Empirical and economic modelling of winery and effluent parameters

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Introduction

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 generally 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, especially 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 analysed 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 study arose from the idea that it should 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 type of project had not been done in the SA wine industry, it was necessary to define the project sensibly, as well as to define the exact scope of the study.

This was difficult because there is a lack of information regarding some aspects of winemaking in South Africa. A significant amount of information was available in terms of cellar throughput, and hectares under vines, but there was little information on, for example, how much water or electricity was used, or what equipment was 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 was 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 (in the middle of 2001). Thirty-seven questionnaires were initially returned, which corresponded to a return of nine percent. This number of cellars could not form a statistically significant database.

After follow-ups, sixty replies were finally returned, which can be regarded as a statistically significant response.

The information on the questionnaire was then converted into a database. This is the first project whereby industry equipment, infrastructure, and conditions have been quantified. As such, some of 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.
- Correlate various parameters with a specific winery input.
- Develop an empirical model of a South African Winery.

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 programmes. These data sets were merged because they contained complementing data.

Physical inputs
Physical inputs can be described as the parameters quantifying all materials which enter the process of winemaking. Typical inputs can be defined as:

- Grapes
- Electricity
- Refrigeration
- Other Electric Consumption
- Chemicals
- Water
- Cellar infrastructure and equipment

These variables have been correlated to tons of grapes pressed per year, wherever it was possible.

Electricity

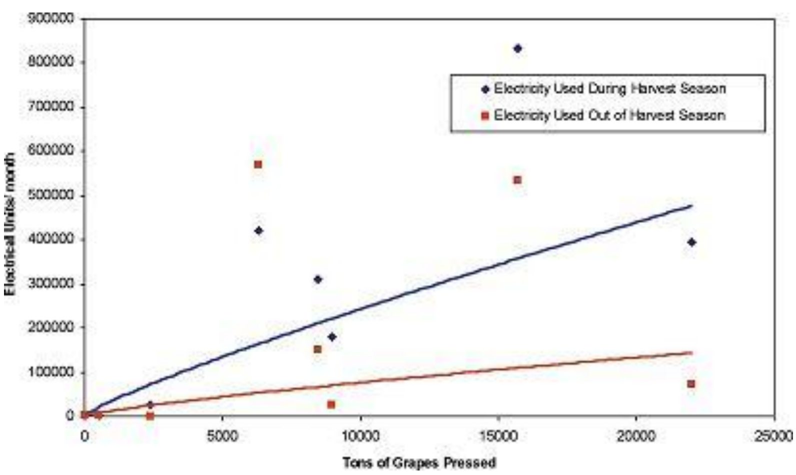

Figure 2.1: Electricity consumed.

Figure 2.1 shows how many electrical units are consumed per month as a function of the tons of grapes pressed. This data was taken from questionnaire respondents that measured cellar electricity consumption. There are two correlations shown - during harvest and out of harvest. Harvest consumption was approximately 2.5 times that of the rest of the year. However, the scatter of the data is greater for the out-of-harvest periods, 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 during winter. Most cellars use refrigeration in summer, which makes up a large percentage of the energy costs.

Water

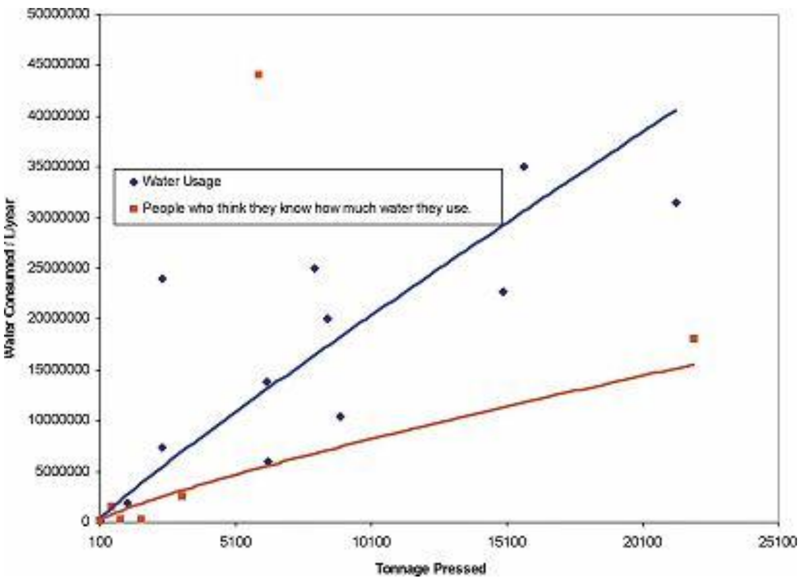

Figure 2.2: Water consumption.

