NATSURV 6: WATER, WASTEWATER AND ENERGY MANAGEMENT AND RECOMMENDATIONS FOR BEST PRACTICE IN THE CANE SUGAR PROCESSING INDUSTRY

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EXECUTIVE SUMMARY

Background to the NATSURV series

Manufacturing and processing industries consume significant quantities of energy and water, and generate large volumes of wastewater. This prompted the Water Research Commission (WRC) of South Africa to commission 16 national surveys (NATSURVs) of various agricultural and non-agricultural industries (malt brewing, poultry, red meat, edible oil, sorghum malt, beer, dairy, sugar, metal finishing, soft drink, tanning/leather finishing, laundry, textile, oil and refining, and power generating), culminating in the publication of 16 separate NATSURV documents between 1986 and 2001. Much of the information in the original series is now out-dated, and the WRC therefore commissioned a new series of NATSURV documents, starting in 2014.

The aims and objectives of the NATSURV series

The objective is for the NATSURV series to serve as guides and benchmark tools for stakeholders, including local governments, industry players, academics, researchers and engineers. The aims of the NATSURV document pertaining to the South African sugar industry were adapted from the WRC terms of reference. The primary aims of this publication are:

- To provide an overview of the sugar processing industry in South Africa, highlighting changes that have taken place since the previous NATSURV was published in 1990 and noting projected changes.
- To provide information about generic industrial processes, with an emphasis on water use and wastewater generation and treatment, and also to provide very basic information on energy use.
- To provide information about relevant national and local legislation and by-laws pertaining to water usage and wastewater generation.
- To provide water consumption, specific water consumption and wastewater generation data (local and global indicators).
- To provide information about typical pollutant loads in different effluent streams.
- To recommend best practices for water use (intake, treatment, and discharge), and indicate the extent to which the "reduce, reuse, recycle" principle has been adopted.

Collection of information and data

Information was collected via desktop studies of current literature, by conducting telephonic interviews and site visits, and by distributing and collecting questionnaires. The South African Sugar Association and South African Sugar Millers Association served as intermediaries between the project team and the sugar industry. A draft document was distributed to industry representatives and to members of the reference group, and a workshop was held to elicit comments that were taken into consideration when compiling the final document.

Document summary

The document consists of eight sections, including an introduction (Section 1), an overview of sugar cane processing (Section 2), and recommendations for best practice (Section 7). The salient points from the remaining sections (Sections 3 to 6) have been extracted for this executive summary:

Section 3: Environmental and water use regulations and policies applicable to the sugar industry

Most of the South African sugar mills and/or refineries are older than 50 years, and are therefore classed as "existing lawful users" for water abstraction in terms of the National Water Act. Permits for water abstraction from rivers are provided by the Department of Water and Sanitation. For the majority (9/12) of the study respondents, the relevant limit for discharge of effluent via irrigation or to rivers is a maximum chemical oxygen demand of 75 mg/L, and there is generally good compliance. One mill discharges to a marine outfall, and is subject to more comprehensive limits stipulated by the relevant Coastal Management Agency, while two mills discharge to municipal sewerage systems and need to comply with municipal limits.

Section 4: Water use and management

Sugar cane contains approximately 70% water, so sugar mills can theoretically operate as net water producers if process water is reused. Water reuse is the norm and the most important means of limiting the need for external water supplies by sugar processing facilities. The quality of water required for each process differs, and recycling loops are tailored so that the water used for each is "fit for purpose".

All of the study respondents indicated that they meter their water use, and have water use targets in place. This is very positive, because it has been shown globally that metering results in reduced water intake by industries because it creates awareness of water consumption. Water sources include river water, potable and raw municipal water, borehole water, and combinations of these.

The specific water intake (SWI) for sugar processing is defined as the volume (in kl) of water used to process one ton of sugar cane. The SWI determined from the questionnaires for stand-alone mills ranged from 0.04 to 1.13 kl/ton cane (average 0.37 kl/ton). The mill with the lowest SWI does not have access to river water for abstraction, with 50% of water intake being potable municipal water. A concerted effort and implementation of "best practice" policies, and water-saving infrastructure, processes and policies has allowed this mill to effect considerable water saving through the years.

Section 5: Wastewater generation and management

In sugar cane processing facilities, different streams of effluent are generated, each having a particular composition. The character and volume is largely determined by the processes and equipment that are used at individual facilities. As a general rule, all streams contain inorganics and suspended solids in varying concentrations that can be removed using primary physicochemical processes, such as settling and flocculation. Process effluent, wash water etc. contain high concentrations of organics (mainly sugars and sugar metabolites), and lend themselves to secondary biological treatment. The temperature of cooling tower blow-down and effluent from boiler scrubbers is elevated; this needs to be taken into account if the effluent is discharged directly to the aqueous environment. Ideally, each stream should be treated and discharged separately, but in practice they are usually combined.

In comparison to water intake, only 75% of respondents indicated knowledge of wastewater discharge volumes (metered or estimated). No wastewater quality data was provided by the industry. To offer readers information about the character of effluent quality from cane sugar processing, global literature data has been included in this document.

Section 6: Energy use and management

The bulk of the energy requirements of the South African sugar industry is provided by combustion (bagasse, coal, wood or spent bark). Less than 4% of energy is derived from the grid, while 81% is derived from combustion of bagasse. The industry is in a position to be a net exporter of electricity, with some mills already selling power derived from the combustion of bagasse to Eskom. This is seen as a carbon-neutral source of energy, and deserves more detailed information. However, the main focus of this NATSURV is water and wastewater management, so the section on energy management has been kept succinct.

ACKNOWLEDGEMENTS

The project team would like to thank:

- The South Africa Sugar Association and the South African Sugar Millers' Association, for providing the vital link between the project team and the sugar industry.
- The Sugar Milling Research Institute for providing valuable feedback.
- The milling companies (in alphabetical order) for providing the data for this document, and the industry representatives for providing feedback and contributing to constructive discussion during the workshop:
    - Gledhow Sugar Company (Pty) Ltd
    - Illovo Sugar South Africa Ltd
    - RCL Foods Sugar and Milling (Pty) Ltd
    - Tongaat-Hulett Sugar South Africa Ltd
    - UCL Company (Pty) Ltd
    - Umfolozi Sugar Mill

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List of Abbreviations

BER	Mill with back-end refinery
BOD	Biological oxygen demand
CIP	Cleaning-in-place
COD	Chemical oxygen demand
CW	Cooling water
DEA	Department of Environmental Affairs
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EAA	Environmental and Agricultural Affairs
EIN	Environmental indicator
EMP	Environmental management plan
IWRM	Integrated water resource management
KZN	KwaZulu-Natal
NA	Not applicable
NAMC	National Agricultural Marketing Council
NATSURV	National survey
NG	Not given
NWA	National Water Act
R	Refinery
SAM	Stand-alone mill
SASA	South African Sugar Association
SASID	South African Sugar Industry Directory
SS	Suspended solids
SWDV	Specific wastewater discharge volume
SWI	Specific water intake
TSS	Total suspended solids
WIN	Water use indicator
WSA	Water Services Act
WRC	Water Research Commission

Section 1: Introduction (background, methodology, delimitation)

Manufacturing and processing industries consume significant quantities of energy and water, and generate large volumes of wastewater. This prompted the Water Research Commission (WRC) of South Africa to commission 16 national surveys (NATSURVs) of various agricultural and non-agricultural industries (malt brewing, poultry, red meat, edible oil, sorghum malt, beer, dairy, sugar, metal finishing, soft drink, tanning/leather finishing, laundry, textile, oil and refining, and power generating), culminating in the publication of 16 separate NATSURV documents between 1986 and 2001. These documents included information about production processes, water usage, solid waste generation, and wastewater quality, quantity, and treatment practices.

In response to a number of inter-related factors, including increasing costs of waste disposal, more stringent legislative requirements, and increasing environmental awareness, more sustainable methods are constantly being implemented by industry to reduce qualitative and quantitative industrial pollutant loads and reuse water and waste. In addition, significant market-related changes have taken place in many industries over the decades. Much of the information in the original NATSURV series is therefore out-dated, and the WRC commissioned a new series of NATSURV documents. The objective of the NATSURV series is to serve as comprehensive guides and benchmark tools for stakeholders, including local governments, industry players, academics, researchers and engineers.

This document is an updated and expanded version of the previous NATSURV entitled "Water and wastewater management in the sugar industry" (WRC TT-47-90). The report includes data stemming from a basic audit of the sugar industry from both a local and global perspective. When compared to the original, the new document includes an additional section on energy management, a report on adoption/non-adoption of sustainable procedures by the industry, and features changes which have taken place over the last two and a half decades since the first NATSURV was published.

The following methodology was used to obtain data. Firstly, background information was obtained using desktop studies. Then, working closely with the South African Sugar Association (SASA), site visits were performed and questionnaires were distributed. Separate questionnaires were prepared for mills with back-end refineries (Appendix 1), stand-alone mills, and stand-alone refineries. Questionnaires were obtained from three of the four mills with back-end refineries (75% compliance), eight of the ten stand-alone mills (80% compliance), and the stand-alone refinery, giving an overall compliance to the request for questionnaire completion of 80%. The processing facilities included in the survey were delimited to those that mill and/or refine sugar cane and raw cane sugar, respectively. Further upstream (agriculture, transport of cane, etc.) and downstream (value-added) processes were mostly excluded. Other mills that produce speciality sugars were excluded (e.g. wet mills that produce glucose from maize).

1.1 Industry overview

1.1.1 What is sugar?

The building blocks of all carbohydrates are monosaccharides and disaccharides, the words being derived from the Latin for one (mono), two (di), and sugar (saccharum). A number of these sugar molecules exist, all with different structures. Common monosaccharides like glucose and fructose can be extracted from various agricultural crops like maize and wheat (Figure 1). Sugar, however, is also the colloquial term for sucrose, which is a disaccharide of glucose and fructose, and is mainly extracted from the juice of sugar beet or sugar cane plants. Unlike other crops, these are grown primarily for sugar extraction. Sugar cane is harvested by chopping off the stems (canes) while leaving the roots so that the plant can grow again, making it a highly sustainable crop. Sugar beets are planted every year and account for less than 20% of sugar production globally. Traditionally, cane is used for the production of edible sugar in South Africa.

For the purpose of this document, the word "sugar" is interchangeable with "sucrose", and other forms of sugar are not alluded to.

The sugar industry combines agriculture and manufacturing to produce raw and refined sugar. The local industry is one of the world's leading producers of cost-competitive, high-quality sugar from sugar cane, accounting for around 1% of global production. The industry makes a vital contribution to employment, particularly in the rural parts of the country, and contributes significantly to the local economy. It also contributes to the South African gross domestic product, with exports to other African countries, as well as Asia and the Middle East.

Figure 1: Monosaccharides and disaccharides can be produced from a range of agricultural feedstock, including glucose and fructose from maize (A) and corn (B), and sucrose from sugar beet (C) and sugar cane

1.1.2 Uses for sugar

It is common knowledge that sugar can be used as a sweetening agent and is added to foods or drinks to make them taste more pleasant. For example, sugar balances the bitterness of coffee or reduces the tartness of sour fruit. In addition, sugar is used as a natural preservative that binds water to prevent the growth of micro-organisms, therefore reducing food spoilage, as in jams and preserves (Figure 2).

Sugar is widely used as a feedstock for the production of bioethanol. Approximately half of the light vehicles in Brazil, the world's largest sugar producer, are capable of running on 18–25% ethanol and almost half of the sugar cane crop in that country is used to produce bioethanol. This is somewhat controversial because rain forests have been cleared to plant sugar cane.

Sugar is also used as a retardant to slow the setting of cement and glues, as a component of detergents (sucrose esters), and in the pharmaceutical industry.

Figure 2: Sugar is used in food and beverages as a sweetener and/or as a preservative. Almost half of the sugar cane in Brazil is used to produce bioethanol.

1.1.3 Global and local sugar production volumes and trends

Cane sugar is produced in regions with tropical or sub-tropical climates, and beet sugar in temperate regions of the northern hemisphere. The European Union, as the largest producer of sugar from beets, accounts for approximately 9% of global sugar production. In comparison, South Africa accounts for close to 1% of global production of saleable sugar from sugar cane.

Brazil is, by far, the largest grower of sugar cane, producing double that of its closest competitor, India (Figure 3).

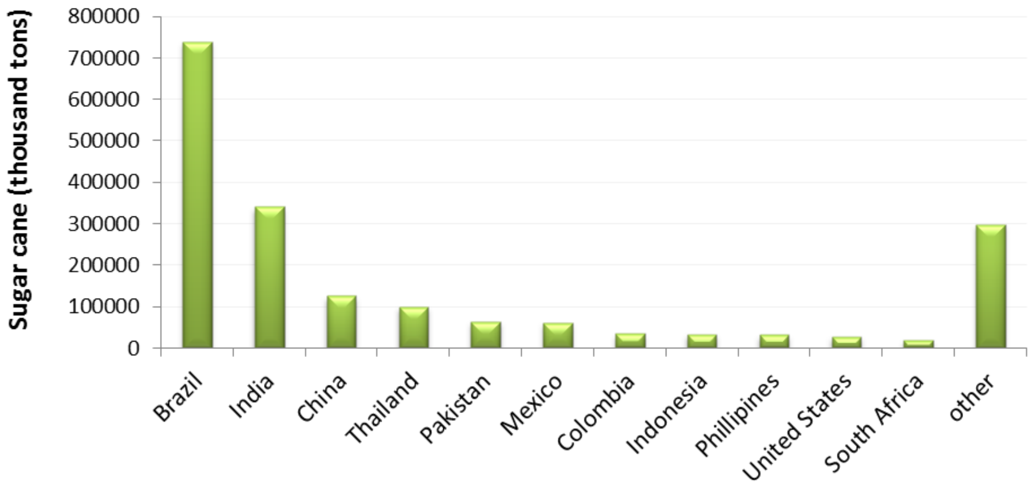

Figure 3: Sugar cane production figures for the ten highest global producers, plus South Africa, in 2013 (FAOSTAT, 2013)

Although almost all cane is destined for sugar production, the optimal growth cycle can be >12 months, so that only around 70% is harvested each calendar year. The area of land planted with cane decreased continuously between the 2001/2002 and 2011/2012 seasons (Figure 4). Other factors, notably the prevailing climatic conditions, have a marked effect on sugar production. This was demonstrated by the recent drought in 2014 and 2015, which led to low yields in the 2015/2016 season. Although a similar area of land was planted to cane in 2014/2015 and 2015/2016, the yield decreased from an estimated 65.14 to 54.36 per hectare of harvested cane, and the amount of cane required for the production of one ton of sugar increased from 8.39 to 9.12 tons. Close to 15 million tons of sugar cane were crushed in 2015/2016, yielding over 1.6 million tons of saleable sugar, but this was 23% less than in 2014/2015 (SASID, 2016/2017).

