface for data entry; audit trails for tracking data manipulation/corruption and export procedures (Harris *et al.,* 2009). In addition to this, the platform allows for automated export procedures to common statistical packages as well as procedures for importing data from external sources. The reasons for choosing an online platform for the purposes of data collection were as follows:

- The respondents work under very demanding and time-consuming conditions. If required to complete a questionnaire they would prefer an instrument that they are able to complete in their own time
- Due to the investigation being at a national scale, face-to-face interviews would be impractical.
- Telephonic interviews, although indeed possible, would be subject to the same constraint as the first point: Individuals with high workloads would prefer a questionnaire that they are able to complete in their own time.

REDCap uses a logical project development process, whereby tasks are systematically completed and checked off. The system uses an ‘online builder’ for the creation of data collection instruments (i.e. questions), which can be formatted according to the type of answer desired from the question. The popular formats include radio buttons; multiple-choice; drop-down lists and slider scales, to name but a few. REDCap also allows the researcher to thoroughly test the project in ‘development mode’ before moving it into ‘production mode’, which will in turn activate supplementary data protection safeguards.

4.2.3.2 Problems associated with internet surveys

The main problems associated with internet surveys are mainly attributable to coverage, lack of suitable sample frameworks, and nonresponse (see 4.2.1.5 & 4.2.1.6) (Lavrakas, 2008).

4.2.3.3 Choice and design of questions

The questions were developed with the assistance of the NATSURV 19 project team. In order to ensure comparability with other NATSURV reports, the questionnaires developed by Swartz *et al.,* (2017) and Welz *et al.* (2017) were used as a template for further development. The questions used in the online questionnaire were as follows (*with an elaboration of key online functionalities in italics*):

General Information (*section header)*

I. Name of person completing the survey (*text box*)
II. Name of company/factory (*text box*)

Production Information (*section header*)

I. Please indicate the production season of your factory by selecting the applicable months below (*check box*)
II. Please indicate the typical/average/previous year’s amount of raw fruit and/or vegetables processed annually (per fruit/vegetable category) (*text box*)

Water Usage (*section header*)

I. Please indicate the source of freshwater intake for your factory (*check box – with options for municipal, river, dam, or/and borehole*)

II. Do you maintain records of freshwater consumption? (*check box with branching logic for 'yes'*)

III. Please provide total annual water consumption (typical/average/previous year), if known (*text box*)

IV. Please provide average daily water consumption (if known) during the production season (*text box*)

V. Please provide specific water volumes used for each fruit or vegetable production process (*text box*)

Water minimisation in your factory (section header)

I. On a scale of 1-5 (1 – Low priority; 5 – High priority) how high a priority do you consider water saving in your facility? (*check boxes*)

II. Are there any water use targets in place? (*check box with branching logic for 'yes'*)

III. Are these water use targets being met? (*check box*)

IV. Please indicate the various means of water saving in your factory:

a. Water Pinch and/or other design optimization platforms
b. Water reuse and recycling
c. Adoption of water free operations
d. Process control and monitoring
e. Avoidance of once-through water use
f. Improved energy efficiency in steam processes
g. Water awareness training for staff
h. Dedicated maintenance (e.g. leak repair)
i. Water-wise cleaning
j. Other (please specify) (*check boxes – multiple options allowed, with branching logic for 'water free operations', 'waterwise cleaning' and 'other', to allow the respondent to elaborate*)

V. Do you utilise, or are you planning to utilise, any of the following "Green"/environmentally friendly technologies?

a. Instant controlled pressure drop technology (DIC)
b. Ultrasound assisted processing
c. Microwave processing
d. Cold plasma
e. Pulsed-electric field processing
f. Infra-red (IR) processing

g. Ohmic heating
h. High Pressure Processing (HPP)
i. Super Critical fluids
j. Ultraviolet (UV) processing and/or sterilization
k. Other (*check boxes – multiple options allowed, with branching logic for 'Other', to allow the respondent to elaborate*)

VI. Have you adopted any of the water-saving measures (conventional or "green") SPECIFICALLY in response to the recent drought? (*Check box*)

Wastewater generation and management (*section header*)

I. Please provide your estimated/average/previous year's annual effluent volume (if known) (*text box*)
II. Please provide your estimated/average/previous year's daily effluent volume during the production season, if known (*text box*)
III. What treatment does the effluent undergo before discharge? (*check box, with options for primary, secondary, tertiary and "other" treatment. Branching logic will allow for elaboration of any the options selected*)

Energy usage (*section header*)

I. What are your energy sources? (*check boxes with multiple options allowed – boiler, grid (municipal), solar, biogas from wastewater, other [additional branching logic for elaboration]*)
II. What is the average/typical/previous year's daily energy usage in your production process, if known (*text box*)
III. What is the average/typical/previous year's annual energy consumption, if known (*text box*)
IV. What is the unit cost (R/kWh) of energy used? (*text box*)
V. Please describe any gaseous emissions from your factory, and what measures are in place to mitigate or reduce these emissions (*text box*).

Supporting documents (*section header*)

I. If you have any supporting documents/reports pertaining to water use and wastewater management, these can be uploaded here (*upload option provided*).

A more intensive description of the above summary can be found in Appendix C as a 'data dictionary codebook', which is a detailed REDCap generated PDF summary of the online questionnaire. The codebook allows for a visual description of how the questionnaire was synthesized along with key functionalities

4.2.3.4 Pilot-testing the questionnaire

The electronic questionnaire was tested at a pilot scale by having it completed by three members of the NATSURV 19 project team. Two of these members have extensive experience with water and wastewater management and therefore were able to confirm the validity and appropriateness of the questions. They were asked to provide commentary on aspects of the questionnaire as related to time for completion; wording and composition of questions; and clarity of instructions. The exportability of the data was then also verified by the author, as well as the compatibility with the computer-based packages to be used. All 3 respondents agreed that the electronic questionnaire was easy to understand and answer, and that it did not take an excessive amount of time to complete (maximum of 20 minutes). Minor changes were recommended, these being mainly to avoid ambiguity in the questions.

4.2.4 Case studies as a data collection instrument

4.2.4.1 Appropriateness of the case study methodology

Case studies can be seen as an in-depth description of an individual, group or organisation based on a variety of different sources. These can be interviews (As used in Valta *et al.,* (2017)), documents, archival records and observations, which seek to create a comprehensive description of the situation being studied, in narrative form (Lavrakas, 2008).

In order to supplement the data collected in the questionnaire, it was decided to engage certain facilities on the database for permission to conduct a walk-through audit (as described by Navarri & Bédard (2008). The walk-through audit finds advantage in its relative low-cost, time-effective nature and allows for the identification of immediate savings opportunities that do not require extensive modifications or capital investments (Navarri & Bédard, 2008). This auditing technique may also be used as a first step for more detailed auditing, in which focus areas could be identified for later investigation (Navarri & Bédard, 2008).

The following methodology was applied when conducting the walk-through audits:

1. The host at each facility was asked to complete a site-visit consent form (Appendix D), in line with the REC requirements
2. An interview was conducted with the plant managers at each facility, with the questions from the online questionnaire being used as a guideline.
3. A walk-through of the primary operations was conducted, with emphasis being placed on understanding the processes involved and identifying potential areas for improvement with regards to water use; and
4. Field notes were compiled for the first six facilities where site-visits were conducted. Recorded interviews were conducted at the remaining nine, with these interviews being transcribed at a later date. The interviews themselves were conducted in a semi-structured approach, using the online questionnaire as a basis.

4.2.5 Exploring case studies using Qualitative Data Analysis (QDA)

According to Koutiva *et al.* (2017), qualitative approaches aim to explore and find the underlying themes and concepts behind a particular phenomenon. QDA is therefore not based on frequencies of certain phrases/words, but instead on identifying common themes in the available data (Koutiva *et al.,* 2017). Within QDA, a widely used technique is thematic content analysis (TCA), where the aim is to build a model to describe a phenomenon in a conceptual form. This is done by reducing the amount of text collected; identifying and grouping categories together, and having done so, seek to form some level of understanding (Bengtsson, 2016). The process of content analysis can be simplified/streamlined using Computer-assisted qualitative data analysis software (CAQDAS).

4.2.5.1 CAQDAS

The advantage of CAQDAS lies in the efficient handling and management of large amounts of data, therefore reducing the workload of the researcher (Cypress, 2019). It is important to note that the available CAQDAS software packages do not necessarily analyse the data per se, but rather make the collected data more manageable (Renz *et al.*, 2018). This data can then be accessed and viewed via a user-friendly interface (Saldaña, 2009). Additional advantages of CAQDAS over the pen-and-paper approach include (Saldaña, 2009; Cope, 2015):

- CAQDAS also permits the researcher to rapidly alternate between multiple analytic tasks such as coding, memo-writing, and exploration of patterns
- The ability of the software to delete, rename, re-organise, un-code and reassign codes is almost a non-event in its simplicity
- Search and querying abilities within the software allow for rapid display of key words and phrases
- Report writing becomes more straightforward, as text generated in the software package can be copied into the final document; and
- CAQDAS also allows multiple researchers to collaborate and share ideas

As is the case with most innovative ideas, CAQDAS does come with its own limitations. Each platform is unique, meaning that some software packages may be better suited to a particular qualitative study than others (Cope, 2015). CAQDAS has also been noted to be more time-costly than more traditional data coding and analysis and despite this, have not yielded superior results (Cypress, 2019). Researchers may also become more focused on the technique of analysing the data, instead of the meaning of the data itself (Cope, 2015; Cypress, 2019). The software platform chosen for the qualitative analysis was Atlas.ti 9.

4.2.5.2 Atlas.ti 9 as the preferred CAQDAS platform

Atlas.ti is a CAQDAS platform that has been used by professionals and researchers from various disciplines (Friese *et al.*, 2018). The software can be incorporated into many theoretical approaches and has proven suitable for thematic content analysis (TCA). (Friese *et al.*, 2018). In addition to other useful functionalities, Atlas.ti allows for the creation of networks for purposes of analysis and eventual reporting (Fig. 18).

Within Atlas.ti networks, central categories/themes are connected to lower order codes by lines called "linkages". These linkages are used descriptive in that they are labelled as per the researcher's requirement. 'Semantic' linkages connect codes to codes, whilst 'hyperlinking' connects 2 or more quotations. Both semantic linkages and hyperlinks can be labelled to explain the relationships. For example, in Figure 18 below, Quotation 2 *criticises* Quotation 3. Codes can be linked to quotations in networks as well, for an explanation or preview of the code. 'Groundedness' refers to the number of times a particular code has been applied and is represented by the symbol **G** in Atlas.ti 9 networks. 'Density' represents the number of linkages that are associated to a code and is represented by the symbol **D**. Density will only have a value other than 0 if the linkage between two codes is pre-defined.

4.2.5.3 Analytical methodology applied within the Atlas.ti 9 framework

Deductive content analysis was chosen as the preferred analytical technique within the TCA umbrella, as the approach is based upon a pre-existing theoretical framework surrounding the phenomenon under investigation (In contrast to the inductive approach, where conclusions are developed from collected data by weaving together new information into theories) (Elo & Kyngäs, 2008; Bengtsson, 2016). With this structure being decided upon, qualitative content analysis can then be approached in three phases, with these being 1) *Preparation*, 2) *Organizing* and 3) *Reporting* (Elo & Kyngäs, 2008; Elo *et al.,* 2016).

Preparation Phase

The preparation phase involves selecting the unit of analysis; deciding on a latent or manifest approach; as well as familiarising oneself with data at hand (which is done by reading through the data several times (Elo & Kyngäs, 2008). As suggested by Elo and Kyngäs (2008), a decision was also made on including latent or manifest analysis in the approach. Manifest analysis (described by Friese *et al.* (2018) as semantic analysis) focuses on what is being said or described, *i.e*. it is coded at ''face value''. (Elo & Kyngäs*,* 2008; Friese *et al.,* 2018). In contrast to this, latent analysis seeks the underlying meaning behind what is stated or apparent (using body language, tone of voice, choice of words etc.) (Elo & Kyngäs, 2008).

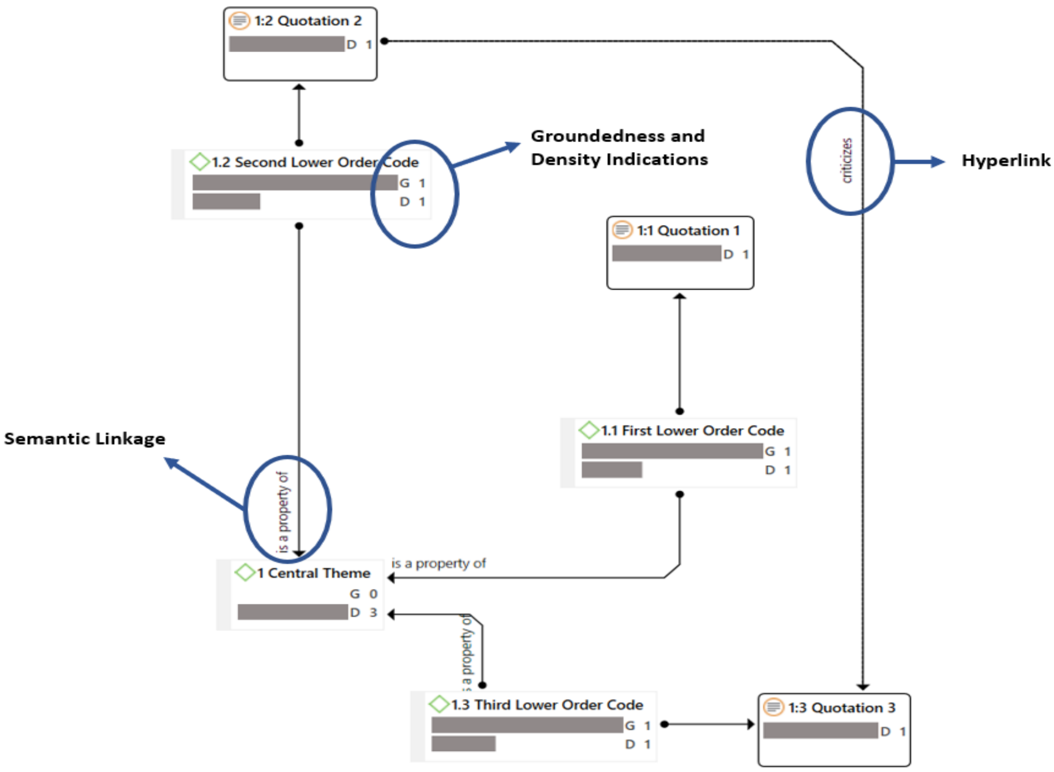

Figure 18 Sample network for explanatory purposes.

As the aim of the investigation was to describe water and wastewater management practices, it was decided that manifest analysis would therefore be the more applicable approach. One of the most basic steps in content analysis involves selecting the unit of analysis (Graneheim & Lundman, 2003). Although definitions of the unit of analysis differ, it basically seeks to describe what is under investigation (*e.g*. a person, a classroom, an organisation *etc*.). It is also recommended that whole interviews or appropriately sized observational protocols be used (Graneheim & Lundman, 2003). The unit of analysis chosen was that of whole interviews or field notes from individual fruit and vegetable processors.

Organizing phase

Elo & Kyngäs (2008) recommend the creation of a categorisation matrix, according to which data can be assigned to codes, although this is meant for the more traditional approach (i.e. pen and paper). CAQDAS allows for provisional coding (Saldaña, 2009), which effectively replaces the need for a categorisation matrix. Provisional coding starts with creating a pre-determined list of codes generated during the initial investigative phase. Sources of these provisional codes include literature reviews, the conceptual framework of the study, previous research findings, experiential data (the researchers experience in the field) and pilot studies (Saldaña, 2009). Figure 19 below shows the conceptual framework used to create the provisional code list and was developed from a combination of literature and experiential input.

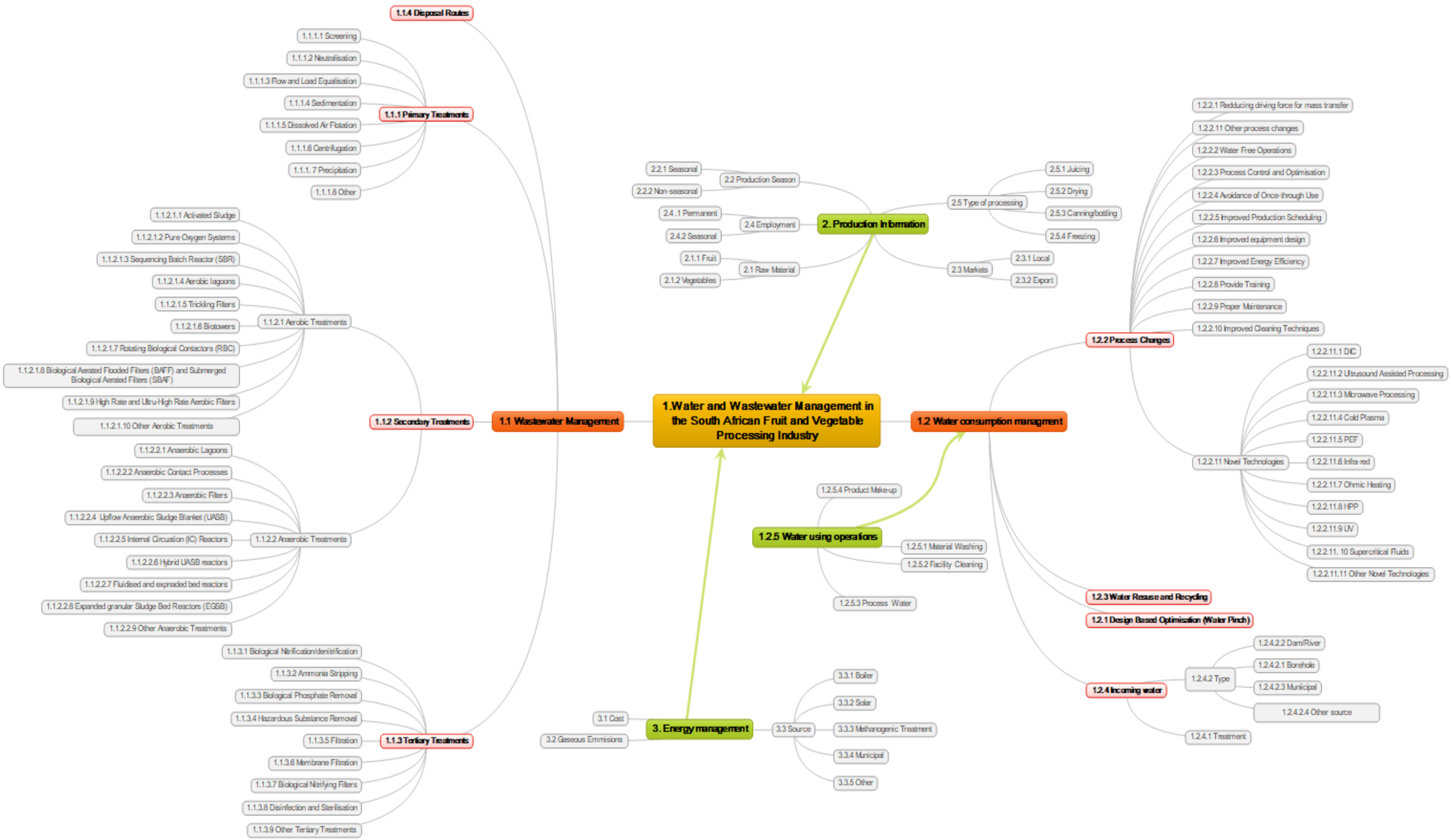

Figure 19 Conceptual mind map used to create the provisional code list.