In figure 2.2, the consumption of water per year was plotted as a function of the tons pressed per year. The data was split into wineries with water measurement and those without.

It is interesting to note the difference between actual water measurement and guessing a value. Guessing water consumption seems to undervalue the consumption of water by approximately 60%. Given that only 20% of responding cellars measure their water usage, this implies that 80 percent would underreport their water consumption, or would under-estimate it if required to report a value. Considering that South Africa is a country with scarce water reserves, data like this becomes valuable as a tool for prediction of water consumption. This correlation allows for the better management of water as a resource, especially when considering the size of the SA Wine Industry in relation to other industrial activities in the Western and Northern Cape provinces.

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.

Wine

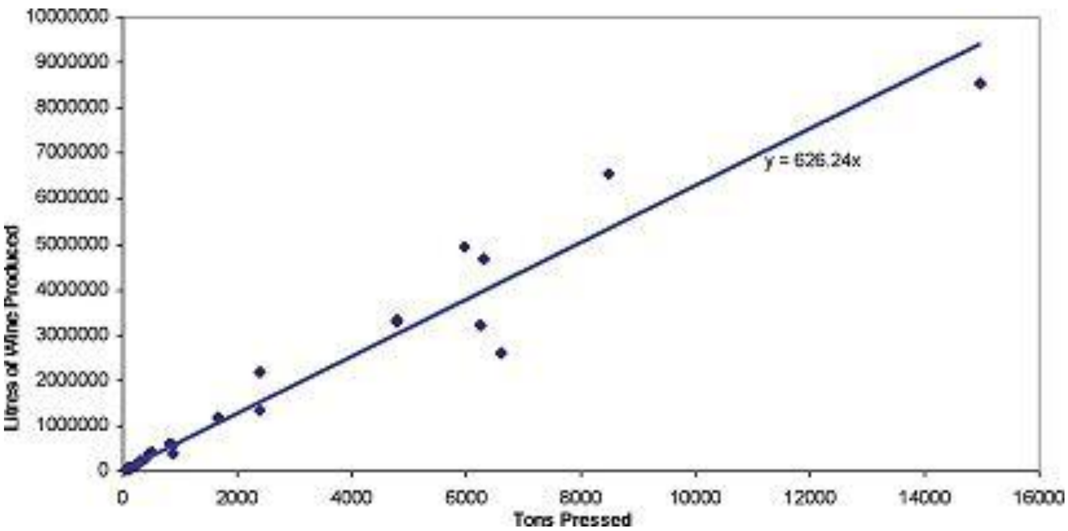

Figure 2.3: Wine Produced as a Function of Tons of Grapes Pressed.

In figure 2.3, the quantity of wine produced was plotted as a function of tons of grapes pressed.

There is a strong correlation between tons pressed and wine produced, as is to be expected. Figure 2.3 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 could be suggested 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. This graph also indicates that those cellars that answered the questionnaire had an average production ratio of 626 litres of wine per ton of grapes pressed.

Effluent
Effluent is defined as waste water 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 article, the effluent has been quantified according to the following classifications:

- Quality of Effluent
- Chemical Oxygen Demand and Total Dissolved Solids
- Sodium Adsorption Ratio

Unfortunately, it was not possible to ascertain how much effluent was produced by each cellar because 95% of questionnaire respondents have no measurement in place. It is expected that the quantity of effluent should be less than the amount of water used, but this needn't be the case, depending on the degree of storm-water separation, etc. Since one cellar had ten percent more effluent than the quantity of water they used, this figure was used for all calculations regarding the quantity of effluent.