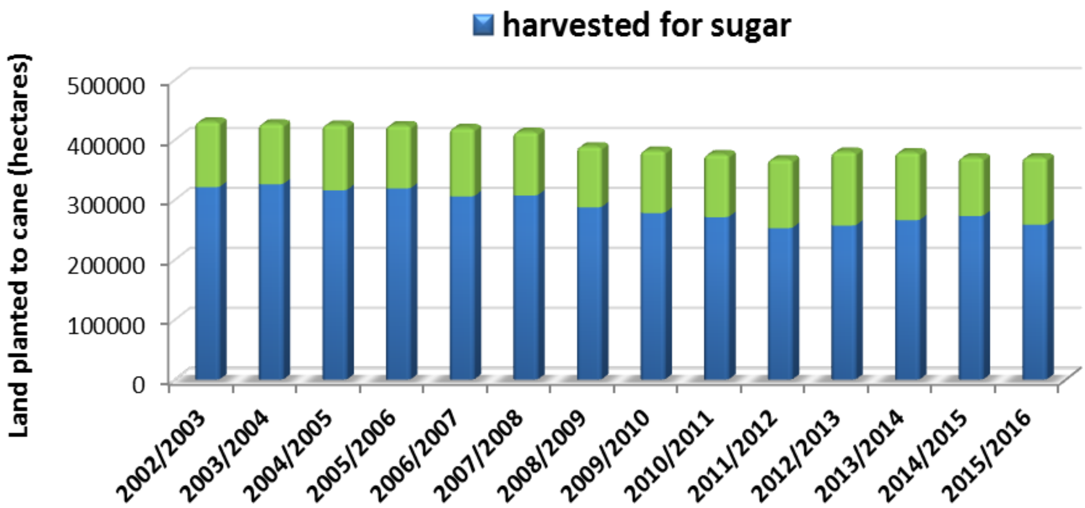

Figure 4: Agricultural land planted to sugar cane (sum of green and blue) and harvested for sugar production (blue) in South Africa (SASID, 2015/2016)

Although sugar is in high demand, global prices are distorted; long-term average prices are less than production costs because some governments provide extensive financial support in the form of subsidies to local industries. To counter this, many countries, including South Africa, apply tariffs and other measures to protect local markets. The highly competitive nature of the global market has made it difficult for countries to export sugar profitably. There has been a decreasing trend in local export sales over the years since 2001, which have been compensated for to some degree by an increase in local sales (NAMC, 2016; Figure 5).

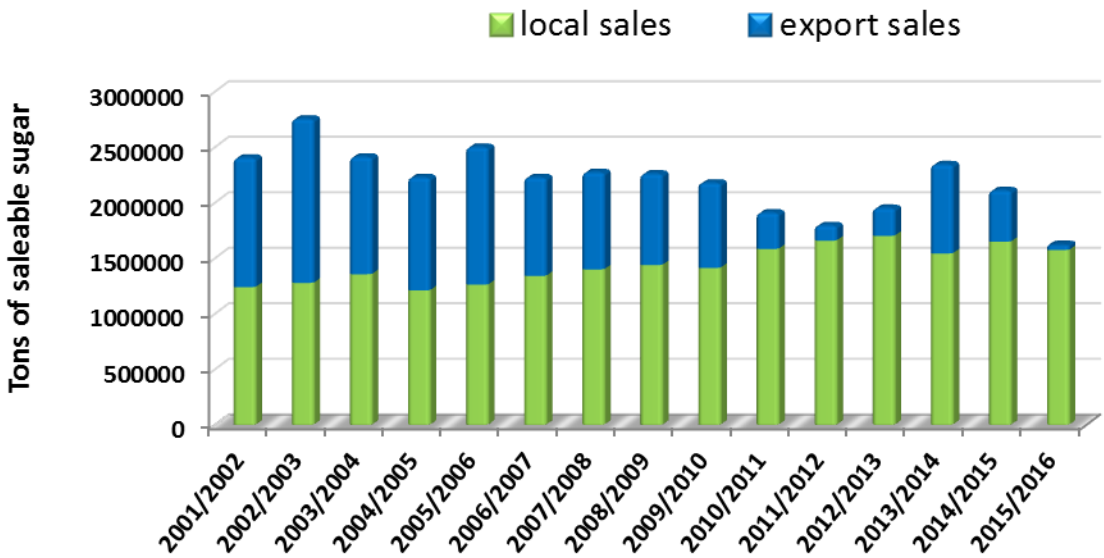

Figure 5: The amount of saleable cane sugar produced in South Africa and sold in global and local markets from 2001/2002 to 2015/2016 (SASID, 2016/2017)

1.1.4 Sugar cane plantations and mills in South Africa

The bulk of the sugar cane plantations in South Africa are in KwaZulu-Natal (Figure 6), but some are located in Mpumalanga and the Eastern Cape. In 2016, there were around 21 889 registered cane growers, of which approximately 94% were small-scale growers that supplied 10.3% of the total crop. Of the 1 327 large-scale growers, about a quarter were black emerging farmers.

Milling companies that own their own estates produce 8.2% of the cane crop (SASID, 2016).

Figure 6: A typical sugar cane plantation in South Africa

To prevent spoilage, sugar cane needs to be processed rapidly after harvesting. For logistical reasons, the 14 sugar mills in South Africa are located in the same regions as the plantations (Figure 7). In 1990, when the original NATSURV was published, there were 16 mills and a central refinery. Some consolidation has taken place, and there are currently 14 mills and a central refinery.

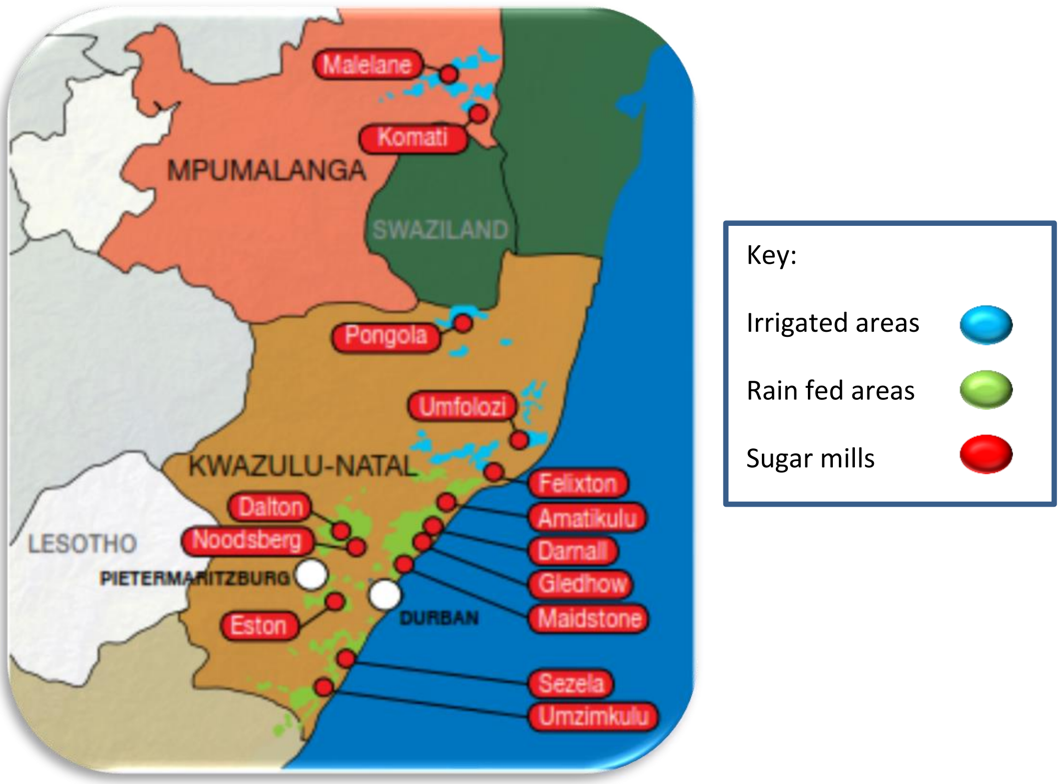

Figure 7: Location of the plantations and 14 sugar mills in KwaZulu-Natal (adapted from the South African Sugar Association website)

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Section 2: Overview of sugar cane processing

The production of white sugar from sugar cane consists of two processes: extraction of raw sugar, and refining. Both consist of a number of sub-processes (Figure 8). The most visible difference between raw and refined sugar is the colour. When sugar has been extracted from the juice of the cane plant, a strong-tasting black syrup, known as molasses, remains. Unrefined (raw) sugar contains residual non-sucrose impurities. The refining process removes most of the impurities resulting in a much whiter product with a slightly higher sucrose content. The more impurities present in the raw sugar, the stickier the crystals, the darker the colour and the stronger the flavour. However, the presence of impurities does not have a substantial effect on the nutritional value of the sugar. Sugar cane consists of approximately 15% dissolved matter (including 13% sucrose), 15% insoluble fibre (bagasse), and 70% water. Typically, from 100 tons of cane, around 30 tons of wet bagasse, 12 tons of sugar, and 4 tons of molasses are produced.

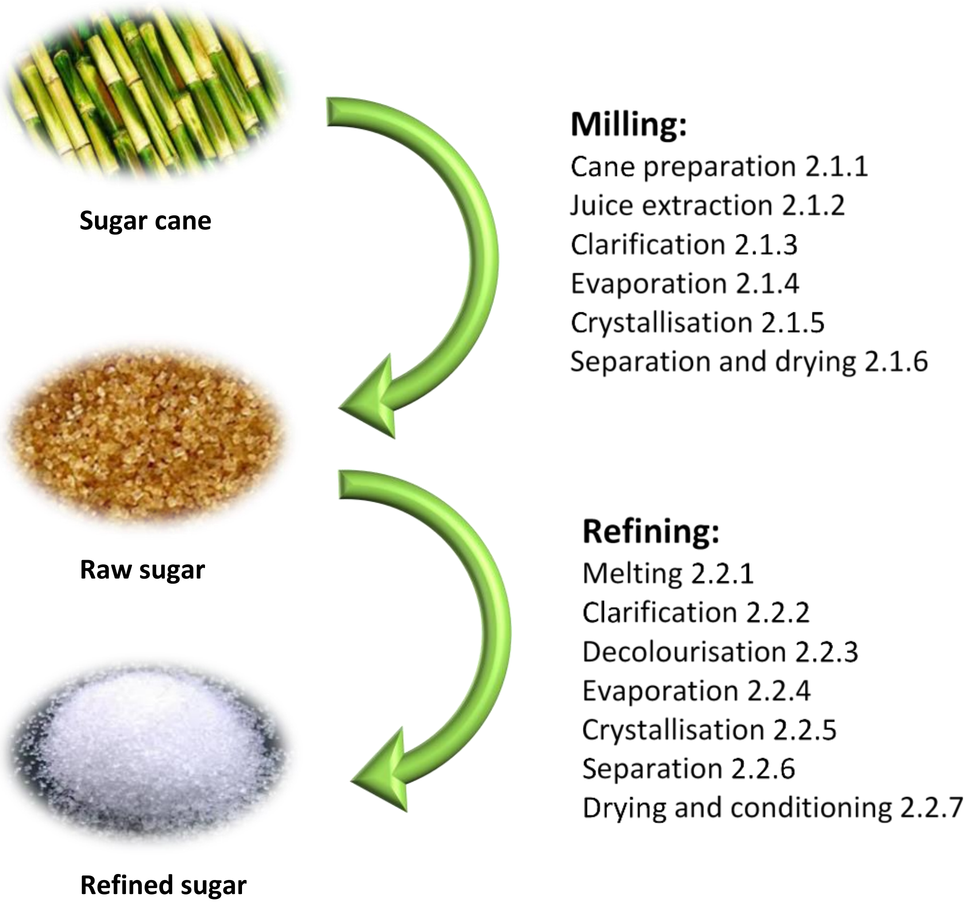

Figure 8: Raw sugar is made from sugar cane in a series of steps, and then refined in another series of steps to produce white (refined) sugar

This report is not intended to provide an exhaustive account of the production processes used by the South African sugar industry. A brief description of the generic processes and principles is given in this section, and Figures 9 and 10 show basic process inputs and outputs. The water use, wastewater generation and energy aspects of sugar production are discussed in more detail in Sections 3, 4 and 5, respectively.

2.1 Production of raw sugar from sugar cane

A number of steps are required to produce raw sugar from cane (Figure 9). All of these processes require energy in the form of mechanical energy and/or heat (mainly from steam). Although water is required in large volumes for juice extraction, minimal (if any) external water is required for the direct recovery of sugar from the cane because cane contains around 70% water, and process water is recycled. However, additional water is usually required for start-up, shut-down and various auxiliary activities in the factory. By-products include wastewater, bagasse, and in some instances, filter mud (Figure 9).

2.1.1 Cane preparation

Cane is mechanically cut and shredded to assist with the extraction of juice from the fibrous tissue.

2.1.2 Juice extraction

Sugar juice, also known as "mixed" juice, is extracted by either of two processes: **milling** or **diffusion**, the latter being the most common method employed in South Africa. Diffusion typically has lower capital and operational costs than milling.

Milling is a mechanical process that involves squeezing the prepared cane through a series of mills containing horizontal rollers (typically six in series). The juice is expelled from the cells, and the by-product is a lignocellulosic (fibrous) plant material known as bagasse. Imbibition water is added to the last mill to recover residual sugar which is entrained in the bagasse. Excess fibre in the juice is removed by mechanical screening before clarification.

The diffusion process relies on liquid extraction of sugar from the prepared cane. During diffusion, the sugar is washed from the surface of the cells, and also diffuses from the cells into the less concentrated surrounding liquid.

2.1.3 Clarification

After extraction, the sugar juice still contains some impurities. These are precipitated out of the solution by the addition of lime ($Ca(OH)_2$). Lime hydrolysis is promoted by heating. The solids, known as mud, are separated from the clarified sugar juice by sedimentation in clarifiers. The mud is then either filtered and the filtrate is returned to the process, or the mud itself is recycled directly to the diffuser. The clarified sugar juice is also known as "clear juice".

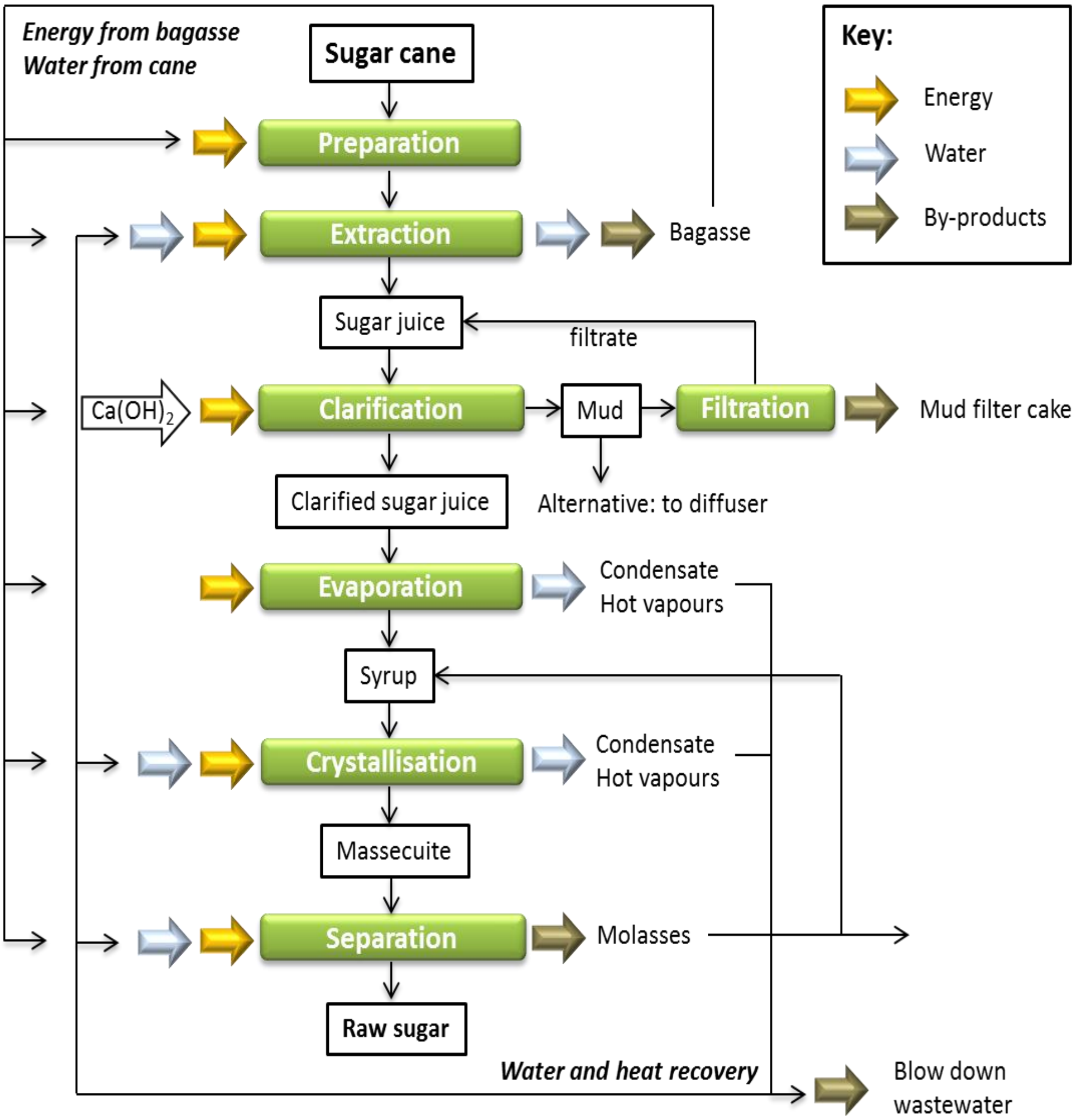

Figure 9: Simplistic schematic flow diagram showing basic steps, intermediate products, and inputs and outputs for a typical sugar mill in South Africa (refining excluded)

2.1.4 Evaporation

The clarified sugar juice contains about 85% water, some of which is removed in a multi-effect evaporation system which consists of evaporators (effects) in series. The use of multi-effect evaporators saves significant amounts of water and energy. Steam is only added to the first effect to provide heat to boil the sugar juice. Thereafter, the vapour produced by evaporation in each effect is used for heating in the next effect. The pressure in each evaporator in the series is lower than in the preceding evaporator, so that the juice continues to boil as it is passed through the series. The concentrated syrup leaves the last effect as a bottom concentrate known as syrup. Syrup contains approximately 65% sugar and 35% water.

