A Critical Process Analysis of Wine Production to Improve Cost Efficiency, Wine Quality and Environmental Performance

by

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Craig Sheridan **Date**

SUMMARY

Wine cellars are diverse in terms of equipment types and process configurations. Whilst other food production processes have, in many cases, been properly analysed and modelled, this process diversity has resulted in an absence of process analyses in the wine industry. Each wine cellar is unique and represents a fully integrated agro-business, starting with a raw material (grapes) and extending to marketing and selling of the final product (wine). This makes the wine industry unique in this context. This study is the first attempt to analyse winemaking procedures in the form of a process audit.

The study was approached in the following manner:

- A questionnaire was developed to assess cellar configurations and conditions. This questionnaire was submitted to a statistically significant number of cellars, and a statistically significant number of questionnaires were returned.
- The data collected from the questionnaire were statistically analysed and associations between equipment or procedures and wine faults were identified.
- Three cellars were studied in depth. These three cellars had their processes audited and their effluent characterised. Additional data were obtained from current sampling projects and these data were analysed to complement the data obtained from the questionnaire
- A preliminary input/output model was developed.

The major results of this study are:

- It was found that certain faults that appear in wine might be associated with equipment and/or process faults. These associations are statistically significant and they show that cellar hygiene is of critical importance when assessing these wine faults. The most important of these faults are VA, microbial contamination of the wine, sluggish and stuck fermentations. A risk hierarchy was derived to indicate which events are associated with others most strongly.
- It was found that few wineries measure water consumption and even fewer wineries measure the quantity of effluent produced.
- Correlations have been developed to predict winery parameters in terms of tons of grapes pressed per annum. These parameters include water and electricity consumed, wine produced and the quantity of effluent produced. Effluent characteristics have also been correlated to the tons of grapes pressed per annum. These characteristics include chemical oxygen demand, sodium absorption ratio and total dissolved solids in solution. Chemical oxygen demand was identified as the most important contributing factor in winery effluent. It was shown that all variables rise with an increase in cellar size, but the rise is not

linear. This implies that large cellars have greater quantities of effluent of lower quality than small cellars. Most cellars have effluent concentrations that require some form of effluent treatment. The characterisation of effluent shows that the most widely used disposal practice is irrigation, and that the effluent disposed in this manner does not meet legislative requirements.

- A preliminary input/output model was developed in order to enable wineries that have not measured the relevant parameters to predict the abovementioned variations. The resolution of these predictions is low but the model serves to provide an initial estimate if there are no data available. The model will give industrial averages for any given cellar size.
- An economic balance was performed using this preliminary model. It was shown that if cellars were to lower the consumption of utilities and to reduce the strength of their effluent (using cleaner practices and not dilution) the reduction of operating costs could be reduced by 14% for smaller cellars to 17% for larger cellars.

This study has shown that it is possible to make wine in a more environmentally friendly manner, producing better quality wines, without incurring extra costs.

OPSOMMING

Wynkelders is diverse eenhede ten opsigte van die tipe toerusting en prosesse wat gebruik word. Terwyl ander prosesse rondom voedselproduksie in baie gevalle reeds geanaliseer en gemodelleer is, het die diversiteit in die wynindustrie gelei tot 'n afwesigheid van prosesanalises. Elke wynkelder is uniek en verteenwoordig 'n ten volle geïntegreerde agro-besigheid wat begin met die rou materiaal (druiwe) en lei tot die bemarking en verkope van die finale produk (wyn), 'n eienskap wat die wynindustrie uniek maak in hierdie verband. Hierdie studie is die eerste poging om die wynmaakproses in die vorm van 'n proses-oudit te analiseer.

Die studie is soos volg aangepak:

- 'n Vraelys is ontwikkel om kelderkonfigurasies en -toestande te ondersoek. Die vraelys is aan 'n statisties betekenisvolle aantal kelders voorgelê, en 'n statisties betekenisvolle aantal vraelyste is terugontvang.
- Die data wat uit die vraelyste ontvang is, is statisties ontleed en verwantskappe tussen toerusting of prosesse en wyngebreke is geïdentifiseer.
- Drie kelders is in diepte bestudeer. Hierdie drie kelders se prosesse is geoudit en die afvloeiwater is gekarakteriseer. Addisionele data is verkry van huidige projekte en hierdie data is ge-analiseer om die data van die vraelys aan te vul.
- 'n Voorlopige inset / uitset model is ontwikkel.

Die belangrikste resultate van hierdie studie is:

- Dit is bevind dat sekere gebreke wat in wyn voorkom geassosieër kan word met tekortkominge in toerusting en/of prosesse in die kelder. Hierdie assosiasies is statisties betekenisvol en toon dat kelderhigiëne van kritiese belang is wanneer gebreke in wyn ondersoek word. Die mees belangrike gebreke wat voorkom is vlugtige suur, mikrobiese kontaminasie van wyn, slepende en gestaakte fermentasie. 'n Risikohiërargie is afgelei om die gebeure te toon wat die sterktste met mekaar geassosieër word.
- Dit is gevind dat min wynkelders waterverbruik meet. Selfs minder kelders meet die hoeveelheid afvloeiwater wat geproduseer word.
- Korrelasies is ontwikkel om kelderparameters te voorspel in terme van ton druiwe gepars per jaar. Hierdie parameters sluit in water- en elektrisiteitsverbruik, wyn geprosuseer en hoeveelheid afvloeiwater geproduseer. Eienskappe van afvloeiwater is ook gekorreleer met die ton druiwe wat per jaar gepars word. Hierdie eienskappe sluit in chemiese suurstofbehoeftes, natrium absorpsieverhoudings en totale opgeloste soliede materiaal in oplossing. Chemiese suurstofbehoeftes is geïdentifiseer as die mees belangrike bydraende faktor tot afvloeiwater in kelders. Dit is getoon dat alle veranderlikes verhoog hoe

groter die kelder, maar hierdie verhoging is nie lineêr nie. Dit impliseer dat groter kelder meer afvloeiwater van 'n laer kwaliteit produseer. Die meeste kelders produseer afvloeiwater van sodanige konsentrasies dat behandeling daarvan nodig is. Die ondersoek van hierdie afvloeiwater toon dat die mees algemene wyse van wegdoening van afvloeiwater besproeiing is, en dat afvloeiwater wat op hierdie manier weggedoen word, nie voldoen aan die wetgewing se vereistes nie.

- 'n Voorlopige inset/uitset model is ontwikkel om kelders wat nie die toepaslike parameters gemeet het nie in staat te stel om hierdie parameters te voorspel. Die akuraatheid van hierdie voorspellings is nie hoog nie, maar die model verskaf 'n aanvanklike skatting waar daar geen data beskikbaar is nie. Die model verskaf industriële gemiddeldes aan kelders van enige grootte.
- 'n Ekonomiese balans is uitgevoer deur van hierdie model gebruik te maak. Dit is getoon dat indien kelders die gebruik van water en elektrisiteit verminder en die konsentrasie van afvloeiwater verlaag (deur van skoner paktyke gebruik te maak, en nie verdunning nie) die bestuurskoste met 14% vir kleiner kelders tot 17% vir groter kelders verlaag kan word.

Die studie het getoon dat dit moontlik is om wyn te maak op 'n meer omgewingsvriendelike wyse, en sodoende beter kwaliteit wyn te produseer sonder addisionele kostes.

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NOMENCLATURE

T :	*Tons of grapes pressed per year*
E_H :	*Electricity used per month during the harvest period – from mid January to mid April*
E_O :	*Electricity used per month during the rest of the year*
W :	*Quantity of water consumed per year*
$Wine$:	*Quantity of wine produced per year*
COD :	*Chemical Oxygen Demand of the effluent*
TDS :	*Total Dissolved Solids of the effluent*
SAR :	*Sodium Absorption Ratio of the effluent*
$Effluent$:	*Quantity of Effluent Produced per year*

BIOGRAPHICAL SKETCH

Craig Michael Sheridan was born in Johannesburg, South Africa on the 12th of February 1977. He attended Jeppe High Preparatory School and matriculated at Springs Boys High School in 1994.

Craig enrolled at the University of the Witwatersrand, Johannesburg and obtained a Bachelor of Science in Chemical Engineering in 2000. Thereafter, he enrolled for an MSc in Wine Biotechnology at the University of Stellenbosch.

CHAPTER 1

INTRODUCTION AND PROJECT AIMS

Wine production in South Africa is strongly delocalised, with numerous small-to-medium sized producers situated in several regions within the Western Cape. The production process, largely, follows traditional methodologies. New technologies have resulted in important changes in winemaking over the last few decades. Whilst adapting to these technological changes, producers also have to respond to increased pressure from consumers regarding the quality of the product and the environmental consequences of winemaking, particularly with regard to water usage and chemical pollution. No systematic analysis integrating all the different aspects of the winemaking process in the South African wine industry has thus far been undertaken. This project therefore systematically analyses the process of wine production during cellar operation, from the reception of grapes to the final product ready for bottling. This analysis aimed to assess all of the physical inputs (e.g. cellar infrastructure, energy, chemical and water consumption); problems associated with processing (occurrence of microbial contamination, problems during clarification, stuck and/or sluggish fermentation) and the output in terms of income, product quality and the amount of effluent/waste generated.

This project arose from the idea that it may be possible to make wine in a more environmentally friendly manner, whilst improving the cost effectiveness of the process, and reducing the risk of making poor quality wine. Since this had not been done before, it was necessary to define the project in a sensible manner, as well as to define the exact scope of the study.

All of the above proved difficult because there is a lack of information regarding some aspects of winemaking in South Africa. A significant amount of information is available in terms of cellar throughput, and hectares under vines, but there is little information on, for example, how much water or electricity is used, or what equipment is used in cellars, or even on the frequency of microbial contamination of the wines, or stuck fermentations.

The project was therefore divided into two phases. The first phase would be raw data collection. This involved the development of a questionnaire that assessed a number of broad parameters. This questionnaire was submitted to 390 cellars in South Africa (at the middle of 2001). Thirty-seven questionnaires were initially returned, which corresponds to return of nine percent. This number of cellars could not form a statistically significant database. Sixty replies were finally returned and these form the basis of much of the data presented in this thesis. This number of returns is regarded as a statistically significant response.

The information on the questionnaire would then be converted into a database. This database will be able to serve many purposes. It can be used as a tool by the University* for

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* University of Stellenbosch

developing future research. Winemakers had the chance to air their views on a number of topics ranging from VA to additional analyses that they require, and this allows the University to prepare itself for future projects that may be applicable. The database also serves as a basic benchmarking exercise. This is the first project whereby industry equipment, infrastructure, and conditions have been quantified. In addition to this, topics such as stuck ferments have previously been recorded, but winemakers are reluctant to admit that it happens, because of the negative connotations of having such an occurrence. Thus, by recording such events, and getting sampling to be done if and when they occur, it may be possible to develop a deeper understanding of them.

In particular, a statistical analysis of the data of the questionnaire has been performed in order to try to predict whether certain cellar conditions could affect the quality of the wine. The results of this analysis are given in chapter 3 and some interesting predictions, which are significant statistically, have been made. In addition to this, many of the data from Winetech projects (Project 120H) were used to develop correlations relating cellar size and various parameters. Unfortunately, much data is missing, and it was necessary to combine different data sets, and cross correlate them.

The second phase of the project was to verify the data given in some of the questionnaire returns. Three cellars were selected from the original 37 that returned the questionnaire and an in depth process audit/analysis was done at these cellars. A process audit is an investigation of the running of any process. Parameters that were investigated include the quality of the effluent water, the methods of winemaking employed and the general day-to-day running of the cellar. Invariably, the effluent water is of very poor quality during the harvest season, and this has already been demonstrated at numerous other cellars and by the continuous sampling programs done by Winetech (Project 120H)

The first phase of this investigation determined the accuracy of the replies on the questionnaire. The second phase was a critical analysis of the engineering of the cellars. This included checking how efficiently the cellar consumed electricity and other consumables. The equipment was rated in terms of how efficient it was and the whole cellar layout was analysed to try to determine how the best use may be made of the space and resources available.

As expected, the three cellars yielded very different results. Cellar A is a large co-operative cellar in the Robertson valley that presses 20 000 to 30 000 tons of grapes per year. The cellar is approximately 60 years old, but has been extended many times, and consequently has an ad-hoc type of design. This cellar is classified as a large cellar. Cellar B is in the Devon Valley region of Stellenbosch, and presses between 500 and 1000 tons per year. This is an estate winery that produces wines that retail for approximately R50 per bottle. The cellar is also approximately 60 years old, and has been modified over the last 60 years, but not to the same extent as cellar A. This cellar is classified as a medium cellar. Cellar C is a small winery in the Helderburg region. It presses between 50 and 100 tons of grapes per annum, and can be considered a boutique winery. The winery is less than ten years old, and has not been modified in any significant way since it was built. This cellar is classified as a small cellar.

These three wineries were chosen out of a list of possible candidates because of the differences between them. They are all in different wards, or in different regions, and each represents a different style or focus of winemaking, as is usually the case between wineries of such different sizes. Cellar B is a family run affair, where wine is made in the traditional way – red wine is made in open fermenters, and this is labour intensive. Cellar A is an industrial sized operation, although a new section has been built in an attempt to separate high quality grapes from certain blocks, to make lower volumes of limited release type wines. Cellar C is very modern, focuses on research and innovation, and is very efficient – the whole farm employs only five people to work in both the vineyards and the cellar. The cellars were also chosen based on their willingness to participate in this program.

It is also necessary to include a note on the 2001/2002 harvest. The rains lasted well into November, which caused a high occurrence of downy mildew. This caused rot on the grapes, which led to lower harvests. On some farms, the harvest was down by as much as 50%, but it is generally not as low as that. Because of this, it is possible to classify the harvest as atypical, which means that data collected may not be representative of the norm. However, this industry is based on natural processes and weather does fluctuate so there is no reason to exclude the data.

Thus, the objectives of this study were to:

- Develop a questionnaire for submission to wineries that could be used as a basis for further development and data collection.
- Obtain a set of data with input from as many wineries as possible.
- Develop a database for use by the University for possible research purposes.
- Perform a statistical analysis of the data to ascertain the effect certain items of equipment or processing options have on the quality of the wine.
- Correlate various parameters with a specific winery input.
- Develop a mathematical model of a South African Winery.

CHAPTER 2

LITERATURE REVIEW

Wine Quality, Winemaking and Effluent Production

2.1. INTRODUCTION

As described in the chapter 1, this is a broad study, which attempts to unite many different aspects of winemaking. In addition to this, this study has a typical "Process Engineering" flavour, primarily because it is a process audit of winemaking. However, because there is an attempt to unify two distinct bodies of knowledge – namely engineering and winemaking – there has not been much research in this area before.

As such, it is very difficult to present a literature survey that unifies all of the aspects of this study. Therefore, it was decided to separate this literature survey into different sections for the different types of readers of this thesis. The survey starts with a very basic description of the winemaking process and its equipment, which is primarily for readers of an engineering background. The second part of the survey seeks to describe the concept of wine quality, because wine quality is *the factor* that wine is sold by, all over the world. Finally, the third part of this survey seeks to describe the effluent that a winery produces. This section also describes the legal requirements for the disposal of effluent, as well as the different methods used to dispose effluent.

2.2. WINEMAKING PRINCIPLES

Since this study is about how to improve the process of winemaking, it makes sense to begin this section with a brief description of how wine is made. The study includes both red and white table wines, so the method for making both will be presented, as described by Rankine (1989). Note that the following are brief descriptions of the methods of how these wines are made. For a more detailed description, consult Rankine (1989) or Boulton *et al* (1996).

2.2.1. WHITE TABLE WINEMAKING

Grapes are harvested when deemed ripe, and depending on the style of wine being made. Typically the grapes are harvested at a ripeness level of between 10° and 12.5° Baumé and are transported to the cellar as quickly as possible. Ideally, the grapes should be as cool as possible when harvested. Sulphur is added to the grapes to prevent bacterial growth, and the grapes are then de-stemmed and crushed. This is normally carried out in a single unit operation called a crusher-destemmer.

Enzymes and tartaric acid may also be added to maximise the extraction of juice, as well as to reduce the pH of the must. When making white wines, reductive conditions should be maintained as far as possible, as an oxidative flavour is a fault in white wines.

The must is then drained and the remaining berries are pressed. The juice is cooled to below 15° Celsius and more sulphur may be added. The juice is then usually left to settle overnight for clarification. Settling usually occurs in stainless steel tanks with cooling plates on the inside or cooling jackets on the outside.

Typically, the juice is then inoculated with the desired yeast strain, and alcoholic fermentation begins in the stainless steel tanks. Nutrient additives may also be provided for the yeast, depending on the composition of the must. The rate of fermentation varies considerably according to temperature, but fermentation normally lasts between seven and twenty-one days, and is carried out anywhere between 10° and 16° Celsius. The final sugar content of the resulting wine depends on the initial sugar content, as well as the style and type of wine that is being produced.

After fermentation, the wine is allowed to settle, and is then racked to remove the lees. Typically, sulphur is once again added at this stage. The wine is then cold stabilised to remove excess tartaric acid and prevent protein haze at a later stage. Bentonite is often used as a fining agent, which encourages the settling out of the fine lees. The wine is then racked from the fine lees, and may be chemically analysed before being bottled. This process is shown in figure 2.1. (Adapted from Marais, 2001)

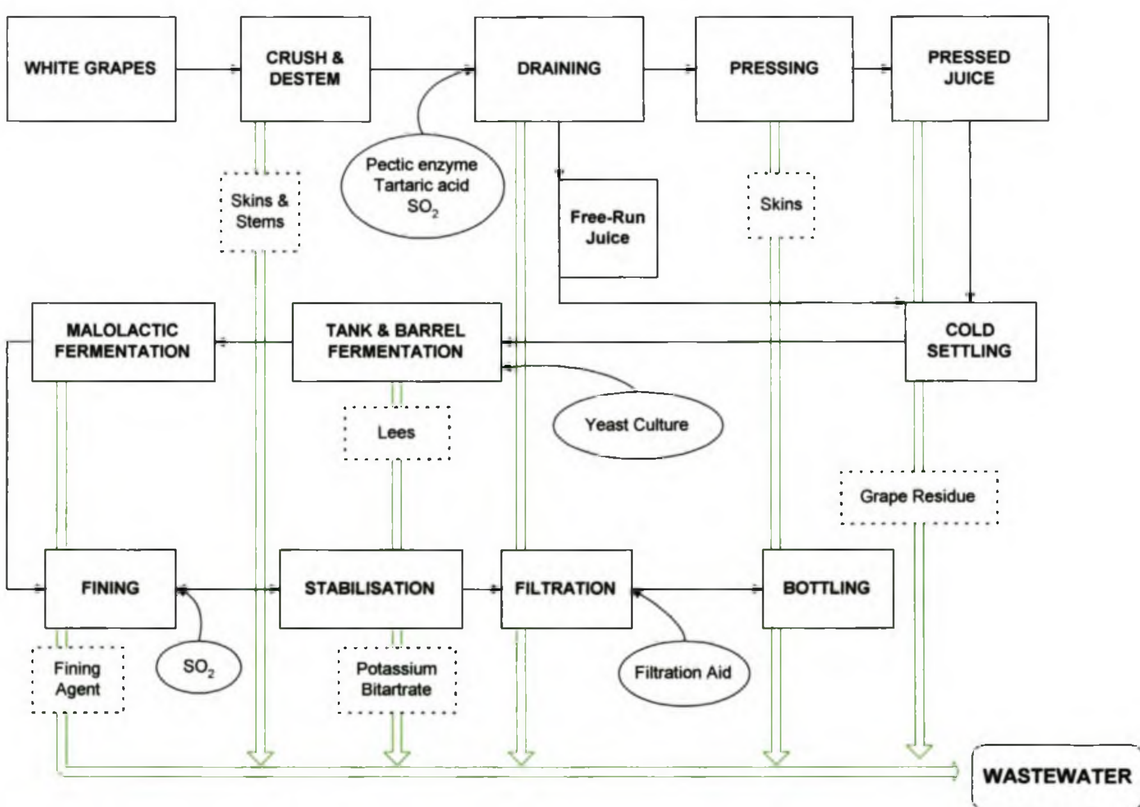

Figure 2.1 – Process Flow Diagram of White Winemaking and Potential Wastewater Components

2.2.2. RED TABLE WINEMAKING

The procedure for red winemaking is different to that of white winemaking. The grapes are harvested at similar levels of ripeness, and crushing and de-stemming occur in the same way. The crushed and de-stemmed must is then pumped to the fermentation vessel, where the wine is inoculated and fermentation may begin. The ferment occurs with the skins, as this is what imparts the red colour to the wine as well as tannins and flavour characteristics. The juice must be mixed with the floating cap of berry skins at regular intervals during fermentation in order to achieve the maximum colour extraction. There are various ways of doing this. These include manual stirring and automatic fermenters that rotate at specified time intervals, among others.

