Influence of winemaking practices on the chemical characteristics of winery wastewater and the water usages of wineries.

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With all my love to FMC.

Miss you.

Declaration

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

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Abstract

The production of wine globally has increased over the past years, increasing the volume of water used and wastewater generated for every litre of wine produced. In the past, the small volumes of winery wastewater that were produced by wineries had little effect on the immediate environment. However, with the increasing wine production all around the world, winery wastewater is a rising concern for the contamination of soil and subsurface flow. In order to fully understand the impacts of winery wastewater, it is important to establish the volumes and chemical characteristics of the wastewater, before considering possible treatments.

The first aim of this study was to determine the influence of certain winemaking practices on the water usage. Two wineries in the Stellenbosch Winelands District were monitored during two harvests and one post-harvest season. It was evident through this study that water plays a vital role during the production of wine and that water is needed at virtually all the winemaking steps. However, the volume of clean water needed differs immensely during the course of the production process. It was noticed that throughout the harvest period at both wineries the clean water demand was highest and decreased during the course of the post-harvest period and steadily increased again towards the end of the year. The harvest period contributes between 30 and 40% of the yearly water usage at the respective wineries.

It was also noticed that certain winemaking practices including filtering with a bulk filter, washing of barrels and bottling contributes heavily to the water usage throughout the year. Activities that increase water usage during harvest include the washing of the press and processing a combination of red and white grapes on the same day.

Furthermore, it was identified that one of the wineries used a smaller volume of water on a daily basis and per tonnage during harvest than the other, indicating that the cleaner production strategy established 10 years earlier has a positive impact on their water usage.

The second aim of this study was to monitor the raw and treated winery wastewater from the two wineries during a period of 15 months, including two harvests and one post-harvest season. This was done to investigate the characteristics of the raw and treated wastewater. Firstly, to determine the impact of the different winemaking practices on the chemical composition of the wastewater and secondly, to determine the efficiency of the existing constructed wetlands on the wastewater and the characteristics of the treated wastewater. From this study it was possible to make two main observations concerning the chemical oxygen demand (COD) concentrations of the two wineries. Primarily, it was observed there were variations in the raw wastewater characteristics of the two wineries and above all, that both wineries showed a decrease in the COD of the raw wastewater produced.

Not only did the decrease in the raw wastewater COD over this period show promising results when a cleaner production plan is established and managed it also seems to show a decrease in the volumes of water used by the respective wineries and increase in quality.

Opsomming

Gedurende die afgelope paar jaar het wynproduksie wêreldwyd toegeneem en as gevolg hiervan toenemende hoeveelhede water gebruik en afvalwater gegenereer. In die verlede het die klein volumes kelderafvalwater wat deur wynkelders geproduseer is min effek op die onmiddelike omgewing gehad, maar gegewe die toenemende produksie van wyn regoor die wêreld is daar groeiende kommer oor die besoedeling van gronde en ondergrondse vloei deur kelderafvalwater. Dit is belangrik om die volumes en chemiese eienskappe van die afvalwater te bepaal om die impak van die water ten volle te verstaan, voordat moontlike behandelings oorweeg word

Die eerste doel van hierdie studie was om te bepaal hoe sekere wynmaakpraktyke watergebruik beïnvloed. Twee wynkelders in die Stellenbosch Wynland Distrik is gedurende twee parsseisoene en een na-pars seisoen gemonitor. Hierdeur het dit duidelik geword dat water ‘n noodsaaklike rol speel in wynproduksie en benodig word vir feitlik alle stappe in die wynmaakproses. Die volume skoon water wat benodig word verskil wel noemenswaardig tydens die produksieproses. Die gebruik van skoon water van beide kelders was hoog tydens die parsseisoen, het afgeneem gedurende die loop van die na-pars periode en het geleidelik weer toegeneem teen die einde van die jaar. Die parsseisoen dra tussen 30 en 40% by tot die jaarlikse waterverbruik van die onderskeie kelders.

Dit is ook opgemerk dat sekere wynmaakpraktyke, insluitend filtrasie met ‘n grootmaat filter, die was van vate en bottelering, grootliks bydrae tot die waterverbruik deur die loop van die jaar. Aktiwiteite wat waterverbruik tydens parstyd verhoog sluit in die gebruik van die pers en die verwerking van ‘n kombinasie van rooi en wit druiwe op dieselfde dag.