2.1.5 Crystallisation

The syrup is further concentrated by boiling in large pans to which magma (small crystals from lower-grade boiling) or slurry (finely milled sugar) are added as seed (nuclei) for the growth of larger sucrose crystals. A mixture of crystals and mother liquor, known as massecuite is formed. The moisture and temperature are closely controlled to achieve the desired (supersaturated) concentration necessary for optimal crystal formation. The massecuite is transferred to stirred tanks (crystallisers) where cooling promotes the continuation of crystal growth.

2.1.6 Separation and drying

The massecuite is centrifuged to separate the viscous black liquor (molasses) from the sugar crystals. Water and steam may be added to assist with the removal of impurities. Efficient extraction and separation via centrifugation are needed to produce raw sugar with low ash and colour content, and a sucrose content of ≥99.3%. This high-value raw sugar is known as very high polarisation (VHP) sugar. The raw sugar is either directly refined in back-end mills, or air-dried (e.g. in rotary driers) to reduce the moisture content and prevent spoilage.

After separation, the molasses still contains sugar, so it is boiled again in vacuum pans and the sugar crystals separated again. This may be repeated a third time. To ensure that the end product is of high quality, the crystals formed from re-boiling are melted and added to the syrup to be processed again.

2.2 Sugar refining

Refining consists of a number of steps, and results in the production of white sugar, wastes, and secondary products and by-products. All the processes require energy in the form of mechanical energy and/or heat (mainly from steam) (Figure 10). Different terminology is used for the various stages and intermediate products.

If low-grade raw sugar is used, it is first mixed with heavy syrup to soften the outer coating of residual molasses on the surface of the sugar granules, and the sugar granules are separated out by centrifugation. This process (affination) is usually not applied in South African refineries, as the raw sugar is typically very high polarisation (VHP) grade.

2.2.1 Melting

The raw sugar is melted in high-purity, hot, sweet water to produce melt liquor (melt) with a sugar content ranging between 68 and 72 degrees Brix. The sweet water is typically process water “contaminated” with sugar. Hot vapour derived from the evaporators provides the energy for heating.

2.2.2 Clarification (primary decolourisation)

Clarification (also known as primary decolourisation) is achieved by adding lime ($Ca(OH)_2$) and chemicals and/or gas to the melt liquor under controlled temperature, pressure and pH conditions. Chemical precipitates are formed that that agglomerate with colour molecules and other impurities. The impurities in the ensuing mud are removed by separation. Filtration is used for separation, and, in some instances, skimming or settling may also be employed. Clarification can be achieved by carbonatation (2.2.2.1), sulphitation (2.2.2.2), phosphatation / phosfloatation (2.2.2.3), or combinations thereof.

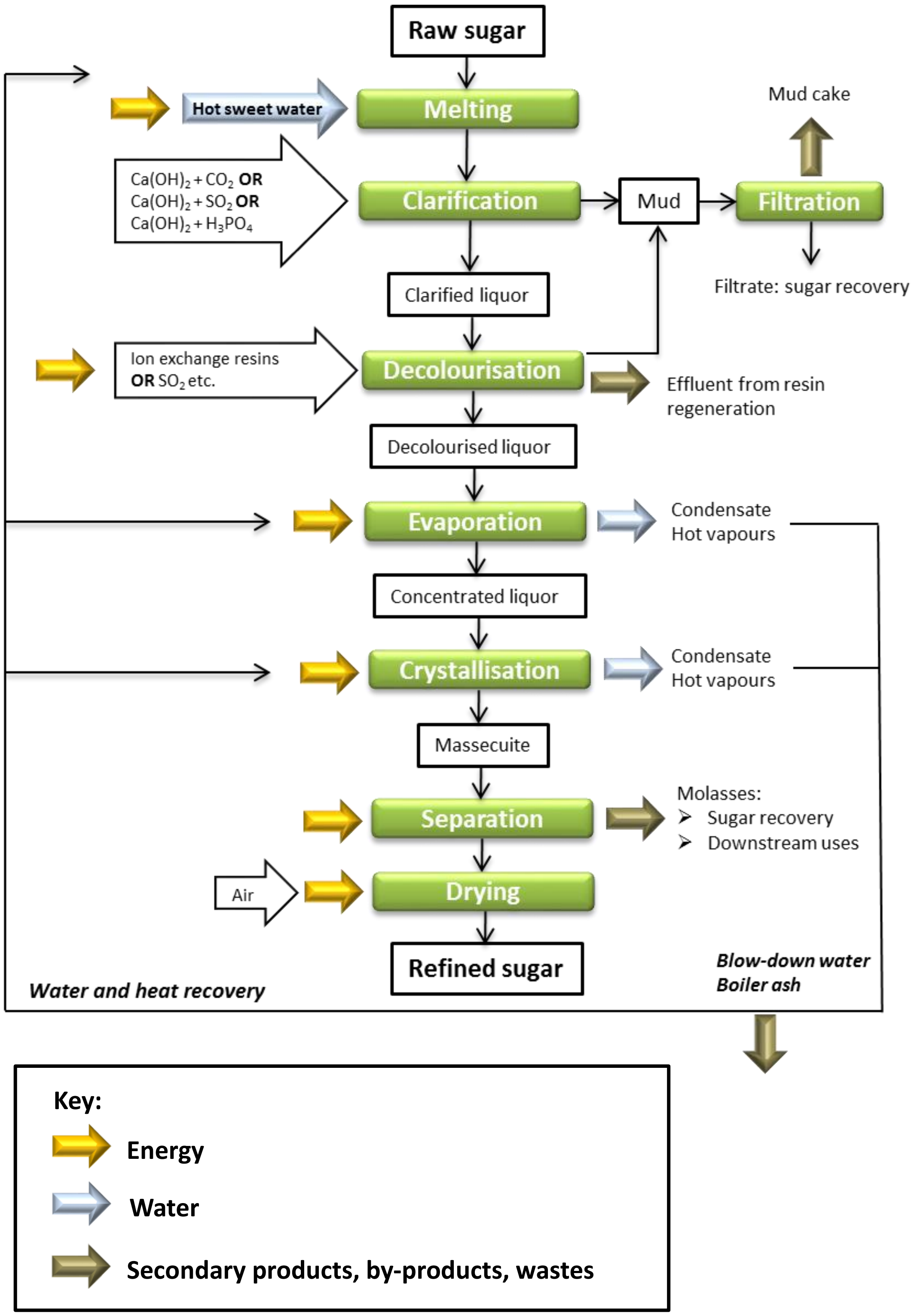

Figure 10: Basic schematic flow diagram showing process steps, intermediate products, and inputs/outputs for a typical sugar refinery in South Africa

2.2.2.1 Carbonatation
Carbonatation is a cheap and robust process that achieves about a 30–50% reduction in the colour of the melt liquor. $Ca(OH)_2$ is added, and carbon dioxide (CO_2) is bubbled into the melt liquor to form a calcium carbonate precipitate ($CaCO_3\downarrow$).

2.2.2.2 Sulphitation
Sulphitation can be used for either primary or secondary purification. The principle is similar to carbonatation. In this case, sulphur dioxide gas (SO_2) is added instead of CO_2, resulting in the formation of a calcium sulphite precipitate ($CaSO_3\downarrow$).

2.2.2.3 Phosphatation/floatation (phosfloatation)
Phosphoric acid (H_3PO_4) is added with $Ca(OH)_2$ to the melt liquor to form calcium phosphate ($Ca_3(PO_4)_2\downarrow$).

In phosfloatation, the clarifying tank is aerated, and impurities become entrained in flocs that attach to rising air bubbles. A scum forms on the surface, and is removed by a device.

2.2.3 Decolourisation
Decolourisation following clarification is often referred to as "secondary decolourisation". The two main methods used in South Africa to remove residual colour and impurities after primary clarification are sulphitation and ion exchange. The addition of SO_2 without lime can be used after carbonatation to remove residual calcium together with colour molecules and other impurities. If an ion-exchange decolourisation step is used, then the ion-exchange resins are regenerated chemically after their functional capacity has been expended. This creates an effluent stream.

2.2.4 Evaporation
The decolourised liquor (juice) is concentrated in a multi-effect evaporator (see 2.1.4).

2.2.5 Crystallisation
The concentrated liquor (syrup) is crystallised in pans to form massecuite (see 2.1.5).

2.2.6 Separation of sugar crystals and molasses
The massecuite is centrifuged to separate the white sugar crystals from the molasses (see 2.1.6).

2.2.7 Drying and conditioning
After separation, the refined sugar contains around 1% moisture that needs to be reduced to prevent spoilage and/or caking. The moisture is present in three forms: free, bound, and inherent. Most of the free moisture on the surface of the crystals is easily removed in rotary driers. After drying, the residual free moisture, as well as the bound moisture responsible for caking, is removed by exposure to low humidity air for an extended period (conditioning).

2.3 Sugar milling and refining in South Africa

Although some upgrades have taken place over the years, most of the infrastructure at the majority of sugar mills in South Africa is more than 50 years old. Some of the NATSURV respondents indicated that they had replaced particular infrastructure specifically to save water, and/or energy. Details of these are given in Sections 4 and 6, respectively.

Refining generally takes place throughout most of the year, with short end-of-year and maintenance shut-down periods of between three weeks and two to three months. Milling is more seasonal as it only takes place when cane is harvestable. Of the eight stand-alone mills included in this survey, all indicated that they were fully operational between May and November (Figure 11).

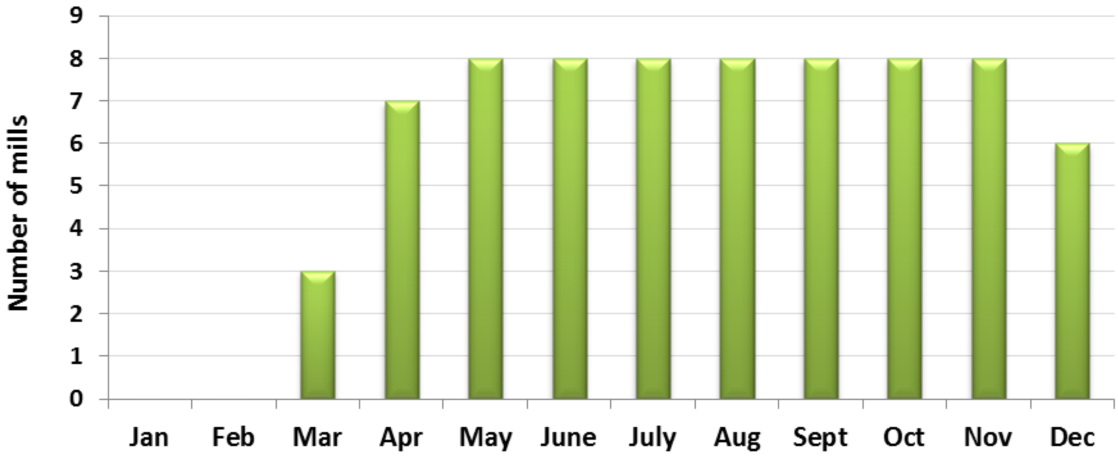

Figure 11: Seasonal operation of South African stand-alone mills

According to the data submitted via the questionnaires, the amount of cane milled by the participating industries (2012 to 2014 average) ranged from 720 000 to 1 829 009 tons /annum, while the amount of raw sugar refined ranged from 161 434 to 540 000 tons /annum (Figure 12). Production figures were compared with the latest South African Sugar Industry data (SASID, 2016) to test the integrity of the data. In 10 out of 11 cases, there was minimal to no variation, but in one instance, significant variation warranted that the mill be contacted for data verification. It was discovered that there was a typographical error in the questionnaire, which was subsequently corrected and all relevant indices pertaining to this mill were re-calculated.

Only one third of NATSURV respondents were willing for their names to be mentioned. Because of the small size of the cohort and the need to maintain anonymity, it was decided not to categorise the mills/refineries in terms of size when analysing the data presented in Sections 2, 3, 4, and 5.

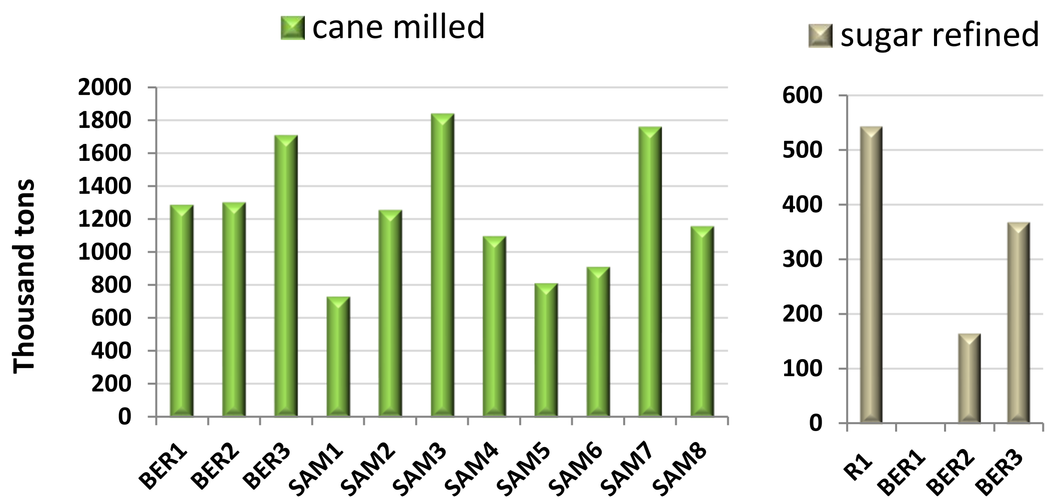

Figure 12: The amount of sugar cane milled and raw sugar refined in South African sugar mills and refineries (averages from 2012-2014). BER1 – not given

BER: mills with back-end refineries SAM: stand-alone mills R: refinery

2.4 2.4 Process inputs and outputs: beneficial uses for by-products

The sugar industry is well organised to efficiently deal with solid process residues. Transport of by-products off site for value-added processes or beneficial use is often cost effective because of the relatively small geographical location of a large industry. Downstream industries that generate value-added products are therefore located in KwaZulu-Natal.