The fermentation is normally carried out at between 15° and 30° Celsius and can last from 4 to 14 days. After fermentation (when the winemaker has deemed there is sufficient colour, and the sugar is low enough for the style of wine) the wine is pressed. Pressing separates the berries from the juice. After pressing, malo-lactic fermentation usually occurs to the wine. Malo-lactic fermentation (MLF) converts malic acid to lactic acid, and there is usually a rise in pH. MLF is carried out by lactic acid bacteria, which may be inoculated if there are insufficient native bacteria. After malo-lactic fermentation, the wine may be fined, and may then be wood aged if desired. Wood ageing can take anywhere from six to twenty-four months, and generally imparts complexity to the wine.

The wine is then racked, and blended, and is then ready for filtration and bottling. The process is shown in figure 2 (Adapted from Marais, 2001)

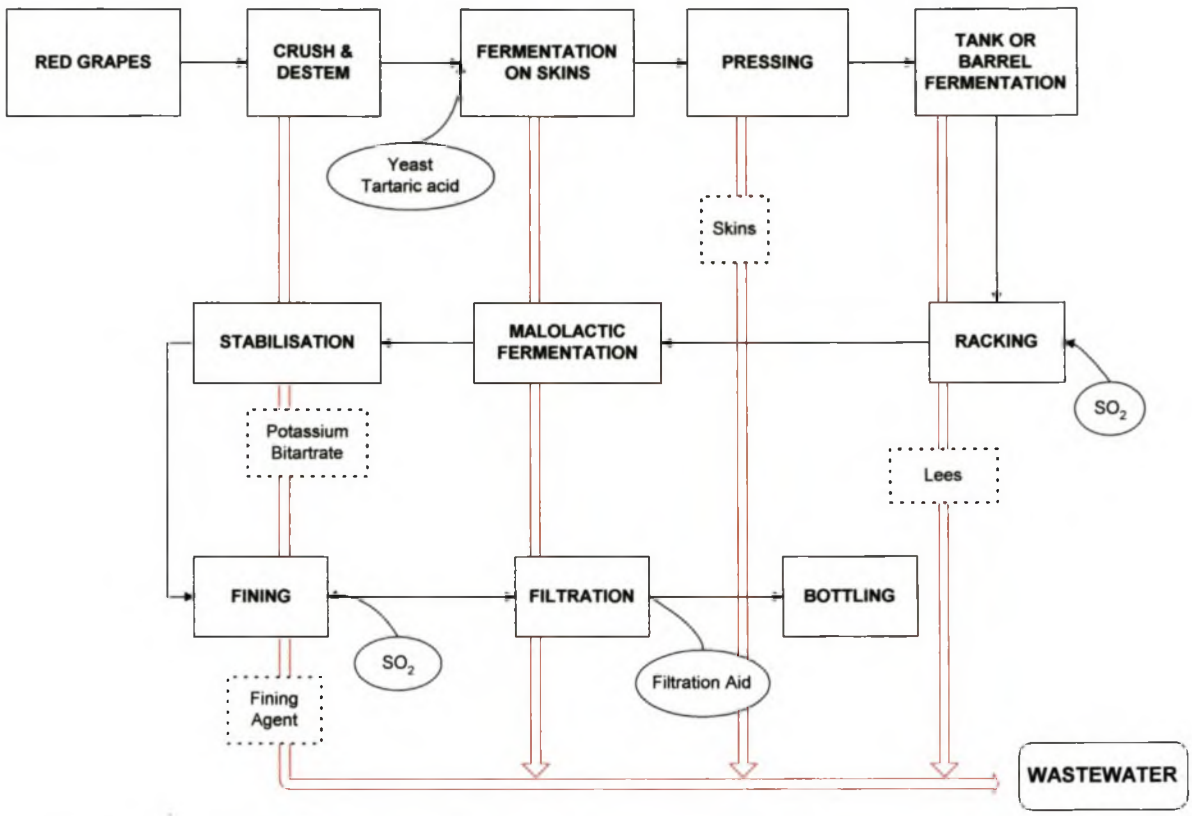

Figure 2.2 – Process Flow Diagram of Red Winemaking and Potential Wastewater Components

2.3. WINEMAKING EQUIPMENT

It is useful to give a description of some of the equipment used in any winery since the process has been described in the section above. A list of process operations will be given with the type of equipment that is usually used.

1. Crushing and Destemming: Early equipment utilised separate units but modern units are combined – destemming normally occurs in a perforated drum with a screw that rotates. Berries fall through the perforations and stems are ejected. Once through the perforations in the drum, berries fall into the crusher part of the unit. The crusher looks like two geared sprockets placed slightly apart. This ensures that the berry is pressed open to release juice, but the skin must not be too badly damaged as this imparts harsh characteristics to the wine.
2. Pumping: Pumping is normally performed with peristaltic or positive displacement pumps.
3. Pressing: Most modern presses are of the inflatable bag type. A drum screen with an inflatable bag is filled with berries and juice. The bag is inflated slowly, and the berries are pressed against the screen and the juice or wine is removed.

4. Tanks: Tanks are varied in any cellar. Fermentation, clarification, cooling, storage and blending occur in tanks. Most cellars use vertical cylindrical stainless steel tanks, with external evaporating water film cooling, jacket cooling or internal plate cooling. However, many cellars have vertical epoxy/glass fibre tanks. Many older cellars have enclosed concrete tanks and open concrete tanks that are used for red wine fermentation. There are also wooden tanks available that can be used for fermentation purposes.
5. Filtration and Clarification: Bulk filters and sheet filters are the two most common types of filters. Certain cellars however have centrifuges for juice clarification, and may have rotating vacuum drum filters for final juice/wine filtration.
6. Heat Exchange: Juice coolers are sometimes used to cool incoming grapes. This unit is normally called a mash cooler. The mash cooler is usually a pipe in pipe heat exchanger. Coolants used range from chilled water to ethylene or propylene glycol.

2.4. WINE QUALITY

Wine quality is a subjective topic and as such is very difficult to quantify scientifically. It is necessary to revert to sensorial analyses to effectively quantify a wine's quality. Wine is a complex substance. Many non-linear interactions occur between the different components that occur in wine.

Wine is susceptible to spoilage from poor equipment and processing, from exposure to the environment, and from exposure to organisms, whether they are yeast or bacteria. Therefore, a good way to discuss wine quality is to focus on what affects wine in a negative way. The following is a list of problems that may be found in wine as described by Rankine (1989).

Metal Haze – Wine appears hazy, caused by exposure to iron and copper, and sometimes aluminium. This is typically caused by the equipment used to process the grapes. (Incidentally – if the plastic inside an aluminium screw cap were to perish, it could cause this fault. This is important to note as the current trend is to move away from cork to screw caps and this fault may occur in wines that are left to mature in the bottle for ten years or even less.)

Protein Haze – wine appears hazy, caused by unstable proteins that polymerise at elevated temperatures. These proteins are typically present in poor quality grapes that have been infected by the *Botrytis cinerea* mould.

Volatile Acidity (VA)– this *usually* indicates the presence of acetic acid bacteria (other factors such as wild yeast contamination may also cause this fault) and is caused by the oxidation of ethanol to acetic acid and ethyl acetate. VA is usually exacerbated by higher fermentation temperatures, the presence of air, lowered SO_2 levels, and in low alcohol wines. VA is classified as a serious fault in wine, and is difficult to rectify. It can be rectified by means of reverse osmosis but this is not yet approved by the Office International de la Vigne et du Vin (OIV).

Mousiness – usually caused by *Brettanomyces* yeasts and lactic acid bacteria. The wine has an unpleasant smell, and a taste reminiscent of mice. This is a very serious fault in a wine.

Yeast spoilage – this occurs unexpectedly when a wine in a bottle becomes cloudy, or wine in a bag begins to swell. The wine normally has a lower quality, and it can be very costly to treat as the wine has to be disgorged, perhaps treated, sterile filtered, and then re-packaged. The yeasts involved are normally *Saccharomyces*. The yeasts normally grow after packaging, and prevention is best effected by sterile filtration before bottling. The source of these yeasts can be corks, air, the bottles, or the items of equipment in the cellar.

Other contaminants – these include chlorophenols, which impart a medicinal type taste to the wine. This is normally caused by chlorine-based detergents used in the cellar. Another serious fault is naphthalene contamination from corks. Corks are superb adsorbents, and if they are not stored properly, can adsorb foreign chemicals. These foreign chemicals can then desorb from the cork and leach into the wine. Machinery oil, and chemical adhesives can also contribute to wine spoilage if equipment is faulty.

Numerous other faults occur during winemaking. For a more complete list of these faults, consult Rankine (1989) or Boulton *et al* (1996). Most components in wine have a beneficial contribution towards the overall complexity of a wine, but only up to a certain threshold. The threshold level is complex and is related to the specific compound being examined as well as other compounds present in the wine. It is only when a compound rises above the threshold level that it is perceived to be detrimental to perceived wine quality.

Since most of these faults are not apparent until the wine is bottled, it is best for the winemaker to follow a policy of contamination prevention, and adopt principles of good cellar hygiene. By doing so the risks are substantially reduced, and the cost of treatment, or savings due to wine loss are minimised.

2.5. WINERY EFFLUENT

The South African Wine industry has a duty to protect and care for the environment. This is enshrined in our constitution. Protection of the environment forms the basis of sustainable development. Since wine is an agricultural product, it is in the best interests of all wineries to produce less effluent to reduce environmental damage. All environmental damage ultimately affects those that cause it – and in this case, a healthy environment is of obvious importance because vines grow in this same environment.

There is no dispute that winery effluent is an environmental and social risk. The South African Wine Industry is obliged to produce wine in more environmentally friendly ways

(Vision 2020). Some environmental impacts that winemaking can have (Chapman [1996] and Goliath [1998]) are listed below:

- The loss of potential downstream surface or groundwater use.
- Degradation of the soil by structure decline, salinisation, waterlogging, chemical contamination or erosion.
- Ecosystem disruption by the increase of organic load, salts or chemical contaminants.
- Discomfort caused by bad odours or a loss of aesthetic appeal.
- Loss of public amenity

Further negative aspects that may be noted in South Africa are:

- Loss of Biodiversity
- Ecological damage to sensitive Eco-systems

2.5.1. EFFLUENT CHARACTERISATION

It is important for the purposes of this study to accurately describe the characteristics of winery effluent streams. Literature was sought that would describe a typical winery's effluent. It is quite interesting that there seems to be a lack of data that accurately describes the effluent. Data are contradictory, and there seems to be little similarity between different wine producing countries. Typical values are given by Chapman (1996) and Radford (2002). Table 2.1, however, is compiled from data given by Levay because these data most accurately describes the quality of winery effluent in South Africa. Currently this problem is being studied in the Winetech project entitled, "The development of an integrated management plan for the handling, treatment and purification of effluents in the wine, spirits and grape juice industries."

Table 2.1 – General Characteristics of Liquid Winery Effluent (Australia)

Parameter	During Harvest	Out of Harvest
Total Organic Carbon (mg/L) (COD)	1000-5000	>1000
Biochemical Oxygen Demand (mg/L) (BOD)	1000-8000	<1000-3000
Suspended Solids (mg/L) (SS)	100-1300	100-1000
PH	4-8	6-10
Total Dissolved Solids (mg/L) (TDS)	<550-2200	<550-850
Sodium Absorption Ratio* (SAR)	4-8	7-9
Total Kjeldahl Nitrogen (mg/L)	5-70	1-25
Sodium (mg/L)	110-310	250-460
Total Phosphorus (mg/L)	1-20	1-10
Calcium (mg/L)	13-40	20-45
Magnesium (mg/L)	6-50	10-20
Sodium Absorption Ratio* (SAR)	4-8	7-9
Potassium	80-180	40-340

It is necessary to give a brief explanation of some environmental jargon, as it can be confusing. Marais (2001) and Sincero & Sincero (1996) explain the meaning of the following terms:

- COD – Chemical Oxygen Demand – this is defined as a measure of the oxygen requirement for full oxidation of the organic and non-organic species present in the effluent stream. Typically, this is the most important variable when discussing winery effluent as it has the greatest immediate impact. COD causes the effluent to smell bad. High COD levels in the effluent can kill aquatic and soil life by asphyxiation because bacteria deplete the oxygen as they utilise the organics as a growth and metabolic substrate.
- BOD – Biological Oxygen Demand – this is defined as a measure of the oxygen requirement for biological oxidation – primarily of the organics present in the effluent stream. This constitutes the bulk of the COD present in winery effluent.
- SS – Suspended Solids – these are the particles left over after a sample is washed and dried after filtering. SS consists of organic and inorganic deposits and forms the sludge in all evaporation ponds in the wine industry. The SS is normally correlated to the COD, and can be reduced through settling of the effluent prior to treatment. Suspended solids also cause problems with blockages of screens, clogging of pipes and clogging of irrigation points when effluent is sprayed.

* In this instant, this value is specific to the Australian Wine Industry

- pH – This is an indication of the acidity or alkalinity of the effluent. Winery wastewater is generally quite acidic. However, if caustic rinses and solutions are disposed of, the pH of the wastewater can easily rise above 12 for the duration of the disposal.
- TDS – Total Dissolved Solids – this is a measure of the total quantity of dissolved inorganic salts dissolved in the effluent. In conjunction with other variables, this has a large effect on the corrosiveness or scaling potential of the effluent. This is very closely linked to the Electrical Conductivity (EC). EC can be correlated to TDS, and is usually done so by a pH meter that can measure EC. This is far easier to measure in the field, so in many cases, the TDS will be calculated from the EC of an effluent sample.
- Sodium and the Sodium Absorption Ratio (SAR) – The SAR is an index of the potential of an effluent, when irrigated for the purposes of disposal, to induce caustic soil conditions. When the SAR of the effluent rises to above three, it can upset the stability of the clay particles. A disruption of the soil profile is not the only problem with high SAR effluent; there may be a lowered availability of soil water for both plants and soil organisms. Sodium usually enters the effluent in the form of caustic soda or soda ash, which are used to remove tartrates from tanks. The SAR can be calculated with the following formula:

$$SAR = \frac{[Na]}{([Na]+[Mg])^{\frac{1}{2}}} \qquad \text{Equation 2.1}$$

where concentrations are given in mmol/L

2.5.2. CURRENT SA LEGISLATIVE REQUIREMENTS REGARDING THE USAGE OF WATER AND THE HANDLING, TREATMENT AND RELEASE OF EFFLUENT.

The current laws governing the usage of water and the disposal of winery effluent are contained in the general authorisations in terms of Section 39 of the National water Act. The applicable limits on effluent disposal into a water resource are given in table 2.1. A description of how the current water laws apply to the wine industry is given in the Enviropros Bulletin (See References). Guidelines for environmental management systems (EMS) are also given in the Enviropros Bulletin.

It is important to note certain aspects of the law. Winery wastewater is classified as "Biodegradable industrial wastewater". This means that a winery may not store more than five million litres of effluent for the purposes of re-use. A winery may not store more than ten million litres of effluent for the purposes of disposal, unless this is done in a wastewater pond system, in which case up to fifty million litres may be stored. If effluent water is stored, the winery has to register the storage of such wastewater. The winery also has to register to dispose wastewater if more than fifty kilolitres of water are disposed on any given day. Many small or boutique wineries will dispose less than fifty kilolitres per day, but larger cooperatives will dispose more than this. If more than 18 250 000 litres of water are used per year, then effluent disposal must be registered. Registration means that the winery has to get a licence from the Department of Water Affairs and Forestry (DWAF).

Table 2.2 – SA Legislative Requirements for Effluent Disposal

SUBSTANCE/PARAMETER	GENERAL LIMIT	SPECIAL LIMIT
Faecal Coliforms (per 100 ml)	1 000	0
Chemical Oxygen Demand (mg/l)	75*	30*
PH	5,5-9,5	5,5-7,5
Ammonia (ionised and un-ionised) as Nitrogen (mg/l)	3	2
Nitrate/Nitrite as Nitrogen (mg/l)	15	1,5
Chlorine as Free Chlorine (mg/l)	0,25	0
Suspended Solids (mg/l)	25	10
Electrical Conductivity (mS/m)	70 mS/m above intake to a maximum of 150 mS/m	50 mS/m above background receiving water, to a maximum of 100 mS/m
Ortho-Phosphate as phosphorous (mg/l)	10	1 (median) and 2,5 (maximum)
Fluoride (mg/l)	1	1
Soap, oil or grease (mg/l)	2,5	0
Dissolved Arsenic (mg/l)	0,02	0,01
Dissolved Cadmium (mg/l)	0,005	0,001
Dissolved Chromium (VI) (mg/l)	0,05	0,02
Dissolved Copper (mg/l)	0,01	0,002
Dissolved Cyanide (mg/l)	0,02	0,01
Dissolved Iron (mg/l)	0,3	0,3
Dissolved Lead (mg/l)	0,01	0,006
Dissolved Manganese (mg/l)	0,1	0,1
Mercury and its compounds (mg/l)	0,005	0,001
Dissolved Selenium (mg/l)	0,02	0,02
Dissolved Zinc (mg/l)	0,1	0,04
Boron (mg/l)	1	0,5

Typically speaking, most wineries dispose of their effluent by irrigation on to pastures. The act also makes provision for this, and the limits applicable to the irrigation of wastewater are given in table 2.3.

Table 2.3 – Legislative Requirements for the Irrigation of Effluent

Substance / Parameter	Less than 500m^3 / day	Less than 50m^3/day
Faecal Coliforms (per 100ml)	<200	<200
Chemical Oxygen Demand (mg/L)	400	5 000
PH	6-9	6-9
Electrical Conductivity (mS/m)	100 000	100 000
SAR	<5	<5

Also of importance with respect to effluent disposal are the Environment Conservation Act (Act 73 of 1989), the Atmospheric Pollution Prevention Act (Act 45 of 1965), Conservation of Agricultural Resources Act (Act 43 of 1989), Health Act (Act 63 of 1997), Cape Nature and Environmental Ordinance (No 19 of 1974) and the Occupational Health and Safety Act (Act 85 of 1993). All of these are discussed briefly in the Enviropros Bulletin number 6 (SEE REFERENCES).

2.5.3. TREATMENT STRATEGIES

At present, by far the majority of cellars audited in this study irrigate their effluent onto a pasture. However, considering the high COD values and occasional high SAR present in winery wastewater, it is likely that as environmental law enforcement becomes more aggressive more cellars will begin to treat their effluent using more conventional means. These include digesters, woodlot irrigation and constructed wetlands amongst others. Some of these treatment options will be discussed below.

2.5.3.1. AEROBIC AND ANAEROBIC DIGESTION

Verstraete et al (2002) discuss the benefits of treating winery wastewater through conventional digesters. They compare anaerobic to aerobic treatment and found that aerobic treatment requires greater capital expenditure (CAPEX) per ton of effluent treated, requires more space and produces more sludge per ton of effluent treatment than anaerobic treatment. However, aerobic treatment allows for electricity generation though the collection of biogas and it is feasible to recover nutrients from the effluent stream. They also discuss different items of equipment and the costs associated with effluent treatment for the different types of treatment strategies

2.5.3.2. WOODLOT IRRIGATION

Marais (2001) discusses the use of eucalyptus groves for the treatment of effluent. Generally, solids are separated from the effluent and this stream is then pumped to a grove of eucalyptus trees. Eucalyptus trees are noted for their ability to transpire water at very high rates (a point of major concern in South Africa's river systems as there are many gum trees near our rivers). This treatment strategy is not considered suitable for the South African Wine Regions because of the ecological sensitivity of our wine producing areas. Introduction of alien vegetation is not a good solution.

2.5.3.3. EVAPORATION PONDS

Many wineries use evaporation ponds as a form of wastewater treatment. Rankine (1989) describes this practice in some detail, and recommends it as a form of effluent treatment for high strength effluent if there is wastewater separation in the cellar. In California up to 1000kL/day of water is pumped into half-hectare ponds that have a liquid depth of less than 10cm. The effluent is then allowed to evaporate. This should be discouraged in South Africa, because of the scarcity of our water reserves.

2.5.3.4. CONSTRUCTED WETLANDS

Shepherd (2001) describes the use of constructed wetlands for winery effluent treatment in California. She notes that constructed wetlands have the ability to significantly reduce the COD of winery effluent, although the TDS levels increase due to evaporation effects. Constructed wetlands are very sensitive to high COD levels. These high COD levels cause the system to become anaerobic which may kill the plants. The system normally works under anoxic conditions. Anoxic conditions imply that the system is nearing anaerobic conditions. There are still traces of oxygen available.

Pilot research on constructed wetlands is being performed in South Africa and is described by Van Schoor (2002). It is felt that this may be the best option for small winery effluent treatment within the South African context, because water can be re-circulated and re-used.