The conceptual framework used to create the code list and was developed from a combination of literature and experiential input. Figure 19 was expanded and added to as the study progressed, and as more potentially relevant concepts and themes were discovered (which in turn, mimics the functionality of an unconstrained matrix as discussed in Elo & Kyngäs (2008)). The actual coding was completed using Atlas.ti 9 and constituted working through each facility's field notes/transcript three times. Codes where assigned to appropriate portions of text, and then verified by the subsequent cycles. See Appendix E for the code report generated for the study.

Reporting of the analysing process and results

The output of the organizing phase can be the creation of a model, conceptual map, conceptual system or categories (Elo & Kyngäs, 2008) and more specifically, a description of the categories (Elo *et al.*, 2014) via themes identified by coding (Friese *et al,* 2018*).* A theme is an outcome of coding, but is very rarely represented by a single code (Friese *et al*., 2018) .The outputs and analysis of the current study can be seen in Section 5.3 (*Content analysis of water and wastewater management using ATLAS.ti 9*)

4.2.5.4 Ensuring trustworthiness in qualitative analysis

In qualitative research, trustworthiness is commonly referred to using terms such as *credibility* (the most important); *dependability; confirmability; transferability* and *authenticity* (Connely, 2016).
To ensure trustworthiness, every phase of the analytic process (preparation, organizing and reporting) needs to be scrutinized and dissected, and the validity of results confirmed (Elo & Kyngäs, 2008; Elo *et al.*, 2014). Elo *et al.* (2014) have developed a checklist for researchers attempting to improve the trustworthiness of the content analysis. An adaptation of this checklist can be found in Table 13 below and was referred to extensively to monitor the trustworthiness of the analytic process.

Table 13 Checklist to improving trustworthiness of content analysis (adapted from Elo *et al*., 2014)

Phase of the study	Questions asked of the researcher
Preparation phase	*Data collection method*
	How can the most relevant data be collected?
	Is content analysis the method best suited to answer the research question?
	Should descriptive or semi-structured questions be used?
	How can I pre-test my procedure for data collection
	Sampling strategy
	What sampling method is best suited to my study?
	Who qualifies as the best informants for the investigation
	What criteria qualifies the informant for inclusion in the study?
	Is my sample appropriate, and is the data saturated?
	Unit of analysis
	Is the unit of analysis defined?
	Is the unit of analysis to broad or too narrow?
Organising phase	*Categorisation*
	How should the categories or concepts be synthesised?
	Are there to many categories, and do they overlap?
	Interpretation
	What is the degree of interpretation?
	How can it be ensured that the data accurately represents the information gathered?
	Representativeness
	How can the trustworthiness of the analysis be checked?
Reporting phase	*Reporting results*
	Are the results logically and systematically prepared?
	How is the link between the data and results reported?
	Are concepts presented in a clear and logical way?
	Are the results transferable?
	Are quotations used in an ordered fashion?
	Do the categories cover the data well?
	Are there similarities within categories, and differences between them?
	Is scientific language used to effectively convey the results?
	Reporting the analytic process
	Is a full description of the analytic process included in the report?
	Is the trustworthiness of the content analysis based upon defined criteria?

Chapter 5 RESULTS AND DISCUSSION

An overview of the survey responses and site visits is provided below. To ensure confidentiality in the reporting, each facility has been codified as 3013.1; 3013.2 *etc*. The use of the '3013' is due to fruit and vegetable processing falling under the Standard Industrial Classification (SIC) code 3013 (StatsSA, 2018). The purposes of 5.1 (Survey Responses) and 5.2 (Case studies of water and wastewater management in the FVPI) are to provide context to the discussion in 5.3 (Thematic analysis of water and wastewater management using ATLAS.ti 9).

5.1 Survey responses

From an original 74 facilities included on the database, the online survey revealed a total of 16 responses. Of these, 7 responses were incomplete or lacked data of sufficient quality, and therefore were deemed unfit for the purposes of the study. This resulted in a final sample size of 9 facilities, or a response rate of 12,16 %. The response rate was found to be an improvement over a similar study by Swartz *et al.* (2017), where a 5% response rate was achieved. Due to the small sample size, as well as the extreme homogeneity of the products and inputs, statistical analysis of the survey responses were deemed to be null and void. Four of the responses were from facilities later visited on a case study basis, during which more detailed information was collected and are therefore discussed under 5.2 (*Case studies of water and wastewater management in the FVPI*) Therefore, the responses reflected in Table 14, Table 15, Table 16 below, are from the remaining five facilities (3013.1 to 3013.5).

Table 14 Production and water consumption data for survey responses

Industrial unit	Production	Production season	Source of fresh water	Annual freshwater consumption (m^3)
3013.1	15 000 tons of grapes to produce 12 000 m^3 of juice annually	January - December	Municipal	3 000
3013.2	60 000 tons of apples and 10 000 tons of pears annually to produce fruit juice	January - May	River/Dam	277 000
3013.3	10 000 tons of grapes for raisin production	February - November	Municipal	13 173
3013.4	6 000 tons of grapes for raisin production	February - September	Municipal River/Dam	No records kept
3013.5	50 466 tons of citrus and 4461 tons of guava annually for juicing	February - September	Municipal	123 870

Table 15 Water saving measures from survey responses

Industrial unit	Prioritisation of water minimization (Scale 1 - 5)	Water use targets in place (Yes/No)	Water saving measures in use	Measures implemented in response to recent drought? (Yes/No)
3013.1	3	No	Process Control and Monitoring Dedicated Maintenance Water-wise cleaning (High pressure spray units)	No
3013.2	5	No	Water reuse and recycling Process control and monitoring Avoidance of once-through use Improved energy efficiency in steam-based processes Water awareness training for staff	No
3013.3	5	No	Dedicated maintenance	No
3013.4	3	No	Water awareness training for staff Dedicated maintenance	No
3013.5	5	Yes	Water reuse and recycling Improved energy efficiency in steam-based processes Dedicated Maintenance Water awareness training for staff	Yes

Table 16 Wastewater treatment in survey responses

Industrial unit	Annual effluent volume (m^3)	Effluent treatment
3013.1	130 000	***Primary treatment*** Treatment with Eco-Tabs™ * ***Secondary treatment*** None ***Tertiary treatment*** None
3013.2	415 000	***Primary treatment*** Filtration for solids removal ***Secondary treatment*** Aerobic and anaerobic bacterial reaction (*undefined*) ***Tertiary treatment*** Chlorination and treatment with Aluminium sulphate [$Al_2(SO_4)_3$]
3013.3	96 000	***Primary treatment*** Filtration for large and fine solids removal Neutralisation ***Secondary treatment*** Aerobic treatment (*undefined*) ***Tertiary treatment*** None

3013.4	No response	***Primary treatment*** Filtration for large and fine solids removal Neutralisation ***Secondary treatment*** Biological treatment (*undefined*) ***Tertiary treatment*** None
3013.5	14040	***Primary treatment*** Filtration for large and fine solids removal Neutralisation ***Secondary treatment*** None ***Tertiary treatment*** None

*Eco-Tabs™ are dissolvable tablets designed to oxygenate wastewater, prevent corrosion, remove odours due to hydrogen sulphide and initiate the aerobic biological breakdown of organic sludge, (including natural oils and greases)

5.2 Case studies of water and wastewater management in the FVPI

The FVPI is highly competitive and protective, but even so a total of 14 facilities were visited on a case-study basis. Interviews were conducted at all of the 14 visited facilities, although the decision to record and transcribe interviews was only made after the first 6 facilities had been visited. The field notes collected from the earlier facilities were, however, still of sufficient quality to be included in the qualitative analysis that the recorded interviews were subjected to.

Industrial unit 3013.6 is located in the Limpopo province and is involved in the juicing of citrus fruits, with grapefruit and oranges being the main varieties. The only output is juice concentrate, which is mainly export orientated. The permanent staff contingent comprises of 102 individuals, with seasonal staff totalling 84 people in the current season (February to middle October). Water is supplied from a local dam, although recent drought has encouraged the facility to sink a borehole on the premises. The main water using operations in the facility were found to be raw material washing, cooling towers for the freezers, and the pasteurisers. The water used in the oil extraction was also deemed to be of concern. Water saving techniques exhibited by the facility include two recycling strategies, namely the reuse of evaporator water for facility and equipment cleaning, as well as collecting the defrost water from the freezers (which is, in turn, used to top up the cooling tower water). High pressure hoses were reportedly used for cleaning, although it was noted that some of the hosepipes used in the facility where not equipped for this purpose. Dedicated leak repair was also mentioned as a mitigation technique. The wastewater treatment at 3013.6 consists of screen filtering for solids and pH neutralisation (Table 19). The effluent is then used to irrigate pastures surrounding the facility. The facility was unwilling to provide figures for water consumption, effluent volumes or wastewater quality parameters (Tables 17, 18 & 19).

Industrial unit 3013.7 is involved in the processing of fruits, with the tropical varieties being the main inputs. Three different facilities on site manufacture juice concentrates/blends/purees, fruit cubes, individually quick frozen (IQF) fruit pieces and canned products. The peak season for juicing occurs from November to January, with the IQF and canned products being in production from March to early July, when grapefruit is found to be in season. Water is obtained from municipal sources as well as a borehole on site, which is temporarily stored in a small reservoir. The water is then treated before use in the factory. The physiochemical properties of the incoming water are tested every morning by laboratory staff. Within the IQF and canned products facility, the washing of raw materials was found to be the main user of water, with floor cleaning (a near continuous operation to prevent slipping) following suite. The juicing and sweets facilities both experience the cleaning operations to be the main users of water. Active water minimisation techniques include the reuse of water used in the IQF washing operations (water used in first and second rinses is chlorinated, then mixed with fresh potable water to be used again in the same operations again); and the recirculation of water used to operate the conveyor bringing washed fruit into the IQF facility. Primary wastewater treatment involves the neutralisation of pH, followed by physical screening (The water after screening is pumped to a holding tank, which has a tap to allow for the water to be used in outside cleaning). The effluent is then pumped to sedimentation tanks, and thereafter a dam that functions to further separate the liquid effluent from floating solids. Secondary treatment is accomplished by using anaerobic lagoons (covered with sails) followed by aerobic lagoons. Final effluent is pumped to a holding dam, where it is then used for orchard irrigation (Table 19). The facility was unwilling to provide figures for water consumption, wastewater volumes or effluent quality parameters.

Industrial unit 3103.8 is a relatively small facility located in the Cederberg region and is involved in the bottling of jams and other preserves, mainly for the domestic market. The raw materials are mainly of the deciduous variety and include apricots, blueberries, apples and pears (amongst others). Total employment is small and comprises 17 permanent staff and six seasonal workers. Fresh water is supplied by a borehole, with the water itself being treated by a filter, brominator and UV light system before use in the factory. Calculations of specific water intake (SWI) were not possible as the facility did not keep suitable production records (Table 17). The main water users where found to be the pasteurising and cooking operations. Water minimisation employed in the facility was largely in response to the severe drought experienced in the Western Cape, and consists of the following measures:

- Reusing of the pasteuriser water
- Reduction in amount of water used for raw material washing (200 litres per day to 60 litres per day) as well as for cooking; and
- Reducing the number of times coats are washed (from three times per week, to once per week)

Wastewater treatment in 3013.8 consists of a septic tank, with a French drain system leading into a holding tank. The water then runs through a peat filtration system before being pumped into a smaller tank to be used for garden irrigation (Table 19).

Industrial unit 3013.9 is a potato processing facility located on the west coast of South Africa. Other vegetables are used in secondary or tertiary processes; however, these are usually bought in a pre-processed state. 90 tons of potatoes are processed daily, 4 days a week, for 52 weeks of the year (shutdown occurs during December). Production is geared mainly towards the local market, although limited exports do occur to Namibia, Botswana and Zambia. The facility's water sources are a combination of seawater (used for initial washing and transport); borehole water (used for cleaning and secondary washing of potatoes); and municipal water (used for direct contact after peeling). Although SWI for the facility is shown to be 6,2 m^3/ton, it must be taken into consideration that the volume of seawater and borehole water used in the process actually raises the SWI to 10 m^3/ton. According to literature this is slightly higher than American facilities and much higher than EU facilities, with SWI figures of 9,4 and 6,75 m^3/ton, respectively. The main water using operations were reported to be the facility cleaning and process water (more specifically the peeling and blanching operations), whilst freezer defrosting was also said to be a water intensive operation. Active water saving measures implemented by 3013.4 include:

- the installation of 10 electronic flow meters to assist in identifying water saving opportunities
- replacing old/incorrectly sized nozzles in the peel remover
- automatic switches to stop water flow once machinery is switched off; and
- triggers on the hosepipes ensure no wastage during cleaning operations

Wastewater treatment in the facility is simplistic, with sedimentation tanks being used to separate the majority of the solids from the process water. The process water and seawater (used in initial conveying and washing) is then mixed and discharged into the ocean (Table 19). Effluent quality in relation to pH, COD and TSS (Table 18) was found to be very similar to that found in literature (Table 10).

Industrial unit 3013.10 is a vegetable processing facility located in the Limpopo province. Four processing lines are active at the facility, with canned tomatoes; tomato puree; gherkins; and atchar (mango and vegetable varieties) being the main outputs from each, respectively. Production is geared towards the local market, although cherry peppers are exported in very small quantities. Employment stands at 146 permanent staff, with a seasonal staff contingent comprising 300 to 500 at any one time. Boreholes supply the 80 000 to 160 000 litres required per day, with the main water requirements being the washing of raw materials and cleaning operations. The SWI of 1,6 m^3/ton was found to be better than both European and American counterparts (Table 17). Active water saving measures include the use of triggers on hosepipes, staff training as well as the installation of water dispensing points (accompanied by dispensing units for cleaning chemicals). Water from the pasteurisers and double jacketed vessels goes through a condensate return to be re-heated by the boiler (thus, a form of regeneration reuse). Wastewater treatment includes the use of settling dams, through which the effluent is directed. Moving screen filters within the same settling dams further separate the solids, with the final wastewater then being used for irrigation purposes (Table 19). Although COD figures were not provided, the TSS figure of 1740 mg/L (Table 18) was greater than values for similar vegetable processing found in literature (Table 10).

Industrial unit 3013.11 is a manufacturer of frozen vegetables products and is located in southern Gauteng. The facility provides employment to 426 permanent staff, with seasonal workers averaging 100 per 12-hour shift. The annual water use in the facility of 188 976 m^3 per annum, is apportioned as follows:

- 1 089 for employee uses
- 41 525 for cooling tower evaporation
- 33 975 for boiler operation
- 112 387 for other plant requirements (facility cleaning, material washing and other)

The main water using operations were found to be the material washing and facility cleaning operations. Active water saving measures include design-based optimisation; recirculation of water in the slither remover; dedicated maintenance and water-wise cleaning (nozzles on hosepipes); and staff training. Wastewater treatment before discharge into the municipal system includes screening, lye addition, flocculation treatment and decanting (Table 19). Effluent quality varies according to the type of raw material, with pH ranging from 4.4 to 8.0; COD from 410 to 5810 mg/L and TSS from 330 to 1840 mg/L.

Industrial unit 3013.12 is located in the Limpopo province of South Africa and is involved in the production of bottled picante peppers, as well as other value-added vegetable products including atchar, salsas, pickles and sauces. Production occurs year-round, with a peak between January and June (due to the picante season). 80% of the outputs are geared towards the export market, with Europe and North America being the main export destinations. Employment figures are comprised of 230 permanent staff, with a day and night shift of seasonal workers making up approximately 2500 individuals. Fresh water is supplied by the municipality, with the facility's daily water requirements being approximately 300 m^3 per day. Active water saving measures found in 3103.12 included the reuse of wash-water (replaced once per day) and pasteuriser water (replaced once every two weeks). Water awareness training for staff, as well as the use of water-wise cleaning techniques (dry cleaning of certain areas and nozzles on hosepipes). A weakly leak check of the entire facility is also practiced. Effluent treatment consists of screen filtering before discharge into the municipal sewerage system (Table 19). The low effluent volumes (Table 18) as compared to the freshwater consumption (Table 17), are claimed to be as a result of evaporative losses during the processes. This however seems unlikely and leads to suspicion surrounding the accuracy of the flow meter. Effluent quality parameters (Table 18) vary according to the type of raw material being processed.