2.4.1 Bagasse

Sugar milling and refining is energy intensive. Bagasse is an important by-product of cane sugar extraction (Figure 13). All the mills burn sugar cane bagasse as a major source of energy. In some instances, excess energy is produced. The industry has the potential to make a significant contribution to the grid, and there are a number of reports available that outline how this may be achieved (see Section 6). Emissions from burning bagasse are lower and less noxious than from conventional fuels such as coal. In addition, sugarcane captures carbon during growth, making bagasse a carbon-neutral energy source.

South Africa is one of the major global producers of furfural and furfuryl alcohol, and the high-value speciality chemicals diacetyl and 2,3-pentanedione are also extracted from bagasse. One NATSURV respondent indicated that bagasse was also sold for animal fodder, while another also sold bagasse for paper production.

2.4.2 Molasses

Molasses is initially recycled back to upstream processes to maximise product recovery. All spent molasses in South Africa is utilised further (Figure 13). Fermentation of molasses to alcohol can be a lucrative downstream process; seven of the twelve respondents send molasses to one of two facilities that produce large volumes of various grades of ethanol (including pharmaceutical grade) via fermentation. Molasses is typically sold as animal feed if the facility is located far from the distilleries and/or is low grade.

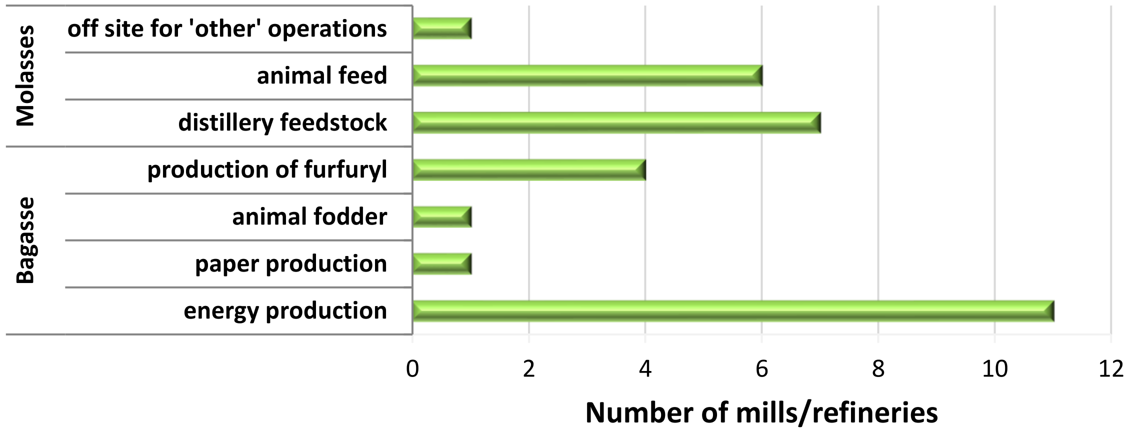

Figure 13: Downstream uses of by-products of sugar cane processing in South Africa

2.4.3 Filter and clarification mud cakes

The mud cake is sought after as an effective soil conditioner/emollient for cane fields, and many companies are using or selling the residue for this purpose (Figure 14). One facility indicated that they recycle the filter mud cake back into the process, and another that they send it to settling dams. In the case of the latter, the sludge from the dams is used as a fertiliser. In South Africa, some of the refineries still use sulphitation in the clarification process, so sulphur species can be present in the mud cakes.

2.4.4 Sludge

Respondents were asked how they dispose of the sludge from wastewater treatment facilities or ponds. Four indicated that they use sludge from wastewater treatment and/or settling ponds as a fertiliser, while one indicated that they dispose to an on-site landfill, and that they have a permit for this activity. One of the refineries indicated that they sent spent resins to a commercial landfill site.

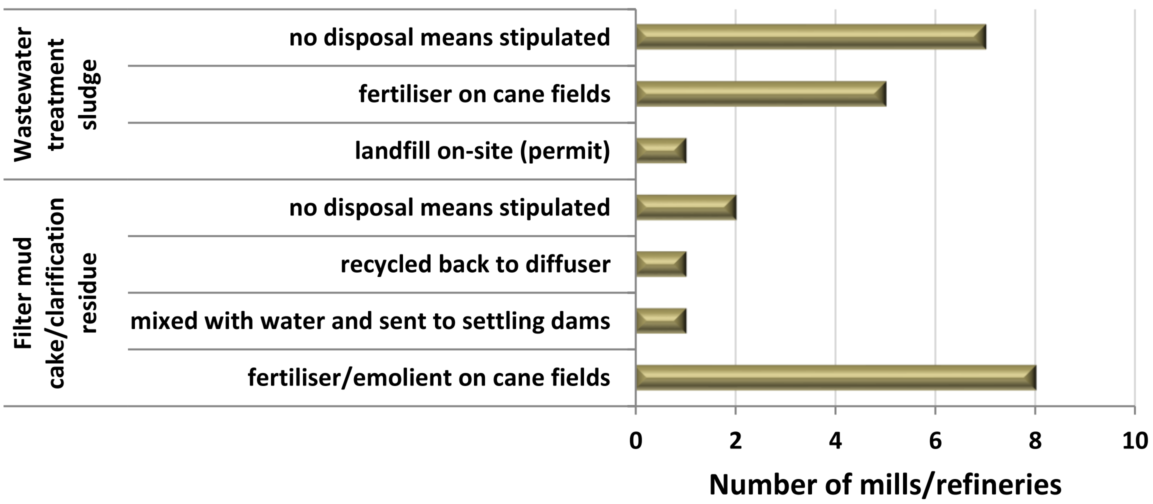

Figure 14: Fate of solid waste generated by the sugar processing industry in South Africa

Section 2 References:

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Section 3: Environmental and water use regulations and policies applicable to the cane sugar processing industry

3.1 Introduction

3.1.1 National policies

The Constitution of the Republic of South Africa (Act 108 of 1996) stipulates that everyone has the right to an environment that is not harmful to his or her health or well-being. This includes the right to environmental protection for the benefit of present and future generations through reasonable legislative and other measures to prevent pollution and ecological degradation, promote conservation, and secure ecologically sustainable development and use of natural resources. These rights must be balanced with the promotion of justifiable economic and social development. Regulations that address these rights fall under the responsibility of the Department of Environmental Affairs. The Bill of Rights, which forms part of the constitution, enshrines the concept of sustainability. Rights regarding the environment, water, access to information, and just administrative action are specified in the act. These rights and other requirements are further legislated through the National Water Act (NWA; Act 36 of 1998). The NWA provides the legal basis for water management in South Africa. It ensures ecological integrity, economic growth, and social equity when managing water use. Other policies relevant to the sugar processing sector are the National Environmental Management Act (Act 107 of 1998), the National Environmental Management: Waste Act (Act 59 of 2008), and the National Environmental Management: Air Quality Act (Act 39 of 2004) (Figure 15). Broadly speaking, these acts outline the requirements for the storage and handling of waste on-site, licensing requirements, the establishment of waste management plans, the setting of limits for air emissions, and the setting of penalties for offences.

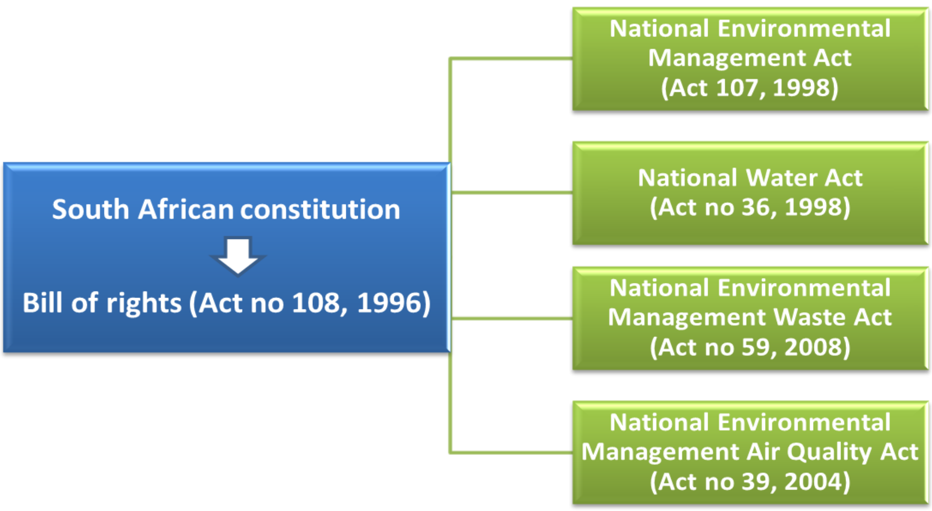

Figure 15: National environmental and water policies relevant to the sugar industry

The NWA introduced the concept of integrated water resource management, which provides for resource- and source-directed measures to manage the aquatic environment. Resource-directed measures aim to protect and manage the environment that receives water, while source-directed measures aim to control the impact on the receiving environment by preventing pollution, reusing water, and treating wastewater. The integration of resource- and source-directed measures forms the basis of the hierarchy of decision making aimed at mitigating the effect of waste generation. This hierarchy is based on a precautionary approach and the order of priority for water and waste management decisions and/or actions is shown in Figure 16.

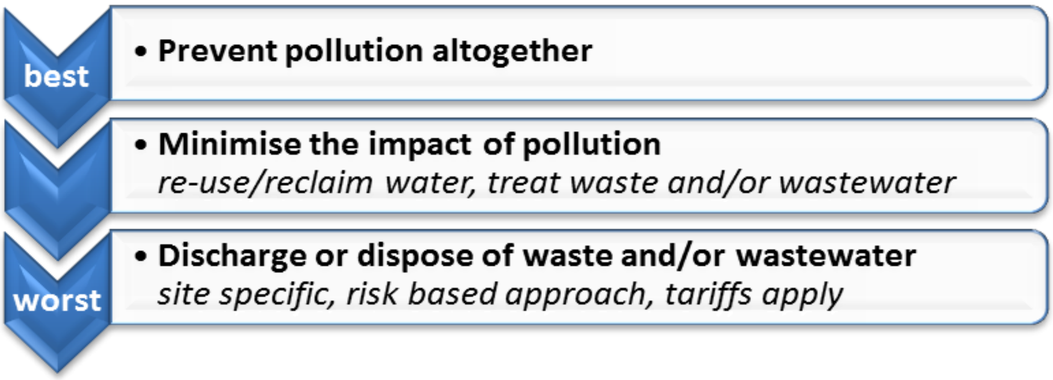

Figure 16: Hierarchy of decision making intended to protect the environment

3.2 Water and wastewater policies

The South African sugar processing industry uses municipal water, and/or water abstracted from rivers or boreholes (Section 4). Final effluent from the sector is evaporated, discharged to rivers or municipal reticulation systems, or disposed of via irrigation (Section 5).

All water bodies in the hydrological cycle, including underground water, are regarded as water resources, and are defined in the NWA as "a river or a spring; a natural channel in which water flows regularly or intermittently; a wetland, lake or dam into which, or from which, water flows; any collection of water which the Minister may declare to be a watercourse; and surface water, estuaries and aquifers (underground water)".

The recently formed Department of Water and Sanitation [DWS, 2014 – formerly the Department of Water Affairs (DWA) and, before that, the Department of Water Affairs and Forestry (DWAF)] is the water and sanitation sector leader in South Africa. DWS is the custodian of the country's water resources and of the NWA and the Water Services Act, Act No.108 of 1997 (RSA, 1997). DWS is also the national regulator of the water services sector.

In the various acts and ancillary legislation, the term "**water use"** refers to water abstraction, storage, disposal, and related activities (Figure 17). There are different **schedules** of water use. **Schedule 1 water use** includes small-scale abstraction for "reasonable" domestic use, non-commercial farming, grazing (not feed-lots), emergency use (e.g. for fighting fires), and drinking water, as well as discharge to third party infrastructure or environments (e.g. municipal reticulation systems, marine outfalls) where the third party (e.g. a municipality) holds the authority for discharge. Schedule 1 uses are permissible in terms of the NWA and are not subject to further legislation, barring compliance for discharge with third party requirements where applicable. There are no set limits for schedule 1 abstraction or discharge. **The sugar processing industry is not a schedule 1 user**.

For other schedules of use, the legislation differs according to when the water use activity first took place, and is classified as either existing or new. "**Existing lawful use"** mainly applies when **first use was before October 1999.** Existing lawful users may be required to register their water use activities. Due to the age of the South African sugar processing facilities, many fall into the existing water use category.

New lawful use legislation applies to instances where first use took place **after October 1999.** Two scenarios are applicable: (i) Water use is permitted without a licence provided certain stipulations are met. These stipulations can be found in documents supplementary to the NWA, known as the **General Authorisations** (RSA, 1999). Users still need to register their water use activities. (ii) A licence must be obtained from the DWS if the new lawful water use does not comply with the stipulations set out in the General Authorisations.

Figure 17: In terms of South African legislation, the term "water use" refers to water abstraction, storage, disposal, and related activities

At a municipal level, the WSA sets out the regulatory framework for institutions tasked with the supply of water services. The act makes provision for different water service institutions to be established as follows:

- The water services authority – i.e. the responsible municipality
- The water services provider – the entity whose role is to physically provide the water supply and sanitation services to consumers

Municipal units are governed by municipal policies and by-laws for the provision of water and sanitation services, water services development, and sewage disposal. The latter includes the discharge of domestic, commercial and industrial effluent. Tariffs are set for these services at a municipal level, and are generally revised on an annual basis.

3.2.1 Water abstraction

For industrial wastewater, permission to abstract water must be obtained in terms of Section 7 of the WSA which states that "no person may obtain water for industrial use from another source other than the distribution system of a water services provider nominated by the water services authority having jurisdiction in the area in question, without the approval of that water services authority". It is the duty of the designated water services authority in a particular area to formulate and administer a water services development plan.

According to the General Authorisations, and subject to stipulated exclusions, a registered water user can abstract (i) up to 100 kl/day of surface water, and (ii) between 60 and 750 kl/hectare/annum of ground water, without a licence, provided that use is metered and monitored. Wetlands and certain drainage regions are excluded from the General Authorisations.

3.2.2 Water and wastewater storage, including dams and treatment and evaporation ponds

In the NWA, a dam is defined as "any structure which is capable of containing, storing or impounding water". This includes weirs, even though these may not have been constructed for the purpose of storing water. Safety of dams is regulated in terms of the NWA and the Dam Safety Regulations (Government Notice R1560, 1986). Registration of dams with a safety risk is required. These are dams with a storage capacity greater than 50 000 kl, and/or a dam wall height greater than 5 m, or those that have been declared a safety risk by the Minister.

In terms of the General Authorisations, users may store up to 5 000 kl of domestic or biodegradable industrial wastewater for reuse, up to 10 000 kl for disposal, or up to 50 000 kl in wastewater pond systems, provided it does not adversely affect the environment or human health. Up to 100 kl/day can be discharged into wastewater treatment or evaporation pond systems. The General Authorisations do not apply to storage of effluent in stipulated water control areas. These sites can be found in the General Authorisations document.

In term of the sugar processing industry, one of the NATSURV respondents indicated that they were subject to restrictions on the height of the dam wall of their settling dam under the authority of the KwaZulu-Natal Department of Agricultural and Environmental Affairs.

3.2.3 Effluent disposal

For industrial wastewater, permission to discharge effluent must be obtained in terms of Section 7 of the WSA. Irrigating with wastewater and/or discharging waste or water containing waste directly into a water resource through a pipe, canal, sewer, sea outfall or other conduit are water use activities to which the act applies. The legislation also applies to municipalities, but not to users discharging directly into municipal sewers.