2.5.3.5. IRRIGATION PADDOCKS/PASTURES

Rankine (1989) and Radford (2002) both describe the disposal of winery effluent through the practice of irrigation onto a pasture. This can be performed if one has low strength effluent. Low strength effluents have not had much contamination with organic pollutants. Effluents with a high COD cause the soil to become anaerobic, which kills aerobic soil bacteria that are vital for the normal plant functioning. In addition to this, if the effluent has SAR levels that are too high, the soil structure can be permanently damaged. This can also decrease the availability of water for plants. Stray metal ionic species can also leach down to the water table, which causes pollution of groundwater.

2.6. CURRENT RESEARCH

Literature was sought to determine whether there has ever been a study similar to the one here, but it appears as though this is the first such study in South Africa.

Duarte et al (1998) analysed the process of wine production in Portugal in a typical engineering manner. Their study analysed parameters such as COD, BOD, TDS etc. and performed a simple mass balance over a winery. However, their data was specific for one winery. This study found that that the daily water flow during the harvest was twice that of the first racking period, which is useful to dimension any wastewater treatment plant.

This study also performed an input/output assessment, which is shown in table 2.3.

Some important conclusions from this study are summarised below:

- The compositions of effluents from red and white wine production are different.
- When selecting technology for wastewater treatment, the year round activities cannot be ignored.

Table 2.4 – Findings from Duarte et al.

Parameter	Red Wine	White Wine
Grapes (Kg)	47430	35390
Wine (L)	30420	22610
Pomaces (kg)	6640	4780
Lees (kg)	1420	1240
Vinification Ratio (L Wine/ Grapes Pressed)	0.64	
Water for Cleaning Operations (L)	37176	
Litres Wastewater / Litre of Wine	0.7	
Litres Wastewater	0.45	

Rozzi et al (1998) tried to estimate specific polluting loads for 17 different European wineries. The specific load (gCOD/100kg grapes.day) ranged from 4.3 to 12. This study concluded that higher polluting loads occurred during the harvest period, and that the polluting load could be correlated to the quantity of grapes harvested. The data showed, however, that there was no clear correlation between the quantity of grapes harvested and the polluting load during the racking season.

Balsari and Airoldi (1998) developed a software package for winery waste management. In order for such a system to work, correlations had to be developed. The data presented in this paper showed that both the washing water (Equation 2.2) and the COD of the washing water (Equation 2.3) could be correlated to the quantity of grapes pressed according to the following equations:

$$WashingWater(L) = 1.535 \cdot Capacity(hL) + 232.5$$ **Equation 2.2**

$$COD(g) = 76 \cdot Capacity(hL) + 900$$ **Equation 2.3**

These correlations were developed from experimental data collected at various cellars in the Cuneo area in 1995 and 1996.

2.7. CONCLUDING REMARKS

The purpose of any literature survey is to provide the reader with a thorough background to the field of study. This is done so that discussions of results may be understood and put into perspective. Since this study will be read by both engineers and winemakers, this study has to be understood by both winemakers and engineers. Unfortunately this means that there will be shortfalls in both areas – the discussion on winemaking is not fully inclusive, but serves to introduce the winemaking process to engineers. Similarly, the discussion on different treatment strategies is not fully inclusive, and merely serves to introduce certain effluent treatment strategies and items of equipment to winemakers.

CHAPTER 3

RESEARCH METHODOLOGY AND RESULTS

A Critical Process Audit of Wine Production to Improve Overall Processing Efficiency and Environmental Performance

3.1. QUESTIONNAIRE DEVELOPMENT

One of the reasons for initiating this study was to acquire statistically significant sets of data regarding certain aspects of the South African Wine Industry. Currently, there is a lack of information about certain aspects of winemaking in South Africa. Equipment types, processing configurations, processing options and other critical parameters are absent from the body of scientific knowledge. A primary reason for this is that the wine industry often follows traditional practices and procedures that have not changed or measured before.

Therefore, before any study could be carried out, it was important to obtain information from the industry. To achieve this, a questionnaire was developed (see appendix 1) and submitted to all of the wine cellars in South Africa. Email, post and hand delivery were the methods of submission of the questionnaire. In order to maximize the number of returns, confidentiality agreements were entered into with all cellars that completed the questionnaire. For this reason no winery's name will appear on any of the data.

The questionnaire aimed to assess the following cellar parameters:

- Cellar Details – Name of cellar, address, winemaker, varietals pressed and wine made.
- Cellar Infrastructure – this was divided into the following subsections
  - Primary processing – aimed to describe the machinery used during primary processing, which was defined as weighing, destalking-crushing and de-stemming.
  - Tank farm – this aimed to asses the number of tanks, the materials of construction, the condition of the tanks and the uses of the tanks
  - Filtration and Clarification – types of wine were specified in terms of whether they were filtered or not, and if so, how many times with which types of filters. Fining agents were also specified.
  - Fermentation Details – the different varietal fermentations were specified in terms of the temperature and pressure of the ferment, the duration of the ferment, fermentation systems and other parameters.
- Cellar Operations – this section related to operating practices within the cellar. It asked questions on how items of equipment were cleaned, how often maintenance was performed and sought to ascertain the physical problems that may have occurred. It was subdivided into the following sections:
  - Primary processing
  - Tank Farm
  - Filtration and Clarification

  - Fermentation
  - Cooperage – questions were asked about barrel replacement policies, and chemical usage amongst others.
  - Cellar Maintenance – the frequency and budget thereof
  - Processing Problems – sought to ascertain the occurrence and frequency of rust, odours, vinegar flies and any other problems that may have occurred.

- The second section of the questionnaire aimed to assess the chemical, electrical and heating/cooling requirements of the cellar. This section was divided into the following sections:
  - Chemical Consumption
  - Electricity
  - Heating/Cooling Loads

- The third section aimed to assess water related topics. It sought to assess the following parameters:
  - Water Distribution – the source as well as the annual consumption.
  - Effluent Disposal – the method of effluent disposal, the quantity of effluent disposed, and simple effluent descriptions.
  - Cleaning Practices
  - Measurement Practices

The final section of the questionnaire sought to assess various other perceptions and miscellaneous issues that were not dealt with in the main body. These included winemakers' perceptions on financial return, environmental systems, chemical analyses performed on the wine, and the biological problems that occurred in the wine amongst others.

There were some inaccurate returns to some of the questions especially in cases where questions may have been ambiguous, or not well enough defined. In addition to this, care has to be taken when assessing data obtained in this way. There is no way to define a 'believability index' for the data returned, so scepticism is required when interpreting the results obtained from these data.

A further purpose of this questionnaire was to identify areas where research may be required. These data have been analysed and the conclusions in this regard are presented in section 5.2 of this study.

At the time of submission of the questionnaire, there were in excess of 390 wine producers in South Africa. Of the original contact group, thirty-seven cellars returned questionnaires. This represents a 9% return, which is what one can expect for normal questionnaire submission. In this case, however, the sample group is not sufficiently large. Discussion with the statistics department at the University of Stellenbosch led us to believe that sixty replies would be a sufficiently large return of these questionnaires and to this end sixty replies were collected.

It is disappointing that so few people were willing to participate in this study by returning the questionnaires, and surprising that the wine makers appear to be indifferent to learning more about environmental management and their own processes. This is indicative of the apathy that exists within this industry concerning science and research. Unfortunately, it seems that the cellars that returned the questionnaire are generally those that have an interest in scientific research, and this could lead to a bias in the results. This effect is however not measurable.

3.2. RESULTS OF THE QUESTIONNAIRE

This section discusses the replies to the questionnaire. Statistical analyses were done by Dr Martin Kidd at the Centre for Statistical Consultation, University of Stellenbosch.

3.2.1. WINE FAULT ASSOCIATION STATISTICS

After collection of all the returns, the data was captured electronically. A list of causes and effects was drawn up, and Chi-Square* tests were used to investigate the dependence of variables on each other. A 55 significance level was used as a guideline for assessing the dependencies between variables. Probabilities were calculated for the associations that showed significant dependencies. Results are given in table 3.1 and 3.2.

It is important to make a comment on the importance of scientifically linking factors that appear to be common sense. It is possible to argue that the statistics are trivial but this is not the case. The statistics provide a valuable tool for quantifying risks and benchmarking a process that is otherwise unknown. In many cases, the statistics show what was already known, but probabilities can now be associated with these known events. This is novel and not trivial. It will help cellars to assess the importance of various risks, and an importance hierarchy can be developed, based on the frequency of occurrence of each risk, and the severity that each risk poses.

The statistical analysis and data counts for statistically significant associations are shown in appendix 2.

* Using StatSoft, Inc. (2001). STATISTICA (data analysis software system), version 6. www.statsoft.com

3.2.1.1. POSITIVE ASSOCIATIONS

For the positive associations, some interesting co-relationships can be seen. For example, there is a 60% probability that filtration problems occur, given that there were midge flies present at the tank farm. (Data taken from row 1 of the table 3.1.) This is a set of P(B/A) calculations. The probabilities of P(B/Not A) are shown in appendix 2. These probabilities would be, for example, the probability of filtration problems occurring, given that midge flies were not present at the tank farm.

Table 3.1. – Positive Wine Fault Associations

Row	Probability that	Event B	Occurs is	X %	Given that	Event A	Has occurred	P Value
1	Probability that	Filtration Problems	Occur is	60%	Given that	Tank farm midge flies	Have occurred.	0.01
2	Probability that	Microbial Contamination	Occurs is	43%	Given that	Floor/drain mould/odours	Have occurred.	0.03
3	Probability that	Microbial Contamination	Occurs is	56%	Given that	Fermentation off odours	Have occurred.	0.05
4	Probability that	Stuck Fermentation	Occurs is	63%	Given that	Microbial Contamination	Has occurred	0.07
5	Probability that	VA	Occurs is	60%	Given that	Microbial Contamination	Has occurred.	0.05
6	Probability that	VA	Occurs is	90%	Given that	Fermentation off odours	Have occurred.	0.0003
7	Probability that	VA	Occurs is	80%	Given that	Primary processing odours	Have occurred.	0.06
8	Probability that	VA	Occurs is	100 %	Given that	Tank farm odours	Has occurred.	0.005
9	Probability that	VA	Occurs is	58%	Given that	Stuck Fermentations	Have occurred.	0.02
10	Probability that	Sluggish Fermentations	Occur is	92%	Given that	Primary processing rust	Has occurred.	0.001
11	Probability that	Stuck fermentations	Occurs is	55%	Given that	Sluggish ferments	Have occurred.	0.06

It is possible to develop a risk hierarchy from this table.

- The first risk to be assessed is the risk of Microbial Contamination of the wine. From table 3.1, it is clear that fermentation off odours indicate a larger risk than floor/drain mould/odours towards the wine developing to microbial contamination. Fermentation off odours are indicative of a fault within the wine and should be addressed immediately when they become apparent.

- The factors leading to or indicating VA can also be structured. As with microbial contamination, off odours are strongly associated to VA. Thus, the cause of off odours should be treated as quickly as possible. The probability of microbial contamination or stuck fermentations leading to VA is lower than the probability of off odours during processing leading to VA (note that VA is also an off odour). Microbial contaminations and stuck fermentations are still important contributors, so they should be addressed too.
- Rusty processing equipment has a high risk factor when discussing sluggish fermentations, and sluggish fermentations have slightly more than 50% probability of leading to stuck fermentations. Microbial contamination of the wine also has a significant probability of leading to stuck fermentations.

3.2.1.2. NEGATIVE ASSOCIATIONS

Table 3.2 shows the negative associations, which are also valuable. These negative associations show the probability of events not occurring, given that other events do not occur. For example, (row 2), it has been shown that the probability that microbial contamination does not occur, given that floor or drain mould or problems do not occur is 83%.

It is important to note, once again, that these data are based on the replies that winemakers gave and there may be certain instances where winemakers have omitted data for a number of reasons and the data may be biased. However, the nature of this bias suggests that these results reflect the best-case scenario. In other words – one should look at the positive associations for a minimum risk associated with equipment, and one can look at the negative associations for the maximum chance that a problem will not occur.

The importance of scientifically assessing "common sense" associations was mentioned earlier in this study, but the point needs to be reiterated here. Without assigning values to common sense knowledge, it is impossible to evaluate common sense data critically. If two events are known to be contributing factors towards a third event, it is not possible to say which event contributes more to that third event without a scientific assessment. This can be shown by using some of the associations shown above. It can be seen that the there is a chance that microbial contamination of the wine will occur given that there are floor or drain problems (event 1) or that there are fermentation off odours (event 2). Practical cellar knowledge can predict either of these events leading to bacterial contamination of the wine but it cannot predict the probabilities of such events occurring. Given that the probability is nearly 30% greater for fermentation off odours, it can be suggested that this risk is more important

Table 3.2 – Negative Wine Fault Associations

Probability that	Event B	Does not Occur is	X %	Given that	Event A	Has not occurred	P Value
Probability that	Filtration Problems	Do not occur is	80%	Given that	Tank farm midge flies	Have not occurred.	0.01316
Probability that	Microbial Contamination	Does not occur is	83%	Given that	Floor/drain mould/odours	Have not occurred.	0.02910
Probability that	Microbial Contamination	Does not occur is	78%	Given that	Fermentation off odours	Have not occurred.	0.05216
Probability that	Stuck Fermentation	Does not occur is	64%	Given that	Microbial Contamination	Has not occurred	0.06597
Probability that	VA	Does not occur is	69%	Given that	Microbial Contamination	Has not occurred.	0.05018
Probability that	VA	Does not occur is	70%	Given that	Fermentation off odours	Have not occurred.	0.00029
Probability that	VA	Does not occur is	63%	Given that	Primary processing odours	Have not occurred.	0.05753
Probability that	VA	Does not occur is	64%	Given that	Tank farm odours	Have not occurred.	0.00548
Probability that	VA	Does not occur is	72%	Given that	Stuck Fermentations	Have not occurred.	0.02244
Probability that	Sluggish Fermentations	Do not occur is	57%	Given that	Primary processing rust	Have not occurred.	0.00113
Probability that	Stuck fermentations	Do not occur is	69%	Given that	Sluggish ferments	Have not occurred.	0.06139

3.2.2. DISCUSSION OF WINE FAULT ASSOCIATIONS

The following points are felt to be relevant:

Floor/drain problems increase the risk of bacterial contamination of the wine. This is expected. Given that if there are stagnant pools of water lying on the floor, one may expect that there is a possibility of bacterial contamination. More importantly, the probability of no bacterial contamination occurring if these floor or drain problems are eliminated is very high. Thus, it is of in the winemaker's best interest to ensure that the cellar floors are smooth, and slope properly towards the drains. It is also important that the floors are made of a surface that is strong enough to prevent cracking or chipping, and that it does not support bacterial growth. The cellar drains should be fast flowing with no dead spots, and growth substrates like spilt wine or juice should be removed from the cellar as rapidly as possible. It may be justified to occasionally flush the drain with sulphated water or with some environmentally friendly anti fungal/anti bacterial agents to sterilise it. This should be sufficient to prevent bacterial contamination of the wine from this source.

Microbial contamination may also be indicated by the presence of off odours occurring during fermentation. Even for those cases where the off odours have been identified as being due to nitrogen deficiencies, there is still a strong association between off odours and microbial contamination. The best way to prevent microbial contamination in this instance is to assess the must, prior to fermentation, for adequate nitrogen requirements. In addition to this, fermenters should have no flaws, be they rust flecks, or cracks. These provide a niche habitat wherein bacteria may grow and reproduce prior to spoiling the wine. This is especially important for the old concrete open fermenters used for red winemaking. Off odours are also correlated to VA of the wine. The lowest probability of VA occurring is 60% if microbial contamination has occurred, and the maximum probability is 100% if tank farms odours occur. The number of cases however is not sufficient to justify this percentage. Suffice to say, there is a high risk. Thus, in any instance during the winemaking process where "bad" smells occur, it is in the winemakers best interest to correct this. Bad odours are indicative of bacterial contamination, and foreshadow VA in the wine.

Sluggish fermentations show a close association with primary processing equipment rust. These sluggish fermentations have a more than fifty percent probability of developing into stuck fermentations. This can be explained by the presence of competing yeasts and/bacteria that may grow in the rust carbuncles that form on the primary processing equipment. It is well known that bacteria exacerbate rust and even cause rust (Askeland, 1996). The way to correct this fault is to ensure that high quality steels are used. Only food grade stainless steels should be used in the food industry. These stainless steels will not rust and are easy to clean. Conversely, mild steel tanks and equipment are known to rust and be susceptible to pitting corrosion. Chlorine based detergents should also not be used for cleaning the cellar. Chloride ions are responsible for the breakdown of the protective patina that forms on the surface of most stainless steels, and the steels will rust. This phenomenon is very evident with vehicles that are kept near the ocean. Another reason to eliminate chlorine-based detergents is the formation of trichloroanisoles in the wine. This is a serious taint, which leads to a mouldy/musty off taste in the wine. 2,4,6-Trichloroanisole has been shown to be synthesised by micro flora originating in infected cellars, and a *Penicillium* species in the presence of chloride or hypochlorite. The flavour threshold of TCA contamination in a red wine is 1.4ng/L. Thus, eliminating chlorine based detergents and antiseptics removes the risk of corrosion and wine spoilage.

There is a 60% probability that the presence of midge flies (miggies) on/in the tanks during fermentation and/or the storage of wine is associated to filtration problems such as blocked filters. This may be due to the *Drosophila* flies carrying acetic acid bacteria. These bacteria may contaminate the wine and then produce the proteins that are typically responsible for filtration problems. Acetic acid bacteria are also responsible for the formation of VA in the wine.

3.3. WINERY INPUT/OUTPUT CORRELATIONS

The following set of graphs is based on the results obtained from using different data sets. These sets of data include the questionnaire database and the Winetech effluent sampling programs. These data sets were merged because each data set was missing certain items of data. For example, the questionnaire had no data relating to the quantity of effluent, or the quality of the effluent, but had much data relating tonnage pressed to wine produced. The Winetech database has much information relating to the sampling and characterisation of the effluent streams at various cellars over the past three years. However, this database has no data pertaining to quality of the wine. The manual sampling performed over the 2002 harvest provides a link whereby it was possible to assess the causes of poor quality effluent, and assess the cellar visually to ascertain where processing may affect quality.

This study aimed to assess all of the inputs, outputs as well as problems associated with processing. The problems associated with processing have been discussed in section 3.2.2 of this study. The following sections aim to analyse the physical inputs, as well as the physical outputs of the winemaking process.

3.3.1. PHYSICAL INPUTS

Physical inputs can be described as the parameters whereby something enters the process of winemaking. Typical inputs can be defined as:

- Grapes
- Electricity
    - Refrigeration
    - Other Electric Consumption
- Chemicals
- Water

All variables have been correlated to tons of grapes pressed per year because this is the main material input.

3.3.1.1. ELECTRICITY

Figure 3.1 shows how many electrical units are consumed per month as a function of the

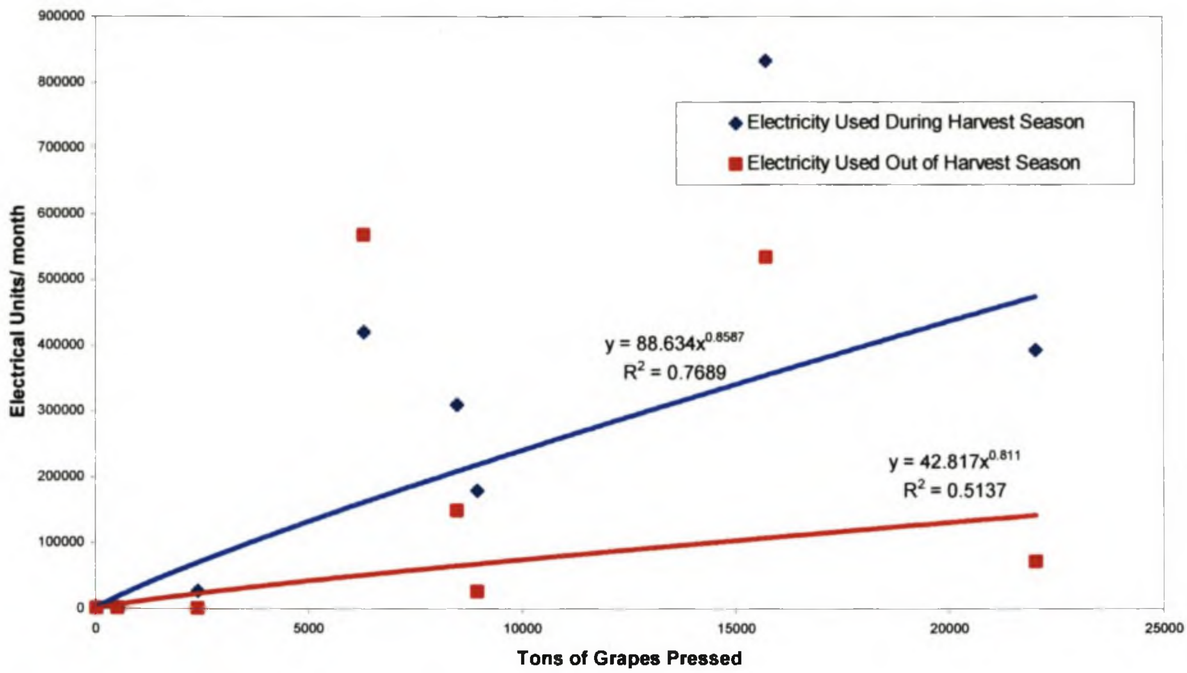

Figure 3.1 – Electricity Consumed

tons of grapes pressed. These data are taken from questionnaire respondents that measure cellar electricity consumption. There are two correlations shown – during harvest and out of harvest. During the harvest, equation 3.1 may be used, where E_H is electrical units per month, and T is the tons pressed per season. This correlation has a co-efficient of regression value of 0.7689, which indicates low level of data scatter.