Effluent Characterisation

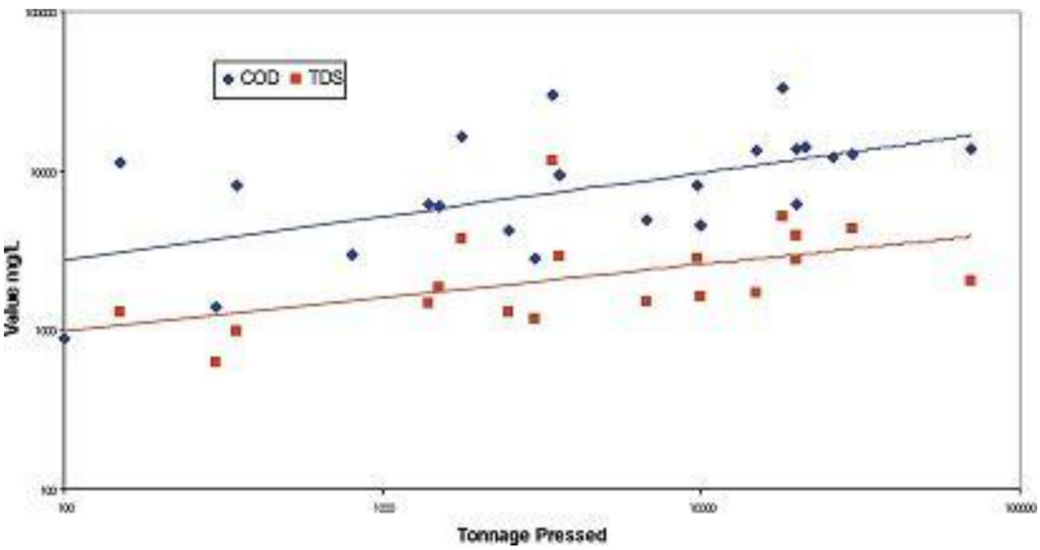

Figure 2.4: Effluent Characterisation - COD and TDS as a Function of Tons of Grapes Pressed.

In figure 2.4, various effluent characteristics are correlated to the tons of grapes pressed by the cellar per year. It is evident from the graph that as the size of the cellar increases, the quality of the effluent decreases (the concentration of COD and TDS rises). On the same figure, the TDS has also been plotted as a function of tons pressed. Unfortunately, these correlations are not accurate and have high data scatter, but they do provide industrial averages which are useful. 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.

In figure 2.5, the Sodium Adsorption Ratio (SAR) of the effluent streams was plotted as a function of the tons of grapes pressed. This graph indicates that the SAR is not too important as an effluent parameter because the values were quite low even for very large cellars. This implies 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 to concern themselves primarily with removal of the COD in the effluent. SAR should always be checked though, in case it does exceed legal limitations for disposal.

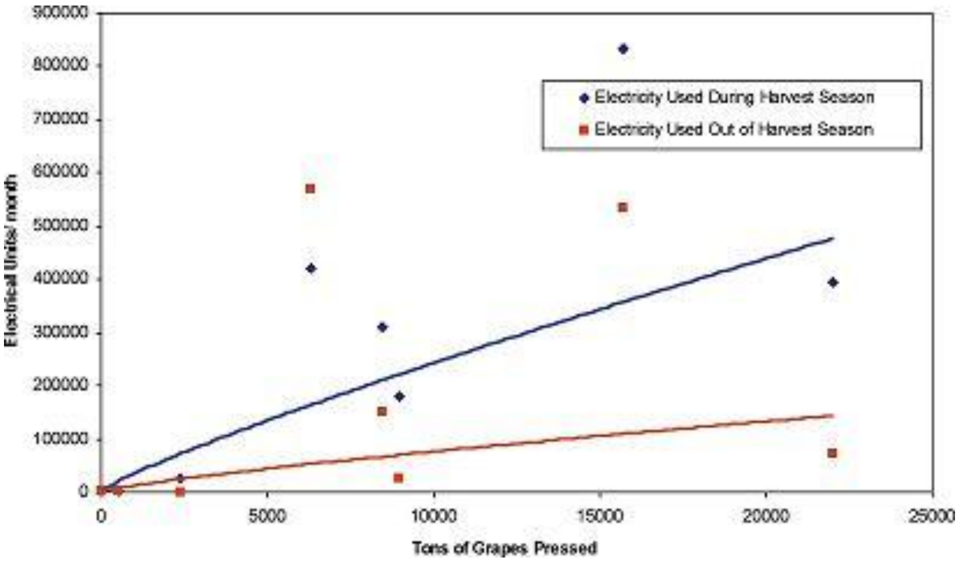

Figure 2.5: Effluent Characterisation - SAR as a Function of Tons of Grapes Pressed.