The General Authorisations applicable to wastewater have recently been revised (RSA, 2013). As previously, sugar mill effluent is categorised as "biodegradable industrial wastewater", i.e. "wastewater that contains predominantly organic waste arising from industrial activities and premises”. In order to discharge sugar industry wastewater to the environment, or use it for irrigation purposes, industries need to register with the applicable water services authority. Existing water users may be subject to different requirements to new water users.

3.2.3.1 Irrigation with biodegradable industrial wastewater

The General Authorisations

The General Authorisations stipulate limits for certain physicochemical parameters in biodegradable industrial effluent (Table 1). In addition, it is stipulated that: (i) irrigation is only permitted above the 100-year flood line, or further than 100 m from the edge of a water resource or a borehole that is utilised for drinking water or stock watering – whichever is further, (ii) irrigation is not permitted on land that overlies a major aquifer, (iii) the wastewater quality and quantity needs to be metered, measured and monitored, and the results recorded, (iv) precautionary practices need to be undertaken to ensure the consistent, effective and safe performance of the irrigation systems, and (v) the user needs to register the use with the water services authority.

Table 1: General Authorisations: Stipulated physicochemical limits for irrigation with biodegradable industrial wastewater

Volume (kl/day)	≥500 but ≤2000	≥50 but ≤500	≤50
pH	5.5 to 9.5	6 to 9	6 to 9
Chemical oxygen demand (mg/L)	≤75	≤400	≤5000
Electrical conductivity (mS/m)	70 to 150	≤200	≤200
Sodium adsorption ratio	-	≤5	≤5
Faecal coliforms (per 100 ml)	≤1000	≤1000	≤1000
Ammonia as N (mg/L)	≤3	-	-
Nitrates/nitrites as N (mg/L)	≤15	-	-
Free chlorine (mg/L)	≤0.25	-	-
Suspended solids (mg/L)	≤25	-	-
Ortho-phosphate (mg/L)	≤10	-	-
Fluoride (mg/L)	≤1	-	-
Soap, oil or grease (mg/L)	≤2.5		

3.2.3.2 Discharge of wastewater into a water resource through a pipe, canal, sewer, or other conduit

The General authorisations

The General Authorisations do not apply to discharge of wastewater to marine outfalls, groundwater resources (including aquifers), or water resources with closed drainage systems. As with the General Authorisations for irrigation, the quality and quantity of the wastewater must be measured, metered, monitored, and recorded, relevant precautionary practices to safeguard human and environmental health need to be adopted, and users must register their water use. Different discharge parameters, called special limits, apply to sensitive river systems and catchments.

The general limits for discharges are given in Table 2. Apart from these parameters, limits are also stipulated for toxic metals. However, these are not generally relevant to the sugar industry. In addition to the general limits, industries also need to monitor substances that may have been added or concentrated by industrial processes, and substances that may be harmful to humans or the environment. All analyses need to be conducted on grab samples taken from the point of discharge and processed in laboratories accredited by the South African National Accreditation System (SANAS).

For discharge volumes of 10 to 100 kl/day, the minimum parameters that must be determined are the pH, electrical conductivity, and faecal coliforms. For discharge volumes of 100 to 1 000 kl/day, the chemical oxygen demand (COD), ammonia, and suspended solids concentrations must also be determined. Determination of nitrate/nitrite, free chlorine and ortho-phosphate is added to the list for discharge volumes of 1 000 to 2 000 kl/day.

Table 2: General Authorisations: Stipulated physicochemical limits for discharge of wastewater into a water resource through a pipe, canal, sewer or other conduit

	General limits	Special limits
Discharge volume (kl/day)	≤2000	≤2000
pH	5.5 to 9.5	5.5 to 7.5
Chemical oxygen demand (mg/L)	≤75	≤30
Faecal coliforms (per 100 ml)	≤1000	0
Ammonia as N (mg/L)	≤6	≤2
Nitrates/nitrites as N (mg/L)	≤15	≤1.5
Free chlorine (mg/L)	≤0.25	0
Suspended solids (mg/L)	≤25	10
Ortho-phosphate (mg/L)	≤10	1 (median), 2.5 (maximum)
Fluoride (mg/L)	≤1	≤1
Soap, oil or grease (mg/L)	≤2.5	0
Electrical conductivity (mS/m)	70 above intake to a maximum of 150	50 above background receiving water, to a maximum of 100

Discharge to municipal wastewater treatment works

Any industry wishing to discharge to a wastewater treatment works must apply to the relevant municipality for a trade effluent permit. Trade effluent may not be accepted if it contains concentrations of substances above stated limits, which vary from municipality to municipality. In terms of by-laws, municipalities are entitled to take random or scheduled samples of effluent to ensure compliance with regulations and permits. Separate limits may apply for wastewater treatment facilities with different capacities, or for discharge to sea outfalls for coastal municipalities. Depending on local by-laws, requirements for obtaining permits may include stipulations about discharge days and/or times, and requirements for up-front assessments to identify possible means of reducing water consumption and wastewater generation at source. The effluent discharge costs may include punitive fines for non-compliance to stipulated limits. However, many municipalities strive to rather work with industry to attain acceptable water usage and wastewater discharge quality, than to apply punitive measures.

Due to its location in the heart of the sugar industry, the eThekwini municipality has been chosen as an example. This metropolitan municipality requires that the volume of trade effluent must be determined - either by an effluent meter, or, if no meter is in place, from a water balance questionnaire which is filled in by the company. In this case, the effluent volume is calculated by deducting the volume of domestic effluent, process water, and evaporative losses from the incoming water volume.

Industrial, commercial and institutional customers are charged for the acceptance of sewage into the municipal sewerage system by means of a volume-based sewage disposal charge, which replaced sewerage rates from 1 July 2010.

In addition, industries permitted to discharge trade effluent with a pollution load exceeding that of typical domestic sewage, are charged for disposal according to Equation 1. Data on basic unit costs for water and effluent and the values for V and Z used in Equation 1 are provided in Table 3.

Equation 1:

$$\text{Volume based charge} + V\left(\frac{COD}{360} - 1\right) + Z\left(\frac{SS}{9} - 1\right)$$

Where:

COD = chemical oxygen demand in mg/L, SS = settleable solids in L/L, V = rate for the treatment of domestic effluent (COD <360 mg/L), Z = rate for the treatment of domestic effluent (SS <9 ml/L)

Table 3: Basic unit costs for industrial effluent discharge at eThekwini municipality

Period	Unit cost (R/kl)	COD charge (V) (R/kl)	SS Charge (Z) (R/kl)
2011-2012	5.34	0.57	0.52
2012-2013	5.68	0.60	0.56
2013-2014	6.07	0.65	0.59
2014-2015	6.54	0.71	0.64
2015-2016	7.06	0.76	0.69
2016-2017*	7.62	0.82	0.74

***predicted values**

3.2.3.3 Water service authorities and wastewater discharge compliance by the South African sugar processing industry

The mills, and mills with back-end refineries, are generally located in agricultural areas. In most instances (75% of NATSURV respondents), the DWS is the water service authority and the applicable discharge limit is either COD (limit of 75 mg/L), or a volumetric maximum which varies from site to site (Table 4). Two NATSURV respondents indicated that they were required to comply with municipal legislation, and one with legislation of the Integrated Coastal Management Agency.

Table 4: Legislative compliance by the South African sugar processing industry

Statutory body	Parameters	Compliant	Comments
DWS	COD (75 mg/L)	yes	Not discharged to river if non-compliant
DWS (*n* = 2)	COD (75 mg/L)	yes	
DWS	COD (75 mg/L)	mostly	
DWS	COD (75 mg/L)	no	Upgraded plant capacity, presently upgrading wastewater treatment capacity to cope with load
DWS	COD (75 mg/L)	NG	
DWS (*n* = 3)	Volumetric max.	yes	
Local municipality	NG	NG	
Metropolitan municipality	NG	yes	
Integrated Coastal Management Agency	pH >2 SOG 220 mg/L Furfuryl 200 mg/L Formate 6 100 mg/L Acetate 16 000 mg/L O_2 absorption 1 000 mg/L COD 20 000 mg/L TDS 900 mg/L TSS 200 mg/L	yes	Effluent discharged via marine outfall

DWS = Department of Water and Sanitation
COD = chemical oxygen demand **TDS = total dissolved solids** **TSS = total suspended solids**
SOG = soap, oil and grease **NG = not given**

Section 3 References:

Ethekwini metropolitan municipality by-laws and tariffs: www.durban.gov.za [accessed August 2015]

Department of Water Affairs (2011) South African Department of Water Affairs: National Water Resource Strategy - Annexure D. South Africa.

Water Services Act (Act No. 108 of 1997) Department of Water Affairs and Forestry.

National Water Act (Act No. 36 of 1998) Department of Water Affairs and Forestry.

General Authorisations in terms of section 39 of the National Water Act (Act no 1191 of 1999). Department of Water Affairs and Forestry.

Revision of General Authorisations in terms of section 39 of the National Water Act (Act no 169 of 2013). Department of Water Affairs.

Section 4: Water Use and management

4.1 Introduction

The South African Sugar Association is currently in the process of formulating an integrated water resource strategy for the industry in line with the national counterpart. In terms of water saving, much of the effort of the industry at large is directed at reducing the volume of irrigation water for cane crops. In comparison to irrigation water, factory process and cooling water only constitute a small fraction of overall water usage. In addition, cane itself consists of 70% water which is typically extracted during the milling process and recycled into the process. In fact, if sugar mills employ best practice scenarios, they can theoretically function as net water producers.

Nevertheless, factory water use is still significant, and without concerted recycling and reuse, vast quantities of water can be wasted in sugar milling and refining. For example, in Mauritius in 1991, it was found that the sugar industry abstracted 45 x 10^6 kl of process water per annum, an amount equal to the domestic consumption on the island.

Most of the cane sugar mills and/or refineries in South Africa have ageing infrastructure that was installed before water saving became a priority. In some cases, upgrades have taken place. In instances where the process water is costly (e.g. potable water), there is an economic incentive to save water. Water scarcity is another driver for saving water. This was brought to the fore during the drought of 2014/2015.

Two of the South African respondents indicated in the questionnaire that they have effected major upgrades over the past 10 years specifically to save water: At one mill, approximately half of the water requirements are met through the use of potable municipal water at the current (2016) cost of R13.20/kl. The high cost of water served as an economic driver for the facility to install a new plate and frame heat exchanger, filters, a pump, valves, pipes, and a cooled condensate holding tank so that process condensate could be used instead of potable water for flocculent preparation.

At a second mill, fill and drift eliminators have been installed on the cooling towers to reduce water losses. These measures have resulted in these two mills having the lowest specific water intakes (SWI) of 0.04 and 0.15 kl/ton cane, respectively (Section 4.3).

4.2 Sources of water for sugar processing

The major source of water used by the South African sugar industry is a combination of river water and potable water; borehole and raw municipal water are also used (Figure 18). Two NATSURV respondents indicated that potable water was obtained by in-house treatment of river water to potable standard.

The cost of municipal water for three respondents that bought water from a water service provider in 2016 was R10.20/kl (raw), R13.20/kl and R18.56/kl (potable).

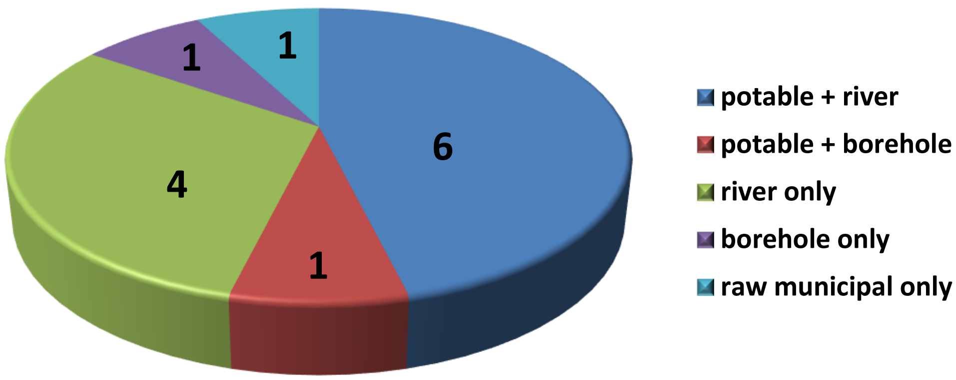

Figure 18: Sources of water used by the South African sugar industry

4.3 Specific water intake – local and global

Sugar cane contains around 70% water that can theoretically contribute around 0.7 kl/ton to the process water. Specific water intake (SWI) is the basic measurement used to assess overall water consumption by industry. For the sugar industry, this parameter is used globally, and is defined as the volume of external water (i.e. excluding water from cane) used to process each metric ton of cane. Stand-alone refineries are completely reliant on external water supplies, and in mills with back-end refineries, the number and scale of activities utilising water are greater than those of stand-alone mills. It is therefore expected that the SWI from these facilities will be higher than stand-alone mills with similar cane intake and extraction processes.

All the sugar processing facilities in South Africa monitor their water intake with meters, so reliable water usage data was available for analysis. In the 1990 NATSURV, an average SWI value was calculated, with the exclusion of two high outliers. The number of study participants was not reported, and the SWI was not split into that from stand-alone mills and refineries and combined mills/refineries. Table 5 gives the SWI values calculated for the latest NATSURV respondents. For statistical validity, no direct comparisons are made with the averages reported in the 1990 document.

The SWI was the lowest at one of the mills that does not have access to river water, where potable water constitutes almost half of the external water supply (SAM2: 0.04 kl/ton cane). The SWI was highest at one of the mills with a back-end refinery (BER3). Although the total SWI at this facility was significantly reduced from the value reported in the 1990 NATSURV (20 to 9.75 kl/ton cane), it was still significantly higher than at the other two mills with back-end refineries (0.7 and 0.343 kl/ton cane). The large SWI at BER3 is attributable to large volumes of river water that are used for cooling on a "once-through" basis, i.e. the majority of this minimally contaminated water is returned directly to the river.

Table 5: Specific water intake in the South African sugar processing industry

		potable	river	other	total
	SWI: kl/ton cane (mill, combined) and kl/ton raw sugar (refinery)				
R	refinery	0.13	1.67	-	1.8
BER1	combined	-	-	0.343**	0.343
BER2	combined	-	0.7	-	0.7
BER3*	mill	1.0	5.3	-	6.3
	refinery	0.45	3.0	-	3.45
	combined	-	-	-	9.75*
SAM1	mill	-	0.15	-	0.15
SAM2	mill	0.019	-	0.021**	0.04
SAM3	mill	-	-	0.55***	0.55
SAM4	mill	0.065	0.410	-	0.475
SAM5	mill	-	0.384	-	0.384
SAM6	mill	0.081	0.436	-	0.517
SAM7	mill	-	0.480	-	0.48
SAM8	mill	0.41	0.720	-	1.13

R = refinery BER = mill with back-end refinery SAM = stand-alone mill

***Cooling tower water not recycled **borehole ***raw municipal**

Global literature values for SWI range from 0.09 to 14.85 kl/ton cane (Table 6). The high-end values are from Mauritius, a region with higher water availability than South Africa (Ramjeawon, 2000).

Table 6: Available global values for specific water intake

Type of facility	No.	Specific water intake	Reference
		Range (kl/ton cane)	
Unknown	Unknown	0.50 to 0.90	IFC, 2007
Unknown	1	0.09 to 0.91	Gunjal & Gunjal, 2013
Unknown	Unknown	0.20 to 0.40	Deshmukh et al., 2014
Unknown	8	1.8 to 14.85	Ramjeawon, 2000

4.4 Water recycling and reuse

The sugar processing industry at large recycles and reuses water. Although the infrastructure at most South African mills and refineries is old, most recycle cooling water and condensate. The use of external water and recycled water depends on the specific environmental, geographic and equipment constraints of each mill. Water recycling constitutes the major means of water “saving” by the industry. When implementing water recycling in the sugar industry, the quality and quantity of the water emanating from each process needs to be critically evaluated to ensure that it is “fit for purpose”. For example, Ingaramo and his colleagues (2009) divided water use into six cycles (Figure 19).