Equation 3.2 shows the electricity consumption of the cellars outside of the harvest season. As is expected, the consumption of electricity is lower. Harvest consumption is approximately 2.5 times that of the rest of the year. However, the scatter of the data is greater, so this correlation is not as accurate as the harvest data. This is possibly due to different types of lights and different heating regimes used by cellars in winter. Most cellars use refrigeration in summer, which makes up a large percentage of the energy costs.

$$E_H = 88.63 \cdot T^{0.8587}$$ **Equation 3.1**

$$E_O = 44.82 \cdot T^{0.811}$$ **Equation 3.2**

3.3.1.2. WATER

Figure 3.2 and figure 3.3 show different aspects of water usage within the industry. Figure 3.2 shows the sources of water for the various cellars. It is interesting to note that half of the cellars obtain their water from boreholes.

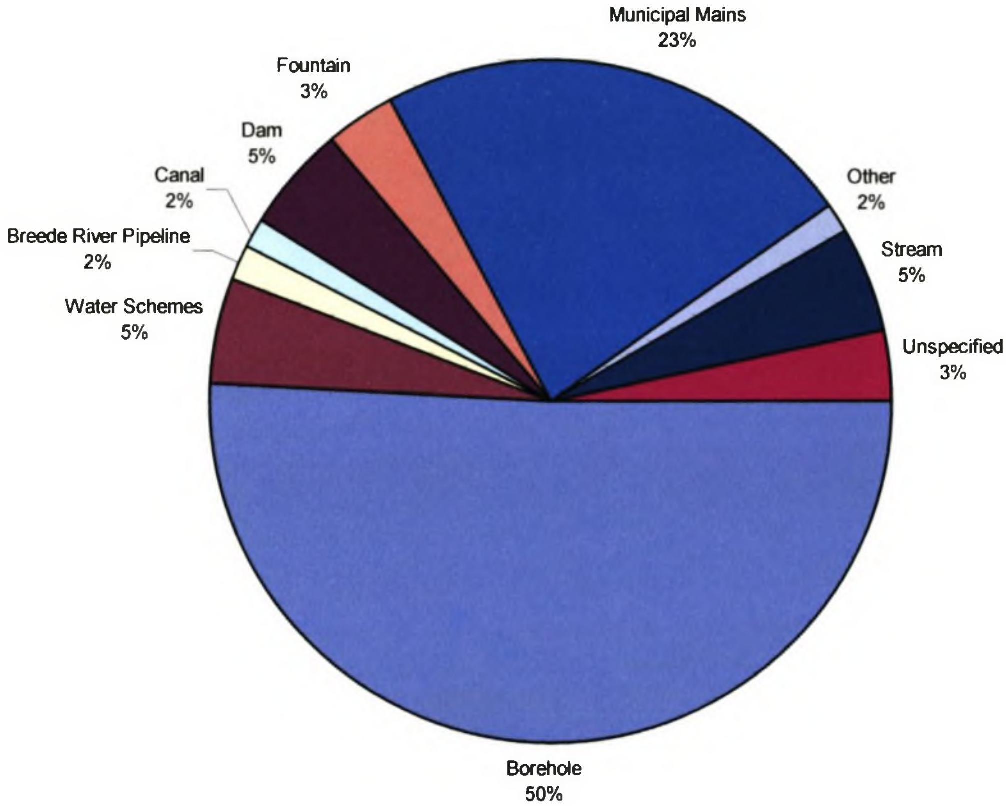

Figure 3.2 – Water Source Statistics

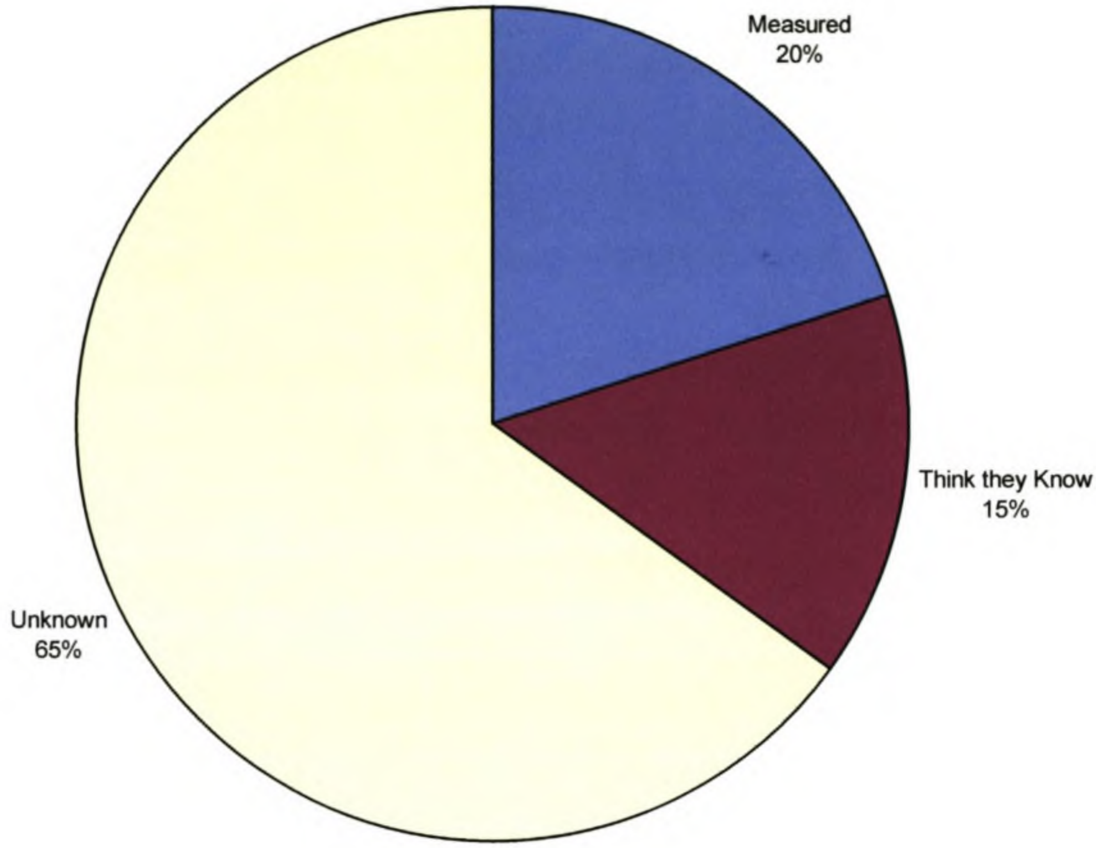

Figure 3.3 – Water Measurement Statistics

Figure 3.3 shows that only 20% of the respondents measure the consumption of water. This may seem to contradict the fact that 23% of the cellars obtain water from municipalities, but can be explained by noting that in certain cellars a water bill is supplied for the whole farm. Often it is not possible to distinguish between water used by the cellar and water used for other purposes due to a lack of water meters. What is of great concern is that 65% of wineries do not know how much water they use. A further 15% think they know, but it can be shown in figure 3.4 that this is not true, so in fact, 80% of wineries have no knowledge of how much water is consumed. Data from the questionnaires were classified as "Think they know" if there was an answer but that answer was an obvious guess. In some cases, the respondent admitted as such.

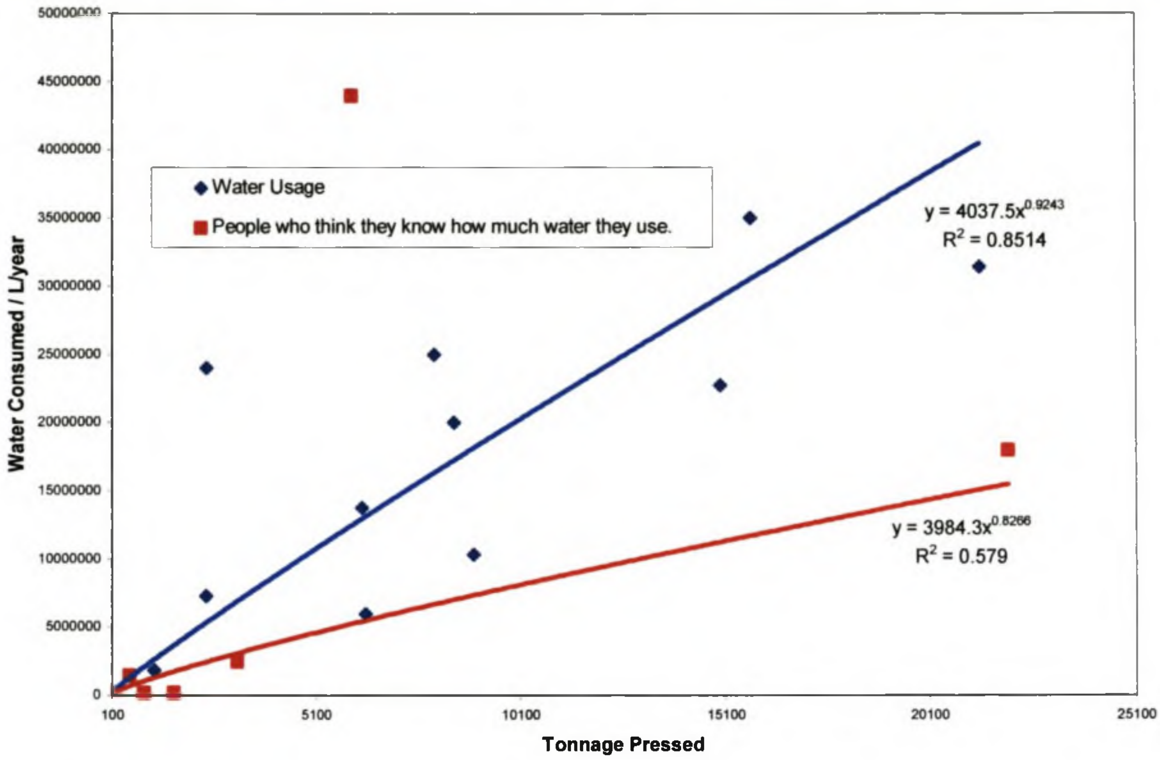

Figure 3.4 – Water Consumption

In figure 3.4, the consumption of water per year was plotted as a function of the tons pressed per year. The data was split, according to the definition above, into wineries with water measurement and those without.

$$W = 4037.5 \cdot T^{0.9243}$$ **Equation 3.3**

This equation has low scatter, and can thus be considered accurate. What is interesting to note from this graph is the difference between real water measurement and guessing. Guessing seems to undervalue the consumption of water by approximately 60%. Given that only 20% of cellars measure their water, this implies that 80 percent would underreport their water consumption, or would under-guess it if required to report a value. Considering that South Africa is a country with scarce water reserves, data like these become valuable as a tool for prediction of water consumption. The wine industry contributes 9,7% to the Western Cape's gross geographic product. (WOSA Statistics, 2002). This correlation allows for better utilisation of water and management of water as a resource, especially considering the size of the Wine Industry and its consumption of these scarce water resources.

3.3.2. PHYSICAL OUTPUTS

Physical outputs may be defined as all of the products leaving the cellar. These include:

- Wine
- Solid Waste
    - Stems, skins and stalks from the presses
    - Lees
- Waste Water

These variables were correlated to the tonnage pressed, and the following set of graphs was developed.

3.3.2.1. WINE

In figure 3.5, the quantity of wine produced was plotted as a function of tons of grapes pressed.

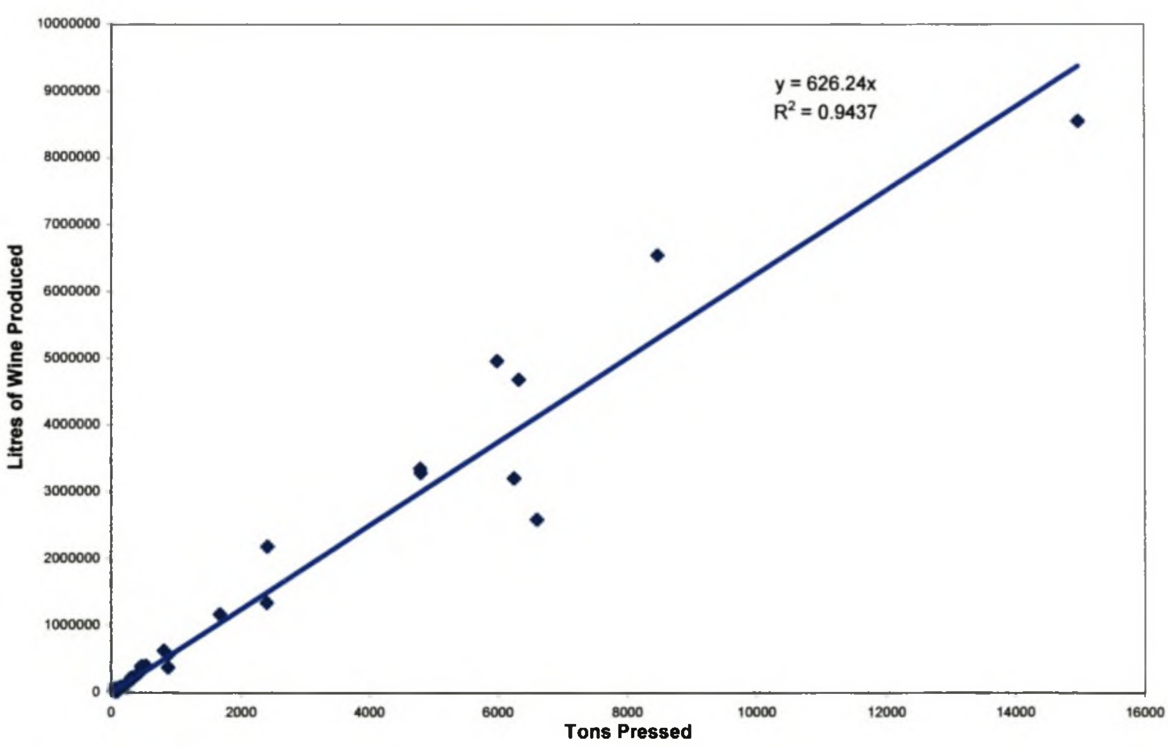

Figure 3.5 – Wine Produced as a Function of Tons of Grapes Pressed

There is a strong correlation (equation 3.4) between tons pressed and wine produced, as is to be expected. Figure 3.5 may seem trivial, but it allows the correlation of all variables to wine produced, instead of tons pressed. This is useful because wine is ultimately the product that is sold. It can be noticed that there are significant variations between producers. These variations do have a significant economic effect. It is normally expected that those wineries that produce less wine per ton of grapes pressed (those points below the correlation line) make better quality wines. This is not the case in this data set. All three wineries that have data points far below the correlation line tend to make "lower quality" wine. A possible explanation for this is that the pressing equipment is old and not as efficient as the more modern presses.

$$Wine = 626.24 \cdot T$$ **Equation 3.4**

3.3.2.2. Effluent

Effluent is defined as the wastewater that is discharged from a cellar during normal and abnormal operation. Abnormal operation could be defined as any problem that occurs during processing. This could include extra busy harvest periods or the accidental release of wine or juice etc into the drains. For the purposes of this study, the effluent has been quantified according to the following classifications:

- Method of disposal
- Quantity Disposed
- Quality of Effluent
  - COD, TDS
  - SAR

3.3.2.2.1. Effluent Disposal

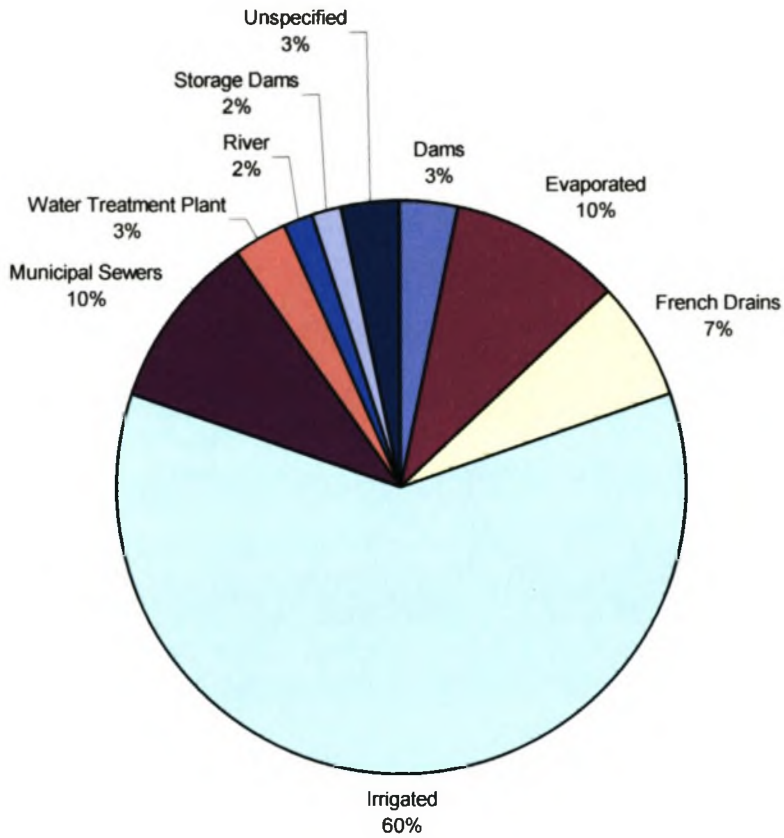

Figure 3.6 – Types of Effluent Disposal

Figure 3.6 shows the methods of disposal of winery effluent. It can be seen that 60% of wineries irrigate their effluent onto a pasture or paddock of some sort, with a further 10% disposing to municipal sewerage and 10% disposing their water by evaporation. Up to now, the ratio of different effluent disposal strategies has not been known. This is interesting if one considers how few cellars meet the legislative requirements for disposal of effluent by irrigation, combined with the proportion of cellars that do irrigate their effluent.

3.3.2.2.2. Quantity of Effluent

In figure 3.7, a chart was made to show how many people know how much effluent they dispose. It is shown that only 5% of all cellars have effluent quantity measurement. A further 5% answered with guesses but 90% of respondents were prepared to say that they had no effluent measurement. These data are alarming if they are considered in conjunction with the previous graph (figure 9) as this means that more than 50% of cellars are irrigating their effluent indiscriminately onto pastures or paddocks.

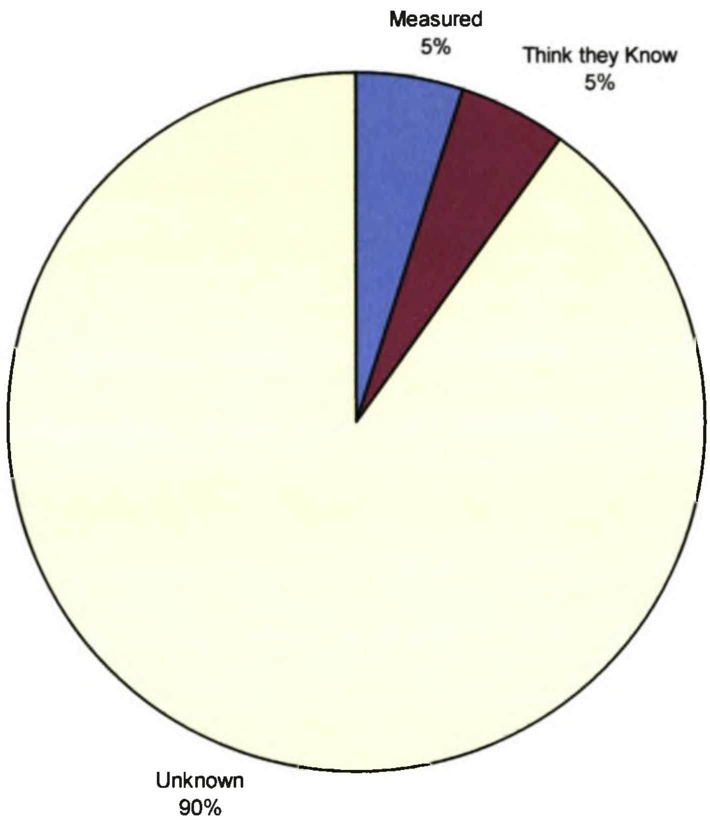

Figure 3.7 – Effluent Quantity Disposal

3.3.2.2.3 Effluent Characterisation

In figure 3.8, a plot was made to correlate various characteristics of the effluent with the tons pressed by the cellar. It is evident from the graph that as the size of the cellar increases, the quality the effluent decreases (the concentration of COD and TDS rises).