COD values vary from 3429 up to 10 059 mg/L, whilst TSS varies from 813 up to 1500 mg/L. An average pH value of 5,98 was reported by the facility (Table 18).

Industrial unit 3103.13 is located in the Western Cape province and incorporates two separate facilities (East and West). The eastern plant is involved in the canning of deciduous fruits, whilst the western plant is responsible for the production of canned vegetables. The two sites have a permanent staff of 500, with 4 500 seasonal employees. Water requirements are split roughly one third as a raw ingredient, with the remaining two thirds being allocated to facility cleaning and material washing. Water minimisation has been a very important focus at the facility since 2016, with the intervention being triggered by threats of drought. The following projects were implemented:

- Central Shut-off valves installed. Once work in a specific part of the plant is completed, water for the entire section is isolated
- Water efficient urinals
- Use of mountain/stream water instead of municipal
- Closed system for water pumps
- Pressure reduction at handwashing stations; and
- More efficient lye-peeling heat exchangers

The above achieved a drastic reduction in water consumption, which can be evidenced by Figure 20 below. From 2016, the above water saving strategies have resulted in a 54% reduction in two years (From 1 014 668 KL in 2016 to 465 458 KL in 2018).

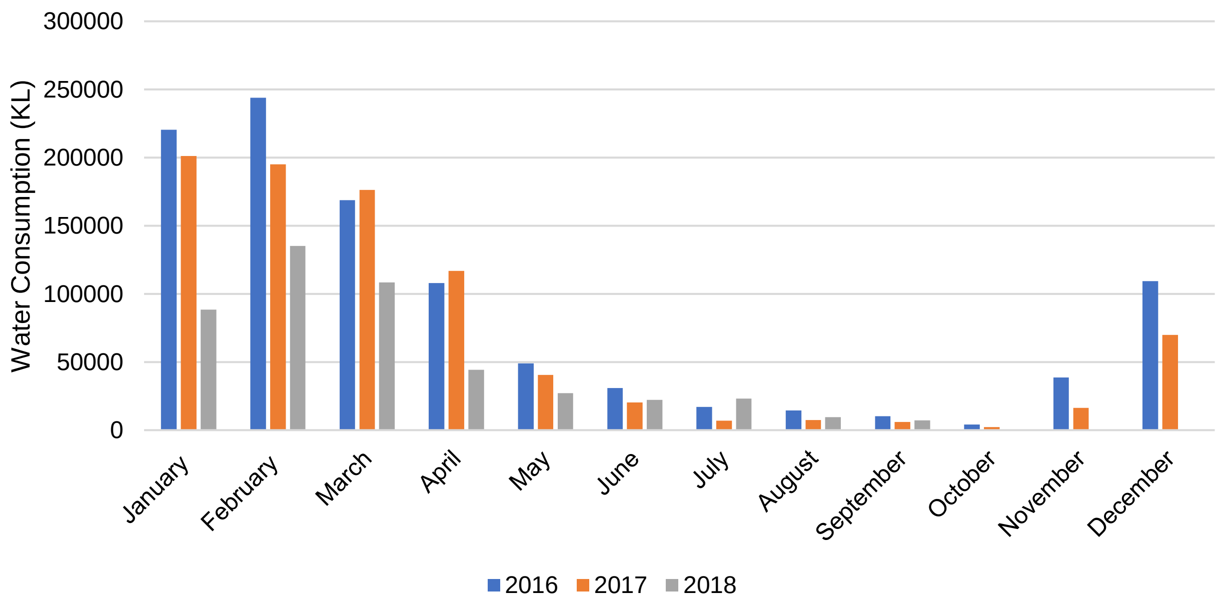

Figure 20 Water consumption at facility 3013.13 from 2016 to 2018.

An SWI of 6.16 m^3/ton was determined for facility 3013.13, which was higher than figures reported for both European and American facilities (Table 17). Effluent streams (300 000 kL per annum) can be split into lye-peeling wastewater (COD 10 000 – 15 000 mg/L) and other water (COD 7 000 – 9 000 mg/L) (Table 18). with the treatment thereof consisting of screening for solids, followed by aeration before pumping into dams. Effluent is then consistently pumped between dams until a sufficiently low COD has been obtained, after which the water is used for field irrigation of the company farm (Table 19). 'Sufficiently low' COD as referred to above, means a COD level within the range specified by the Revision of General Authorisations in Terms of Section 13 of the National Water Act, 1998 (Act no. 36 of 1998) (DWA, 2013). The General Authorisations stipulate that with increased wastewater-based irrigation, the maximum allowable COD levels will decrease. In addition to maximum allowable COD levels based on daily irrigation volumes, the General Authorisations also stipulate other parameters which must be adhered to. Figure 21 below shows the 2018 annual production (tons) in relation to the water consumption (kilolitres) at facility 3013.13. The highly water dependant nature of production, as well as the seasonality in production becomes very apparent.

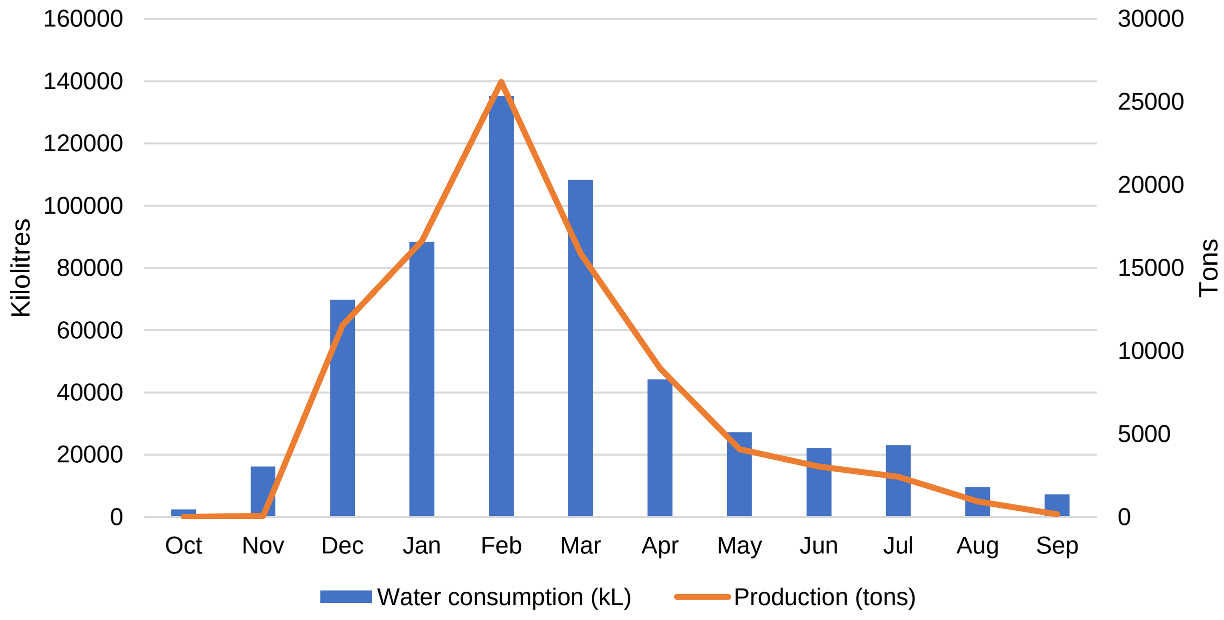

Figure 21 Annual water consumption and production at facility 3013.13 in 2018.

Industrial unit 3013.14 is a dried fruit producer located in the Western Cape. The company employs 130 permanent staff, with the year-round supply of raw inputs (dried tree fruit from a variety of sources) ensuring no seasonality in employment. The company produces approximately 1000 tons of dried fruit per annum. Considering that national dried tree fruit production was 6181 tons (2017), 3013.9 represents approximately 16% of this. The daily water requirements of 60 m^3 are supplied by a 60 m^3/hour borehole, which is treated for high iron and manganese content before use in the plant. The main water using operations in the plant were found to be washing of raw materials (Fig. 22) followed by the cleaning of equipment. Active water saving measures include timely maintenance and leak repair, water-wise cleaning, as well as staff training. Replacing the worn-out nozzles in the initial fruit cleaning operation (Fig. 22) reduced the water requirements of the equipment by approximately 75%. Effluent management at the facility involves initial filtering using a bag filter, after which the effluent and sewerage from the facility are mixed and discharged into a 3-stage aerobic bioreactor. After this the treated water is filtered using a peat bed, after which it held in a reservoir. The water is either discharged into the municipal system or used to water the lawn (Table 19). The system can reduce COD levels from above 4000 mg/L to below 100 mg/L, with typical effluent COD levels ranging from 2165 – 3110 mg/L (Table 18).

Figure 22 Initial raw material washing at industrial unit 3013.14.

Industrial unit 3013.15 is located in the coastal region of the Eastern Cape province and is involved primarily with the freezing of fruit products for niche overseas markets. Limited Piquante Pepper canning also takes place on the premises. The company provides employment to 500 permanent staff, with seasonal employment raising this figure to 1 500 during peak periods (this occurs during the citrus season. 7 000 tons of raw fruit is processed annually. The summer months (January to April) mainly involve the processing of deciduous fruit, whilst citrus is the main commodity processed during the winter months. 3013.1 is also involved in sorbet production, with acquisition of the fruit juice ingredients being made from a variety of suppliers. Production is determined in units, with 15 million units (of approximately 100 grams each) being produced in the past year. The facility uses between 6 000 and 13 000 kL of fresh water per month, with the water itself being provided by Fish River Transfer system (ensuring a constant supply even during the most intense period of drought). Incoming water quality is considered very important, with special emphasis being placed on chlorine limits and microbial loadings (UV filters are used to treat the incoming water). No data on water use within specific operations were available, although the main water using operations were known to be the cleaning and washing operations. No data on specific water intakes for various products were available either. The company has admitted that water minimisation is currently not a focus, due to the constant supply provided by the Fish River Transfer System, as well as a focus on reducing the high energy requirements of the processes (approximately 1 200 kWh per month). 3013.15 estimates that effluent volume is approximately 80% of their incoming water, with the sole treatment thereof being the screen filtering of solids before discharge into the municipal system (Table 19). No information pertaining to effluent quality was provided by 3013.15.

Industrial unit 3013.16 is an apple juicing facility located in the Southern Cape. The facility employs 100 permanent staff and does not rely on seasonal employment, due to the highly mechanised process involved. Production runs from January through to July, with a variety of different cultivars being juiced. Total raw material consumption at the facility totals approximately 65 000 tons. Fresh water consumption amounts to approximately 300 000 cubic meters of fresh water per annum. The facility is fortunate that for most of the season it is self-sufficient in terms of process water, with the condensate being reused for most of the processing requirements. The major users of fresh water are the cleaning and material washing operations. Water minimisation was indicated as a focus area for the facility, evidenced by the planned installation of a UV filtration system in the initial washing area. By treating the washing water with the UV system, it is hoped that longer periods between wash water changeover can be achieved. A major advantage of the concentration process is the ability to collect and reuse the condensate as process water. Timely maintenance of leaks is also practiced, as well as separation of cleaning chemicals from wastewater for reuse. Effluent treatment consists of screening and lye addition, after which it is pumped to an Up-flow Anaerobic Sludge Blanket (UASB) reactor 2 km from the facility. Although the facility would ideally want to pump all effluent to the reactor, about 20% is pumped directly to a settling dam. The treated water from the UASB reactor is then also pumped into the settling dam, from which irrigation takes place (Table 19). Biogas from the reactor can supply 25% of the approximately 3 500 000 kWh annual energy requirements. An average pre-treatment COD of 13 265 mg/L and pH of 6.31 of reported by 3013.16. This was higher than fruit juicing process found in literature (Table 10).

Industrial unit 3013.17 was up until 2007/2008 involved with pineapple canning. With the unprofitable nature of the canning industry, the decision was reached to retrofit the factory into a juicing operation. Today, the factory is only involved in the production of pineapple concentrate, with small volumes of 100% fresh juice being produced. The company provides employment to approximately 120 individuals (when the canning line was still in operation, this figure was 1000). In 2018, 3013.17 processed approximately 81 000 tons of raw fruit, with production in 2019 expected to increase to 87 000 tons. Pineapples are potentially available year-round; therefore, processing occurs from late February until December. 85% of production is exported, with the main destinations being Europe, Russia and South America. Water minimisation has been stated as a focus area for the facility. They have recently replaced their ‘Dumper Baths’ in favour of dumping the fruit directly onto conveyor belts (Fig 23.), where initial rinsing takes place. This measure has reduced water consumption by approximately 20%, with estimated annual savings of R 1 million per annum. In addition to this, the facility also reuses condensate from the evaporation process for cleaning of floors and stainless-steel surfaces (the lower pH of the condensate restricts its use for other surfaces). The facility also uses Clean-in-place (CIP) in certain equipment (such as the concentrate holding tanks). Effluent treatments performed are the filtering of solids using a screen filter (Fig. 24) and pH buffering (most often addition of lye). Solid waste is sold to local farmers as animal feed. The COD levels of 5976 mg/L were found to be slightly higher than the 5157 mg/L reported in literature, with the TSS being much higher (1552 mg/L compared to 323 mg/L.) (Tables 10 & 18).

Figure 23 Facility 3013.17 replaced the 'dumper baths' with conveyor belts.

Figure 24 Screen filter used in facility 3013.17 (prior to neutralisation treatment).

Industrial unit 3013.18 is located in the Eastern Cape Province and is involved in the canning and bottling of various members of the *Capsicum* (Pepper) family. Typical products include the red cherry pepper, sweetheart pepper and Jalapeño. 3000 tons of packed product is produced from December until end of March and is mainly export orientated. The facility creates employment opportunities for 1280 seasonal employees (for approximately 8 months of the year), with a permanent contingent of 23 staff. 3013.18 has faced a uniquely challenging situation in the last 2 seasons in that the local municipality was unable to provide the water requirements of the facility (Due to drought pressure and municipal mismanagement). In response to this, the facility has resorted to trucking in the daily requirements of 148 m^3 from a nearby borehole. Active water saving measures in the facility include:

- Use of a sanitisation protocol (sanitiser and water applied using compressed air) instead of traditional cleaning with a hosepipe
- Use of broom and squeegee for basic cleaning
- Reduced change-over of washing tank water; and
- Staff training.
- The installation of more water efficient toilets.

The specific water intake of 5,9 m^3/ton was slightly higher than comparable processes in literature (Table 17). No effluent treatment is applied at 3013.18. Catch pots are however used to reduce the number of large solids entering the municipal system. Effluent quality records are not maintained at the facility.

Industrial unit 3013.19 is located in the Eastern Cape and is involved in the juicing of citrus for concentrate production. 90 000 tons of citrus is juiced annually from March until end of October, with a facility shutdown and capital projects phase occurring from November until February. The facility employs 160 seasonal staff with a permanent contingent of 37 individuals. The facility obtains all its water from a local irrigation canal system. The main water users were found to be the evaporators and boilers. Water saving measures implemented in the facility include:

- Redesigning of piping for improved water efficiency
- Reuse of condensate water, and planned reuse of vacuum pump water
- Monitoring of water consumption
- Recirculation of boiler water
- Improving the energy efficiency of the steam-based systems (redesign of boiler layout and insulation of steam piping); and
- Water-wise cleaning (high pressure cleaning)

Effluent treatment at 3013.19 consists of static screens to remove the solids, then pH buffering by means of lime addition. The wastewater is then directed through a decanter, after which it is then split into two separate streams. 50% of the wastewater is treated via means of an oxidation ditch, after which it is directed to a clarifier where additional solids are allowed to settle. The other 50% of the wastewater is directed through a trial system, consisting of an aerobic and anaerobic reactor arranged in series. A membrane system removes any additional solids. Both the effluent streams are irrigated onto pasture post treatment (Table 19). Effluent quality parameters were not provided by the facility.