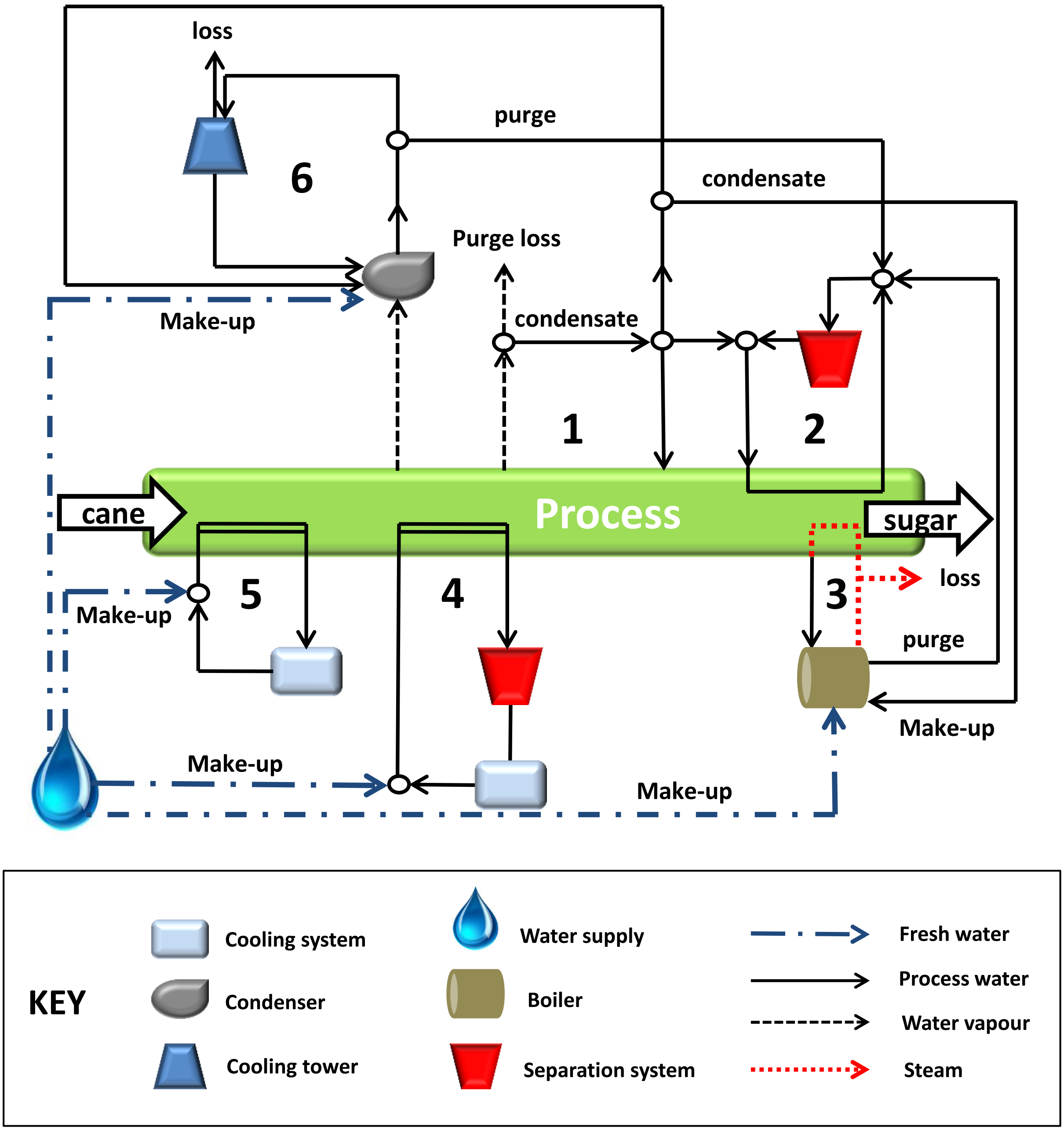

Figure 19: Six water cycles in sugar cane plants that can be used to determine pathways of recycle and reuse of water. Adapted from Ingaramo et al. (2009).

Cycle 1: The vapour-condensate system: Water vapour from evaporation systems and crystallisation pans is condensed and can be used for different processes, e.g. imbibition, sugar washing and melting.

Cycle 2: The scrubber and chimney water system: Purged water from the boilers (cycle 3) and/or condensate from cycles 1 and 6 can form make-up water for this system, while wastewater from the scrubbers and chimneys themselves can be treated to remove ash and be reused as wash water in the same cycle.

Cycle 3: The boiler water system: The condensate from the boilers can be reused in the boilers themselves. Blow-down and other losses can be made up with fresh water or, preferably, with condensate from other cycles.

Cycle 4: The turbine and machinery refrigeration system: Provided the refrigeration water is de-oiled, it can be recycled using a cooling system with only negligible losses.

Cycle 5: The crystallisation and filter system: The water can be recycled within the system, with minimal evaporative losses.

Cycle 6: The condenser water system: Barometric condensers require large volumes of water. Recycling of this water can result in large water savings. However, solids need to be removed by continual purging, and make-up water needs to be added to make up the deficit.

Water recycling can reduce the need for external water considerably. For example, in a sugar factory in Mauritius, the SWI was reduced by 90% from 0.91 kl/ton cane to 0.09 kl/ton cane by instituting water recycling. It was shown that external water requirements for condensers could be almost halved by partial recirculation (Figure 20).

Further information about water reuse and recycling can be found in Section 7 of this document (Best practice guidelines for water and wastewater management).

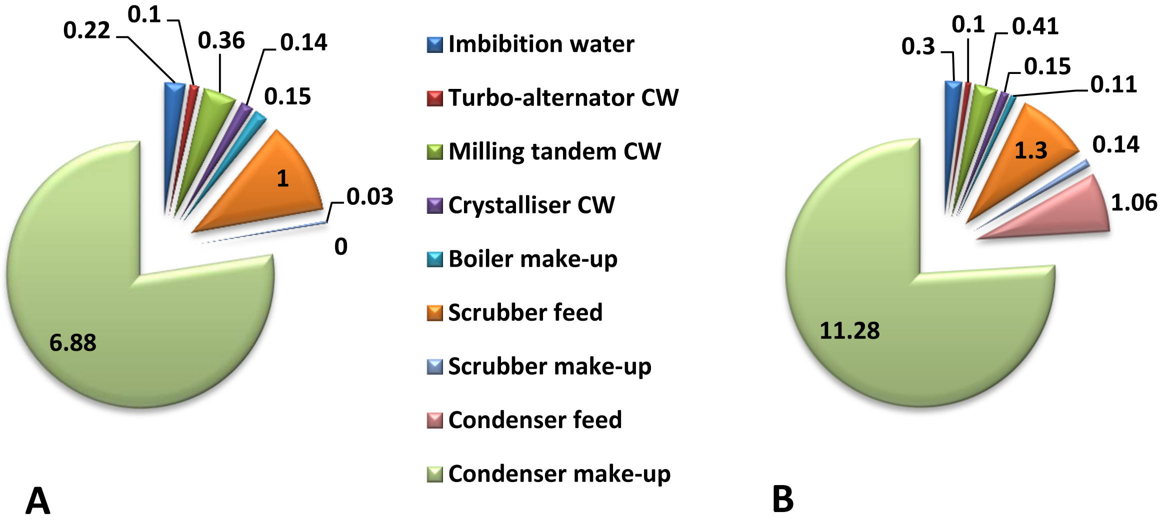

Figure 20: Example breakdown of raw water inputs (in kl/ton milled cane) for two Mauritian sugar factories with high specific water intake: (A) with partial recirculation of condenser cooling water and scrubber water, and (B) partial recirculation of scrubber water only
CW = cooling water **Adapted from Ramjeawon (2000)**

4.5 Simple water-saving measures

Although recycling (reuse) is volumetrically the largest contributor to water saving, other simple measures are also recommended. For example:

- **Simple equipment upgrades**: It is relatively affordable to upgrade water sprayers (e.g. nozzles that use less water, self-closing nozzles), high-pressure low-volume washing systems, and auto shut-off valves. It has been shown that the use of these can save significant volumes of water.
- **Dry clean-up techniques:** Unless products are being recovered, equipment and spills should be wiped up before washing or rinsing with water (e.g. floors, vessels).
- **Water use targets:** It has been shown that if targets are in place, water saving is more successful.
- **Wet clean-up operations:** Unless the water is recycled, wet clean-ups operations waste water. In many instances, mechanical cleaning or dry cleaning techniques are equally effective. Dry mopping of spills should precede wet operations, unless product and water is being simultaneously recovered.
- **Monitoring water use:** It has been shown that when water use is metered, water use is reduced because areas of wastage are highlighted.

Some YES/NO questions about adoption of these simple measures were posed in the NATSURV questionnaires (Appendix 1). From the answers, it is clear that the industry as a whole is aware of the need to reduce water usage, and 11/12 of the NATSURV respondents indicated that they have water usage targets in place. In some instances, targets have been exceeded by implementing water-saving measures (Table 7).

Most sugar cane processors recycle spillages back into processes, either directly, by hosing down, or by employing both of these methods (Table 7). Apart from saving water, this allows recovery of product. As this water is recycled back to the process, none of the respondents mop up spills prior to hosing down.

Only 5/12 and 1/12 NATSURV respondents indicated that they use high-pressure nozzles and self-closing nozzles, respectively, on hoses, despite the fact that the installation of these is an inexpensive and effective way to reduce water usage. This is an area for improvement.

Table 7: Response of 12 South African cane sugar processors to selected "best practice" questions for efficient water use

	Question	Response			Individual response details
		yes	no	none	
Spillages	Hose down and recycle to process?	6	5	1	Use process condensate for hosing (1)
	Recycle directly to process?	8	3	1	
	Mop up before hosing?	0	11	1	

Equipment	Cleaning-in-place equipment installed?	4	7	1	On reverse osmosis and nano-filtration plant (1) Caustic CIP plant on evaporators (1) Caustic CIP plant on juicers (1) High-pressure water CIP (1)
	High-pressure nozzles on hoses?	5	3	4	
	Self-closing nozzles on hoses?	1	5	6	
Water use targets	In place?	11	1	0	To optimise condenser efficiencies Potable water intake (1) Part of environmental management plan (EMP) (1)
	Being met? Comments? *Refer to last column	3	*	2	“Mostly” met (2) 90% met (1) 60% met (1) Yes: 2014 exceeded objective to reduce potable water intake from 2.72% to 2.00% on cane. New milestone 1% (1) EMP and targets reviewed periodically (1) Readings monitored and discussed on a daily basis (2)

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Section 5: Wastewater generation and management

5.1 Quality and quantity of wastewater produced

5.1.1 Volume of wastewater generated: monitoring and metering

Of the 12 NATSURV respondents, two indicated that they monitor the total effluent discharge as well as discharge from specific streams, three that they monitor only the total discharge, and four that they only monitor one or more specific effluent streams, but not the total volume (Figure 21A). Half of the respondents indicated that they use meters to measure the volume of wastewater generated (Figure 21B).

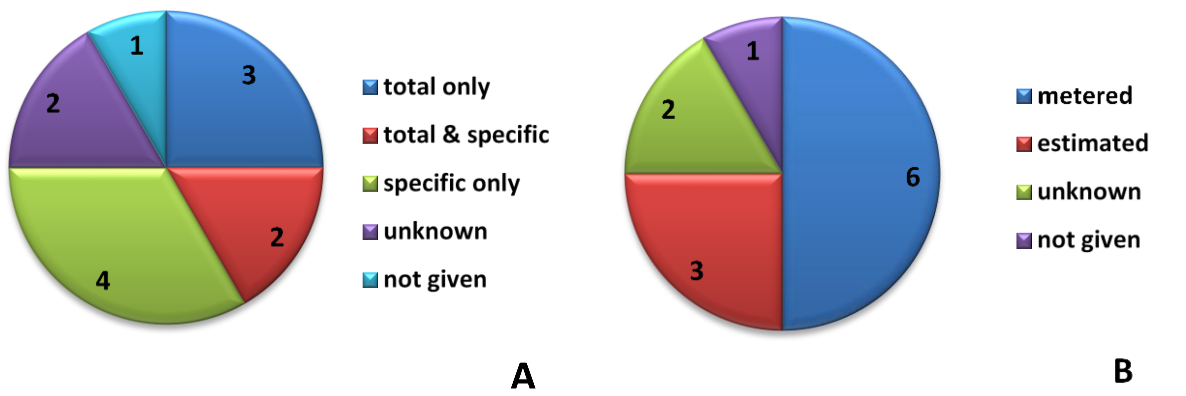

Figure 21: Monitoring of wastewater volumes by 12 South African sugar industry NATSURV respondents: Type of effluent (A) and method of measurement applied (B)

5.1.2 Recycling of wastewater and specific wastewater discharge

It was difficult to obtain reliable data on the specific wastewater discharge volumes (SWDV) given in Table 8 because South African mills do not necessarily meter specific flows. For example, at one mill, a large volume of water from the scrubbers is discharged to a settling dam for cooling and ash settling. The SWDV is based on the gross requirements of the scrubbers. However, a substantial portion of the settled water is reused, so that the net (actual) SWDV cannot be calculated.

In the case of the mills with back-end refineries, one of the facilities uses once-through river water in the cooling towers, which contributes significantly to the total SWDV. The measured value at this facility is 11.53 kl/ton cane (Table 8). Another combined mill and refinery, despite having relatively new infrastructure and stringent water-saving measures, receives large volumes of raw sugar from other mills. This naturally increases its process water requirements and subsequently the water intake and total SWDV.

In the previous NATSURV, it was stated that the wastewater discharge of plants in South Africa is “about 30% of water intake” which the authors calculated to be approximately 0.18 kl of wastewater per ton of sugar cane (Figure 8), and that facilities produce between 750 and 2 500 kl of wastewater per day. However, it was not reported whether the figures were derived from stand-alone mills and/or combined facilities. There was also no indication of the number and size of the facilities included in the calculations.

After an extensive literature search, only one publication was found that contained SWDVs. These values were taken from five mills in Mauritius, where the SWI (Section 4) and SWDV were considered as "high".

Table 8: Total specific wastewater discharge volumes: local and global

Type of facility	No.	Average (kl/ton cane)	Range (kl/ton cane)	Reference
Unknown	6	5.9	2.5 to 12.8	Ramjeawon, 2000
Unknown	?	0.18	Not given	NATSURV, 1990
BER	2	0.10	0.06 to 0.15	NATSURV, 2016
BER	1	11.53*	-	NATSURV, 2016
SAM	3	1.26	0.29 to 3.12**	NATSURV, 2016

*** Once-through cooling water used**
****recycling of boiler stack scrubber wastewater not accounted for in calculation**
R = refinery BER = mill with back-end refinery SAM = stand-alone mill

Effluent from boiler stacks and cooling towers contributes significantly to effluent volume, but this can be reduced substantially by recycling.

To enable industries to decrease the volume of wastewater generated, it is important to measure recycled wastewater volumes and discharge volumes from specific processes and streams.

Four of the NATSURV respondents provided metered values for wastewater discharges from specific processes or operations, while two provided estimated values (Table 9). Ideally, effluent volumes should be metered as part of a sound environmental management plan.