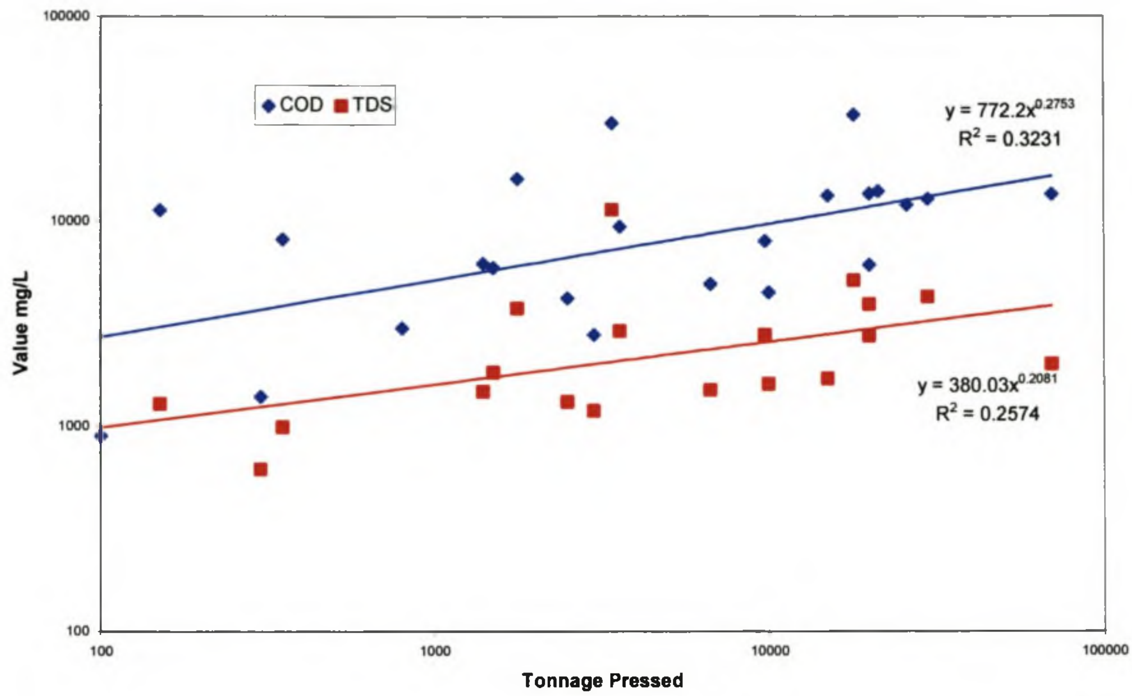

Figure 3.8 – Effluent Characterisation – COD and TDS as a Function of Tons of Grapes Pressed

The COD can be correlated to the quantity of tons pressed with equation 3.5. However, this equation has a very low co-efficient of regression which implies a high level of data scatter and consequent poor predictability.

$$COD = 772.2 \cdot T^{0.2753}$$ **Equation 3.5**

On the same figure, the TDS has also been plotted as a function of tons pressed. This correlation has an even lower regression co-efficient. What this shows is that these correlations are not particularly accurate, but they do provide industrial averages.

The TDS in solution can be given as a function of the tons pressed, shown in equation 3.6.

$$TDS = 380.0 \cdot T^{0.2081}$$ **Equation 3.6**

It is necessary to note that the level of the COD increases at a similar rate to the amount of dissolved solids in solution. Normally TDS indicates the presence of ionic species such as sodium or potassium. This indicates that as a winery presses more grapes, they have proportionately more COD in their effluent and use proportionately more chemicals like caustic soda.

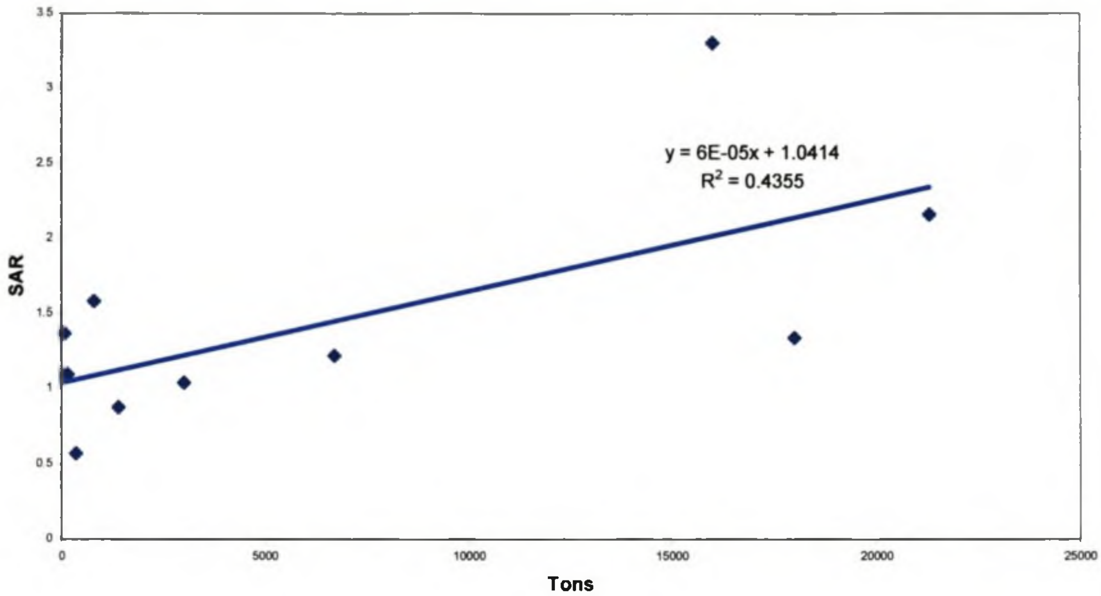

Figure 3.9 – Effluent Characterisation – SAR as a Function of Tons of Grapes Pressed

In figure 3.9, the SAR (Sodium Absorption Ratio: - for definition see section 2.5.1 of this study) of the effluent streams was plotted as a function of the tons of grapes pressed and correlated. It must be noted that from all the data only one cellar exceeded the permissible limit for the SAR for irrigation of effluent (The legal limit for irrigation of effluent is 3 [See section 2.5.1 of this study)]). This indicates that future work need not be too concerned with this aspect of environmental law, unless this law is altered. In addition to this, effluent treatment systems need concern themselves primarily with removal of the COD in the effluent.

$$SAR = 6 \cdot 10^{-5} \cdot T + 1.0414$$ **Equation 3.7**

In light of all of this, and in line with Vision 2020 (1999), wineries should attempt to reduce the SAR and use more environmentally friendly chemicals. It is therefore recommended that the caustic soda (NaOH) be no longer used for cleaning. Potassium hydroxide (KOH) should be used as an alternative as it is as effective and has fewer negative environmental effects, specifically, it does not damage soil. Unfortunately, KOH it is more expensive than NaOH.

3.4. CELLAR STUDIES

The following sets of graphs are plots of data obtained from sampling at the three different cellars, as discussed in chapter 1 of this study. The reason for these in depth studies was to verify the data obtained from the cellars. In fact, in all three cellars, most conditions corresponded to the responses given on the questionnaire. There were some disparities, but these can be considered negligible. Thus, full effluent sampling was performed at these cellars at different periods of the harvest season.

This in itself also proved difficult, as the 2002 harvest was atypical, especially in the smaller wineries. As such, the data sets are incomplete, but do provide information, especially in terms of visible trends.

3.4.1. EFFLUENT CHARACTERISTICS

Figure 3.10 shows the relationships between metal ions in the effluent, and the conductivity of the effluent. It is apparent that there is a trend that links potassium and sodium to the conductivity of the solution, but not magnesium. As the sodium and/or potassium levels of the effluent rise, so too does the conductivity. Cellar B has confusing data in this regard. There are too many other variables however that may have an influence. It can be seen that as the potassium level decreases and the sodium level increases, the conductivity remains constant.

This trend linking the potassium and sodium to the conductivity of the solution can be easily explained. Potassium is typically the most abundant ionic species present in wine or grape juice. This is the cause of such high levels of potassium in the effluent.

To explain the presence of the sodium is also simple. Large quantities of sodium hydroxide and/or sodium carbonate are often used for cleaning purposes. Caustic soda in particular is excellent at breaking down the tartrate crystals that precipitate out of the wine onto the processing equipment.

These curves indicate that the conductivity is below the legal limit for disposal of effluent by means of irrigation. These data confirm an earlier conclusion (that the SAR is not the most significant effluent parameter) and can extend on it to confirm that metals in solution in the effluent are not, and should not be classified as highly important. As stated before, thought should still be given to these parameters whenever assessing the quality of the effluent or designing a new effluent treatment system.

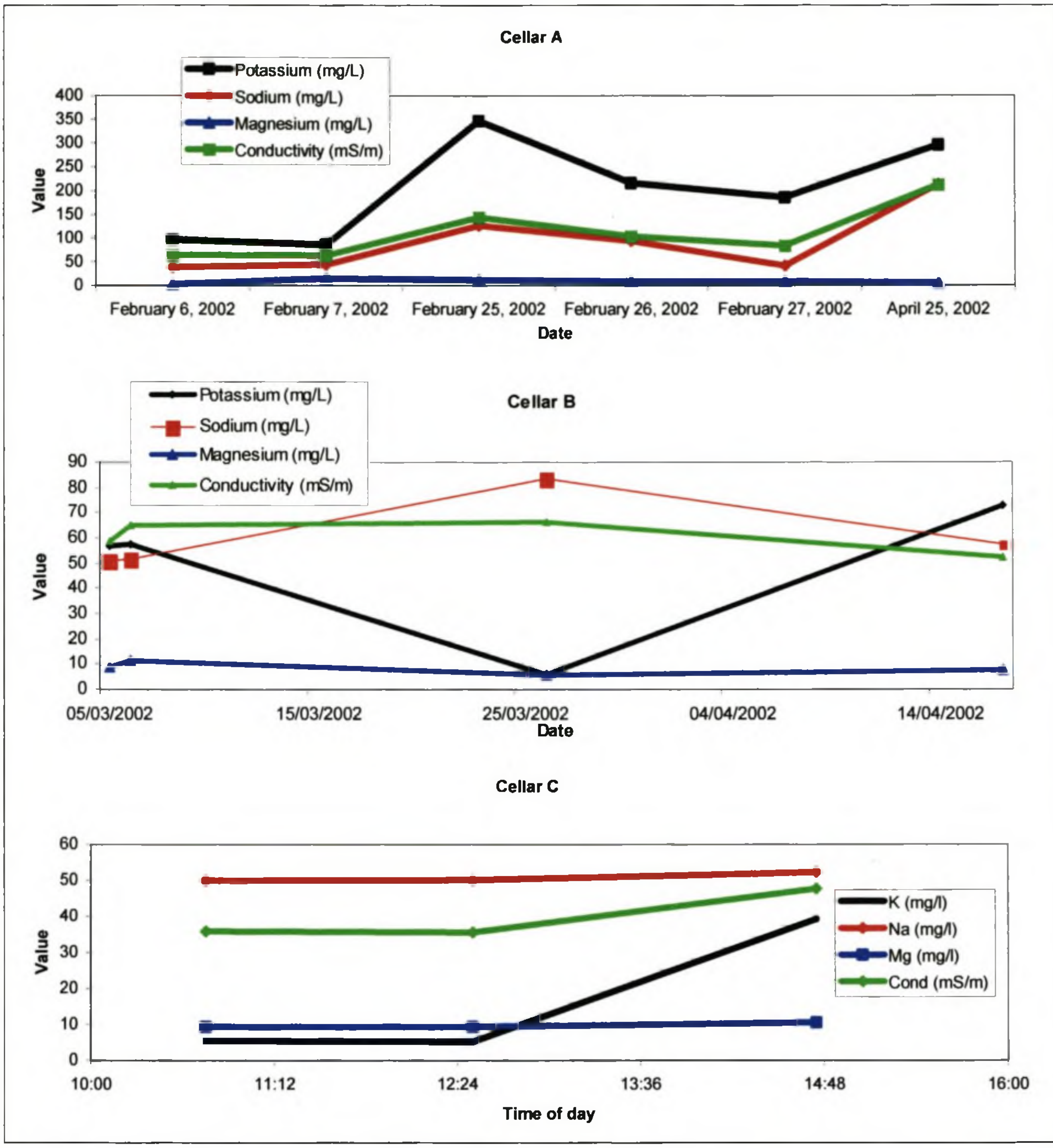

Figure 3.10 – Metals vs. Conductivity

In figure 3.11, suspended solids, total dissolved solids and the COD of the effluent were plotted on the same axes for the three different cellars. The purpose of this was to show how these parameters are related. As with the previous figure, there is no perfect correlation, but trends may certainly be drawn for all three cellars.

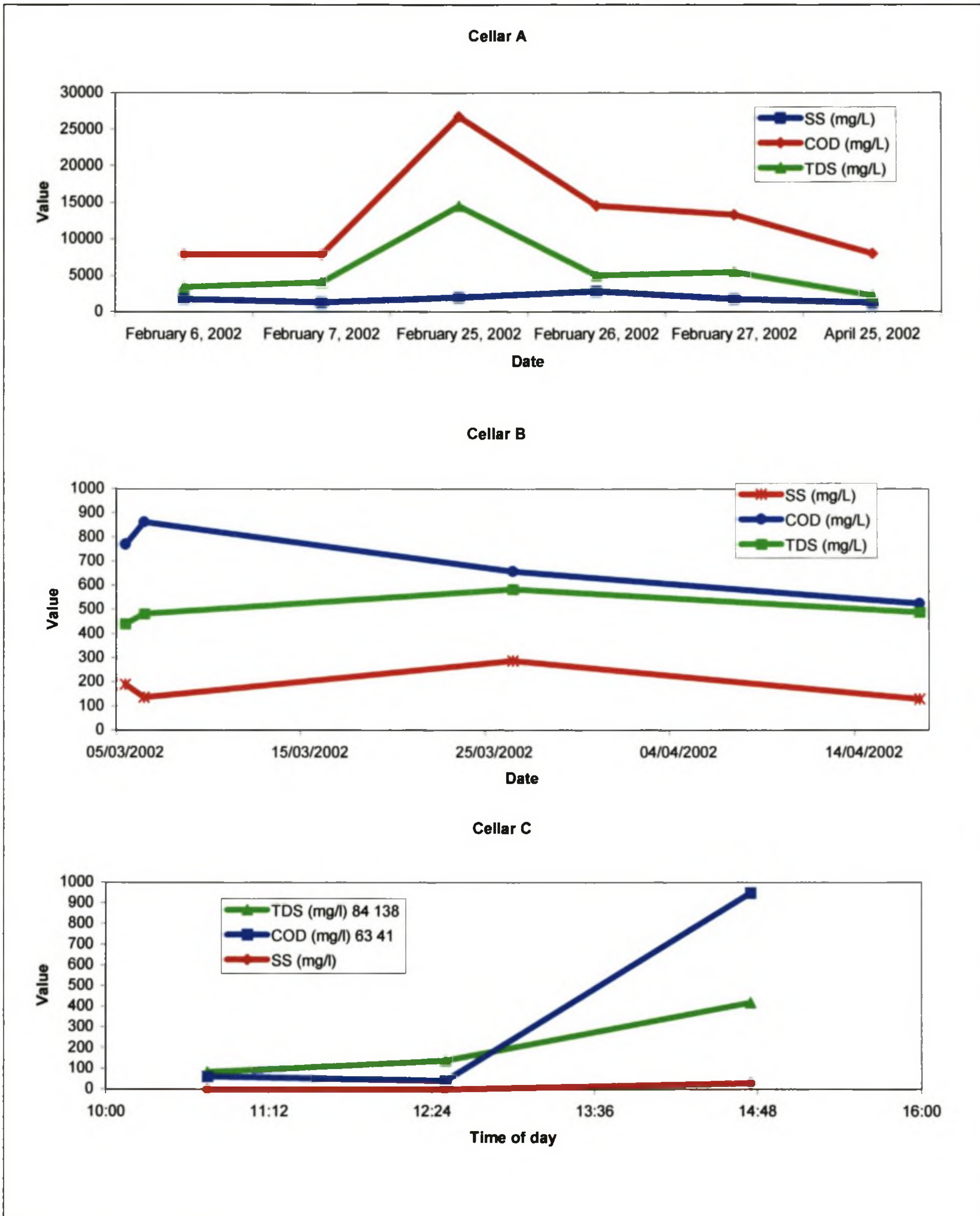

Figure 3.11 – Effluent Solids and COD

In all three cellars, there is a positive trend between TDS, SS the COD of the effluent. This is in line with results found by Balsari and Airoldi (1998). It is clearly visible that as the SS and the TDS rise, so too does the COD. This is important in that the COD is the most important parameter when discussing the effluent of a cellar. Thus, by reducing the levels of solids, either dissolved or suspended in the effluent, one should be able to reduce the COD of the effluent.

Hence, any design work towards designing an effluent treatment plant should first concentrate on reducing the sources of the COD.

3.5. WINE INDUSTRY PERCEPTIONS AND CONDITIONS

This section was added to this study, because it discloses information about the wine industry, which cannot be quantified mathematically, but is of importance. This section deals with a list of different perceptions or conditions that occur at cellars. These data were extracted from the questionnaire, in reply to certain questions.

3.5.1. PERCEPTIONS PERTAINING TO ENVIRONMENTAL MANAGEMENT

The following graphs show the perceptions of the ***wine maker/person*** filling in the questionnaire of the importance of an environmental management system (EMS). This may not be the case in reality since it is a perception, but makes for interesting conclusions.

In figure 3.12, the perceived importance of an EMS by cellar management is shown. It is quite clear that the management view some form of an EMS to be critical. As such, one may assume that environmental issues are critical to cellar management.

In figure 3.13, the perceived importance of an EMS by the skilled employees at the cellar is shown. It can be seen that most skilled employees are perceived to view an EMS as being highly important, rather than critical.

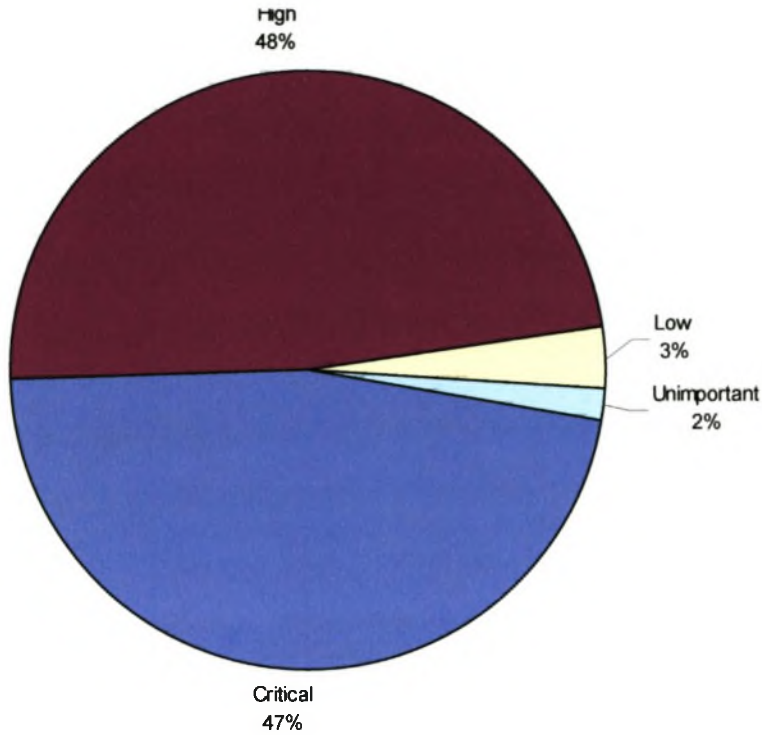

Figure 3.12 – EMS Importance according to Cellar Management

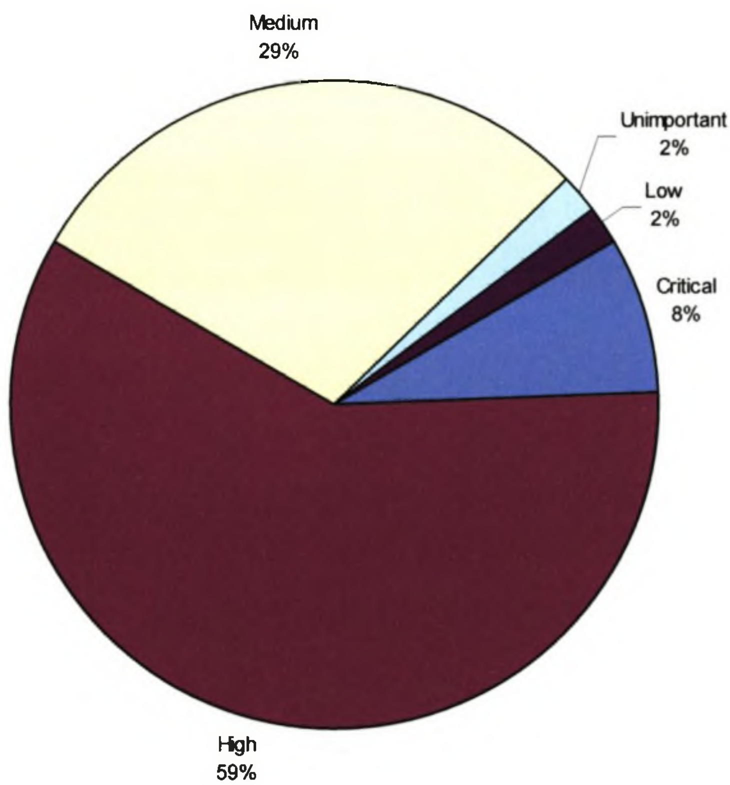

Figure 3.13 – EMS Importance according to Cellar Skilled Labour

Figures 3.12 and 3.13 contrast starkly to figure 3.14, which shows how the importance of an EMS is perceived to be for unskilled labour. In the first two categories, which typically include employees with a higher level of education, the importance of an EMS is high or critical, as opposed to the views of unskilled labour where 35% (which is the majority of respondents) see this as being unimportant.