Table 17 Production and water consumption data for South African fruit and vegetable processors

Facility	Main raw inputs and quantities	Fresh water consumption (m^3)	SWI (m^3/ton product)	SWI (m^3/ton product) according to literature
3013.6	Citrus	Not provided	Not provided	Fruit Juice (EU): 6,5 Fruit Juice (UK): 3,5
3013.7	Tropical fruit Citrus	Not provided	Not provided	Fruit Juice (EU): 6,5 Canned Fruit (EU): 3,25 Canned Fruit (USA): 5,8 Frozen fruit/vegetables (USA): 9,4
3013.8	Deciduous fruits: 100 -120 tons p/a	1,58 p/d	Not available	Jams (EU): 6,0
3013.9	Potatoes: 90 tons per day 23 000 tons p/a	560 p/d 143 018 p/a	6,2	Frozen fruit/vegetables (USA): 9,4 Frozen vegetables (EU): 6,75
3013.10	Vegetables (unspecified): 11 350 tons p/a	14 400 p/a	1,6	Canned vegetables (EU): 4,75 Canned tomato (USA): 2,93
3013.11	Vegetables: 92 701 tons p/a	188 976 p/a	3,3	Frozen fruit/vegetables (USA): 9,4 Frozen vegetables (EU): 6,75
3013.12	Picante Peppers: 6212,2 tons p/a Other vegetables: 696,3 tons p/a	300 p/d 78 545 p/a	19,2	Canned vegetables (EU): 4,7 Canned tomato (USA): 2,93
3103.13	Deciduous fruits and vegetables	553 824 p/a	6,16	Canned Oranges (China): 30 Canned Fruit (USA): 5,8 Canned Fruit (EU): 3,25 Canned vegetables (EU): 4,75
3013.14	Tree fruits	60 p/d	15	Dehydrated fruit (USA):0,3
3013.15	7000 tons raw fruit p/a (unspecified)	6000 -13 000 p/m	Not available	Frozen fruit/vegetables (USA): 9,4 Canned vegetables (EU): 4,75
3013.16	Apples: 65 000 tons p/a	74 213 p/a	5,37	Fruit Juice (EU): 6,5 Fruit Juice (UK): 3,5
3013.17	Pineapples: 79 349 tons p/a	101 164 p/a	10,15	Fruit Juice (EU): 6,5 Fruit Juice (UK): 3,5
3013.18	Peppers and vegetables: 4762 tons p/a	17 700 p/a	5,9	Canned vegetables (EU): 4,7
3013.19	Citrus: 90 000 tons p/a	90 918 p/a	Not provided	Fruit Juice (EU): 6,5 Fruit Juice (UK): 3,5

Table 18 Effluent volumes and characterisation for South African fruit and vegetable processors

Facility	Effluent volume (m^3)	pH	COD (mg/L)	TSS (mg/L)
3013.6	Not provided	Not provided	Not provided	Not provided
3013.7	Not provided	Not Provided	Not provided	Not Provided
3013.8	500 p/a	6,1	23 350	78
3013.9	177 710	4,7 - 6,2	4155 - 6340	533 - 2 068
3013.10	10 000 (tons per annum)	7,0	-	1740
3013.11	381 779	4,4 - 8	410 - 5810	330 - 1844
3013.12	800 p/a*	4,13	3429 - 10 059	813 - 1500
3013.13	332 294 p/a	5,98	7000 -15000	-
3013.14	30 p/d	-	2165 - 3110	-
3013.15	Not provided	Not provided	Not provided	Not provided
3013.16	100 000	6,31	13 265	-
3013.17	589 p/d	3,6	5976	1552
3013.18	10 380 p/a	No records	No records	No records
3013.19	Not provided	Not provided	Not provided	Not provided

* facility 3013.12 claims that the very low effluent volume (compared to annual water consumption of 78 545 m^3) is due to evaporative losses during the processes. This however seems unlikely and leads to suspicion surrounding the accuracy of the water meter

Table 19 Effluent treatment techniques currently employed by various South African fruit and vegetable processors

Facility	Treatment description	Method of disposal
3013.6	***Primary treatment*** Screen filter for solids removal Neutralisation	Irrigation
3013.7	***Primary treatment*** Screen filter for solids removal Neutralisation Sedimentation ***Secondary Treatment*** Anaerobic lagoons Aerobic lagoons	Irrigation
3013.8	***Primary Treatment*** None ***Secondary Treatment*** Septic tank with French drain	Irrigation
3013.9	***Primary treatment*** Sedimentation tanks and large solids screen	Discharge into seawater
3013.10	***Primary treatment*** Settling dams Screen filter for solids removal	Irrigation
3013.11	***Primary treatment*** Screening filter for solids removal Neutralisation via lye addition Flocculation and sedimentation	Municipal waterworks
3013.12	***Primary treatment*** Screen Filter	Municipal
3013.13	***Primary treatment*** Screen filter for solids removal ***Secondary treatment*** Aerobic lagoons	Irrigation
3013.14	***Primary treatment*** Bag filter ***Secondary treatment*** 3 stage aerobic bioreactor ***Tertiary treatment*** Filtering through peat bed	Irrigation
3013.15	***Primary treatment***	Municipal waterworks

	Screen filter for solids removal	
3013.16	***Primary treatment*** Screening filter for solids removal Neutralisation ***Secondary treatment*** UASB reactor and settling dam	Irrigation
3013.17	***Primary treatment*** Screening filter for solids removal Neutralisation	Municipal waterworks
3013.18	***No treatment applied***	Municipal water works
3013.19	***Primary treatment*** Static screen Neutralisation Sedimentation ***Secondary treatment*** Anaerobic and aerobic batch process arranged in series ***Tertiary treatment*** Membrane process	Irrigation

5.2.1 Critical comparison of recalculated specific water intake findings versus those in the 1987 NATSURV

When it comes to determining the performance of the surveyed facilities in comparison to the 1987 NATSURV, a few problems were encountered. First of all, the 1987 NATSURV determined specific water consumption in relation to raw material consumption – which is in contrast to the international norm of determining SWI in relation to production. Secondly, the facilities surveyed in this study did not readily fit into the categories presented by the original NATSURV. For example, “drying” as a category was not included in the original NATSURV, whilst three drying facilities formed part of this study (two from the electronic survey, and one visited on a case study basis). For an attempt at comparing the SWI’s of the 1987 NATSURV against those of the present study, SWI’s were recalculated for those surveyed facilities with sufficient raw material data. Thereafter the facilities which held some similarity to processes in the 1987 report were tabulated below (Table 20).

Table 20 Recalculated SWIs (m^3 per ton raw material) from current study versus similar processes in the 1987 NATSURV

SWI’s NATSURV 1987		SWI’s Current study	
Freezing	26,97	Frozen potato products	6,22
Juicing of apples	3,48	Juicing of apples	1,14
Canning and juicing of pineapples	2,94	Juicing of pineapples	1,27
Canning and juicing of citrus	2,1	Juicing of citrus	1,01

It is unfortunate that many of the facilities did not provide adequate raw material data for recalculation of the SWIs to match those of the 1987 NATSURV. In addition to this, for many of those facilities for which calculations were possible, there did not exist similar processes against which they could be benchmarked. Although Table 20 above is by no means extensive or detailed, it does provide evidence that water consumption efficiency has improved in South African facilities over the last three decades. If one regards juicing of apples for instance, one can see that water use efficiency in terms of raw material processed has improved by more than a factor of three. Likewise, freezing has seen a rather dramatic improvement when compared to frozen potato products in the current study. Despite a very limited number of facilities suitable for the purposes of comparison, it can be stated with reasonable confidence that water use efficiency has improved since the publishing of the last NATSURV.

5.2.2 Critical comparison of specific water intakes from current study versus those from international literature

Specific water intake calculations in most of the published literature is reported in terms of production. (i.e. cubic meters of fresh water per ton product). This data was more easily obtainable and revealed comparable SWIs for 9 of the surveyed facilities. Table 17 shows calculated SWIs compared to international figures. Facilities were colour graded according to whether they had:

- SWIs better than international counterparts: **Green**
- SWIs seen as intermediate when compared to international literature: **Orange**; and
- SWIs worse than that found in international literature: **Red**.

Three of these facilities (3013.9; 3013.10; and 3013.11) had SWIs better than those for similar processes found in international literature (Table 17). Facilities 3013.13 and 3013.16 showed SWIs that were intermediate in terms of efficiency. They performed better than some of the international counterparts but there were, however, some studies that demonstrated better SWIs. Four of the facilities demonstrated SWIs worse than those found in international literature (Table 17). It would therefore appear that South African facilities varied in terms of their performance against international counterparts. Some performed better and others less so, whilst some were found to be intermediate in terms of their water use efficiency.

5.3 Qualitative data analysis (QDA) of water and wastewater management using ATLAS.ti 9

As previously mentioned, the output of the organizing phase in content analysis can be the creation of a model, conceptual map, conceptual system or categories (Elo & Kyngäs, 2008) and more specifically, a description of the contents of the categories (Elo *et al.*, 2014). In the next section can be found the content analysis of 4 major themes as identified using the deductive approach, these being production information; water management; wastewater management and energy management, respectively.

5.3.1 Production information

Analysis of the various processing categories has revealed the following generalisable themes in production. Facilities usually only fall under a single processing category (Juicing; Canning/Bottling; Drying; or Freezing). Only two of the 19 surveyed facilities partake in multiple processing avenues (Table 21). Due to the seasonal nature of raw inputs, there is usually a dependence on temporary staff for a large portion of the season. 10 of the 14 facilities visited on a case-study basis indicated the use of seasonal employment, with the exceptions being 3013.9 (potato processor), 3013.14 (drying facility); as well as 3013.16 and 3013.17 (both of which are single variety juicing facilities). The potato processor (3013.9) has access to an almost year-round supply of raw inputs, which is why the permanent staff contingent is viable. 3013.7 is a pineapple juicing facility and also has a near constant supply of raw material year-round, thus making the use of permanent staff a viable option. The process is also highly mechanized and automated. 3013.16 is an apple juicing facility and has indicated that the high level of automation is the reason why seasonal staff are not required. This despite the fact that the raw inputs are very seasonal in nature.

Many facilities place much importance on the export potential of their products (Fig. 25). European countries specifically are a common consumer, which is in support of the economic analysis conducted in the literature review. There are however facilities that rely solely on the domestic market for marketing of their products. Reasons for why the export market was not pursued in these facilities were not easily apparent nor homogenous. Two of these facilities, which both produce relatively small quantities, were both heavily dependent on the domestic market. Although it must be mentioned that they both had one of South Africa’s major retailers as client, which could explain the apparent security in only supplying domestically.

None of the facilities have employed the use of novel/’green’ technologies discussed in the literature review. Ronquest-Ross *et al*. (2018) have recommended that the South African food industry in general still needs to conduct and apply research into novel technologies. Therefore, the apparent lack of these techniques in the FVPI comes as little surprise.

Table 21 Processing categories at surveyed facilities

Facility	● 2.5.1 Juicing	● 2.5.2 Drying	● 2.5.3 Canning/Bottling	● 2.5.4 Freezing	Totals
3013.1	1	0	0	0	1
3013.2	1	0	1	1	**3**
3013.3	0	0	1	0	1
3013.4	0	0	0	1	1
3013.5	0	0	1	0	1
3013.6	0	0	0	1	1
3013.7	0	0	1	0	1
3013.8	0	0	1	0	1
3013.9	0	1	0	0	1
3013.10	0	0	1	1	**2**
3013.11	1	0	0	0	1
3013.12	1	0	0	0	1
3013.13	1	0	0	0	1
1013.14	0	0	1	0	1
1013.15	1	0	0	0	1
3013.16	1	0	0	0	1
3013.17	0	1	0	0	1
3013.18	0	1	0	0	1
3013.19	1	0	0	0	1
Totals	8	3	7	4	22

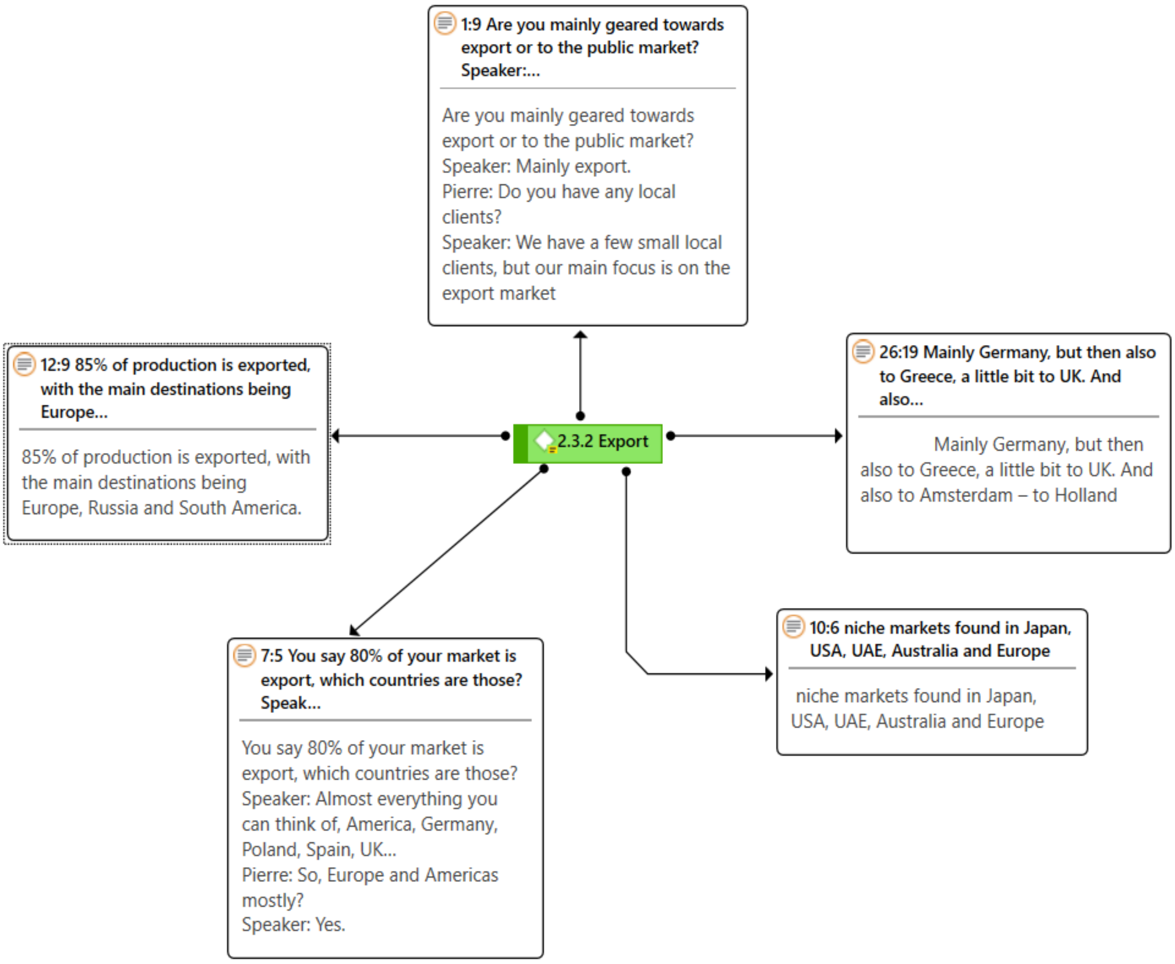

Figure 25 Network exploring the export driven side of the FVPI.

5.3.2 Water management

5.3.2.1 Importance of water saving as an agenda

Most facilities have indicated that water saving is at the least an intermediate priority in their agenda (Fig. 26). Only one facility has outrightly expressed that water saving is not a priority, with the energy intensive nature of the freezing process receiving more attention. The constant water supply ensured by the local canal system has meant that drought pressure was not a concern. When it comes to other facilities however, the incentives behind water saving measures seem to be not only environmental or drought induced. Financial reasons for saving water were also apparent, as can be seen from the following quotations:

"Interviewer: Is that in response to drought, is it finances?

Speaker: One I can say its finance. I just want to be open so that we can at least have common ground on such issues because I'm also an environmentalist so realistically *speaking on finance I don't think, most of the companies they focus more on production than conservation of water and wastewater. So, here its finances I think that's the biggest…"*

And indeed, another facility also makes mention of the financial implications:

"Interviewer: So, it's a money incentive for you?
Speaker: The more water you use the more you need to pay. On the other side you need to make sure that the food that you produce is 100% compliable to your standards and legislation. So, if you need to make sure that your product is clean and fit for human consumption"

One company specifically makes mention of the financial benefits of replacing their "dumper baths" with a dry conveying system at the raw material reception. The measure has reduced water consumption by 20%, with estimated related savings of over R1 million anually (2019).

Jermann *et al.* (2015) makes note of the fact that adoption of environmentally friendly technologies in food processing has much to do with reducing energy and water costs. Therefore, the financial incentives for water-saving in this study are to be expected.

5.3.2.2 Water using operations

Table 22 below demonstrates the code occurrence across the 4 different processing categories and supports literature in that *material washing* and *facility cleaning* are the main water using operations in the industry. This is, however, only a generalisable statement and is subject to assumption that interviewed persons were assumed to have intimate knowledge of the water requirements within their facility, and indeed, each operation.

Looking at the code occurrence for *canning/bottling facilities*, process water (code 1.2.5.3) was only found to be a major water user at one facility. This facility is the small canning/bottling facility located in the Western Cape, and the outlier may be due to the small scale of the facility in comparison to other plants (*i.e*. as the size of the plant increases, process water becomes proportionately less). The only code occurrences for *product make-up* (code 1.2.5.4) occur within the canning/bottling category.

Two juicing facilities received codes for process water. Both facilities are involved in citrus juicing and describe the *evaporators* and *boilers* as large consumers of water. The *citrus oil extraction* process was also reported as being a large consumer of water.

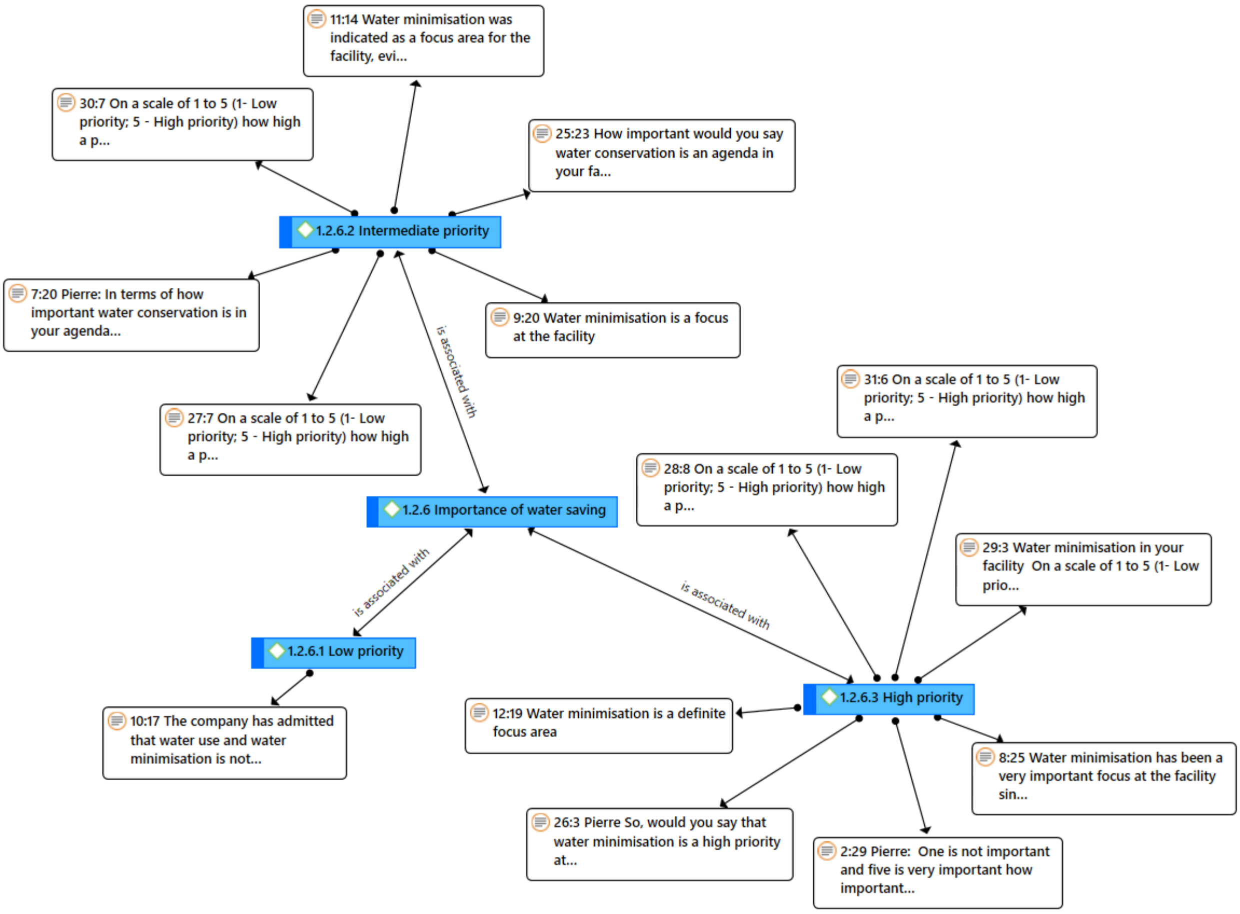

Figure 26 Network exploring the importance of water saving as an agenda at surveyed facilities.