Table 9: Specific wastewater discharge volumes from various operations

Type of facility	Boiler stacks	Equipment cleaning	Evaporators	Cooling towers	Other	Comments
	kl/ton cane	kl/ton cane	kl/ton cane	kl/ton cane	kl/ton cane	
BER	0.362 (M)	0.05 (M)	0.006 (E)	11.11 (M)	-	Once-through cooling tower water from river
SAM*	2.98 (M)*	-	-	-	0.14 (M)	Other: Combined from all other operations & sewers
SAM	0.29 (M)	-	-	-	0.07 (M)	Other: Combined from all other operations
SAM	0.08 (E)	-	-	-	0.001 (E)	Other: Combined from equipment cleaning and wash-down
SAM	-	-	-	0.688 (M)	-	

***significant volume of boiler stack effluent is recycled M = metered E = estimated**
BER = mill with back-end refinery SAM = stand-alone mill

5.1.3 Wastewater quality: local and global

The major liquid effluents from sugar factories are condenser water, floor (and other) wash-water, scrubber water, boiler blow-down, and contaminated cane yard run-off. The character of the effluent from each can differ considerably. If streams are kept separate, they require different levels of treatment and/or management before disposal of the final effluent.

Despite a specific request in the questionnaire (Appendix 1), none of the respondents supplied historical wastewater quality data. Data was also not forthcoming from government sources. Although 50% of the respondents indicated that they would allow sample collection, the project team decided that unless long-term analyses could be conducted, once-off sampling could present a distorted picture of the wastewater quality.

For the purpose of the NATSURV document, it is important that readers are provided with information about the character of wastewater emanating from the sugar industry. In the absence of data from South Africa, global values from literature sources are presented in Table 10. Most of the parameters given in the table reflect the character of the effluent from different sources, or the final combined effluent **before any form of treatment**. The South African mills all attempt to comply with the legislative standards (Section 3), which usually require treatment before discharge.

The results from these studies indicate that the pH of combined effluent from sugar cane processing plants is slightly acidic, although some waste streams may be alkaline. The presence of sugar and other organics in the wastewater can lead to high COD concentrations. Although the effluent can contain phosphates, the COD:N ratio is typically high, making it nutrient-limited for biological treatment. This can be overcome by treating sugar mill/refinery effluent simultaneously with domestic effluent. However, this may render the treated effluent unsatisfactory for irrigation or discharge to water courses, unless it is properly sterilised to remove potential pathogens.

Although COD is seen locally and globally as the most important parameter used to assess wastewater quality from the sugar cane processing industry, the effluent can contain high concentrations of suspended solids. The effluent may also be highly coloured, both before and/or after conventional treatment. In addition, oil from machinery such as mills can be present in the wash wastewater. Some waste streams, such as boiler blow-down, may have elevated temperatures which need to be taken into consideration if the water is being directly discharged before cooling. These parameters all need to be considered by the legislative bodies, and should also ideally be monitored at timely intervals.

The ratio of BOD_5:COD serves as a proxy to determine whether the organic fraction of wastewater is biodegradable. The ratio in domestic wastewater is typically around 0.6. The BOD_5:COD ratios of untreated final effluent from the sugar industry reported in literature range from 0.25 to 0.57.

Table 10: Wastewater quality data for sugar cane processors: global figures

Wastewater source	Colour	pH	COD (mg/L)	BOD_5:COD (ratio)	TSS (mg/L)	TDS (mg/L)	TP (mg/L)	Cl (mg/L)	Reference
Final untreated effluent	Dark yellow	5.5	3682	ND	540	ND	5.9	50	Sahu et al., 2015
Not given	Black	4.2	3140	0.31	ND	1480	ND	ND	Sajani and Muthukkaruppan, 2011
Final untreated effluent	Green-yellow	5.1	6400	0.35	380	1008	0.8	ND	Shivayogimat and Rashmi, 2013
Not given	ND	6.6	290	ND	ND	617	3.9	255	Muhammad and Ghulam, 2015
Final untreated effluent	Black-grey	6.7	6820	0.44	447	ND	ND	522	Anand et al., 2009
Final untreated effluent	Dark yellow	5.5	3682	0.26	790	1480	5.9	250	Poddar and Sahu, 2015
Final untreated effluent	ND	6.2	3400	0.53	344	ND	ND	ND	Ramjeawon, 2000
Cooling water and washings									
Condensate excess	ND	7.6	630	0.60	5	ND	ND	ND	Ramjeawon, 2000
Boiler blow-down	ND	10.1	300	0.43	65	ND	ND	ND	Ramjeawon, 2000
Scrubber overflow	ND	8.5	1210	0.08	1480	ND	ND	ND	Ramjeawon, 2000
Spray-pond overflow	ND	7.1	110	0.55	55	ND	ND	ND	Ramjeawon, 2000

ND: not determined

Wastewater source	COD (kl/ton* cane or mg/L)			BOD_5:COD (ratio)		TSS (mg/L)		Reference
	Number	Average	Range	Average	Range	Average	Range	
Process effluent	5	6100*	740 to 2790*	0.49	0.25 to 0.57	622*	230 to 1590*	Ramjeawon, 2000
Final untreated effluent	1	NG	1000 to 4340	-	-	NG	760 to 800	Hampannavar et al., 2010
Final untreated effluent	4	2536	639 to 3683	0.22	0.19 to 0.30	401	272 to 660	Jadhav et al., 2013
Process effluent**	4	1421	392 to 2120	0.22	0.16 to 0.30	263	159 to 342	Jadhav et al., 2013

****Process effluent from washing juice heaters, evaporators, crystallisers, rotary filters and condensers. Number = number of facilities included in analyses**

5.2 Treatment, management and disposal of wastewater by the local sugar cane processing industry

Two of the NATSURV respondents indicated that they discharge their final effluent to marine outfalls, one directly, and one via the municipal reticulation system. Irrigation, followed by discharge to river systems is currently the most common means of disposal of final effluent (Figure 22).

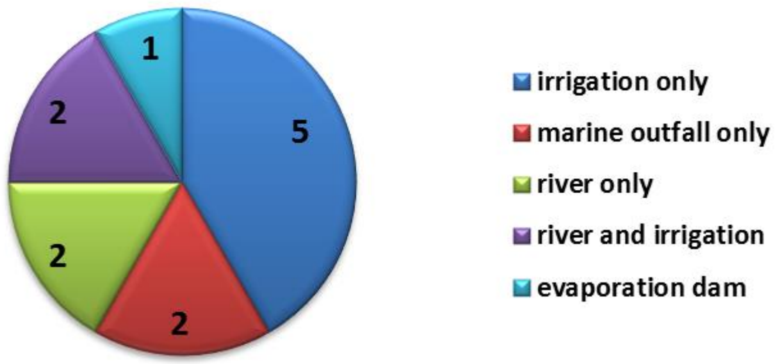

Figure 22: Disposal of final effluent by the South African sugar industry

Globally, primary physicochemical and/or secondary biological technologies are typically used to treat sugar industry effluents, e.g. coagulation with alum in the presence of lime followed by biological oxidation. Apart from basic solids settling, 4/12 NATSURV respondents indicated that they currently perform some type of physicochemical treatment: two add lime, one adds a flocculant, and one dilutes the wastewater (Table 11). Fifty percent of the respondents indicated that they perform some type of biological treatment: pond systems (4) or activated sludge (2). One also uses a wetland system as a polishing step, and one treats by natural percolation through sand. These may also be seen as combined physicochemical/biological treatment systems (e.g. planted and unplanted constructed/treatment wetlands). An example of a more sophisticated treatment system that has been installed and is operational at a South African mill is shown in Figure 23.

Table 11: Wastewater treatment and management by South African sugar processors

Type of facility	Treatment	Final discharge
R	In process of implementing	Municipal sewer → marine outfall
BER	Anaerobic and aerobic ponds	Irrigation
BER	Dilution	Irrigation
BER	Scrubber effluent mixed with spent lime and other effluent streams	Irrigation
SAM	Solids settling, addition of flocculant, anaerobic and aerobic dams, aeration basin	River Irrigation
SAM	Mixed with domestic effluent after treatment in a rotating biological contactor → aeration ponds → clarifier → mixed with scrubber effluent in settling dam (**see Figure 24**)	River Irrigation
SAM	Scrubber water to settling ponds and recycled. Activated sludge treatment for combined storm water , domestic sewage, chemical plant waste, process water etc.	Marine outfall
SAM	Anaerobic and aerobic ponds → treatment wetland	River
SAM	Natural percolation through sand	Evaporation dam
SAM	No treatment	Irrigation
SAM	Activated sludge	River
SAM	Solids separation, lime addition	Irrigation

R = refinery   BER = mill with back-end refinery   SAM = stand-alone mill

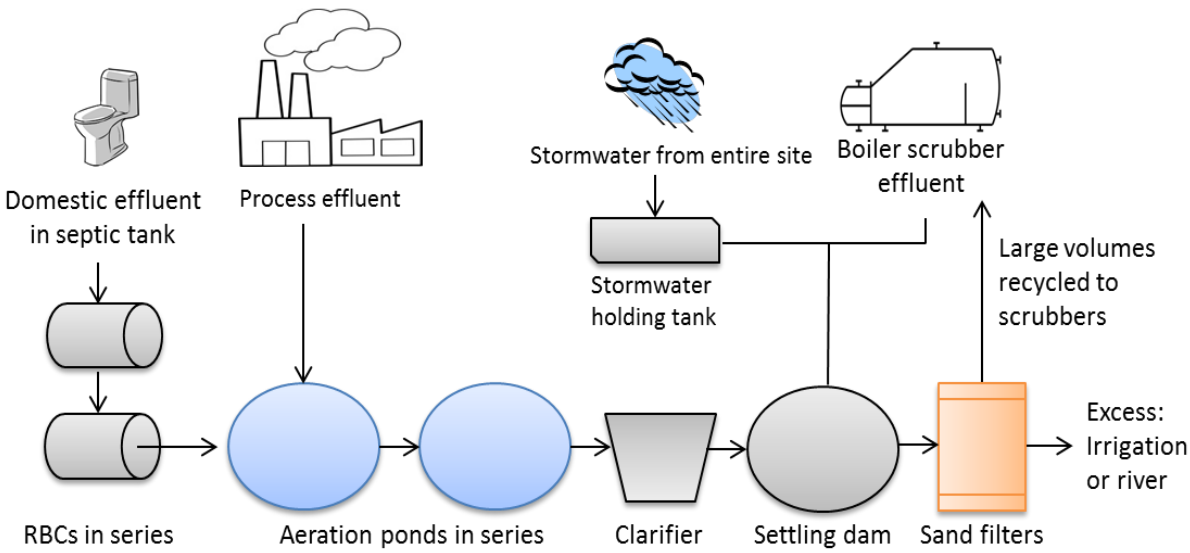

Figure 23: Schematic of the treatment system at a South African sugar processing mill, where the effluent is mixed with domestic effluent that has been partially treated in rotating biological contactors, and scrubber water is recycled

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Section 6: Energy use and management

The main focus of this NATSURV is water and wastewater management, so this section on energy management has been kept succinct. The sugar industry is in the position where much of the energy can be produced by combustion of bagasse, which is seen as carbon neutral. Other means of energy are coal, wood or spent bark, and diesel (Figure 24).

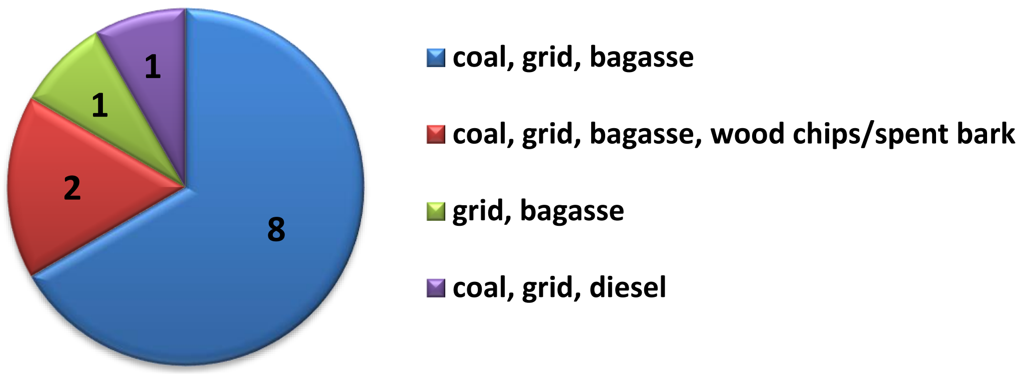

Figure 24: Different combinations of energy sources, and number of sugar cane processing facilities using each combination

To maintain anonymity, individual energy usage is not provided in this document. Of the study respondents, only the stand-alone-refinery does not have the option of using bagasse, as no milling is performed. Over 1 000 mWh/annum (>80% of the energy requirements of the sugar processing industry) is provided by burning bagasse (*n* = 10/14, including the stand-alone refinery (Figure 25). Less than 4% of energy requirements is derived from the grid.

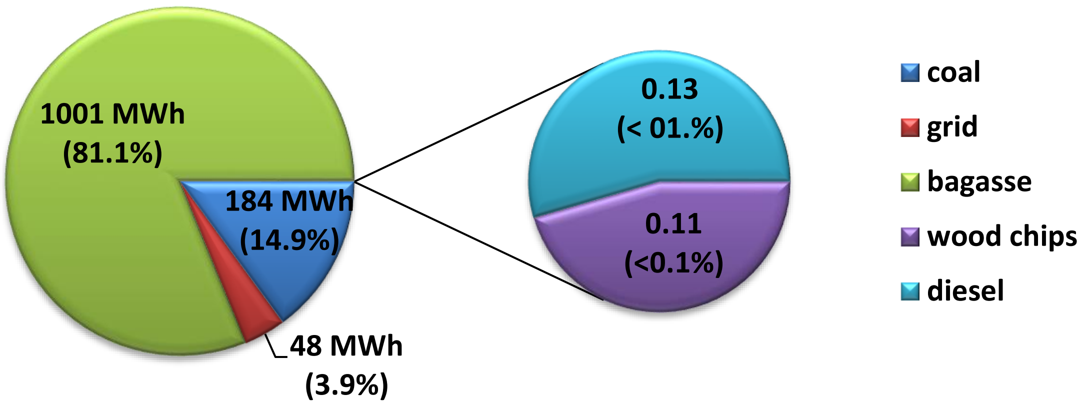

Figure 25: Combined amount of energy produced per annum (MwH), and percentage contribution of different sources of energy, from 10 (of 14) sugar processing facilities in South Africa. Energy conversions applied in calculations: 1 kWh = 3.6 MJ, 1 MT coal = 29 308 MJ, 1 L diesel = 38.79 MJ (higher heating value)

Of the 12 NATSURV respondents, none currently use solar or wind power, but two have plans to produce bioethanol from cane. Three respondents indicated that they produce excess energy from bagasse. One company exported 29 GWh of electricity to Eskom in 2016.

Half of the respondents indicated that they had specifically upgraded infrastructure to reduce emissions and/or save energy. These include:

- An upgrade of the boiler plant to reduce coal consumption and emissions, as well as the installation of new process technology to save steam and energy.
- A change of crystalliser drives from worm wheel to planetary gearboxes.
- The installation of a Venturi wet scrubber system to reduce emissions.
- A "major upgrade" which is currently underway to maximise energy use and reduce coal dependency, and thus emissions of nitrous oxide and sulphur dioxide (no specifics given).
- The installation of continuous pans and bypassing the press-water clarifier to save energy.
- A "modification" to limit emissions (no specifics given).

Section 7: Best practice for water and wastewater management in the sugar industry

7.1 Introduction

The catch-phrase “reduce, reuse, recycle” applies to just about all the world’s resources, including water, and forms part of the best practice hierarchy (Figure 26).