For any given system to work, people need to understand a little bit about the system, especially those people that use the system. Thus, if an Environmental Management System is to be introduced at a cellar, it is a critical importance that the labourers understand how the system works, and why it is in place.

An example of this was observed during the in-depth analysis of a cellar during this project, during the harvest period. Occasional spillage of skins and pips tended to block the holes of the drain traps. As a result, the floors of the cellar started to flood. This flooding was rectified by the labourers, by pulling out the drain traps, and solids could then enter the effluent stream. Once these solids entered the effluent stream, they increase the COD of the effluent. This increase is a function of the time the effluent is in contact with these skins (Drew, 2001).

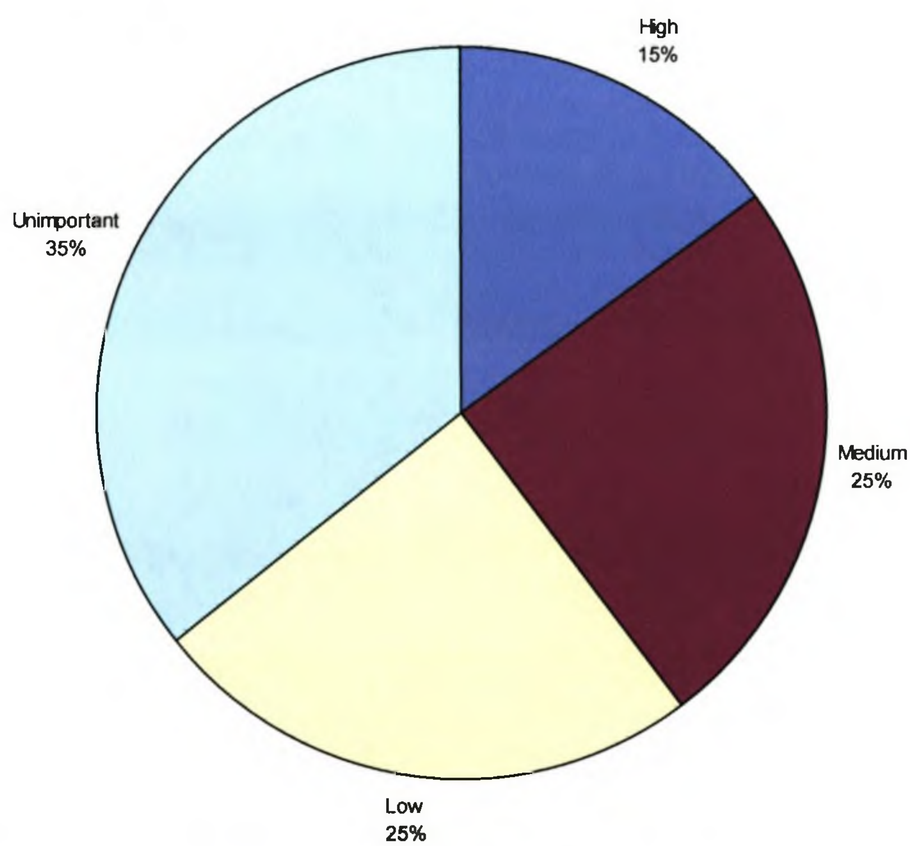

Figure 3.14 – EMS Importance according to Cellar Unskilled Labour

This makes the installation of cellar drain traps a needless expense since they are not used.

Labourers in the cellar need to be educated to understand the point of certain processing or equipment changes that are made, and need to understand the consequences of not adhering to the process guidelines given. Perhaps there should be some sort of disciplinary action taken against labourers that neglect such issues.

In addition to this, the cellar management also needs to be educated to understand why, for example, it is important for the drains to have their traps in place. It is not acceptable for the cellar manager to see occurrences like these and yet think they are unimportant. The era of winemaking as a distinct niche career is past. A modern wine maker needs to be part engineer, part biologist as well as wine maker. Cellars and their management need to accept the responsibility that is theirs – ***i.e. accept that winemaking causes environmental degradation and accept that costs are incurred to reduce or remedy this problem.***

However, one of the purposes of this report is to show that by reducing the effluent produced and water consumed one may reduce environmental degradation. By reducing water and chemicals used and the COD of the effluent, the economic savings may be significant.

Figure 3.15 shows what the respondents feel to be the biggest hurdle that needs to be overcome in order to implement an EMS. Fifty-two percent of respondents feel that cost is the most important issue, but according to Barnardt (2002)[*], the economic savings from reduced chemical usage, incurred by implementing an EMS can in fact pay for the implementation and maintenance of the EMS.

It would appear that lack of information and a lack of education and training are the two key factors that are responsible for causing difficulty in implementing effective EM systems in the wine industry. This study attempts to rectify the lack of information problem to a certain degree, and highlights where further information needs to be gathered (for example – effective water and effluent *quantity measurement* and characterisation).

However, education and training, as discussed above, cannot be addressed by this study. This requires active participation by the cellars, and this cannot be forced. It is felt that once these two issues are fully addressed, as they have been in other industries, the effective implementation of EM systems will become a reality.

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[*] Verbal Communication With Dr Barnardt, September 2002

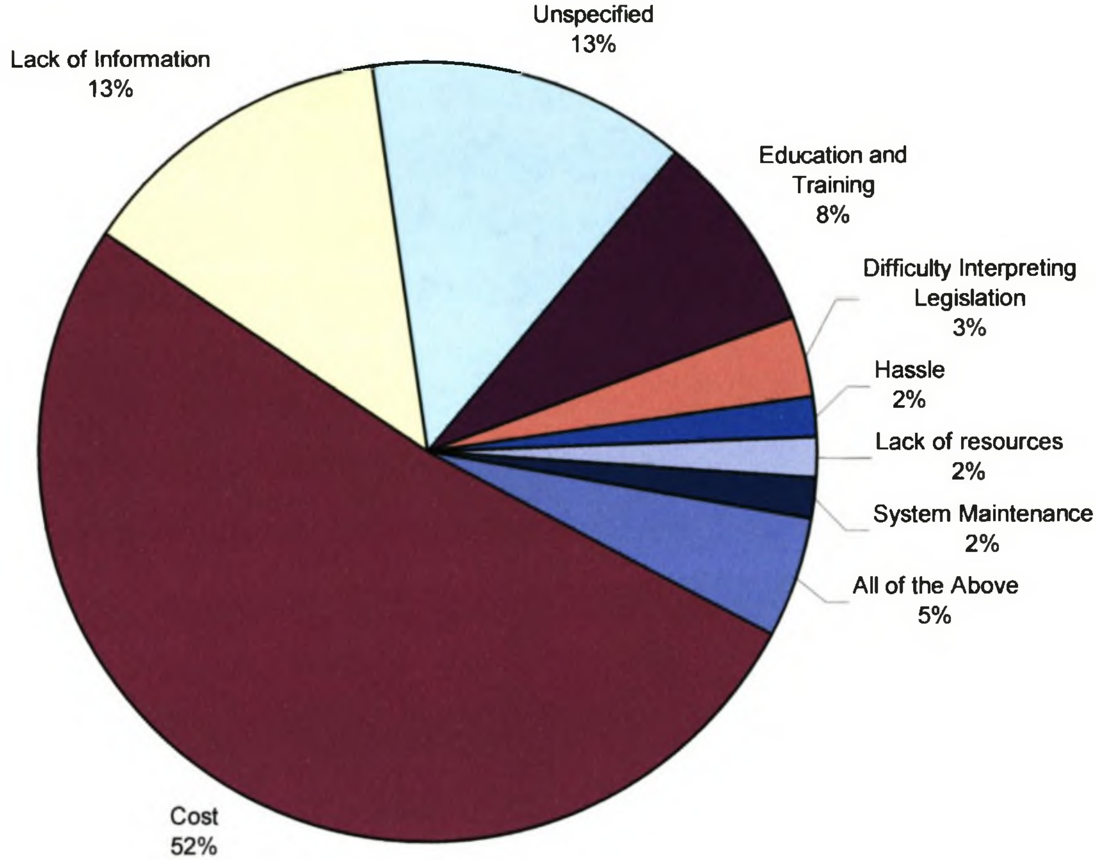

Figure 3.15 – EMS Implementation Hurdles

3.5.2. PERCEIVED AREAS OF POOR CELLAR OPERATION

It was asked in the questionnaire where the respondent felt that they lost the greatest amount of money during normal cellar operations. These results were then collected and classified into two categories. The first category is based on first choice answers. This means that the respondent felt this to be *the* area where the most money was lost. Then there is a second category which is the second choice given. This second choice was also important but not to the same extent as the first choice of answer.

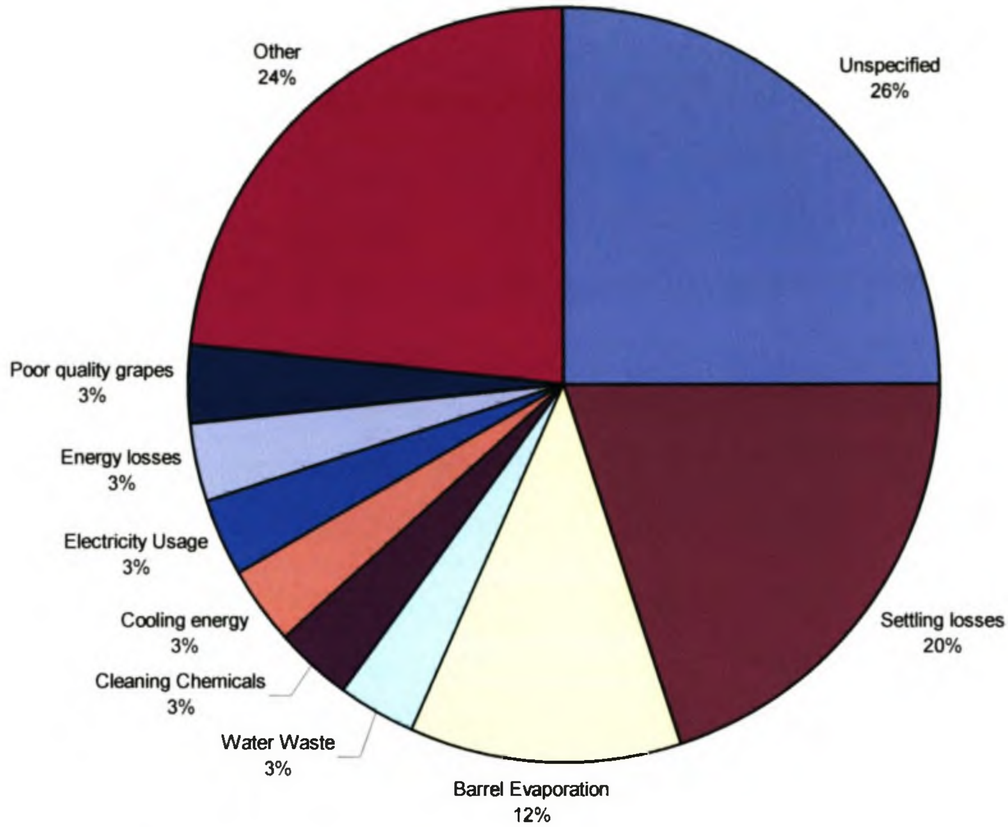

Figure 3.16 – Areas of Poor Cellar Efficiency – Primary Concern

Figure 3.16 shows category one of answers. Fifteen respondents gave no answer to this question, so unspecified is the largest value. A further 24% (14 respondents) chose a unique answer and these were classified into a group classed as other. Other included answers such as staff housing, rot in the vineyards, and tartaric acid addition etc. Twenty percent (12) of respondents felt that settling losses were too large. Settling losses are the loss of wine incurred during racking of wine, which may be full of lees, or which may sit in dead spaces inside the fermentation vessel. A further twelve percent (7) of respondents felt that barrel evaporation was the area where the largest amount of money was lost.

However, when considering the second category of answers, the order of importance of the areas of poor cellar efficiency changes. Category two answers are shown in figure 3.17. Fifteen respondents gave answers for the variable that they felt was the largest waste of money. As before, the category 'Other' is all of the options with low scores. For the second category of replies, barrel evaporation was classified as a problem by 40% of respondents (6 respondents). Two respondents felt that the cost of barrels was a waste of money.

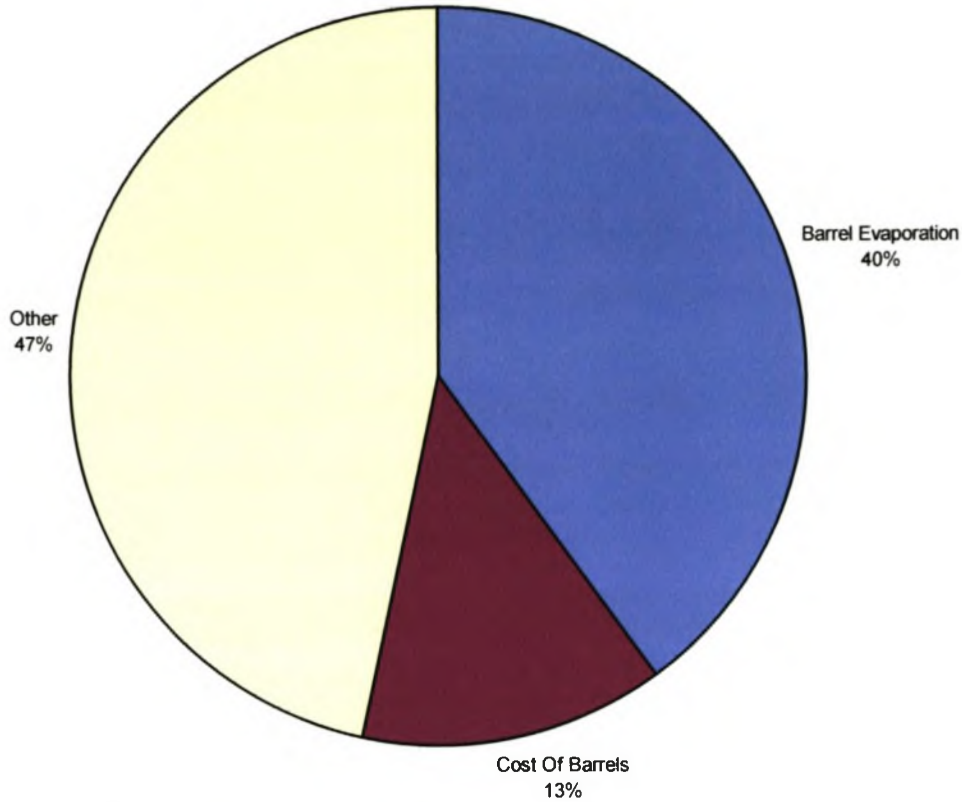

Figure 3.17 – Areas of Poor Cellar Efficiency – Secondary Concern

Thus, by combining the first and second categories, a clearer picture emerges. Twelve respondents in total felt that settling losses were important, and 13 respondents felt that barrel evaporation was a waste of money. As such, these two issues should be investigated further by academia to reduce the losses incurred by wineries.

3.6. CONCLUDING REMARKS

The findings presented in this chapter are summarised below:

- Wine and winery faults have been statistically correlated to process occurrences and certain items of equipment.
- Water used, effluent produced, effluent COD levels, effluent TDS levels, effluent SAR levels and electricity consumed have been correlated as functions of tons of grapes pressed per year.
- Winery measurement statistics have been collected. These statistics show the level of measurement of water and effluent at the sample group of wineries. This

includes a section on winemaker/respondent perceptions on environmental management systems.

These findings can be used to develop a preliminary model to predict the outputs and certain inputs of a winery, based only on the tons of grapes pressed per year. The effluent quality should also be able to be predicted by using the findings presented above.

One variable not presented, which is significant, is the consumption of chemicals per winery per year. Unfortunately, the questionnaire was too vague which lead to ambiguous data, or data which could not be interpreted. For example – a question sought to ascertain the consumption of sulphur per year. One respondent answered, "Three tanks" whilst another answered "50 litres of meta" which implies that 50 litres of potassium/sodium meta-bisulphite were consumed. The concentration was however not given. Neither answer provides any meaningful data.

CHAPTER 4

PRELIMINARY MODEL DEVELOPMENT

4.1. DEVELOPMENT OF AN ECONOMIC MODEL

By gathering the data presented in chapter 3, it is now possible to develop a 'preliminary' model of a winery in the more typical process engineering sense of the word. Correlations have been developed, by which it is possible to predict winery characteristics, based only on the tons of grapes pressed.

This study was designed to be a preliminary since it is the first of its kind. As such, the model presented below has limitations. It is limited by the validity of the data and some correlations have low coefficients of regression. There are also data that are not available. An example of this is the quantity and nature of chemicals that are used by cellars. The questionnaire sought to obtain this information, but was on occasion too vague, and as such, received answers that were too varied.

The preliminary model will be discussed fully in the section below.

4.2. MATHEMATICAL MODEL OF A SOUTH AFRICAN WINERY

Figure 4.1 is a pictorial representation of a mathematical model developed to perform mass balance and financial balance calculations for South African wineries based solely on the tons of grapes pressed.

The winery is called a 'Black Box' winery. Black box implies that one knows nothing about the process inside the box – it is unseen, and is often used in chemical engineering modelling because one doesn't need to know what is occurring in the process. All that is required to develop a black box model is information on process inputs and outputs. Due to very different processes and equipment used by individual wineries a black box model is the best possible model to develop which would have the greatest predicting ability for the widest number of wineries.

An input is defined as something that is added to the process. In this case, grapes, water, chemicals and energy are defined as the inputs. Typically, inputs have an associated cost. Outputs are things removed from a process. In this case, the outputs are designed as wine, wastewater, solid waste, lees, energy losses and evaporation losses. Outputs may have associated costs, but may also be value added products. These are not however exclusive definitions. There are many more inputs and outputs, but for the purposes of this study, these are the most important.

Processing parameters are defined as those parameters that can be changed by adjusting or modifying the way wine is made. An example of a processing parameter would be applying pinch technology heat exchange (Ficarella and Laforgia, 1999)). Another example would be adjusting the residence times of the drainage sumps to lower the 'leaching' of COD from pips and skins into the juice.

Design or Equipment Parameters are defined as those parameters that are changed by adjusting the equipment in the process. Equipment parameters may be very costly to change but not necessarily so. These parameters range from fixing up the cracks and chips in open fermenters, to replacing mild steel tanks with stainless steel ones.