Table 22 Main water using operations per processing category

	Canning/bottling facilities	Drying facilities	Freezing facilities	Juicing facilities	Totals
• **1.2.5.1 Material Washing**	5	1	2	2	**10**
• **1.2.5.2 Facility Cleaning**	4	1	2	1	**8**
• **1.2.5.3 Process Water**	1	0	1	2	4
• **1.2.5.4 Product Make-up**	2	0	0	0	2
Totals	12	2	5	5	24

5.3.2.3 Water saving strategies

Water saving strategies in South African FVPI are wide and varied, with a ‘clear cut’ generalisable plan not being possible due to the extreme process heterogeneity in the industry. Using Figure 27 below as a reference, it can be seen that water saving strategies within the industry are mainly focused on process changes and reuse/recycling. Design-based improvements/water pinch strategies were only found at three facilities. The codes that were not reflected in any of the facilities were those for *reducing driving force for mass transfer* (1.2.2.1); *improved production scheduling*

(1.2.2.5); and adoption of *novel technologies* (1.2.2.11). It must however be mentioned, that although UV technology was not used in the actual processing at any facility, industrial unit 3013.16 is planning on installing a UV filtration system in the initial washing step. The purpose of this is to hopefully extend the time between wash water change overs. Another noticeable feature of the investigation was that there were at times a disconnect between what was said during interviews, and what as actually practiced at floor level. One of the most notable instances, was the mentioning of water-wise cleaning as a water saving strategy (specifically the use of nozzles on hosepipes), whereas at factory level a clear contradiction was observed (Fig. 28)

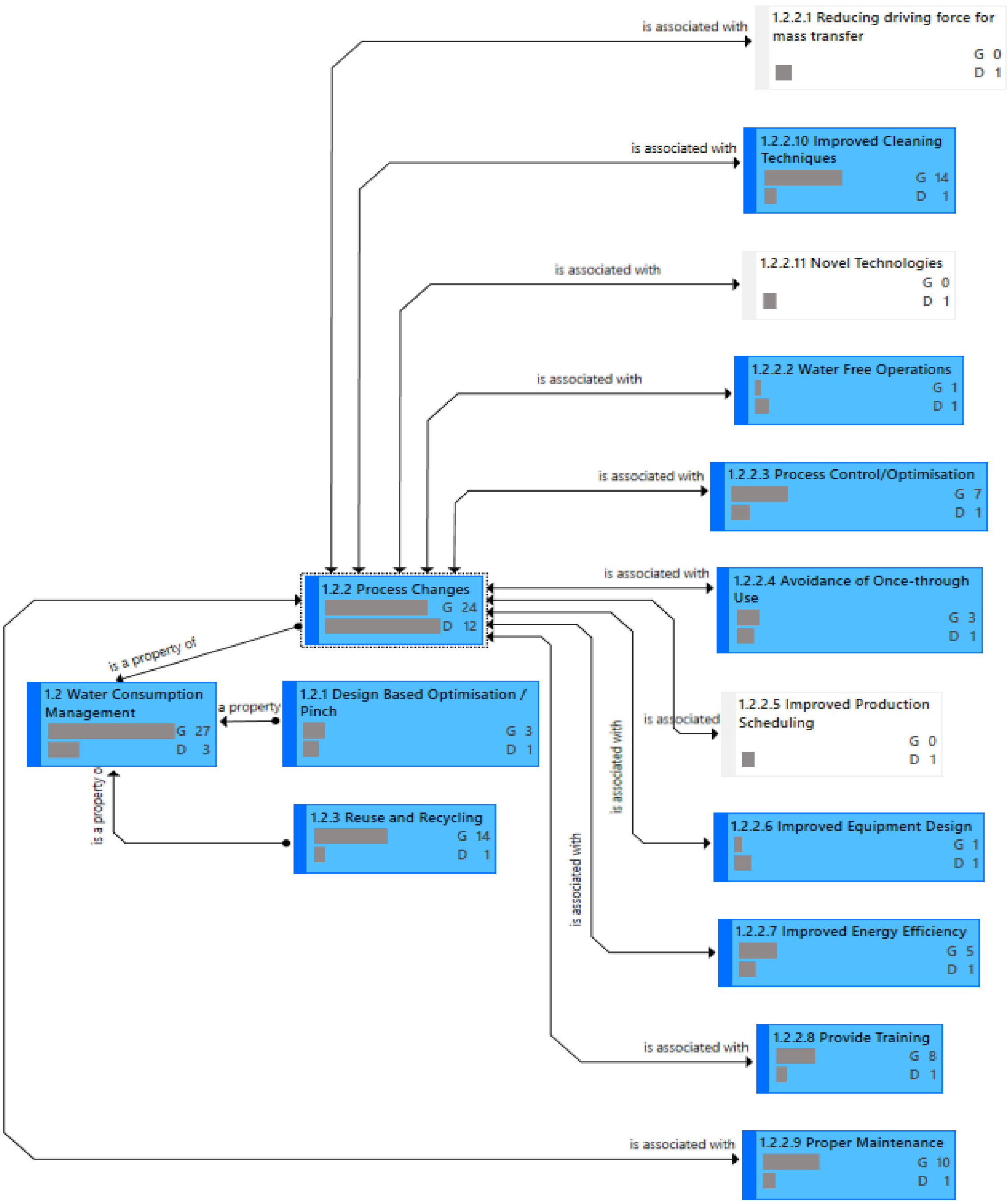

Figure 27 Network describing water saving strategies employed by the South African FVPI.

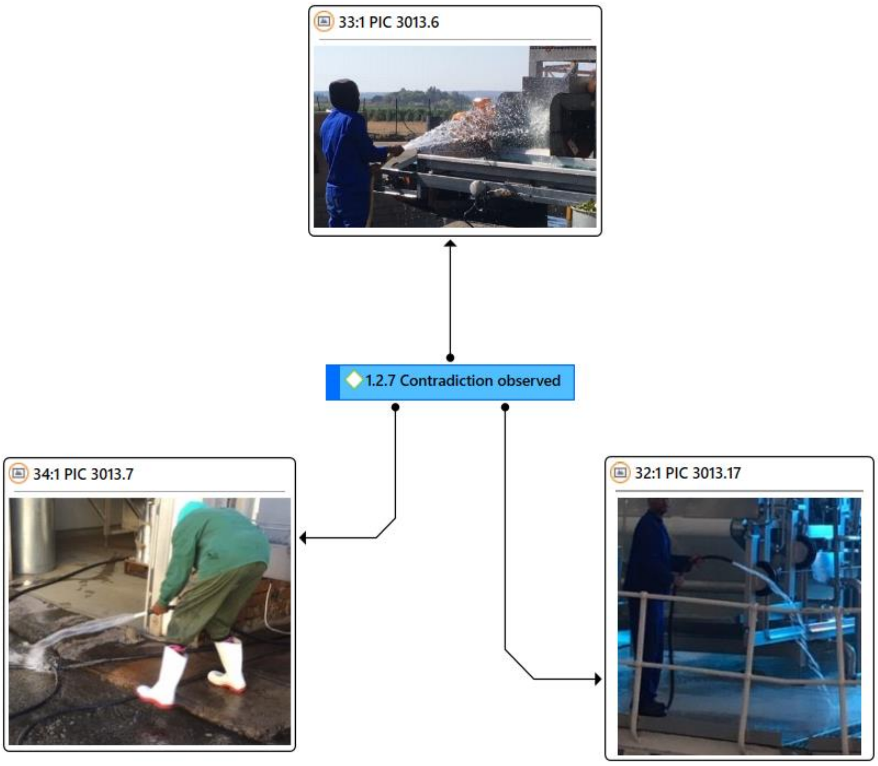

Figure 28 Contradictions observed in relation to water-wise cleaning, where the use of open-ended hosepipes was discovered.

The various water saving measures adopted by South African fruit and vegetable processors are described below, according to processing category.

Active water saving strategies adopted by juicing facilities

The following water minimisation strategies were found at juicing facilities:

- Redesigning and restructuring of pipework for more efficient water use
- High pressure hoses used for facility cleaning
- Use of CIP in equipment
- Replacing of 'dumper baths' with dry conveying at initial raw material reception
- Process control and monitoring
- Planned reuse of vacuum pump water at the evaporators
- Reuse of condensate from evaporators for facility cleaning
- Recovery of defrost water from freezers
- Planned installation of a UV disinfection system for in the initial raw material washing
- Recirculation of boiler water
- Water awareness training for staff

- Timely maintenance of leaks

Active water saving strategies adopted by canning/bottling facilities

The following water saving strategies were found at canning and bottling facilities:

- Installation of a ring main water distribution system
- Reduced floor washing, as well as dry-cleaning using brooms
- Reducing the frequency of washing of employee coats (from 3 times per week, to once per week)
- Nozzles on hosepipes
- Elbow/knee operated water distribution points to replace manual turning of taps
- Pressure reduction at handwashing stations
- Sanitising equipment and surfaces using compressed air, water and sanitiser instead of using hosepipes.
- Limiting the amount of water used in the preserve (jams, marmalades, etc.) cooking process
- Installation of central shutoff valves
- Process control and monitoring
- Closed system for water pumps
- More efficient lye-peeler heat exchangers
- Water awareness training for staff
- Dry cleaning of certain areas (brooms)
- Weakly leak checks and follow up repairs
- Reuse of process water and wash water to clean the outside of buildings; and
- Recycling of pasteuriser water and other water from other double-jacketed vessels

Active water saving strategies adopted by freezing facilities

The following water saving strategies were adopted by South African freezing facilities:

- The design and use of an optimisation platform for controlling water
- Triggers installed on hosepipes with nozzles
- Solenoids installed in machinery, so that when the equipment stops running, the water automatically stops as well.
- Installation of 10 electronic flow meters across a facility to identify water saving opportunities
- Process control and monitoring
- Improved equipment design by replacing old/incorrect nozzles in slither removers
- Staff training
- Dedicated maintenance according to schedules and inspection sheets

- Recycling of initial wash water by disinfection with chlorine (followed by mixing with potable water); and
- Recycling of water used to push conveyor belts

Active water saving strategies adopted by drying facilities

The following water saving strategies were adopted by surveyed South African drying facilities:

- Timely maintenance and leak repair
- Water-wise cleaning (unspecified)
- Water-wise training for staff; and
- The replacement of worn-out nozzles in the initial fruit cleaning operation

5.3.3 Wastewater management

From Table 23 below it is apparent that complex multistage wastewater treatment methods are not prevalent in the South African FVPI. Although the majority of processors utilise at least some form of primary treatment, the use of secondary and tertiary treatments seems to be less prevalent. Only three facilities reported the use of up to and including tertiary treatments. It was also observed that wastewater treatment at many of the facilities was applied in a rudimentary fashion, and not receiving much attention from management (Fig. 29 & Fig 30). Interviews with production managers also revealed interesting anecdotal information, that for the sake of confidentiality will not be mentioned in relation to any facility in particular. One facility does no testing of wastewater quality and chooses rather to perform weekly testing on the local river. The reason for this being that the municipal wastewater treatment plant is unserviceable, and that wastewater flows through the works into the river. A manager at another facility also admitted that they are irrigating above legal pollutant limits, and he/she suspects that the reluctance of many other facilities to provide information pertaining to wastewater quality would be due to this reason as well.

5.3.3.1 Primary treatment exploration

Looking at Table 24 below (Count of primary treatments applied at various facilities), it can be seen that screening is a commonly applied practice at most processors, although very often these were found to be only designed to remove large solids. Static rundown screens were also present at many facilities (Fig. 31). Neutralisation and sedimentation were the next most commonly applied primary treatments, respectively. Flow and load equalisation, as well as precipitation achieved one count each. The ‘other’ primary treatment (code 1.1.1.8) is the use of ‘Eco-Tabs™’, which are dissolvable tablets designed to oxygenate wastewater, prevent corrosion, remove odours due to hydrogen sulphide and initiate the aerobic biological breakdown of organic sludge.

Table 23 Levels of wastewater treatment applied at surveyed facilities

	• 1.1.1 Primary	• 1.1.2 Secondary	• 1.1.3 Tertiary	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	0	1
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
1013.14	1	1	1	**3**
1013.15	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**
Totals	**17**	**9**	**3**	29

Figure 29 Rudimentary 'settlement dam' at one facility.

Figure 30 Aerobic lagoon at another facility with only one functioning aerator.

5.3.3.2 Secondary treatment exploration

The use of secondary treatments in the FVPI was found in 9 of the 19 facilities surveyed (Table 23). with Figures 31 and 32 below exploring the variety of biological treatments found to be present. The most advanced form of biological treatment was found to a UASB at facility 3013.16. The use of lagoons was also found at two facilities. Unfortunately, the descriptions provided by the facilities replying to the online survey were ambiguous, in that they only went as far as describing whether the processes were aerobic or anaerobic. This led to these responses being coded as *Other Anaerobic Treatments* (Fig. 32) and *Other Aerobic Treatments* (Fig. 33), respectively. Customised units at visited facilities, which did not fit under any of the traditional classifications were also classified as 'Other'. It is clear that from Figures 32 and 33, that many of the possible secondary treatments recommended by literature are not applied within the industry.

Looking specifically at Figure 32 which describes secondary anaerobic treatment options available to the FVPI, we can see that only the codes for 'anaerobic lagoons' (1.1.2.2.1), 'UASB' (1.1.2.2.4) and 'other anaerobic treatments'(1.1.2.2.9) received 'groundedness' indications other than zero. All the other possible treatments recommended by literature where not apparent in the industry.

Table 24 Count of primary treatments applied at surveyed facilities

Treatment	Totals
• 1.1.1.1 Screening	15
• 1.1.1.2 Neutralisation	7
• 1.1.1.3 Flow and Load Equalisation	1
• 1.1.1.4 Sedimentation	5
• 1.1.1.5 DAF	0
• 1.1.1.6 Centrifugation	0
• 1.1.1.7 Precipitation	1
• 1.1.1.8 Other	1

Figure 31 Static rundown screens were common at many facilities.

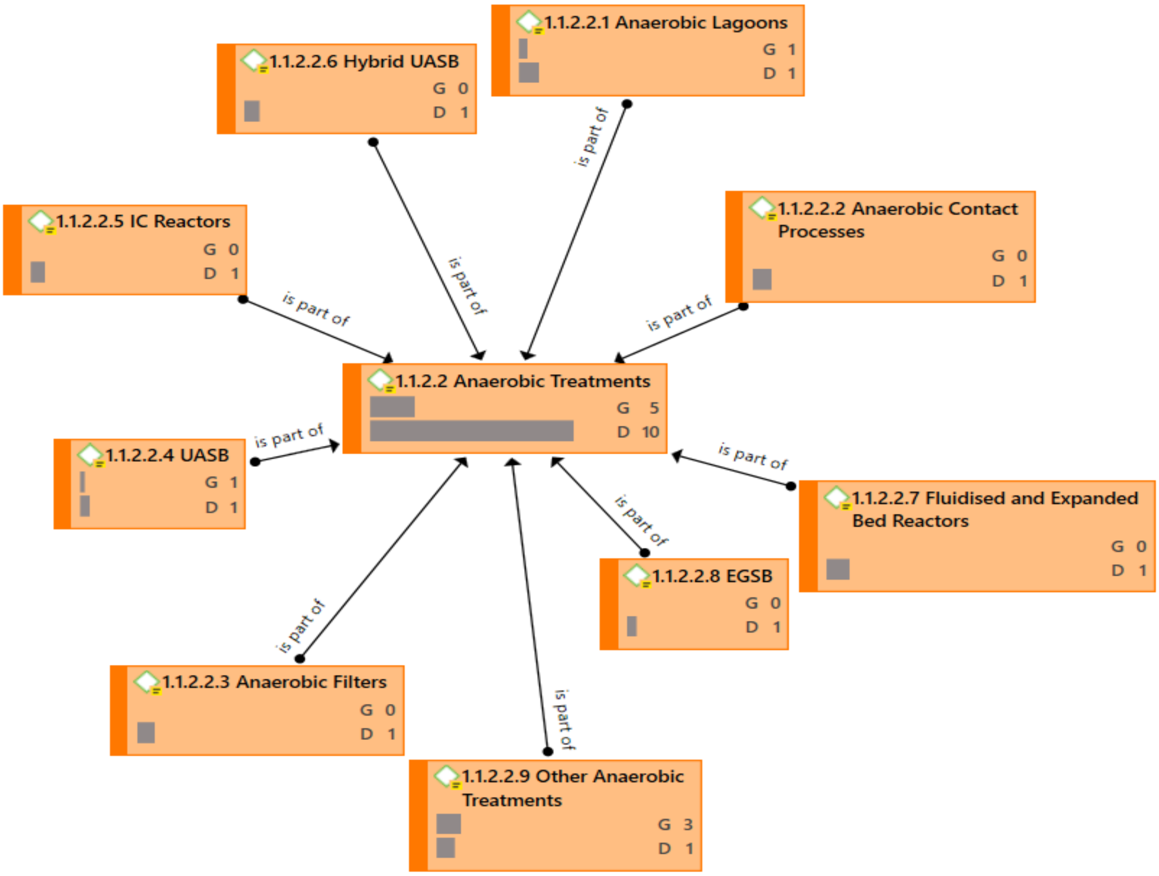

Figure 32 Network of possible and discovered anaerobic treatments present in the South African FVPI.