Daar is ook vasgestel dat een van die wynkelders tydens parstyd ‘n kleiner volume water gebruik op ‘n daaglikse basis asook per tonnemaat wat daarop dui dat die “skoner” produksie strategie wat dié kelder 10 jaar gelede gevestig het wel ‘n positiewe impak op waterverbruik het.

Die tweede doel van hierdie studie was om die onbehandelde en behandelde afvalwater van hierdie twee wynkelders te monitor oor 'n tydperk van 15 maande, wat twee paste en een na-pars seisoen insluit. Dit is gedoen om die impak van verskillende wynmaakpraktyke op die chemiese samestelling van die afvalwater te ondersoek asook om die doeltreffendheid van bestaande kunsmatige vleilande in terme van afvalwaterbehandeling te bepaal en die eienskappe van die behandelde afvalwater te ondersoek. Gevolglik is twee belangrike waarnemings oor die chemiese suurstof behoefte (CSB) konsentrasie van die twee wynkelders gemaak. Variasies in die onbehandelde afvalwater eienskappe is waargeneem by beide wynkelders en daar was ‘n afname in CSB van die onbehandelde afvalwater by beide wynkelders.

Die afname in CSB van die onbehandelde afvalwater oor hierdie tydperk is belowend en dit blyk dat wanneer ‘n “skoner” produksie plan opgestel en bestuur word dit wel ‘n afname in waterverbruik en verhoog in kwaliteit by die kelders tot gevolg het

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Table of contents

CHAPTER 1
INTRODUCTION

The wine industry around the world is a growing industry and has grown by 44% since 1997 in South Africa (SAWIS, 2013; OIV, 2014). The increasing number of wineries and the demand for wine globally are adding to this progression (Agustina *et al*., 2007; Andreottola *et al*., 2009). This increase in wine production goes hand in hand with the volume of water used and wastewater generated for every litre of wine produced (SAWIS, 2013).

Water is used in practically all the different steps of the winemaking process and therefore, produces wastewater from the reception of the grapes all the way to the final packaged product (Devesa-Rey *et al*., 2011). Throughout the year the water volume and pollution load varies in relation to the different processes taking place (Arienzo *et al*., 2009).

Winemaking generates wastewater characterised by high concentrations of biodegradable compounds and suspended solids (Rodriguez *et al*., 2007). Large volumes of wastewater are produced by winemaking and may vary from one winery to another depending on the production period and the unique style of winemaking of different wineries (Agustina *et al.,* 2007). Adding to this is the difference that can be noticed when comparing the water use of different wineries depending on the type of tanks, processing equipment and various winemaking techniques (Walsdorf *et al*., 2004). Therefore it is vital for detailed characterisation of the wastewater to fully understand the problem before managing it (Mosse *et al*., 2011).

Most of the wastes generated in a cellar (80 – 85%) are organic wastes (Ruggieri *et al*., 2009; Valderrama *et al.,* 2012). The difference in the composition of the organic material in wastewater is due to uncontrolled chemical reactions that takes place in the wastewater (Mosse *et al*., 2011). Organic acids (acetic, tartaric, malic, lactic and propionic), alcohols, esters and polyphenols play an important role in the composition of winery wastewater (Zhang *et al*., 2006; Mosse *et al*., 2012). An analysis of winery wastewater showed that there are noticeable differences in wastewater generated around the world ranging from 340 to 49 105 mg Chemical oxygen demand (COD).L^{-1} (Bustamante *et al*., 2005; Mosse *et al*., 2011).

While wine production does not have a reputation as a polluting industry, the wastewater volume worldwide is increasing and is characterised by a high organic load, low pH, variable salinity and nutrient levels - all of which indicate that the wastewater has the potential to pose an environmental threat (Mosse *et al*., 2011). More than 20% of wine production is waste, comprising thousands of tons of organic material with the potential to pollute natural water sources and the environment, if not treated correctly (Arvanitoyannis *et al*., 2006).