Development of an economic model

By gathering the data presented above, it was possible to develop a 'preliminary' model of a winery in the more typical process engineering sense of the word. Loose correlations have been developed, by which it is possible to guess winery characteristics, based only on the tons of grapes pressed.

This study was designed to be preliminary. 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 (which implies that the predictive ability of the model is limited). Much of the data is also missing from the current data set. 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.

Empirical model of a South African winery

Figure 3.1 is a pictorial representation of the empirical model developed to perform mass balance and financial balance calculations for South African wineries based solely on the tons of grapes pressed.

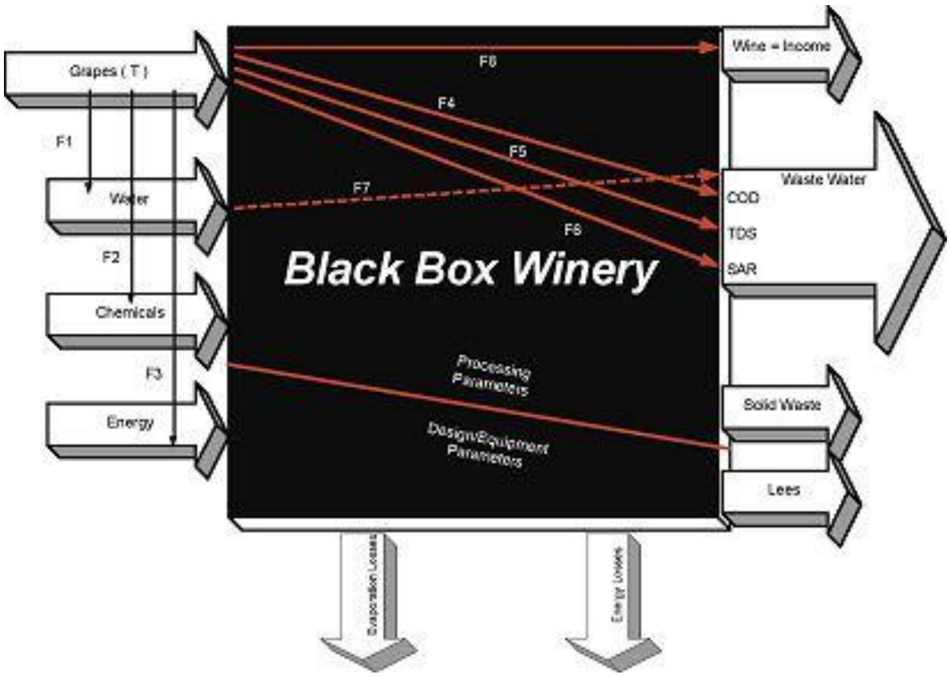

Figure 3.1: Empirical Model of a Winery.

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 this type of model is used in chemical engineering modelling because one may not always have information on 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 the 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, waste water, 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, the ones just described were defined as being 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.

The correlations (equations) are not included in this article for the sake of brevity.

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.

Base scenario

The following scenario will be called the base case scenario, and is defined for a cellar that presses 11 550 tons of grapes per year (equivalent to about 7.2 million litres of wine). The base economic values used are shown in table 3.1. Many of these values are unknown, so a 'Best Guess' was obtained, and these were used throughout.

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

Table 3.1: Economic Indices.

Variable	Quantity	Cost
Expenses		
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		*R 768 387*

Table 3.2: Base Economic Calculation.

Variable	Quantity	Cost
Expenses		
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		*R 661 437*
Reduction in Costs:		***R 106 950***

Table 3.3: Economic Calculation with Combined Environmental Savings.