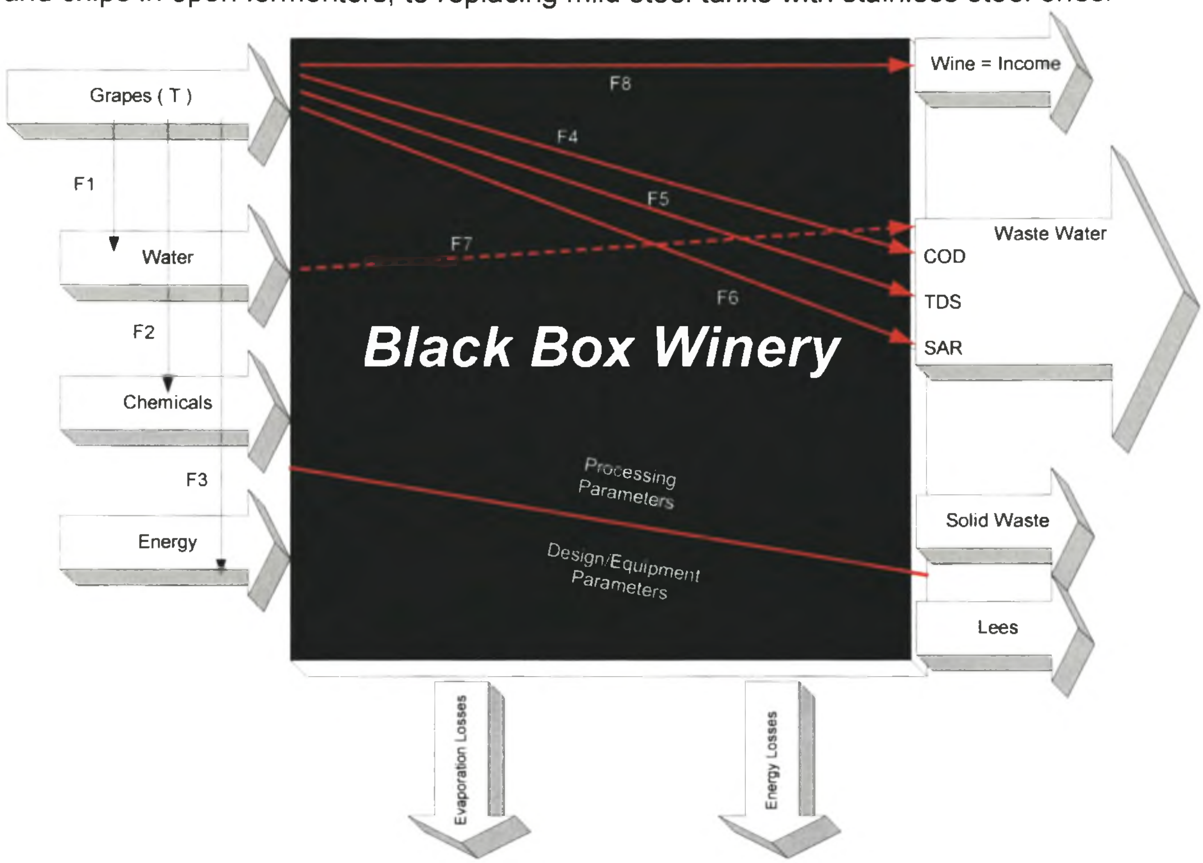

Figure 4.1 – Mathematical Model of a Winery

The model works in the following way. The grapes (T) coming into the cellar are normally quantified. The mass of grapes is known. The water, chemicals and energy are correlated to the tons of grapes pressed by the functions F1, F2 and F3, where:

F1: $Water = 4037.5 \cdot T^{0.9243}$ **Equation 3.3**

F2: Unknown parameter

F3: $E_H = 88.63 \cdot T^{0.8587}$ **Equation 3.1**

$E_O = 44.82 \cdot T^{0.811}$ **Equation 3.2**

The outputs can also be correlated to the tons pressed per year by the equations given below:

F4: $COD = 772.2 \cdot T^{0.2753}$ **Equation 3.5**

F5: $TDS = 380.0 \cdot T^{0.2081}$ **Equation 3.6**

F6: $SAR = 6 \cdot 10^{-5} \cdot T + 1.0414$ **Equation 3.7**

F7 can be assumed. Normally, the effluent should be less than or equal to the incoming water. However, one of the cellars measured their effluent flow and found it to be 10% more than the influent water. This could be due to significant quantities of grape juice being lost into the cellar drains. Because this represents the worst-case scenario, it shall be assumed that this is true for all cellars.

F7: $Effluent = 1.1 \cdot Water$ **Equation 4.1**

The final output variable that can be quantified is the wine. The wine produced can be correlated directly from the tons pressed, according to F8:

F8: $Wine = 626.24 \cdot T$ **Equation 3.4**

However, there are parameters that are missing from this model that cannot be so easily quantified. An example of this is the solid waste. No information was obtained so there is no cost that can be assigned to the quantity of solid waste. Similarly, the lees can be sold for tartrate recovery, or dumped with the solid waste, and this alters the economics of the model.

These missing parameters do not make the model less accurate though. Any information that is missing can be added at a later stage and the model can be improved on. This is the purpose of this model. It is the first of its type, and can be used by later studies or by industry. It can also be used by cellars and fine-tuned for their purposes, according to their own unique set of operating conditions e.g. for red and white grapes.

4.3. MODEL APPLICATIONS

This section will demonstrate how the adjustment of certain process parameters can significantly alter the operating cost of a cellar, using the model developed above. Parameters will be held constant, and one parameter will be altered at a time. This will form a series of cases that will be discussed at the end of this section. After all of the cases have been discussed, a maximum saving case will be shown, where the changes are made together, to show the cumulative effect of all of the savings. The model will then be applied over the full range of tons pressed per annum, and a percent savings will be given as a function of tons of grapes pressed per year.

4.3.1. BASE SCENARIO

The following scenario will be called the base case scenario, and will be defined as the average sized cellar, based on the data collected. This value equates to 11 550 tons pressed per year. The base economic values used are shown in table 4.1. Many of these values are unknown, so a 'Best Guess' was obtained, and these were used throughout.

Table 4.1 – Economic Indices

Unit	Cost per Unit	Cost Source
Grapes (Red and/or white)	R5000 per Ton	Arbitrarily Assigned Value
Water	Average - R0.03/kL R0.0337/kL in Berg River Basin R0.028/kL in Breede River Basin	Cape Municipality – Telephone Conversation Prices at 11/09/2002
Energy	R0.26/Unit	Questionnaire Average
Chemical Oxygen Demand Treatment	R1.3055/kg COD	Paarl Municipality (For COD<2000mg/L)
Waste Water Treatment	R0.5328/kL	Paarl Municipality
Wine	R8/L	Assigned Arbitrary Value

According to this, the following balance sheet can be drawn to represent the base case, or normal case for a typical winery. The quantity of grapes pressed is taken to be 11 550 tons per year as this was the average for all the questionnaire respondents.

All inputs and outputs shown are based on the above model. It should be added that capital cost and repayment of loans have not been shown, as this has no effect on the savings presented in this section. Since few cellars currently treat their effluent, but that treatment in future is likely, a cost of municipal was used to show what the expected treatment costs would be. This is open to interpretation though, as there are many factors affecting the cost of effluent treatment.

For the following case, shown in table 4.2, the operating profit would equate to R18.635 million rand. This may seem too high or too low, but this is unimportant, as the savings that can be accrued are the important factors to note. This is a hypothetical financial balance.

Table 4.2 – Base Economic Calculation

Variable	Quantity	Cost
Expenses		
Grapes (Tons)	*11 550*	*R57 750 000*
Water (Kilolitres)	*22 970*	*R 689*
Energy (Units In Harvest/month)	*273 000*	*R 212 919*
Energy (Units for Rest of Year/month)	*88 350*	*R 206 748*
Quantity of Effluent (Kilolitres)	*25 270*	
Effluent COD (mg/L)	*10 150*	
Cost of Effluent Treatment		*R 348 031*
Total Costs		*R58 518 387*
Income		
Wine Sales (HL)	*72 330*	*R77 152 768*

Income:	***R 77 153 000***
Expenses:	***R 58 518 000***
Profit:	***R 18 635 000***

4.3.2. SCENARIO 1 – 10% REDUCTION OF WATER USED

If one compares this scenario (table 4.3) to the base case, the expenses saved per year are significant. It should be noted that a saving could be made. A 10% reduction in the water used is easily obtainable if the cellar installs water saving devices, and educates workers to reduce water consumption. It can also be obtained by re-using water when cleaning tanks, and by avoiding over-washing.

Table 4.3 – Economic Calculation with 10% Water Reduction

Variable	Quantity	Cost
Expenses		
Grapes (Tons)	*11 550*	*R57 750 000*
Water (Kilolitres)	*20 673*	*R 620*
Energy (Units In Harvest/month)	*273 000*	*R 212 919*
Energy (Units for Rest of Year/month)	*88 350*	*R 206 748*
Quantity of Effluent (Kilolitres)	*22 740*	
Effluent COD (mg/L)	*10 150*	
Cost of Effluent Treatment		*R 313 227*
Total Costs		*R58 483 500*
Income		
Wine Sales (HL)	*72 330*	*R77 153 000*

Income:	***R 77 153 000***
Expenses:	***R 58 483 000***
Profit:	***R 18 670 000***
Base Scenario Profit:	R 18 635 000
Additional Profit to be Made:	***R 35 000***

4.3.3. SCENARIO 2 – 10% REDUCTION OF ENERGY USED

In this case (table 4.4), the expense reduction is shown if ten percent less energy were used. A ten percent reduction in energy consumption should be possible by simply installing energy saving light bulbs, but the savings should be greater if pinch technology (heat exchanger integration) is initiated, and if less pumping is done. Where possible, gravity flow of the wine should be employed. This is in line with current winemaking trends.

Table 4.4 – Economic Calculation with 10% Energy Reduction

Variable	Quantity	Cost
Expenses		
Grapes (Tons)	*11 550*	*R57 750 000*
Water (Kilolitres)	*22 970*	*R 689*
Energy (Units In Harvest/month)	*245 675*	*R 191 627*
Energy (Units for Rest of Year/month)	*79 500*	*R 186 073*
Quantity of Effluent (Kilolitres)	*25 270*	
Effluent COD (mg/L)	*10 150*	
Cost of Effluent Treatment		*R 348 031*
Total Costs		*R58 476 420*
Income		
Wine Sales (HL)	*72 330*	*R77 152 768*

Income:	***R 77 153 000***
Expenses:	***R 58 476 000***
Profit:	***R 18 677 000***
Base Scenario Profit:	R 18 635 000
Additional Profit to be Made:	***R 42 000***

4.3.4. SCENARIO 3 – 10% REDUCTION OF THE COD

If the COD were reduced by ten percent (table 4.5), the cost of treatment would drop by R33 000. A ten percent reduction in the COD is easily obtainable if one follows simple procedures to reduce the COD of the effluent. This includes minimising spillage, not washing the lees down the drains, reducing the residence time of any drainage sumps, and not allowing any solids into the effluent drains. These are normally parameters that are most influenced by the labourers operating the cellar, and their education in this regard is of critical importance.

Table 4.5 – Economic Calculation with 10% COD Reduction

Variable	Quantity	Cost
Expenses		
Grapes (Tons)	*11 550*	*R57 750 000*
Water (Kilolitres)	*22 970*	*R 689*
Energy (Units In Harvest/month)	*273 000*	*R 212 919*
Energy (Units for Rest of Year/month)	*88 350*	*R 206 748*
Quantity of Effluent (Kilolitres)	*25 270*	
Effluent COD (mg/L)	*9 100*	
Cost of Effluent Treatment		*R 314 574*
Total Costs		*R58 484 930*
Income		
Wine Sales (HL)	*72 330*	*R77 152 768*

Income:	***R 77 153 000***
Expenses:	***R 58 485 000***
Profit:	***R 18 668 000***
Base Scenario Profit:	R 18 635 000
Additional Profit to be Made:	***R 33 000***

4.3.5. SCENARIO 4 – COMBINED ENVIRONMENTAL SAVINGS

If one were to introduce all of the environmental savings, i.e. reduce water, energy and effluent COD (and chemicals), the saving could be as large as R90 000 per year (see table 4.6). It is suspected that these could even be greater. This is based on the premise that the quality of the wine is not affected. This may not be a large percentage saving, but would certainly be sufficient to employ a person to concentrate solely on environmental issues. This could be marketed (in the sense that the winery is operating in an environmentally friendly manner) which could increase wine sales, especially those earmarked for the export market. As an alternative, this saving could be used to finance an environmental management system, which would produce even greater savings, as this is a yearly, not a once off saving.

With this information, it is hypothesized that the quality of the wine will increase, primarily due to better documentation of the process of winemaking, which leads to a deeper understanding of it.

Table 4.6 – Economic Calculation with Combined Environmental Savings

Variable	**Quantity**	**Cost**
Expenses		
Grapes (Tons)	*11 550*	*R57 750 000*
Water (Kilolitres)	*20 673*	*R 620*
Energy (Units In Harvest/month)	*245 675*	*R 191 627*
Energy (Units for Rest of Year/month)	*79 500*	*R 186 073*
Quantity of Effluent (Kilolitres)	*22 740*	
Effluent COD (mg/L)	*9 100*	
Cost of Effluent Treatment		*R 283 117*
Total Costs		*R58 411 437*
Income		
Wine Sales (HL)	*72 330*	*R77 152 768*

Income:	***R 77 153 000***
Expenses:	***R 58 411 000***
Profit:	***R 18 742 000***
Base Scenario Profit:	R 18 635 000
Additional Profit to be Made:	***R 89 000***

4.3.6. SCENARIO 5 – COMBINED ENVIRONMENTAL SAVING FOR VARIOUS SIZED CELLARS

The model shown in figure 4.1 can be used for economic calculations for any sized cellar. It may be used to predict inputs and outputs. In figure 4.2, a graph has been plotted showing how a ten percent reduction of the aforementioned variables will reduce the operating costs for different sized cellars.

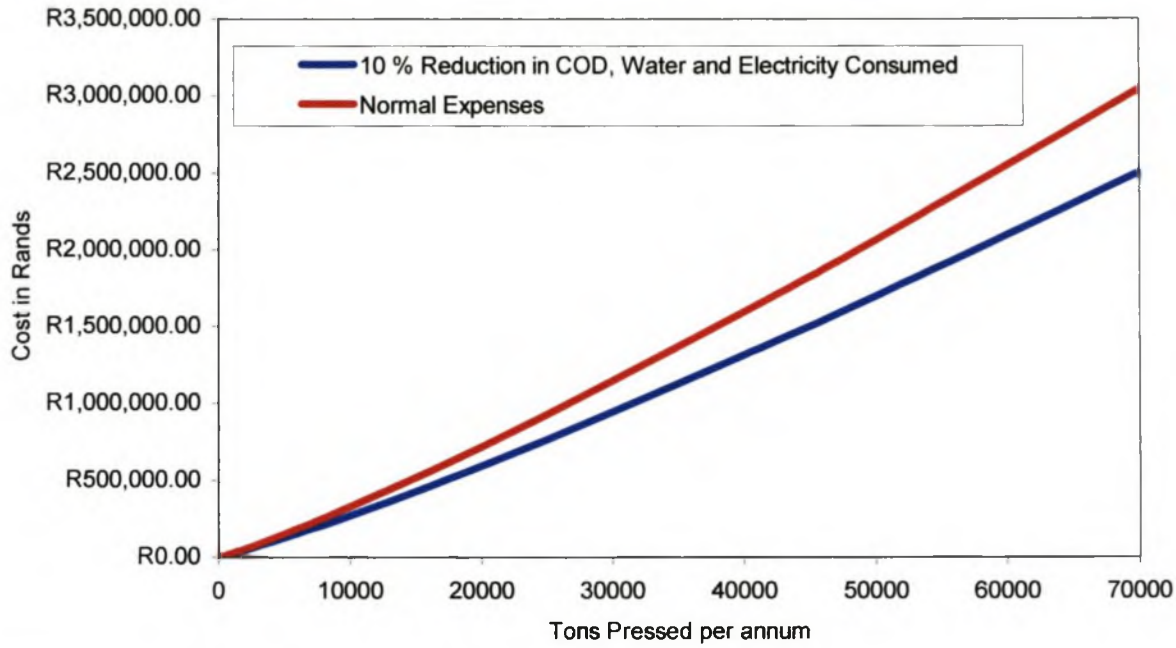

Figure 4.2 – 10% Reduction of Variables for Different Size Cellars

These data show that the percent savings increase with cellar size, due to the non-linearity inherent in the model. For a cellar that presses 100 tons of grapes per annum, the savings are approximately 14%, whereas for a cellar that presses 70 000 tons of grapes per annum, the percentage decrease in costs is nearly 18%.

This implies that although environmental savings significantly reduce operating costs for smaller cellars, large cellars (which generally have the worst levels of pollution) stand to gain the most from implementing cleaner production systems.

4.3.7. DISCUSSION OF SAVINGS

In the above section, different types of savings were shown that could either reduce the operating cost or increase the money made by a cellar. However, these data are unsupported by a practical case, where procedures could be implemented, and an accurate description of the savings calculated.

This does not necessarily negate the value of this study. The purpose of this study was to show that savings were possible, if one made wine in a more environmentally aware manner, with a higher level of focus on producing better quality wines. In this regard, the study has been successful.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

5.1. DISCUSSION

This has been a broad study, which included many parameters and variables, so it is necessary to discuss each section of the study separately. These discussions can then be tied up into a set of recommendations at the end of this chapter.

The first section that needs to be discussed relates to associations between processing and wine faults. These were shown in section 3.2 of this report. It was found that it is possible to correlate certain practices and occurrences within a cellar to wine faults, with statistical validity. The following is a list of associations between processing and wine faults:

- Floor/drain problems may lead to bacterial contamination of the wine.
- Microbial contamination may also be indicated by the presence of off odours occurring during fermentation.
- VA of the wine has also been found to be associated with processing off odours.
- Sluggish fermentations can be associated with primary processing equipment rust. Furthermore, sluggish fermentations have more than fifty percent probability of developing into stuck fermentations.
- Midge flies increase the risk of blocked filters.

The second section of results that need to be discussed are the correlations that have been established and which allow the prediction of winery inputs and outputs. Based on the preliminary model developed, certain inputs and outputs of a normal cellar can be predicted, although there are low coefficients of regression for some of the correlations. This implies lowered accuracy of the predictions. This is indicative of the variation of cellars within the industry.

With regard to the effluent, it was shown that the COD, TDS and SAR of the effluent can be correlated to the tons pressed, and there are loose correlations that show that as the TDS and SS rise, so too does the COD. It was also shown that as the concentration of Na and K ions increases, so too does the conductivity of the solution. However, the SAR and conductivity are not critical factors. The COD has been identified as the parameter that is most important when designing or discussing winery effluent. These other variables must not be neglected though. Chemicals should be used sparingly in any cellar and only if necessary. They reduce the quality of the effluent and can significantly increase the operating costs of a cellar. For minimisation of the effluent COD, solids should be removed from the effluent stream as soon as possible (Drew, 2001). Care must also be taken to minimise spillage of grape juice or wine, and lees should not be rinsed down the drains during racking procedures. It is recommended that cellars invest in environmental management systems, and read up on Best Management Practices (DOE FRAP, 1997).

Based on the correlations derived in this study, a mathematical model of a winery was developed, and this was used to perform costing calculations. It was shown that there are significant savings to be made if one produces wine in a more environmentally friendly manner. Indeed, these savings alone should pay for the implementation of an Environmental Management System. Savings on chemicals used after the implementation of the ISO14001 system at a certain winery paid for the implementation of this system. (Barnardt, 2002)*. These savings could lead to substantial (14% to 17%) decreases in the operating costs of the cellar. It was also shown that the operating cost reduction is greater for large cellars than for small cellars. This occurs because large cellars tend to have higher strength effluent, because they have lower specific water consumption than smaller cellars. This is of great value for the purposes of this study. For those cellars that have higher cash flows, the motivation to become proactive towards implementing cleaner production and EM Systems is greatest. However, since the reduction in operating costs is still significant for smaller cellars, there is sufficient motivation for them to become proactive too. As more information becomes available, and the consumption of chemicals becomes logged, one can expect these percentages of savings to rise even further. Furthermore, since it is likely that environmental law will become more aggressive in the next few years, results such as these become a valuable tool for educating winemakers on the benefits of cleaner production and EM Systems.

This model should be seen as being preliminary, and should be refined by further studies, where further information is assessed.

It was also shown that a winery's workforce should be educated further in processing and environmental problems. It was shown that management and skilled labour view the implementation of an EMS as critical, which contrasts starkly to how the importance of an EMS is perceived to be for unskilled labour. For unskilled labour, 35% (which is the majority of respondents) see this as being unimportant. If an EMS is introduced at a cellar, it is important that the entire workforce understands the reasons behind it, or it is certain to fail.

* Verbal Communication With Dr Barnardt, September 2002

It was also shown that the majority of respondents feel that cost is the largest hurdle towards setting up an EMS. This study shows that an EMS can in fact pay for itself.

It is personally felt that lack of information and a lack of education and training are the two key factors that are responsible for causing difficulty in implementing effective EM systems in the wine industry.

As such, this study fulfils its aims, i.e. to critically analyse the production of wine, from reception of grapes, to the final product ready for bottling. This analysis has shown that it is possible to produce wine in a more environmentally friendly manner, whilst using less water and energy, and by following simple cellar hygiene codes, the wine produced should be of a higher quality.

5.2. RECOMMENDATIONS FOR FURTHER WORK

It appears that one of the largest problems facing the South African Wine Industry at present is a lack of information. As such, any further work needs to concern itself with the collection of data. In light of the difficulty in obtaining the data for this project, this will be difficult. This problem is also being addressed (to a large extent) by the continuing effluent characterisation program being performed by Winetech.