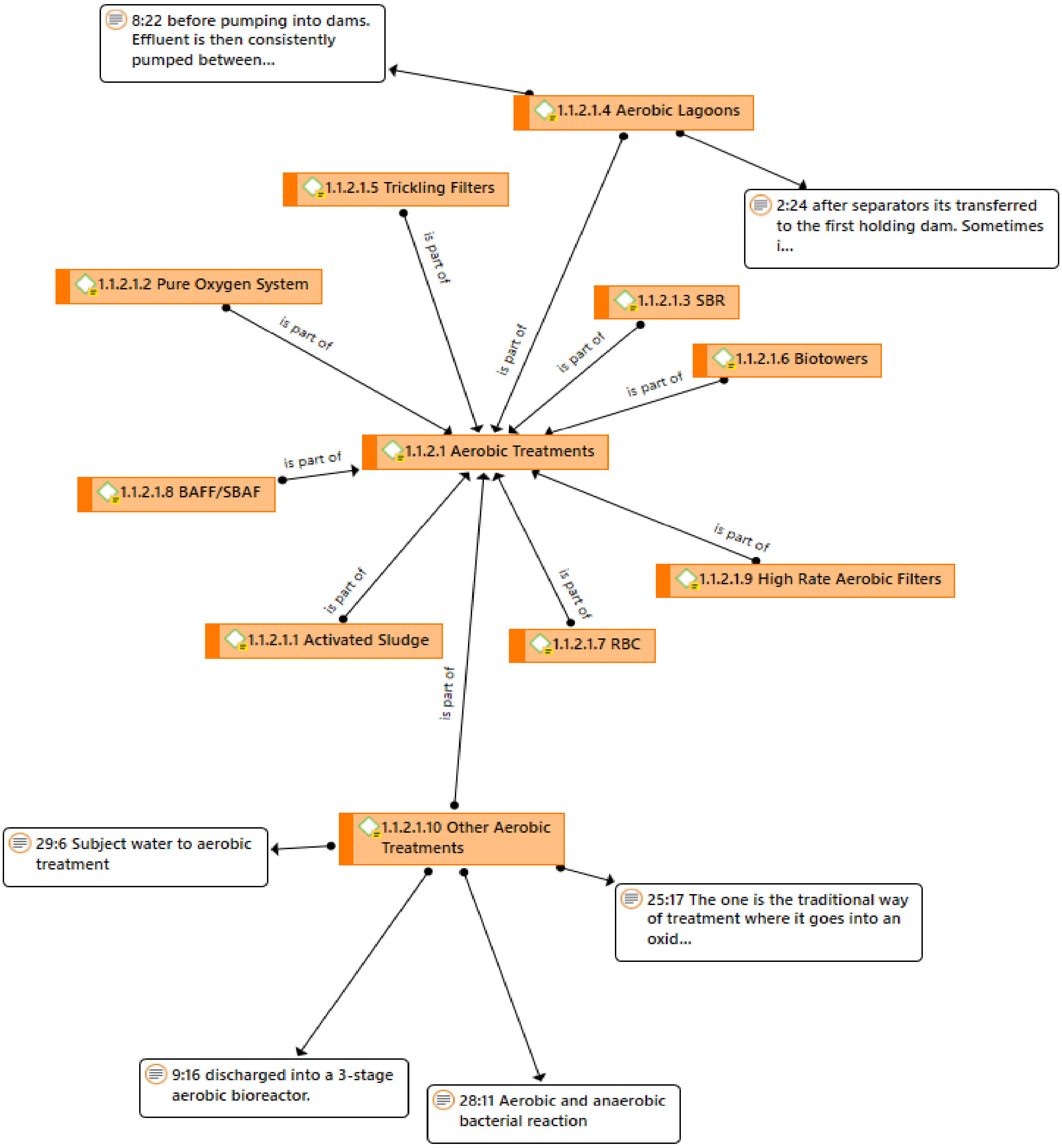

Figure 33 Network of possible and discovered aerobic treatments in the South African FVPI.

5.3.3.3 Tertiary treatment exploration

Figure 34 below explores possible tertiary treatments that can be applied in the FVPI, and those discovered during the survey process. As previously mentioned, only three facilities of the 19 surveyed employed up to and including tertiary treatment. Membrane filtration was in use at one facility, whilst chlorination and aluminium sulphate addition at another. with a peat-bed type filtration unit being employed at the third facility. Figure 34 shows graphically how the quotation “Chlorination & treatment with Al sulphate” is linked to both code 1.1.3.9 (Other Tertiary Treatments) and code 1.1.3.8 (Disinfection/Sterilisation).

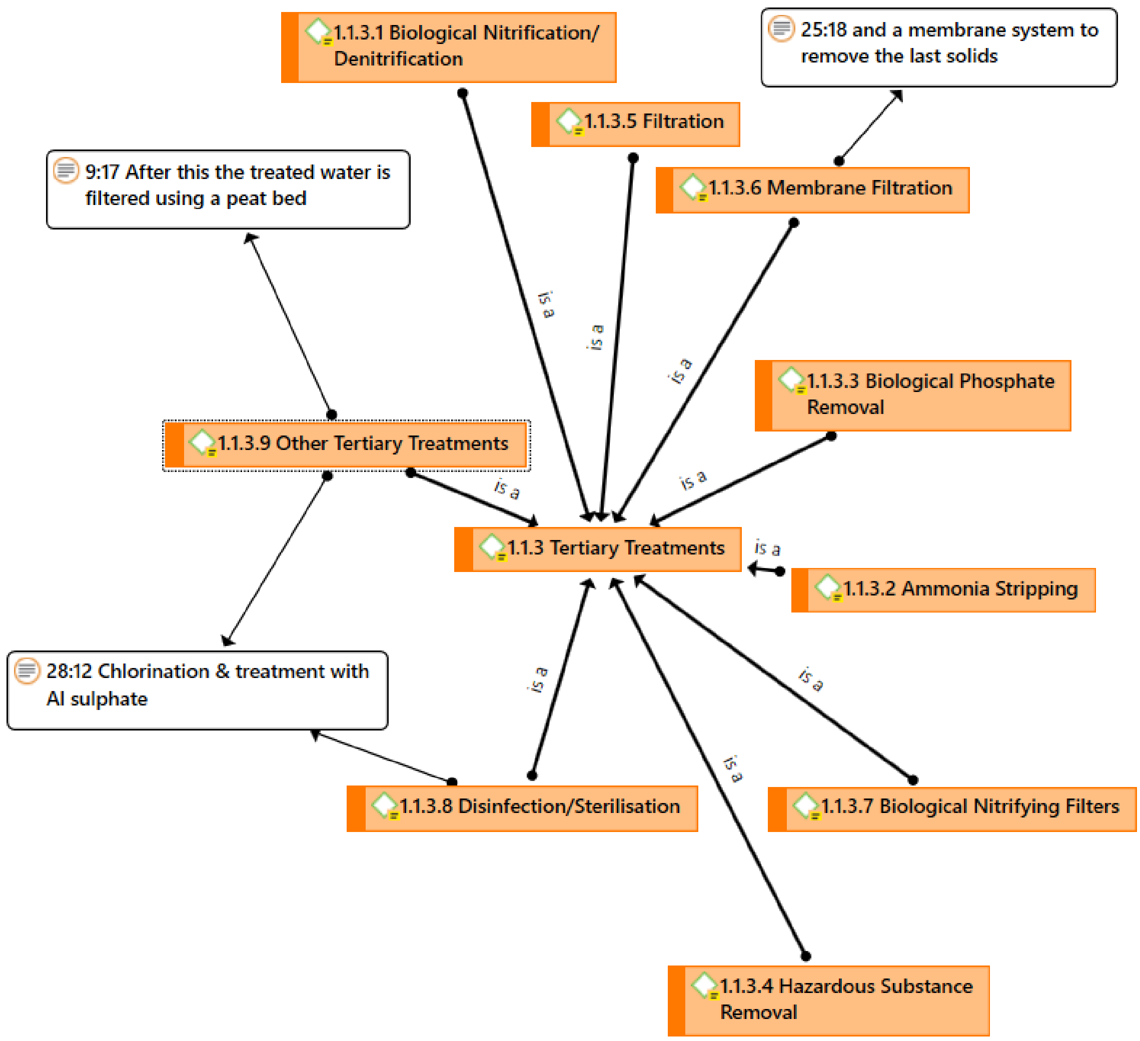

Figure 34 Network of possible and discovered tertiary treatments in the South African FVPI.

5.3.3.4 Effluent disposal routes

Effluent disposal in the FVPI was very much dependant on the locality of the facilities in question. If located in urban environments, discharge into the municipal wastewater system was, not surprisingly, the method in use. For facilities located in rural/agricultural regions, irrigation of the effluent onto pasture or orchards was a common practice. Although, as previously mentioned, the legality of the wastewater quality was questionable when it came to some of these facilities. Only one facility deviated from the irrigation or municipal disposal route. This is the potato processor located in the Western Cape, which was permitted to discharge its wastewater into the ocean.

Chapter 6 CONCLUSIONS AND RECOMMENDATIONS

The knowledge of water and wastewater management in the South African industrial environment found it's nativity in the first edition NATSURV documents published in the late 1980s to early 1990s. Specifically in relation to the fruit and vegetable processing industry, the first edition NATSURV highlighted the water intensive and polluting effect of the industry. Recommendations for improved water efficiency were also provided.

The first objective of this study entailed a detailed economic analysis of the FVPI in South Africa, its changes since the publishing of the first edition NATSURV, as well as its projected changes. Indeed, the structure and nature of the industry has changed drastically in the last 30 years, possibly a consequence of the deregulation of South African agricultural commodities and market liberalisation. A key feature of the industry now is its strong export orientated approach to production, and its focus specifically on intra-Africa trade. The pivotal commodities in the industry are fruit juice concentrates and canned vegetable products, with slightly over ZAR 10 billion and ZAR 6 billion production value (2014), respectively. Another important aspect of the industry is its highly competitive and concentrated nature, with a few key players accounting for large portions of both production and employment. The locations of processing facilities is generally determined by the proximity of the raw inputs, with only a few exceptions. The Western Cape was found to be the leading host of processing facilities, with a heavy focus being placed on the juicing and canning of deciduous fruits. The Eastern Cape, Northern Cape, Limpopo and Mpumalanga provinces also played host to their fair share of fruit and vegetable processing.

Although peer-reviewed articles pertaining to the improvement of water efficiency in fruit and vegetable processing is limited, there exists a fairly wide variety of industry/government produced reports. One of the most useful was the Reference Document on the Food, Drink and Milk Industry (IPPC, 2006), which contains metric comparisons across a wide variety of fruit and vegetable products, as well as techniques that can increase water efficiency. Another useful report was that provided by CLFP (2015), which provided metric comparisons, and active water minimisation techniques practiced by Californian fruit and vegetable processors. The literature review section of this investigation will provide interested parties the opportunity to view all the various water saving measures available, as well as different wastewater treatment options.

This explorative portion of the study commenced with the building of an industry database, which was done using a combination of internet searches, referrals and by contacting the relevant representative bodies. The industry bodies were also notified of the purposes of the study and were asked to encourage their members to participate in any subsequent investigative efforts. After having built the industry database, an introductory letter was sent to all facilities, detailing the aims, objectives and scope of the project. This initial contact was hoped to prepare the facilities for the electronic survey which was made available via email shortly after. The electronic survey was created using the highly secure REDCap online platform. The survey revealed a response rate of

12,16% which was favourable considering the general lack of industry participation observed in other NATSURV investigations. A simultaneous occurrence were the site-visits of facilities willing to accommodate the NATSURV 19 team. The industry is highly competitive and protective, but even so a total of 14 facilities were visited on a case-study basis. Interviews were conducted at all 14 visited facilities, although the decision to record and transcribe interviews was only made after the first five facilities had been visited. The information collected from the earlier facilities was, however, still of sufficient quality to be included in the qualitative analysis that the recorded interviews were subjected to. The qualitative analysis (more specifically, content analysis) was conducted according to the deductive approach (& Kyngäs, 2008; Bengtsson, 2016) using the Atlas.ti 9 CAQDAS platform.

The surveying of the South African FVPI revealed current practice as well as the rate of technology adoption, which related to the second objective of this study. It is therefore encouraging that some of the facilities reported SWI figures comparable or better than that of their international counterparts (Objective 3). In addition to this, some facilities did perform well in relation to the SWI's established for certain products in the original 1987 NATSURV, indicating at least anecdotally an improvement in water-use efficiency over the last three decades. There is, however, room for improvement in other industrial units surveyed during the investigation. Many of the facilities have dedicated long term strategies for improving water use, with one facility in particular having almost halved water consumption over a three-year period. In general, it was found that the raw material and facility cleaning were found to be the main consumers of water, and therefore initial water saving endeavours should be directed at these operations. A pertinent point that must be made is that water saving strategies need not be a complicated affair, with a perfect example being the replacement of dumper baths with dry conveying at one facility, which reduced water consumption by 20%. Many water saving strategies employed by facilities were not found during the literature review, proving that a comprehensive report on water-efficiency improvements cannot only be made according to previous studies. A pertinent example of this would be the planned installation of a UV filtration system in the initial raw material washing at facility 3013.16, to increase the time between wash water change-over. Another example would be the use of a sanitisation protocol employed by facility 3013.18 (a sanitiser and water applied using compressed air instead of traditional cleaning with a hosepipe). In some instances, a disconnect between claims of water-efficient practices, and that which was observed at floor level, was noticed (as evidenced by the use of normal hosepipes, and not nozzles).

It must however be noted that improvements in water efficiency in the South African FVPI are not only motivated by desire for environmental protection or drought risk, but also for financial reasons. The costs of water consumption and effluent disposal can be reduced by improving the water efficiency of the processes.

The final objective of the study was to determine effluent volumes and typical pollutant loads as well as best practice technology adoption. With regards to wastewater management, it can be concluded that advanced treatments are not generally practiced within the industry. Whilst most facilities perform at least a primary wastewater treatment, there seems to be less motivation for facilities to invest in secondary treatments, possibly due to the lengthy pay-back periods associated with the capital expenditure. Only three facilities of the 19 included in the final sample practiced advanced/tertiary treatment. The choice of disposal routes for the final effluent was also determined by the nature of the surroundings. Rural settings most commonly saw irrigation as the preferred disposal route, whilst urban environments provided the means for municipal wastewater systems. Although, specifically in two Eastern Cape facilities, the operational integrity of the municipal wastewater treatment plants receiving the effluent was questioned by the managers. Effluent quality varied between facilities, with some reporting figures in-line with those found in literature, whilst others reported figures higher than expected. Anecdotal evidence suggests that the reluctance of some facilities to provide effluent data may be due to irrigation levels exceeding those permitted by the General Authorisations in Terms of Section 13 of the National Water Act, 1998 (Act no. 36 of 1998) (DWA, 2013).

In conclusion, the current study has achieved the aim of serving as a comprehensive guide and benchmarking tool for the South African FVPI. The investigation has provided a sample of current water and wastewater management practices in the industry, and therefore, future work should seek to focus on individual processes and the optimisation thereof. It is recommended that Individual facilities be targeted for a more detailed water audit, as opposed to the walk-through audit (Navarri & Bédard, 2008) used in this investigation. Detailed water and energy balances can be calculated, and thereafter improvements can be recommended according to literature. Not one facility in this study utilised the design based approach of water pinch as described by Wang & Smith (1994); Klemeš & Perry (2007) and Kim and Smith (2008). Therefore, future work could involve the application of this technique to South African facilities, as done by Thevendiraraj *et al.* (2003). Another potential avenue of investigation would be investigating the degree of government apathy when it comes to the water and wastewater management in FVPI, and indeed, the food industry as a whole (as evidenced anecdotally by some facilities being able to irrigate wastewater of an insufficient quality). It must also be mentioned that The WRC has made funding available for continued investigation into the wastewater component of the FVPI. This supplementary research will build on the findings of this study, with more attention being given to the applicable treatment options available to the industry. In accordance with the capacity-building initiative of the WRC, a portion of this funding will be given to a second Masters student. It is hoped that the findings of the current investigation can assist the newer researcher in narrowing the scope of their future inquires.

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LIST OF APPENDICES

Appendix A: Industry introductory letter

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Introductory Letter

Dear Sir/Madame,

RE: National Survey (NATSURV) of Water and Wastewater Management in the Fruit and Vegetable Processing Industry

During the middle 1980s the Water Research Commission (WRC) with the support of the Department of Water Affairs and Forestry (now the Department of Water Affairs and Sanitation) commissioned a series of surveys relating to water use and wastewater treatment practices in industry. The purposes of these NATSURVs (as they later became known) was to determine minimum specific water intake requirements so that during times of drought, blanket restrictions would not impose an unfair burden on certain facilities. The surveys were also used by regulators to manage wastewater discharges in order to protect downstream infrastructure and treatment facilities. The original NATSURVs have been used by academia, industry and regulators as a valuable benchmarking platform for the last three decades.