For the base case, shown in table 3.2, the operating costs would equate to R768 000. This may seem too high or too low, but it is unimportant, as the savings that can be accrued are the important factors to note. Note that this is a hypothetical financial balance.

Scenario 1 - environmental savings

If one were to introduce environmental savings, i e reduce water, energy and effluent COD (and chemicals) by 10 per cent per year, the saving could be as large as R105 000 per year (see table 3.3). This saving is based on the premises that the quality of the wine will not be affected, and that wineries will have to pay for their effluent treatment.

These savings could be used to finance an environmental management system, which may possibly produce even greater savings, as this is a yearly and 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 will lead to a deeper understanding of it.

Scenario 2 - combined environmental saving for various sized cellars
The model shown in figure 3.1 can be used for economic calculations for any sized cellar. It could be used to predict inputs and outputs. In figure 3.2, a graph has been plotted to show how a ten per cent reduction of the aforementioned variables will reduce the operating costs for different sized cellars.

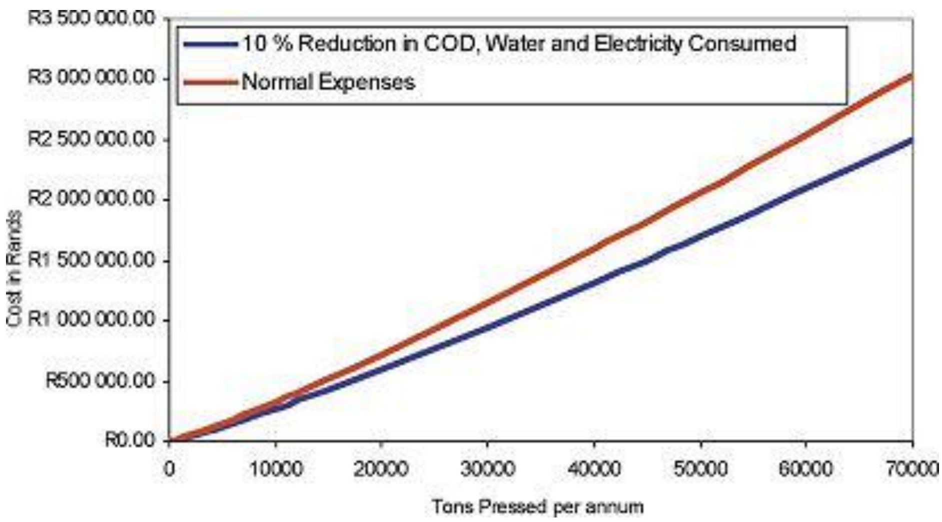

Figure 3.2: 10% Reduction of Variables for Different Size Cellars.

This data shows that the 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 predicted savings are approximately 14%, whereas for a cellar that presses 70 000 tons of grapes per annum, the decrease in costs is nearly 18%.

This implies that although environmental savings may 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.

Discussion
Correlations have been established, which may allow a rough prediction of winery inputs and outputs. Based on the preliminary model developed, certain inputs and outputs of a normal cellar can be assigned if data for a cellar is unknown, although there are low coefficients of regression for some of the correlations. This is indicative of the variation of cellars within the industry. It is clear that more data is required to transform this model into an accurate prediction tool.

With regard to the effluent, it was shown that the COD, TDS and SAR of the effluent can be positively correlated to the tons pressed. It was also shown that the SAR does not appear to be a critical effluent parameter at this stage. The COD has been identified as the parameter that is most important when designing or discussing winery effluent. Other variables should 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). It is recommended that cellars invest in environmental management systems, and read up on Best Management Practices.

Based on the correlations derived in this study, an empirical 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 decreases in the operating costs of the cellar. It was also shown that a reduction in operating costs is greater for large cellars than for small cellars. This occurs because large cellars tend to have higher strength effluent and lower specific water consumption than smaller cellars. 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 showing winemakers 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.

Recommendations for further work

It appears that one problem 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 hard to do. 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 could 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 efficient climate control systems for barrel cellars to reduce the rate of evaporation.

It is this author's opinion 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.

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A full list of study references is available from the author on request.

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All those cellars that completed the questionnaire, and in particular, those three cellars that were kind enough to let me onto their premises over the 2002 harvest.