Future work should concern itself with refinement of the model developed in this study and the collection of additional data to make the model more accurate. It would also be useful to implement a similar study at cellars where EM systems are in place and to develop the models at these cellars to compare different process designs' efficiencies with respect to their environmental impacts.

Further research should also focus on the problems highlighted by the respondents in this study. These include, specifically, designing more efficient systems to reduce the losses of wine that occur from settling and filtration, and designing truly efficient climate control systems for barrel cellars to reduce the rate of evaporation.

It is felt that both Elsenburg College and the University of Stellenbosch should implement a water chemistry/environmental science course for winemaking students at undergraduate level. This would improve the knowledge of future winemakers on environmental and water issues.

It is also felt that the current legislative requirements, especially with regard to the irrigation of effluent, are inadequate. It would be better to have a specific dose of COD that could be irrigated per hectare per day, than the current limits which particularly favour smaller wineries. If a large winery has sufficient pastureland that it can irrigate more than the current maximum limit per day, there is no reason that they should be disadvantaged by the current legislation. However, having said that – nearly all cellars exceed of the current maximum permissible limit for irrigation, which is of concern, especially since 60% of all cellars dispose of their effluent by irrigation to a pasture.

CHAPTER 6

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CHAPTER 7

APPENDICES

7.1. APPENDIX 1 – ENGLISH VERSION OF THE QUESTIONNAIRE

Institute for Wine Biotechnology
University of Stellenbosch

SPI/CPE

Dear Sir/Madam

The South African Wine Industry is facing difficult challenges and severe pressures in the global economy especially with regard to improving the quality of wine whilst minimising the impact of the winemaking process on the environment. To respond most efficiently to these challenges, and to identify the areas requiring improvement most urgently, the department of Chemical Engineering and the Institute for Wine Biotechnology at the University of Stellenbosch have set up this questionnaire, which aims to assess current practices in the SA wine industry. It will also be used to perform a statistical analysis of the problems associated with the winemaking process in South Africa.

The questionnaire attempts to assess all of the physical inputs and outputs of the cellar. Based on this assessment, representative models of the winemaking process will be developed, which will be used to improve production practices and guidelines.

This project has been endorsed by Elsenburg College/EKOV.

The questionnaire addresses a number of very broad issues:

1. Cellar Infrastructure – questions are asked about the type and condition of equipment in the cellar.
2. Utility requirements – the amount of chemicals and energy consumed.
3. Water topics – questions that pertain to the quantity of water, quality of effluent and cleaning practices are asked.
4. Biological and Biotechnological Topics – questions are asked about issues that are of a biological nature, and which may be related to the method of winemaking, and/or which may have an adverse effect on wine quality.

Direct benefits to be expected: -

- ***To set up a database of wine industry practices and conditions.***
- ***To prioritise future research.***

You are invited to fill out the attached questionnaire, and return it as soon as possible to the address given below. This is part of a continuing effort of the Winetech/Chemical Engineering project, and as such is a working document. Please feel free to point out any issues that may have been omitted in the questionnaire, or to make any comments that may be relevant. All of this information will help to determine the focus of future research.

Should you require more information feel free to contact any of the following people:

Name	Telephone Number	Email Address
Craig Sheridan	082 706-7525	sheridan@ing.sun.ac.za
Neil Hayward	(021) 808-4491	djh@ing.sun.ac.za
Dr. F.F. Bauer	(021) 808-3770	fb2@maties.sun.ac.za
Prof. L. Lorenzen	(021) 808-4496	ll1@ing.sun.ac.za

PLEASE NOTE THAT ALL INFORMATION GIVEN WILL BE STRICTLY CONFIDENTIAL.

Cellar Details:

1. Name Of Cellar: ______________________________
2. Cellar Details: Address, Telephone and email address

   ____
   ____
   ____
   ____
   ____

   Tel No:____________________ Fax No:__________

   Email:______________________________

3. Name of Winemaker:______________________________
4. Name of Cellar Manager:______________________________
5. Tonnages Pressed and Wine Produced:

   Tonnage Pressed: / Wine Produced

   Chardonnay:____________ / ____________
   Chenin Blanc:____________ / ____________
   Colombard:____________ / ____________
   Hanepoot:____________ / ____________
   Sauvignon Blanc:____________ / ____________
   Semillon:____________ / ____________
   Other:____________ / ____________
   ____________ / ____________
   ____________ / ____________
   Cabernet Sauvignon:____________ / ____________
   Cinsaut:____________ / ____________
   Merlot:____________ / ____________
   Pinotage:____________ / ____________
   Ruby Cabernet:____________ / ____________
   Shiraz: ____________ / ____________
   Other:____________ / ____________
   ____________ / ____________
   ____________ / ____________

6. What is the design capacity of the cellar (tons pressed/year):____________

Instructions: Please fill out any blank spaces wherever applicable. Wherever an option is printed in italicised bold (e.g. ***Yes/No***) please delete that answer which is not applicable.

Section 1: Cellar Infrastructure and Processing

This section deals with obtaining information about the equipment in the cellar, the condition of equipment in the cellar, processing options during winemaking, as well as assessing the occurrence of processing problems in the winemaking process.

1.1.Cellar Infrastructure

Please provide the details for the following items of equipment, which may be present in the cellar, if applicable.

1.1.1. Primary Processing

	Primary Processing Operation	Machine Type/s	Number of Machines:	Capacity (In tons/day)
1	Weighing			
2	Destalking			
3	Crushing			
4	Pressing			

1.1.2. Tank Farm

Please Specify the number of each of the following types of tanks that you may have in each size category as well as the general purposes of such tanks								
Number of tanks:	Stainless Steel	Purpose	Cement	Purpose	Fibre-glass	Purpose	Wood	Purpose
EXAMPLE	3 In this size class	Ferment						
<225l								
225l								
300l								
300l-1000l								
1000l-2000l								
2000l-5000l								
5000-10000l								
>10000l								

1.1.2.1 Are any of the tanks insulated? ***Yes/No***.
1.1.2.2. Are any of the tanks cooled? ***Yes/No***. If yes, please specify which tanks:

____
____
____
____

1.1.2.3. Are any of the tanks vented? ***Yes/No***.

1.1.3 Filtration and Clarification

Type of Wine – Please Specify	Is it Filtered? Yes/No	How many times?	What type of filter is used?	What Fining agents are used?

1.1.4. Fermentation

This section is not compulsory, but please fill out as many of the details as you can.

Grape Variety Please Specify:	Temp-erature of the ferment / °C	Pressure of Ferment	Duration of Ferment	Fermentation system (e.g. Roto tank, punch Through etc)	Duration of Lees Contact:	Duration of Skin Contact	Aera-tion: Yes/ No

1.2. Cellar Operations

These questions relate to operating practices within the cellar. They require information on how items of equipment are cleaned, how often maintenance is required and what types of problems are present within certain areas of the cellar.

1.2.1. Primary Processing

How are the following four systems cleaned? Please specify the amount of water, steam and/or chemicals used, as well as the method of cleaning:

Weighing: ______________________________

____

Destalking: ______________________________

____

Crushing: ______________________________

____

Pressing: ______________________________

____

1.2.2. Tank Farm

Do these tanks have any visible flaws, either internal or external, such as corrosion, cement abrasion, separation of glass fibre from epoxy or other? ***Yes/No***. If yes, please specify:

____

____

____

____

1.2.2.2. Are there any spare tanks available during peak harvest periods? ***Yes/No***. If yes, how many?

____

1.2.2.3. How are the aforementioned tanks cleaned? Please specify the amount of water, steam and/or chemicals used, as well as the method of cleaning: ______________________________

____

____

____

____

____

____

____

1.2.2.4. Are there plans to expand the tank farm in the immediate or near future? ***Yes/No***. If yes, please give details of proposed expansion.

____

____

____

1.2.3. Fermentation

1.2.3.1. Is the wine vented during fermentation? ***Yes/No***.
1.2.3.2. Is the equipment/machinery showing any signs of corrosion? ***Yes/No***.
1.2.3.3. Are there any noticeable off odours? ***Yes/No***.

1.2.4. Filtration and Clarification

1.2.4.1. Do you experience any problems during filtration, such as blocked filters? ***Yes/No***. If yes, please describe these problems:____

1.2.4.2. How is the filtration media disposed?

1.2.4.3. How is the fining media disposed?

1.2.5. Cooperage

1.2.5.1. What is the barrel replacement policy?

1.2.5.2. How are the wines aged? (E.g. Red wine in new oak for six months, and then into old oak for three months etc.)

Red Wine:

White Wine:

1.2.5.3. How are the barrels cleaned?

1.2.5.4. How much Sulphur or SO_2 is used per barrel?

1.2.5.5. How much water (including steam if applicable) is used per barrel?

1.3. Cellar Maintenance

This section seeks do determine the frequency of maintenance, as well as the cost of maintenance in the cellar.

Section:	How often is Maintenance performed?	Typically, what is done during maintenance?	How long does maintenance take?	What is the maintenance budget for this section?
Primary Processing				
Tank Farm				
Fermentation				
Filtration				
Cooperage				

1.4. Processing Problems

Please make a tick on each of the columns on the table, wherever you experience a certain problem:

Section:	Equipment Rust	Odours*	Vinegar Flies	Others – Please Describe:
Primary Processing				
Tank Farm				
Fermentation				
Filtration				
Cooperage				

*If odours were present, were they strong, ***Yes/No***, and was the source identified? ***Yes/No***? If the source was identified, what was it? ____

____

____

____

Section 2 – Utility Requirements

This section aims to assess all of the chemical, electrical and heating requirements of the cellar to determine where it may be possible to save on any of the above.

2.1. Chemical Consumption

2.1.1. Please list the amount of the following chemicals used per year:

Chemical	kg used per year
Tartaric Acid	
Hydrochloric Acid	
SO_2	
Sulphuric Acid	
Citric	
Other Acids – Please Specify	
Potassium Hydroxide	
Caustic Soda	
Lime	
Other Bases – Please Specify	
Sodium Chloride (Table Salt)	
Organic or other Chlorides	
Quaternary Ammonium Compounds	
Other Water Treatment Chemicals (Please Specify)	

2.2. Electricity

2.2.1. How much electricity is used, in kWh, during the harvest season, and out of the harvest season, and how much does this cost you?
During Harvest: ____________________
Out of Harvest: ____________________

2.2.2. Generally speaking, what kinds of light bulbs are used in the cellar? ***Incandescent bulbs***, ***Fluorescent tubes***, ***energy saving bulbs***, ***other*** (Please Specify)

____

____

2.2.3. Has the cellar ever had a consultant (from an organisation such as Agrilek) visit you to determine ways to reduce the cost of electricity? ***Yes/No***.

2.3. Heating/Cooling Loads

2.3.1. Is the whole cellar cooled, or are the tanks cooled, or both?

2.3.2. How are the tanks cooled?

2.3.3. Is the must cooled? ***Yes/No***. If so, to what temperature?
Red Wine:
White Wine:
2.3.4. Is there any automated temperature control in the cellar? ***Yes/No***.
2.3.5. Do you have the facilities to make steam/hot water for the cellar? ***Yes/No***. If yes, how is this steam/hot water made?

2.3.6. What types of heat exchangers are used to cool the must?

2.3.7. Are any of the cooler/hotter *pipes/heat exchangers/tanks* insulated? ***Yes/No***. If yes, which ones?

2.3.8. What refrigerant is used in the cellar?

Section 3 – Water Related Topics

This section is a follow up of the Winetech questionnaire developed by the University of Stellenbosch, in conjunction with the ARC, and the IAE. If any of the data that may have been supplied on that form is significantly different, it should be updated, or if it wasn't completed, please contact Niel Hayward or Sol Bezuidenhout at the Centre for Process Engineering at the University of Stellenbosch for further details (see cover letter for contact details).

3.1. Water Distribution

3.1.1. Where is the cellar water obtained?
Municipal Mains / Stream / Borehole / Other – Please specify:

3.1.2. How much water is used on an annual basis?

3.1.3. How much water is used per ton of grapes processed?

3.1.4. Has any attempt been made to determine the amount of water used per cleaning operation, or per unit of equipment? ***Yes/No***. If so, please give details of the amounts.

3.2. Effluent Disposal

3.2.1. What quantity of effluent is discharged from the cellar on an annual basis?

____

3.3.2. Are there filters on the cellar drains? ***Yes/No***. If yes, what type?

____

3.2.3. How are solids separated from your wastewater?

____

____

____

____

3.2.4. Has any attempt been made to classify wastewater into categories, depending on how polluted it is? ***Yes/No***.

3.2.5. If so, is any of the wastewater re-used? Please describe any re-use.

____

____

____

____

____

____

3.2.6. How is the effluent disposed? ***Municipal Sewers / Rivers / French Drains / Treatment Plants / Other*** – Please specify

____

____

3.2.7. Do you have a water treatment facility? ***Yes/No***. If so, please describe it.

____

____

____

3.2.8. If yes, how close is this facility to the cellar?

____

3.2.9. Do you have settling ponds or dams? ***Yes/No***.

3.2.10. Are there animals like ducks that live in these dams? ***Yes/No***. If yes, are they there throughout the whole year? ***Yes/No***.

3.2.11. If yes (to 3.2.7), are there reed beds between these dams? ***Yes/No***.

3.2.12. Where does the water go once it leaves these dams?

____

____

____

3.2.13. Do you have evaporation ponds? ***Yes/No***. If yes, how much water is evaporated daily? (Total amount)

____

3.2.14. Are there any off odours that emanate from the cellar wastewater? ***Yes/No***. If yes, is it present only during the harvest season, or the whole year round

____

____

3.3. Cleaning Practices

3.3.1. How often is the cellar cleaned?
During Harvest: ____
Out of Harvest: ____
3.3.2. Please describe the equipment and method of cleaning the cellar:

____
____
____
____
____

3.4. Measurement Practices

Please tick the column to indicate whether records are kept on any of the following process parameters. Please insert any in the blank space that are not mentioned.

Parameter	Yes	No
Cellar Temperature		
Tank Temperature		
Chemical Consumption		
Effluent Composition		

Please describe how much process automation is employed: E.g. Process control, temperature control, pressure control, level control (for tanks).

____
____
____
____

Section 4 – General Questions

4.1. At what point in the winemaking process do you feel that you lose the greatest amount of money? Please explain why:____
____
____
____

4.2. Has the cellar ever experienced any of the following, and if so, was it able to identify the source:
4.2.1. Sluggish fermentation: ***Yes/No***
Source:____
____
____
____
____

4.2.2. Stuck fermentation: ***Yes/No***
Source:____

4.2.2.1. If you answered Yes to 4.2.2., were you able to restart the fermentation? ***Yes/No***. If you were able to restart the stuck ferment, how did you do this? (Adding Nitrogenous chemicals, re-inoculating etc.) Please describe.

4.2.3. Microbial contamination at any point in the cellar: ***Yes/No***.
Source:____

4.2.4. If you answered yes to 4.2.1., 4.2.2., or 4.2.3., was any sampling performed during these events? ***Yes/No***.

4.3. If you answered yes to 4.2.1., 4.2.2., or 4.2.3., how often do these problems occur? Please tick the correct column.

Problem	Yearly	Every 2nd Year	Less than Once Every 5 Years	Less than once every 10 Years	Never
Sluggish Fermentation					
Stuck Fermentation					
Microbial Contamination					

4.4. Do you experience any problems with VA? ***Yes/No***

4.5. Do you perform chemical analyses on your wine? ***Yes/No***. If yes – what analyses are done? ***Total Acidity / Malic Acid / Tartaric Acid / Alcohol / Sugar / Aromatic Compounds (Please specify any not included)***

4.6. Are these analyses done to the must, the wine or both? Please specify at which points in the winemaking process these analyses are done:

4.7. Do you pay for these analyses? ***Yes/No***.

4.8. What additional analyses would you like to have done on your wine/must, that are not done at present? ______

4.9. Do you compost the cellar and vineyard waste? ***Yes/No***.
4.10. If yes, how far from the cellar is composting performed? ______

4.11. Are the lees and bentonite added to the compost heap? ***Yes/No***.
4.12. Is the compost heap sealed underneath to prevent seepage of water into the soil below the compost pit? ***Yes/No***.
4.13. Do the general washing hoses have auto shut off nozzles? ***Yes/No***.
4.14. What type of floor surface does the cellar have? ***PVC***, ***Rough Cement***, ***Polished Cement***, ***Tiles***, ***Painted***, ***Other*** (Please describe) ______

How do you rate the performance of your floor type? Are you happy with it? ______

4.15. Do you have any problems with mildew or bacterial growth in the sewer system, or on or underneath the floors? ***Yes/No***. If yes, where does it occur? ______

4.16. Are there any plans for future investments, or upgrading of the cellar in the next two years? ***Yes/No***. If yes, please describe: ______

4.16.1. When was the last upgrading of the cellar performed, and please describe what was changed: ______

4.17. How important does the cellar workforce perceive the problem of environmental management to be? Please tick the column with the appropriate response.

Personnel	Critical	Highly Important	Medium Importance	Low Importance	Not Important
Management					
Skilled Employees					
Unskilled Employees / Labourers					

4.18. What do you feel to be the biggest hurdle towards implementing environmental management systems? ***Cost / Return on Investment / Lack of Information / Lack of Resources / Education and Training / Difficulty interpreting legislation / Fear of Non-conformance / Other (Please specify)*** ______

4.19. Would you be willing to have an in-depth study performed at your cellar during the 2002 harvest? ***Yes/No***.
4.20. Do you have any processing or quality control problems that haven't been discussed in this questionnaire? ***Yes/No***. If yes, please describe in the space provided below. The purpose of this is to identify problems that may occur and which may be attributed to cellar operating practices. **Please also feel free to make any comments that you may have below.** ______

7.2. APPENDIX 2 – ORIGINAL VARIABLE CASE TABLES

Event A ↓	Event B ↓			P(B/A)	P(B/Not A)	P(Not B/Not A)	Chi-Square Test – P-Value
	Filtration Problems						
		Yes	No	0.60	0.20	0.80	0.01
Tank Farm Midge Flies	Yes	6	4				
	No	9	37				

Event A ↓	Event B ↓			P(B/A)	P(B/Not A)	P(Not B/Not A)	Chi-Square Test – P-Value
	Microbial Contamination						
		Yes	No	0.43	0.17	0.83	0.03
Floor/Drain Moils/Odours	Yes	10	13				
	No	6	29				

Event A ↓	Event B ↓			P(B/A)	P(B/Not A)	P(Not B/Not A)	Chi-Square Test – P-Value
	Microbial Contamination						
		Yes	No	0.56	0.22	0.78	0.05
Fermentation Off Odours	Yes	5	4				
	No	11	38				

Event A ↓	Event B ↓			P(B/A)	P(B/Not A)	P(Not B/Not A)	Chi-Square Test – P-Value
	Stuck Fermentation						
		Yes	No	0.63	0.36	0.64	0.07
Microbial Contamination	Yes	10	6				
	No	15	27				

Event A ↓	Event B ↓			P(B/A)	P(B/Not A)	P(Not B/Not A)	Chi-Square Test – P-Value
	VA						
		Yes	No	0.60	0.31	0.69	0.05
Microbial Contamination	Yes	9	6				
	No	12	27				

Event A ↓	Event B ↓			P(B/A)	P(B/Not A)	P(Not B/Not A)	Chi-Square Test – P-Value
	VA						
Fermentation Off Odours		Yes	No	0.90	0.30	0.70	0.0003
	Yes	9	1				
	No	14	33				

Event A ↓	Event B ↓			P(B/A)	P(B/Not A)	P(Not B/Not A)	Chi-Square Test – P-Value
	VA						
Primary Processing Odours		Yes	No	0.80	0.37	0.63	0.06
	Yes	4	1				
	No	19	33				

Event A ↓	Event B ↓			P(B/A)	P(B/Not A)	P(Not B/Not A)	Chi-Square Test – P-Value
	VA						
Tank Farm Odours		Yes	No	1.00	0.36	0.64	0.005
	Yes	4	0				
	No	19	34				

Event A ↓	Event B ↓			P(B/A)	P(B/Not A)	P(Not B/Not A)	Chi-Square Test – P-Value
	VA						
Stuck Fermentations		Yes	No	0.58	0.28	0.72	0.02
	Yes	14	10				
	No	9	23				

Event A ↓	Event B ↓			P(B/A)	P(B/Not A)	P(Not B/Not A)	Chi-Square Test – P-Value
	Sluggish Fermentations						
Primary Processing Rust		Yes	No	0.92	0.43	0.57	0.001
	Yes	11	1				
	No	21	28				

Event A ↓	Event B ↓			P(B/A)	P(B/Not A)	P(Not B/Not A)	Chi-Square Test – P-Value
	Stuck Fermentations						
Sluggish Fermentations		Yes	No	0.55	0.31	0.69	0.06
	Yes	17	14				
	No	9	20				