One has only to look at the recent drought as evidence for the water-stressed (and arguably water scarce) nature of our country. Considering this, it can be argued that an increased focus on water use and wastewater management practices is required to ensure the environmental feasibility of the private sector, which forms the backbone of the economy.

Since 2013, the WRC has been hard at work updating the NATSURVs. This was done in response to fact that South Africa's industrial landscape has changed significantly in the last three decades. In addition to this, novel technologies and process changes may have had noticeable impacts on water consumption and/or wastewater treatment efficiencies.

The NATSURV 19 project team in collaboration with the National Cleaner Production Centre (NCPC), invites you to be part of this valuable information gathering initiative that we believe can contribute to increased awareness surrounding the importance of water in industry. The data collection will take place by means of an electronic questionnaire that will be made available on the 1st March 2019. Please note that your confidentiality is of the highest importance and if a Non-disclosure agreement (NDA) is required, your request will be accommodated. Please expect a reminder to complete the survey on 1st June and 1st August 2019. The closing date for the survey will be the 31st August 2019.

Our aim is to develop a comprehensive, representative and relevant NATSURV that has the support of all members of the fruit and vegetable processing industry. We are therefore excited to announce the endorsement of the following producer bodies who share our vision for an industry-backed initiative:

WATER RESEARCH COMMISSION · safvca · Dried Fruit Technical Services (DFTS) · SAFJA SOUTH AFRICAN FRUIT JUICE ASSOCIATION · NCPC NATIONAL CLEANER PRODUCTION CENTRE SOUTH AFRICA

South African Fruit and Vegetable Canners Association (SAFVCA) www.safvca.co.za

South African Fruit Juice Association (SAFJA) www.safja.co.za

Dried Fruit Technical Services (DFTS) www.hortgro.co.za/dfts/

It would be greatly appreciated if you could assist the project team in their future endeavours. If you have any further questions or concerns about the research, please feel free to contact me via email (gos@sun.ac.za) or telephonically (072 557 6082). Alternatively, feel free to contact the project leader, **Chris Swartz**, via email (cswartz@mweb.co.za) or telephonically (082 820 4481).

Kind regards,

Prof Gunnar Sigge
Departmental Chair: Food Science, Stellenbosch University

On behalf of the NATSURV 19 Project Team

Appendix B: Electronic survey consent form

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CONSENT TO PARTICIPATE IN RESEARCH

Dear Sir/Madam,

My name is Pierre Volschenk, a student at the Department of Food Science, Stellenbosch University, and I would like to invite you to take part in a survey, the results of which will contribute to a WRC funded project investigating water and wastewater management in the fruit and vegetable processing industry

Please take some time to read the information presented here, which will explain the details of this project. Your participation is entirely voluntary, and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

During the middle 1980s the Water Research Commission (WRC) with the support of the Department of Water Affairs and Forestry (now the Department of Water and Sanitation) commissioned a series of surveys relating to water use and wastewater treatment practices in industry. The purpose of these NATSURVs (as they later became known) was to determine minimum specific water intake requirements so that during times of drought, blanket restrictions would not impose an unfair burden on certain facilities. The surveys were also used by regulators to manage wastewater discharges in order to protect downstream infrastructure and treatment facilities, and the environment in general. The original NATSURVs have been used by academia, industry, regulators and consulting engineers as a valuable benchmarking platform for the last three decades. Since 2013, the WRC has been actively updating the NATSURVs, and it is in light of this that you are invited to partake in an electronic survey (link provided in email) that will be investigating the water and wastewater management practices in your facility. The information collected in the survey process (from approximately 78 identified processing facilities) will help compile NATSURV 19 (Water and Wastewater Management in the Fruit and Vegetable Processing Industry).
The questionnaire will take approximately 15 minutes to complete, and you will have until the 31st August for final submission.

RIGHTS OF RESEARCH PARTICIPANTS:
You have the right to decline answering any questions and you can exit the survey at any time without giving a reason. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact Mrs Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

Your information and response to the survey will be protected. Only the NATSURV 19 project team will have access to the data, and your facilities name or contact details will not mentioned in any publication. Data will be stored in electronic format on a password enabled device

If you have any questions or concerns about the research, please feel free to contact me at 18172601@sun.ac.za. Or if you prefer, the project leader, Mr. Chris Swartz (cswartz@mweb.co.za) and/or my Supervisor, Prof Gunnar Sigge (gos@sun.ac.za).

Please enable editing mode in this document and fill in your name and the name of your company/facility. Please check the 2 boxes below if you are willing to proceed with the survey. Please send the completed document back to the email address from which you received it (18172601@sun.ac.za).

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Name and surname:

Name of company/facility:

I confirm that I have read and understood the information provided for the current study.	YES ☐	NO ☐
I agree to take part in this survey.	YES ☐	NO ☐

Appendix C: REDCap data dictionary codebook

NATSURV 19

Codebook ▾

Data Dictionary Codebook

28/10/2019 14:12

#	Variable / Field Name	Field Label *Field Note*	Field Attributes (Field Type, Validation, Choices, Calculations, etc.)
Instrument: **NATSURV 19** (natsurv_19)			
1	participant_id	Participant ID	text
2	name	Section Header: *General information* Name of person completing survey	text, Required, Identifier Question number: 1
3	facility	Name of company/factory	text, Required, Identifier
4	address	Address	notes, Required, Identifier
5	permission_granted	I, as the authorized person completing the NATSURV 19 electronic survey, hereby knowledge that I have completed and returned the electronic consent form. I also give permission for the NATSURV 19 project team to use the data provided with the assurance that my personal information will be protected and that no addresses or names will be mentioned in any published material.	radio, Required 1 Agree 2 Disagree
6	prod_season	Section Header: *Production information* Please indicate the production season of your factory by selecting the applicable months below	checkbox 1 prod_season___1 January 2 prod_season___2 February 3 prod_season___3 March 4 prod_season___4 April 5 prod_season___5 May 6 prod_season___6 June 7 prod_season___7 July 8 prod_season___8 August 9 prod_season___9 September 10 prod_season___10 October 11 prod_season___11 November 12 prod_season___12 December Custom alignment: LV
7	raw_materials	Please indicate the typical/average/previous year's amount of raw fruit and/or vegetables processed annually (per fruit/vegetable category) *tons per annum*	notes Custom alignment: LV
8	source	Section Header: *Water usage* Please indicate the source of fresh water intake for your factory	checkbox 1 source___1 Municipal 2 source___2 River/Dam 3 source___3 Borehole Custom alignment: RH
9	yn_water_records	Do you maintain records of fresh water consumption?	radio, Required 1 Yes 2 No Custom alignment: RH
10	water_consump Show the field ONLY if: [yn_water_records] = '1'	Please provide total annual water consumption (typical/average/previous year) if known *cubic meters of fresh water*	text (number) Custom alignment: RH
11	daily_consumption Show the field ONLY if: [yn_water_records] = '1'	Please provide average daily water consumption (if known) during the production season *cubic meters of fresh water*	text (number)

12	specific_consumption Show the field ONLY if: [yn_water_records] = '1'	Please provide specific water volumes for each fruit or vegetable production process (if known) *in cubic meters per ton*	notes
13	saving_importance	Section Header: *Water minimisation in your facility* On a scale of 1 to 5 (1 - Low priority; 5 - High priority) how high a priority do you consider water saving in your facility?	radio, Required 1 1 2 2 3 3 4 4 5 5 Custom alignment: LV
14	targets_in_place	Are there any water use targets in place?	radio, Required 1 Yes 2 No Custom alignment: LV
15	targets_met Show the field ONLY if: [targets_in_place] = '1'	Are these water use targets being met?	radio 1 Yes 2 No Custom alignment: LV
16	saving_measures	Please indicate the various means of water saving in your facility *multiple options allowed*	checkbox 1 saving_measures___1 Water Pinch/Other design optimisation platforms 2 saving_measures___2 Water reuse and recycling 3 saving_measures___3 Adoption of water free operations 4 saving_measures___4 Process control and monitoring 5 saving_measures___5 Avoidance of once-through water use (i.e. use of re-circulation) 6 saving_measures___6 Improved energy efficiency in steam-based processes 7 saving_measures___7 Water awareness training for staff 8 saving_measures___8 Dedicated maintenance (e.g. leak repair) 9 saving_measures___9 Water-wise cleaning 10 saving_measures___10 Other Custom alignment: LV
17	wa_free_op Show the field ONLY if: [saving_measures(3)] = '1'	You have indicated the use of water-free operations. Please describe the operation/s.	notes Custom alignment: LV
18	water_wise_cleaning Show the field ONLY if: [saving_measures(9)] = '1'	You have indicated the use of water-wise cleaning in your facility. Please describe these.	notes Custom alignment: LV
19	other_water_saving Show the field ONLY if: [saving_measures(10)] = '1'	You have indicated "Other" as a water-saving measure. Please describe.	notes Custom alignment: LV

20	green_tech	Do you utilise, or are you planning on adopting any of the following "green"/environmentally-friendly technologies?	checkbox 1 green_tech__1 Instant controlled pressure drop technology (DIC) 2 green_tech__2 Ultrasound assisted processing 3 green_tech__3 Microwave processing 4 green_tech__4 Cold-plasma 5 green_tech__5 Pulsed Electric Field (PEF) processing 6 green_tech__6 Infra-red (IR) processing 7 green_tech__7 Ohmic heating 8 green_tech__8 High pressure processing (HPP) 9 green_tech__9 Super Critical Fluids 10 green_tech__10 Ultraviolet (UV) processing and/or sterilisation 11 green_tech__11 Other Custom alignment: LV
21	other_green_tech Show the field ONLY if: [green_tech(11)] = '1'	You have indicated "Other" under "green"/environmentally-friendly technologies. Please describe.	text Custom alignment: LV
22	drought_response_y_n	Have you adopted any of the aforementioned water-saving measures (conventional or "green") SPECIFICALLY in response to the recent drought?	radio, Required 1 Yes 2 No Custom alignment: LV
23	annual_effluent	Section Header: *Wastewater generation and management* Please provide your estimated/average/previous year's ANNUAL effluent volume (if known) *in cubic meters*	text (number)
24	daily_effluent	Please provide your estimated/average/previous year's DAILY effluent volume during the production season (if known). *in cubic meters*	text (number)
25	treatment	What treatment does the effluent undergo before discharge? *multiple options allowed*	checkbox 1 treatment__1 Primary 2 treatment__2 Secondary 3 treatment__3 Tertiary 4 treatment__4 Other
26	primary_trtmnt Show the field ONLY if: [treatment(1)] = '1'	You have indicated primary treatment of effluent. Please describe the processes/treatments involved	notes
27	secondary_trtmt Show the field ONLY if: [treatment(2)] = '1'	You have indicated secondary treatment of effluent. Please describe this treatment.	notes
28	tertiary_trtmt Show the field ONLY if: [treatment(3)] = '1'	You have indicated the use of tertiary effluent treatment. Please describe the treatments involved.	notes
29	other_eff_treatments Show the field ONLY if: [treatment(4)] = '1'	You have indicated the use of "Other" effluent treatments. Please describe the treatments involved	notes
30	energy_sources	Section Header: *Energy Usage* What are your energy sources? Please select. *multiple options allowed*	checkbox 1 energy_sources__1 Boiler 2 energy_sources__2 Grid (municipal electricity) 3 energy_sources__3 Solar 4 energy_sources__4 Biogas from wastewater 5 energy_sources__5 Other
31	other_energy Show the field ONLY if: [energy_sources(5)] = '1'	You have indicated "Other" as an energy source. Please specify	notes

32	kwh_per_day	What is the average/typical/previous year's DAILY energy use during your production season (if known) *kWh*	text
33	kwh_per_annum	What is the average/typical/previous year's ANNUAL energy consumption (If known). *kWh*	text (number)
34	r_kwh	What is the unit cost (R/kWh) of energy used? *R/kWh*	text (number)
35	gas_emissions	Please describe any gaseous emissions prevalent in your facility, and what measures are in place to mitigate or reduce these emissions	notes
36	docs	Section Header: *Supporting documents* If you have any supporting documents pertaining to water use and wastewater management, these can be uploaded here.	file
37	natsurv_19_complete	Section Header: *Form Status* Complete?	dropdown 0 Incomplete 1 Unverified 2 Complete

Appendix D: Site visit consent form

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Site-Visit Consent

Dear Sir/Madam,

My name is Pierre Volschenk, a student at the Department of Food Science, Stellenbosch University, and I would like to thank you for allowing us the opportunity to visit your facility.

Please take some time to read the information presented here, which will explain the details of this project. Your participation is entirely voluntary, and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

During the middle 1980s the Water Research Commission (WRC) with the support of the Department of Water Affairs and Forestry (now the Department of Water and Sanitation) commissioned a series of surveys relating to water use and wastewater treatment practices in industry. The purpose of these NATSURVs (as they later became known) was to determine minimum specific water intake requirements so that during times of drought, blanket restrictions would not impose an unfair burden on certain facilities. The surveys were also used by regulators to manage wastewater discharges in order to protect downstream infrastructure and treatment facilities, and the environment in general. The original NATSURVs have been used by academia, industry, regulators and consulting engineers as a valuable benchmarking platform for the last three decades.

Since 2013, the WRC has been actively updating the NATSURVs, and it is in light of this that you have been invited to partake in an electronic survey that will be investigating the water and wastewater management practices in your facility. *The purpose of this site-visit is to enrich and contextualise the data obtained in the electronic survey.*

RIGHTS OF RESEARCH PARTICIPANTS
You have the right to decline answering any questions and you can request a discontinuation of the site-visit at any time without giving a reason. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact Mrs Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

Your information and responses during the site-visit will be protected. Only the NATSURV 19 project team will have access to the data, and your facilities' name or contact details will not mentioned in any publication. By signing this consent form, you also give permission for the NATSURV 19 project team to perform a recorded interview. All information obtained in the interview will be transcribed into a written electronic format and stored on a password enabled device. The original recordings will also be securely stored on password enabled devices.

If you have any questions or concerns about the research, please feel free to contact me at 18172601@sun.ac.za. Or if you prefer, the project leader, Mr. Chris Swartz (cswartz@mweb.co.za) and/or my Supervisor, Prof Gunnar Sigge (gos@sun.ac.za).

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I, ... *(Name and Surname)*, an approved representative of .... *(Name of facility and company)*, hereby give permission for the NATSURV 19 project team to conduct a guided site-visit and interview for the purposes of data collection surrounding water and wastewater management in my facility. I acknowledge that my rights, and indeed my companies' rights as a research participant have been fully explained to me.

....

Date *Signature*

Appendix E: Atlas.ti 9 code report

Project: NATSURV 19

Report created by Pierre Volschenk on 2020/09/19

Code Report – Grouped by: Documents

All (115) codes

Documentless

39 Codes:

- **1.1.1.5 DAF**
- **1.1.1.6 Centrifugation**
- **1.1.2.1.1 Activated Sludge**
- **1.1.2.1.2 Pure Oxygen System**
- **1.1.2.1.3 SBR**
- **1.1.2.1.5 Trickling Filters**
- **1.1.2.1.6 Biotowers**
- **1.1.2.1.7 RBC**
- **1.1.2.1.8 BAFF/SBAF**
- **1.1.2.1.9 High Rate Aerobic Filters**
- **1.1.2.2.2 Anaerobic Contact Processes**
- **1.1.2.2.3 Anaerobic Filters**
- **1.1.2.2.5 IC Reactors**
- **1.1.2.2.6 Hybrid UASB**
- **1.1.2.2.7 Fluidised and Expanded Bed Reactors**
- **1.1.2.2.8 EGSB**
- **1.1.3 Tertiary Treatments**
- **1.1.3.1 Biological Nitrification/Denitrification**
- **1.1.3.2 Ammonia Stripping**
- **1.1.3.3 Biological Phosphate Removal**
- **1.1.3.4 Hazardous Substance Removal**
- **1.1.3.5 Filtration**
- **1.1.3.7 Biological Nitrifying Filters**
- ○ **1.2.2.1 Reducing driving force for mass transfer**

- ○ **1.2.2.11 Novel Technologies**
- ● **1.2.2.11.1 DIC**
- ● **1.2.2.11.10 Supercritical Fluids**
- ● **1.2.2.11.11 Other Novel Tech**
- ● **1.2.2.11.2 Ultrasound**
- ● **1.2.2.11.3 Microwave**
- ● **1.2.2.11.4 Cold Plasma**
- ● **1.2.2.11.5 PEF**
- ● **1.2.2.11.6 IR**
- ● **1.2.2.11.7 OH**
- ● **1.2.2.11.8 HPP**
- ● **1.2.2.11.9 UV**
- ○ **1.2.2.5 Improved Production Scheduling**
- ● **1.2.6 Importance of water saving**
- ● **2.5 Processing Category**

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1 FAC 3013.6

32 Codes:

- ○ **1 Water and Wastewater Management**
- ● **1.1 Wastewater Management**
- ● **1.1.1 Primary Treatments**
- ● **1.1.1.1 Screening**
- ● **1.1.1.2 Neutralisation**
- ● **1.1.5 Effluent Disposal**
- ● **1.2 Water Consumption Management**
- ● **1.2.2 Process Changes**
- ● **1.2.2.10 Improved Cleaning Techniques**
- ● **1.2.2.9 Proper Maintenance**
- ● **1.2.3 Reuse and Recycling**
- ● **1.2.4 Incoming Water**
- ● **1.2.4.2.1 Borehole**
- ● **1.2.4.2.2 Dam/River**
- ● **1.2.5.1 Material Washing**
- ● **1.2.5.3 Process Water**

- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.2 Production Season
- 2.2.1 Seasonal
- 2.3 Markets
- 2.3.2 Export
- 2.4 Employment
- 2.4.1 Permanent
- 2.4.2 Seasonal
- 2.5.1 Juicing
- 3 Energy Management
- 3.2 Gaseous Emmisions
- 3.3 Energy Source
- 3.3.1 Boiler
- 3.3.4 Municipal electricity