Best practice is an accepted term that is widely used, and can be defined as “strategies, activities or approaches that have been shown through research and evaluation to be effective and/or efficient”. The term is somewhat controversial, because some people feel that there are always ways to improve, and application of the term suggests that no further innovation is necessary. The term “best available technology” is now used by some individuals and groups.

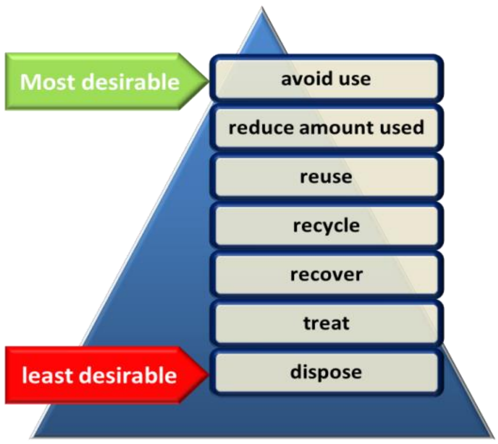

Figure 26: Best practice hierarchy - towards a sustainable future

7.2 Summary of guidelines for best practice

In sugar mills and mills with back-end refineries, water is supplied from the cane and from external sources, and leaves the factory as effluent. Mills can theoretically operate as net water producers, while stand-alone refineries are completely reliant on external water sources. Water and effluent management should not be seen as separate entities, as many so-called effluent streams can be used as water sources. Water recycling is an inherent part of sugar cane processing in South Africa.

As discussed in Section 4.4, there are many areas where water can be reused in sugar factories, and recycling/reuse is the primary method of reducing dependency on external water supplies. The exact manner in which water is recycled and/or reused will differ between each facility according to operational requirements and existing infrastructure.

An example of where a concerted effort was made to improve water use and wastewater quality in a South African sugar factory was described by Jensen and Schumann (2001). At this site, effluent water containing mostly sugar and some organics is used instead of condensate for imbibition (i.e. returned to the process). By doing this, the impurities and product in the effluent are added to those from the cane. Most of the impurities eventually form part of the solid waste and/or by-products (boiler smuts, surplus bagasse, and molasses). The rationale is that instead of a contaminated liquid stream that needs to be treated to comply with discharge standards, the surplus water for discharge is the condensate that requires minimal (if any) treatment. If such a strategy is adopted, a sound management plan needs to be implemented to prevent adverse impacts of poor quality effluent on product quality e.g. during breakdowns or high precipitation. To achieve this, the factory was retrofitted with bunded areas containing a series of drains, sumps and storage facilities for specific overflows. However, there are some drawbacks to this approach, including reduced plant reliability and an increased need for maintenance of water circuits.

Generic best practice guidelines, summarised in Table 12, range from large-scale changes in infrastructure, to small-scale changes such as the installation of self-closing nozzles on hoses and pipes. Factories should scrutinise these to ascertain if and how these measures can be implemented.

Table 12: List of measures that can assist with reducing water use, and/or improving effluent quality and/or reducing effluent quantity

Infrastructure	
➢ Replace water-cooled compressors with air compressors.	↓ SWI
➢ Install cleaning-in-place equipment for tanks and pipes.	↓ SWI ↓ SWDV
Simple equipment and measures	
➢ Upgrade water sprayers (e.g. nozzles that use less water, self-closing nozzles), high-pressure, low-volume washing systems, and auto shut-off valves.	↓ SWI
➢ Harvest rainwater.	↓ SWI
➢ Reduce spillages and/or collect product from spillages for reprocessing. For example, spill collection trays should be installed at appropriate sites.	↓ SWI ↓ EPL ↓ SWDV
➢ Install grids over drains to prevent solids from entering the wastewater.	↓ EPL
➢ Choose the most suitable disinfection chemicals for a particular area. Preferably use more environmentally friendly/biodegradable alternatives. Use cleaning agents in the correct concentrations and apply according to manufacturers' instructions. Too low or too high concentrations are not as effective.	↓ EPL
Management and maintenance	
➢ Perform regular water audits. Measure and monitor effluent quality and quantity from each area to identify where product and consumables are being lost.	↓ SWI ↓ EPL ↓ SWDV
➢ Fix leaking pipes timeously.	↓ SWI ↓ EPL ↓ SWDV
➢ Measure and monitor the use and availability of process water and need for make-up water; adjust recycling/reuse when needed.	↓ SWI ↓ EPL ↓ SWDV
➢ Implement water-use targets.	↓ SWI
➢ Install water meters as part of a water management and monitoring program. This creates awareness of where water is being wasted.	↓ SWI ↓ SWDV
➢ Cooling towers should be kept clean and in good working order to maximise efficiency. Automatic blow-down should be monitored to prevent excessive water losses. Fill and drift eliminators can reduce evaporative water losses.	↓ SWI ↓ EPL ↓ SWDV
➢ Unless products are being recovered, equipment and spills should be wiped up before washing or rinsing with water (e.g. floors, vessels). In many instances, mechanical cleaning or dry-cleaning techniques are equally effective.	↓ SWI ↓ EPL ↓ SWDV
➢ Educate staff about water conservation, and the potential impact of effluent on the environment.	↓ SWI ↓ EPL ↓ SWDV
➢ Educate staff about how to operate equipment properly in order to save water, reduce effluent and improve effluent quality.	↓ SWI ↓ EPL ↓ SWDV
Water recycling (must be fit for purpose)	
➢ Segregate and store wastewater streams for reuse.	↓ SWI ↓ SWDV
➢ Heat condensates should be recovered and reused where possible.	↓ SWI
➢ Use process water of minimum required quality instead of external water.	↓ SWI
➢ Substitute condensate with lower quality process water if possible.	↓ SWI ↓ EPL
➢ Recycled water, such as blow-down water, should be used to moisten coal ash.	↓ SWI ↓ SWDV
➢ If possible use treated effluent for floor washing and/or beneficial irrigation.	↓ SWI ↓ SWDV
➢ Use clean condensate as make-up water in cooling towers.	↓ SWI ↓ SWDV

SWI = specific water intake; EPL = effluent pollutant load; SWDV = specific wastewater discharge volume

Adapted from IFC (2007a, 2007b, 2007c, 2011) and Ingaramo et al. (2009)

7.3 7.3 Application of environmental indicators

SWI is the basic measurement used to assess water consumption by industry. However, there are a number of other eco-efficiency indicators that can be used. These typically require a large range of measured data and elaborate computational tools. The less complex environmental water use efficiency indicator known as WIN (Water use INdex) takes into consideration six inter-related water cycles (systems). To assess whether water from one cycle may be suitable for use in another, the typical water quality from each cycle is taken into account in the model. WIN values range from 0 (minimum water usage) to 1 (maximum water usage).

From a more holistic environmental perspective, it has been suggested that the generation of wastewater by individual sugar cane processing plants should be assessed using indicators such as the Environmental INdicators (EIN) — EIN1 and EIN2 — proposed by Ingaramo et al. (2009). These are simple calculations that take into account the quality and quantity of effluent. These indicators should ideally be used in conjunction with the WIN to provide a holistic environmental assessment of environmental water management practices.

Both EIN1 and EIN2 use COD as the proxy value for wastewater quality. EIN1 also takes into account the local legislative COD limits. However, the COD is not expressed as a concentration, but as the amount (in kg) of COD generated for each 100 tons of cane crushed. This is an extremely useful parameter which allows the use of EIN1, EIN2 and WIN to compare environmental water management across the industry.

From a local perspective, the application of such environmental indicators could allow milling/refining groups to compare the environmental performance of the plants within their group. This knowledge would provide insight into which operational choices provide the best environmental performance outcomes.

WIN can compare water consumption in sugar factories operating under a variety of conditions and configurations, and is represented by Equation 2:

$$(W_c - W_R) \div (W_{UP} - W_R) \qquad \textbf{Equation 2}$$

Where,
W_C = actual fresh water consumption/100 ton cane (make-up water)
W_{UP} = the upper water consumption/100 ton cane, which is the volume required to satisfy all water requirements using external water
W_R = reference water consumption/100 ton cane, which is the volume of water used if all the reuse/recycling in cycles 1 to 6 are implemented under stipulated operating conditions (standard efficiencies).

The $W_{C,}$ W_{UP} and W_R are calculated from mass flows according to Equations 3 to 5:

$$W_C = \sum water\ in\ products\ and\ non\ products\ - water\ in\ cane\ + \sum losses\ + \sum purges$$

Equation 3

$$W_{UP} = \sum water\ in\ products\ and\ non\ products - water\ in\ cane + \sum upper\ losses$$

Equation 4

$$W_R = \sum water\ in\ products\ and\ non\ products - water\ in\ cane + \sum lower\ losses + \sum lower\ purges$$

Equation 5

For details on WIN and other environmental indicators for the sugar cane processing industry, refer to Ingaramo et al. (2009).

Section 7 References:

Ingaramo, A., Heluane, H., Colombo, M., Cesca, M. (2009) Water and wastewater eco-efficiency indicators for the sugar cane industry. Journal of Cleaner Production, 17: 487-495.

International Finance Corporation (IFC) (2007a) Environmental Health and Safety Guidelines for Sugar Manufacturing.

International Finance Corporation (IFC) (2007b) Environmental Health and Safety Guidelines: General: Environmental Wastewater and Ambient Water Quality.

International Finance Corporation (IFC) (2007c) Environmental Health and Safety Guidelines: General: Water Conservation.

International Finance Corporation (2011) Good Management Practices for the Cane Sugar Industry.

Jensen, C.R.C, Schuman, G.T. (2001) Implementing a zero effluent philosophy at a cane sugar factory. Proceeding of International Sugar Cane Technology, 24: 74-79.

Ramjeawon, T. (2000) Cleaner production in Mauritian cane-sugar factories. Journal of Cleaner Production, 8: 503-510.

APPENDIX 1: SUGAR INDUSTRY QUESTIONNAIRE (CONFIDENTIAL): MILL WITH BACK-END REFINERY

Please use average values over the last 3 years (2012-2014) if possible. ***If alternative time frames are used, please stipulate these.***
No proprietary names will be used in any publications unless permission is granted. Non-disclosure agreements will be signed if required.

1. Production figures

How much cane is milled at your facility each year (ave. 2012 to 2014)	………………………………………………………………………………tons/annum
How much raw sugar is refined at your facility each year (ave. 2012 to 2014)	………………………………………………………………………………tons/annum

2. Process infrastructure

How old is the bulk of the equipment in your mill? (tick)	0-10 yrs:	10-25 yrs:	25-50 yrs:	>50 yrs:
How old is the bulk of the equipment in your refinery? (tick)	0-10 yrs:	10-25 yrs:	25-50 yrs:	>50 yrs:

Has any of the major equipment been replaced in the last 10 years specifically to save water or energy, or to limit emissions? Please specify briefly if possible.

3. Operational seasonality

Milling: Over which months of the year does your mill operate?	………………………………………. to …………………………………
Refining: Over which months of the year does your refinery operate?	………………………………………. to …………………………………

4. Clarification

What clarification process is applied in your refinery?	

5. Water management

What is the source and net volume of water used for milling?	Potable water	Borehole water	River water	Other (specify)

<table>
<tr><td></td><td>…………………kl/ton cane</td><td>…………………kl/ton cane</td><td>…………………kl/ton cane</td><td>…………………kl/ton cane</td></tr>
<tr><td>What is the source and net volume of water used for refining?</td><td>Potable water

……………kl/ton raw sugar</td><td>Borehole water

……………kl/ton raw sugar</td><td>River water

……………kl/ton raw sugar</td><td>Other (specify)

……………kl/ton raw sugar</td></tr>
<tr><td>If potable water is used, what municipal tariffs apply (2015)?</td><td colspan="4">……………………………………..R/kl</td></tr>
<tr><td rowspan="2">How do you deal with spillages (tick)</td><td colspan="2">Hose down to waste only</td><td colspan="2">Mop and then hose down to waste</td></tr>
<tr><td colspan="2">Directly recycle back into to process</td><td colspan="2">Hose down and recycle back into process</td></tr>
<tr><td>Do you have any cleaning-in-place (CIP) equipment? Please specify.</td><td colspan="4"></td></tr>
<tr><td>If hoses are used, are these fitted with (tick):</td><td colspan="4">High-pressure nozzles | yes | no | Self-closing mechanisms | yes | no</td></tr>
<tr><td>Are water usage targets and practices in place? To what extent are these being met?</td><td colspan="4"></td></tr>
<tr><td>6. Wastewater generation and management</td><td colspan="4"></td></tr>
<tr><td rowspan="4">What <u>net</u> volume of wastewater is generated from:
*Indicate with <u>"E" or "M" or "U"</u> if these are estimated, measured (metered), or unknown volumes.</td><td colspan="2">Boiler stack scrubbers……………………………..kl/annum</td><td colspan="2">Cleaning of equipment………………………………kl/annum</td></tr>
<tr><td colspan="2">Evaporator blow-down …………………………kl/annum</td><td colspan="2">Blow-down from cooling towers etc…………..kl/annum</td></tr>
<tr><td colspan="4">Wash-down water (floors, spillages etc.)………………………………………………………………………………………kl/annum</td></tr>
<tr><td colspan="2">Other (specify)……………………………………kl/annum</td><td colspan="2">Total………………………………………………………kl/annum</td></tr>
<tr><td rowspan="3">Where is your final effluent being discharged to (tick)?</td><td colspan="2">Municipal sewer</td><td colspan="2">Evaporation dam/s</td></tr>
<tr><td colspan="2">Land irrigation</td><td colspan="2">Water course (river)</td></tr>
<tr><td colspan="2">Marine outfall</td><td colspan="2"></td></tr>
<tr><td>Is the wastewater being treated before discharge? If so, what methods are being used? Have you tried other methods in the past, and if so, how do these compare to your current practices?</td><td colspan="4"></td></tr>
</table>

Which statutory body provides your discharge permit (specify local, district or metropolitan municipality, or DWS)? What are your permitted effluent parameter limits?	
Are wastewater quality and quantity targets in place? If so, to what extent are these being met? How do the targets compare to statutory requirements?	

NB: Please provide us with historical wastewater quality data on different waste streams (if available) and/or the final effluent. This may be provided in a separate document.

7. Energy usage				
What quantity of energy is derived from the following sources/fuel, and if applicable, what is the cost of this energy (tariffs and/or raw material costs)?	Electricity from grid		Coal	
	…………………….kW/annum	…………………………R/kWh	…………………….kW/annum	…………………………R/kWh
	Wood chips		Gas	
	…………………….kW/annum	…………………………R/kWh	…………………….kW/annum	…………………………R/kWh
	Diesel		Bagasse	
	…………………….kW/annum	…………………………R/kWh	…………………….kW/annum	…………………………R/kWh
	Other (specify)		Other (specify)	
	…………………….kW/annum	…………………………R/kWh	…………………….kW/annum	…………………………R/kWh
Do you produce excess energy from burning of bagasse (yes/no)? If so, how much.	……………………………………… kW/annum			

Do you have plans to use or produce alternative energy in future?	Solar energy	Yes	No
	Wind energy	Yes	No
	Bioethanol production from bagasse	Yes	No
	Bioethanol production from cane	Yes	No

	Other (specify)
8. By-product and solid waste generation and management	
Please indicate briefly what the following by-products or wastes are used to produce, or how they are disposed of:	Bagasse……… Molasses from mill……… Refiners molasses……. Filter mud cake…… Residue from clarification…… Spent filter resins etc……. Sludge from wastewater treatment (if applicable)………………………………………………………………………. Sludge from dams/ponds etc. (if applicable)………………………………………………………………………………..

9. Closing questions	Yes	No
Would you allow the name of your company to be acknowledged in this report?		
Would you like to receive a copy of this report and comment prior to publication?		
Would you allow us to collect wastewater samples?		
Would you or a delegate from your company be interested in participating in the workshop that will be held in coming months?		