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2 FAC 3013.7

39 Codes:

- ○ 1 Water and Wastewater Management
- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.1 Screening
- 1.1.1.2 Neutralisation
- 1.1.1.4 Sedimentation
- 1.1.2 Secondary Treatments
- 1.1.2.1 Aerobic Treatments
- 1.1.2.1.4 Aerobic Lagoons
- 1.1.2.2 Anaerobic Treatments
- 1.1.2.2.1 Anaerobic Lagoons
- 1.1.5 Effluent Disposal
- 1.2 Water Consumption Management
- 1.2.2 Process Changes
- 1.2.2.10 Improved Cleaning Techniques

- 1.2.3 Reuse and Recycling
- 1.2.4 Incoming Water
- 1.2.4.1 Incoming Treatment
- 1.2.4.2.1 Borehole
- 1.2.4.2.3 Municipal
- 1.2.5.1 Material Washing
- 1.2.5.2 Facility Cleaning
- 1.2.6.3 High priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.2 Production Season
- 2.2.1 Seasonal
- 2.4 Employment
- 2.4.1 Permanent
- 2.4.2 Seasonal
- 2.5.1 Juicing
- 2.5.3 Canning/Bottling
- 2.5.4 Freezing
- 3 Energy Management
- 3.2 Gaseous Emmisions
- 3.3 Energy Source
- 3.3.1 Boiler
- 3.3.4 Municipal electricity

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3 FAC 3013.8

29 Codes:

- 1 Water and Wastewater Management
- 1.1.2 Secondary Treatments
- 1.1.2.2.9 Other Anaerobic Treatments
- 1.1.5 Effluent Disposal
- 1.2 Water Consumption Management
- 1.2.2 Process Changes
- 1.2.2.10 Improved Cleaning Techniques

- 1.2.2.3 Process Control/Optimisation
- 1.2.3 Reuse and Recycling
- 1.2.4 Incoming Water
- 1.2.4.1 Incoming Treatment
- 1.2.4.2.1 Borehole
- 1.2.5 Water Using Operations
- 1.2.5.3 Process Water
- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.2 Production Season
- 2.2.2 Non-seasonal
- 2.3 Markets
- 2.3.1 Local Market
- 2.4 Employment
- 2.4.1 Permanent
- 2.4.2 Seasonal
- 2.5.3 Canning/Bottling
- 3 Energy Management
- 3.3 Energy Source
- 3.3.2 Solar
- 3.3.4 Municipal electricity

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4 FAC 3013.9

32 Codes:

- 1 Water and Wastewater Management
- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.4 Sedimentation
- 1.1.5 Effluent Disposal
- 1.2 Water Consumption Management
- 1.2.2 Process Changes
- 1.2.2.10 Improved Cleaning Techniques
- 1.2.2.3 Process Control/Optimisation

- 1.2.2.6 Improved Equipment Design
- 1.2.2.9 Proper Maintenance
- 1.2.4 Incoming Water
- 1.2.4.2 Type of Source
- 1.2.4.2.1 Borehole
- 1.2.4.2.3 Municipal
- 1.2.4.2.4 Other water source
- 1.2.5.2 Facility Cleaning
- 1.2.5.3 Process Water
- 2 Production Information
- 2.1 Raw Material
- 2.1.2 Vegetables
- 2.2 Production Season
- 2.2.2 Non-seasonal
- 2.3 Markets
- 2.3.1 Local Market
- 2.4 Employment
- 2.4.1 Permanent
- 2.5.4 Freezing
- 3 Energy Management
- 3.3 Energy Source
- 3.3.1 Boiler
- 3.3.4 Municipal electricity

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5 FAC 3013.10

32 Codes:

- 1 Water and Wastewater Management
- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.1 Screening
- 1.1.1.4 Sedimentation
- 1.1.5 Effluent Disposal
- 1.2 Water Consumption Management
- 1.2.2 Process Changes

- 1.2.2.10 Improved Cleaning Techniques
- 1.2.2.8 Provide Training
- 1.2.3 Reuse and Recycling
- 1.2.4 Incoming Water
- 1.2.4.1 Incoming Treatment
- 1.2.4.2.1 Borehole
- 1.2.5.1 Material Washing
- 1.2.5.2 Facility Cleaning
- 2 Production Information
- 2.1 Raw Material
- 2.1.2 Vegetables
- 2.2 Production Season
- 2.2.2 Non-seasonal
- 2.3 Markets
- 2.3.1 Local Market
- 2.4 Employment
- 2.4.1 Permanent
- 2.4.2 Seasonal
- 2.5.3 Canning/Bottling
- 3 Energy Management
- 3.2 Gaseous Emmisions
- 3.3 Energy Source
- 3.3.1 Boiler
- 3.3.4 Municipal electricity

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6 FAC 3013.11

30 Codes:

- 1 Water and Wastewater Management
- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.1 Screening
- 1.1.1.2 Neutralisation
- 1.1.1.4 Sedimentation
- 1.1.1.7 Precipitation

- 1.1.5 Effluent Disposal
- 1.2 Water Consumption Management
- 1.2.1 Design Based Optimisation /Pinch
- 1.2.2 Process Changes
- 1.2.2.10 Improved Cleaning Techniques
- 1.2.2.4 Avoidance of Once-through Use
- 1.2.2.8 Provide Training
- 1.2.2.9 Proper Maintenance
- 1.2.4 Incoming Water
- 1.2.4.2 Type of Source
- 1.2.4.2.3 Municipal
- 1.2.5 Water Using Operations
- 1.2.5.3 Process Water
- 2 Production Information
- 2.1 Raw Material
- 2.1.2 Vegetables
- 2.4 Employment
- 2.4.2 Seasonal
- 2.5.4 Freezing
- 3 Energy Management
- 3.3 Energy Source
- 3.3.1 Boiler
- 3.3.4 Municipal electricity

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7 FAC 3013.12

33 Codes:

- 1 Water and Wastewater Management
- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.1 Screening
- 1.1.5 Effluent Disposal
- 1.2 Water Consumption Management
- 1.2.2 Process Changes
- 1.2.2.10 Improved Cleaning Techniques

- 1.2.2.8 Provide Training
- 1.2.2.9 Proper Maintenance
- 1.2.3 Reuse and Recycling
- 1.2.4 Incoming Water
- 1.2.4.2 Type of Source
- 1.2.4.2.3 Municipal
- 1.2.6.2 Intermediate priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.2 Vegetables
- 2.2 Production Season
- 2.2.2 Non-seasonal
- 2.3 Markets
- 2.3.2 Export
- 2.4 Employment
- 2.4.1 Permanent
- 2.4.2 Seasonal
- 2.5.3 Canning/Bottling
- 3 Energy Management
- 3.2 Gaseous Emmisions
- 3.3 Energy Source
- 3.3.1 Boiler
- 3.3.2 Solar
- 3.3.4 Municipal electricity
- 3.3.5 Other energy sources

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8 FAC 3013.13

32 Codes:

- 1 Water and Wastewater Management
- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.1 Screening
- 1.1.2 Secondary Treatments
- 1.1.2.1.4 Aerobic Lagoons

- 1.1.5 Effluent Disposal
- 1.2 Water Consumption Management
- 1.2.2 Process Changes
- 1.2.2.10 Improved Cleaning Techniques
- 1.2.2.3 Process Control/Optimisation
- 1.2.2.4 Avoidance of Once-through Use
- 1.2.2.7 Improved Energy Efficiency
- 1.2.4 Incoming Water
- 1.2.4.2.2 Dam/River
- 1.2.4.2.3 Municipal
- 1.2.5.1 Material Washing
- 1.2.5.2 Facility Cleaning
- 1.2.5.4 Product Make-up
- 1.2.6.3 High priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.1.2 Vegetables
- 2.4 Employment
- 2.4.1 Permanent
- 2.4.2 Seasonal
- 2.5.3 Canning/Bottling
- 3 Energy Management
- 3.3 Energy Source
- 3.3.1 Boiler
- 3.3.4 Municipal electricity

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9 FAC 3013.14

33 Codes:

- ○ 1 Water and Wastewater Management
- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.1 Screening
- 1.1.2 Secondary Treatments

- 1.1.2.1.10 Other Aerobic Treatments
- 1.1.3.9 Other Tertiary Treatments
- 1.1.5 Effluent Disposal
- 1.2 Water Consumption Management
- 1.2.2 Process Changes
- 1.2.2.10 Improved Cleaning Techniques
- 1.2.2.8 Provide Training
- 1.2.2.9 Proper Maintenance
- 1.2.4 Incoming Water
- 1.2.4.1 Incoming Treatment
- 1.2.4.2 Type of Source
- 1.2.4.2.1 Borehole
- 1.2.5.1 Material Washing
- 1.2.5.2 Facility Cleaning
- 1.2.6.2 Intermediate priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.2 Production Season
- 2.2.2 Non-seasonal
- 2.3 Markets
- 2.3.1 Local Market
- 2.4 Employment
- 2.4.1 Permanent
- 2.5.2 Drying
- 3 Energy Management
- 3.3 Energy Source
- 3.3.4 Municipal electricity

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10 FAC 3013.15

28 Codes:

- ○ 1 Water and Wastewater Management
- 1.1 Wastewater Management
- 1.1.1 Primary Treatments

- 1.1.1.1 Screening
- 1.1.5 Effluent Disposal
- 1.2 Water Consumption Management
- 1.2.4 Incoming Water
- 1.2.4.1 Incoming Treatment
- 1.2.4.2.2 Dam/River
- 1.2.5.1 Material Washing
- 1.2.5.2 Facility Cleaning
- 1.2.6.1 Low priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.2 Production Season
- 2.2.2 Non-seasonal
- 2.3 Markets
- 2.3.2 Export
- 2.4 Employment
- 2.4.1 Permanent
- 2.4.2 Seasonal
- 2.5.3 Canning/Bottling
- 2.5.4 Freezing
- 3 Energy Management
- 3.3 Energy Source
- 3.3.1 Boiler
- 3.3.4 Municipal electricity

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11 FAC 3013.16

28 Codes:

- 1 Water and Wastewater Management
- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.1 Screening
- 1.1.2 Secondary Treatments
- 1.1.2.2 Anaerobic Treatments

- 1.1.2.2.4 UASB
- 1.2 Water Consumption Management
- 1.2.2 Process Changes
- 1.2.2.9 Proper Maintenance
- 1.2.3 Reuse and Recycling
- 1.2.4 Incoming Water
- 1.2.4.2 Type of Source
- 1.2.4.2.3 Municipal
- 1.2.6.2 Intermediate priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.2 Production Season
- 2.2.1 Seasonal
- 2.4 Employment
- 2.4.1 Permanent
- 2.5.1 Juicing
- 3 Energy Management
- 3.3 Energy Source
- 3.3.1 Boiler
- 3.3.3 Methanogenic Treatments
- 3.3.4 Municipal electricity

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12 FAC 3013.17

28 Codes:

- ○ 1 Water and Wastewater Management
- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.1 Screening
- 1.1.1.2 Neutralisation
- 1.1.5 Effluent Disposal
- 1.2 Water Consumption Management
- 1.2.2 Process Changes
- 1.2.2.10 Improved Cleaning Techniques

- 1.2.2.2 Water Free Operations
- 1.2.3 Reuse and Recycling
- 1.2.4 Incoming Water
- 1.2.4.1 Incoming Treatment
- 1.2.4.2 Type of Source
- 1.2.4.2.3 Municipal
- 1.2.6.3 High priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.3 Markets
- 2.3.2 Export
- 2.4 Employment
- 2.4.1 Permanent
- 2.5.1 Juicing
- 3 Energy Management
- 3.3 Energy Source
- 3.3.1 Boiler
- 3.3.4 Municipal electricity

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25 FAC 3013.19

39 Codes:

- 1 Water and Wastewater Management
- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.1 Screening
- 1.1.1.2 Neutralisation
- 1.1.1.3 Flow and Load Equalisation
- 1.1.1.4 Sedimentation
- 1.1.2 Secondary Treatments
- 1.1.2.1.10 Other Aerobic Treatments
- 1.1.2.2 Anaerobic Treatments
- 1.1.2.2.9 Other Anaerobic Treatments
- 1.1.3.6 Membrane Filtration

- 1.1.5 Effluent Disposal
- 1.2 Water Consumption Management
- 1.2.1 Design Based Optimisation /Pinch
- 1.2.2.10 Improved Cleaning Techniques
- 1.2.2.4 Avoidance of Once-through Use
- 1.2.2.7 Improved Energy Efficiency
- 1.2.3 Reuse and Recycling
- 1.2.4 Incoming Water
- 1.2.4.2.2 Dam/River
- 1.2.5 Water Using Operations
- 1.2.5.3 Process Water
- 1.2.6.2 Intermediate priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.2 Production Season
- 2.2.1 Seasonal
- 2.4 Employment
- 2.4.1 Permanent
- 2.4.2 Seasonal
- 2.5.1 Juicing
- 3 Energy Management
- 3.1 Cost
- 3.2 Gaseous Emmisions
- 3.3 Energy Source
- 3.3.1 Boiler
- 3.3.4 Municipal electricity

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26 FAC 3013.18

26 Codes:

- 1 Water and Wastewater Management
- 1.1 Wastewater Management
- 1.1.4 No treatment
- 1.2 Water Consumption Management

- 1.2.1 Design Based Optimisation /Pinch
- 1.2.2.10 Improved Cleaning Techniques
- 1.2.2.3 Process Control/Optimisation
- 1.2.2.7 Improved Energy Efficiency
- 1.2.2.8 Provide Training
- 1.2.4.1 Incoming Treatment
- 1.2.4.2.1 Borehole
- 1.2.4.2.4 Other water source
- 1.2.5.1 Material Washing
- 1.2.5.4 Product Make-up
- 1.2.6.3 High priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.2 Vegetables
- 2.2 Production Season
- 2.2.1 Seasonal
- 2.3 Markets
- 2.3.2 Export
- 2.4 Employment
- 2.4.1 Permanent
- 2.4.2 Seasonal
- 2.5.3 Canning/Bottling

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27 FAC 3013.1

19 Codes:

- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.8 Other primary treatments
- 1.2 Water Consumption Management
- 1.2.2.10 Improved Cleaning Techniques
- 1.2.2.3 Process Control/Optimisation
- 1.2.2.9 Proper Maintenance
- 1.2.4 Incoming Water
- 1.2.4.2.3 Municipal

- 1.2.6.2 Intermediate priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.2 Production Season
- 2.2.2 Non-seasonal
- 2.5.1 Juicing
- 3 Energy Management
- 3.3.1 Boiler
- 3.3.4 Municipal electricity

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28 FAC 3013.2

25 Codes:

- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.1 Screening
- 1.1.2 Secondary Treatments
- 1.1.2.1.10 Other Aerobic Treatments
- 1.1.2.2 Anaerobic Treatments
- 1.1.3.8 Disinfection/Sterilisation
- 1.1.3.9 Other Tertiary Treatments
- 1.2 Water Consumption Management
- 1.2.2.3 Process Control/Optimisation
- 1.2.2.7 Improved Energy Efficiency
- 1.2.2.8 Provide Training
- 1.2.3 Reuse and Recycling
- 1.2.4.2.2 Dam/River
- 1.2.6.3 High priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.2 Production Season
- 2.2.1 Seasonal
- 2.5.1 Juicing

- 3 Energy Management
- 3.3 Energy Source
- 3.3.1 Boiler
- 3.3.4 Municipal electricity

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29 FAC 3013.3

21 Codes:

- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.1 Screening
- 1.1.1.2 Neutralisation
- 1.1.2 Secondary Treatments
- 1.1.2.1.10 Other Aerobic Treatments
- 1.1.5 Effluent Disposal
- 1.2 Water Consumption Management
- 1.2.2.9 Proper Maintenance
- 1.2.4 Incoming Water
- 1.2.4.2 Type of Source
- 1.2.4.2.3 Municipal
- 1.2.6.3 High priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.2 Production Season
- 2.2.1 Seasonal
- 2.5.2 Drying
- 3 Energy Management
- 3.3.4 Municipal electricity

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30 FAC 3013.4

16 Codes:

- 1.1 Wastewater Management
- 1.1.2 Secondary Treatments

- 1.2 Water Consumption Management
- 1.2.2.8 Provide Training
- 1.2.2.9 Proper Maintenance
- 1.2.4.2.2 Dam/River
- 1.2.4.2.3 Municipal
- 1.2.6.2 Intermediate priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.2 Production Season
- 2.2.1 Seasonal
- 2.5.2 Drying
- 3 Energy Management
- 3.3.4 Municipal electricity

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31 FAC 3013.5

23 Codes:

- 1.1 Wastewater Management
- 1.1.1 Primary Treatments
- 1.1.1.1 Screening
- 1.1.1.2 Neutralisation
- 1.2 Water Consumption Management
- 1.2.2.7 Improved Energy Efficiency
- 1.2.2.8 Provide Training
- 1.2.2.9 Proper Maintenance
- 1.2.3 Reuse and Recycling
- 1.2.4 Incoming Water
- 1.2.4.2 Type of Source
- 1.2.4.2.3 Municipal
- 1.2.6.3 High priority
- 2 Production Information
- 2.1 Raw Material
- 2.1.1 Fruit
- 2.2 Production Season

- 2.2.1 Seasonal
- 2.5.1 Juicing
- 3 Energy Management
- 3.3 Energy Source
- 3.3.1 Boiler
- 3.3.4 Municipal electricity

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32 PIC 3013.17

1 Codes:

- **1.2.7 Contradiction observed**

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33 PIC 3013.6

1 Codes:

- **1.2.7 Contradiction observed**

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34 PIC 3013.7

1 Codes:

- **1.2.7 Contradiction observed**