Research on the composition and volumes of winery wastewater is receiving more attention and the awareness of the effects of winery wastewater is assisting with the establishment and improvement of winery wastewater treatment systems (Devesa-Rey *et al*., 2011). Moderate quantities of winery waste and wastewater applied to soils can increase the organic material (due to the high concentration of soluble organic carbon in winery wastewater), which will in turn, enhance the fertility of the soils (Bustamante *et al*., 2011). Unfortunately continuous application of the organic material can lead to organic overload that blocks the soil pores and lowers the quality of the soils (Vries *et al*., 1972). In addition the continuous addition of winery wastewater to soils can also contribute to high soil salinity that can lead to dispersion (Halliwell *et al*., 2001).

The term 'zero discharge process' is used by Lee *et al.* (2011), referring to the substantial reduction of water and energy usages and ultimately to generate no waste during the production of food and beverages. Avoiding waste is the most cost effective and often the easiest principle to implement - better known as 'Prevention is Better Than Cure' (Chapman *et al*., 2001). There are practices that can be implemented by wineries to help reduce the wastewater volumes by applying cleaner production principles (Van Schoor, 2005). Research has shown that a substantial volume of up to 30% can be reduced with simple changes, without any financial implications (Kirby *et al.,* 2003). These changes include evaluation of water usage in controlled areas; improvement of planning and control of water use; the option to reuse water; water recycling after treatment and lastly the layout of the processing area (Klemeš *et al.*, 2009). A water audit will not only point out the areas of unnecessary wastage, but also will help the winery to understand where the water is used (Klemeš *et al*., 2008). Although some research has been done on characterising winery wastewater composition, not much research has been done in South Africa to determine the influence of winemaking practices and activities in the cellar on the amount of wastewater generated and its subsequent composition.

Therefore, the aim of this study was to firstly compare the water usage and winemaking practices of two wineries (one which implemented a cleaner production strategy 10 years ago and the other systematically striving to improve its water usage) to determine the impact that certain winemaking practices (processing of grapes, racking, filtering and bottling) have on the water usage and secondly, to investigate the influences of the various winemaking practices on the wastewater composition. This was done to establish whether cleaner production practices have a positive effect on the characteristics of winery wastewater.

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CHAPTER 2
LITERATURE REVIEW

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2.1 Background

Wine production is a major agricultural activity around the world (OIV, 2014) The winemaking industry produces large volumes of wastewater (Bolzonella *et al.,* 2010) that pose an environmental threat if not treated correctly (Bustamante *et al.,* 2007). The increasing numbers of wineries and the demand for wine around the world are adding to the growing problem (Agustina *et al*., 2007; Andreottola *et al*., 2009).

The vinification process includes all steps of the winemaking process from the grape all the way to the final packaged product (Devesa-Rey *et al*., 2011). In order to fully understand all the aspects of winery wastewater it is important to know the winemaking process before considering possible end uses and treatments if needed (Van Schoor, 2004). Winemaking is seen as an art and all wineries are individual and thus treatment solutions should be different (Andreottola *et al*., 2009). Furthermore, wastewater differs from one winery to another regarding the volume and composition and therefore is it vital for detailed characterisation of the wastewater to fully understand the problem before managing it (Mosse *et al*., 2011).

There is a number of winemaking practises that can help lower the volume of wastewater produced. It is important to have the necessary knowledge of the different winemaking processes that produce wastewater as this can also help to improve the volumes and improve the composition (Walsdorff *et al*., 2004).

The biggest problem with winery wastewater is the identification of low cost water treatment methods for the differences that wineries exhibit (Mosse *et al*., 2011). The conventional methods available are biological, physical and chemical, but unfortunately, not all the treatments are suitable for all winery sizes (Zang *et al*., 2006).

2.2 Winemaking

2.2.1 Statistics of the wine industry

Wine production plays a big role in the agricultural industry around the world. In 2012 a volume of 252. 9 x 10^6 hL was produced worldwide (OIV, 2014). The top producing wine countries are Australia, Chile and United States, followed by Argentina, France, Germany, Italy, Spain and South Africa (SA), (Devesa-Rey *et al*., 2011).

In 2012 SA produced 9. 2 x 10^6 hL of wine and was ranked as the 8^{th} largest wine producing country in the world (OIV, 2014). Table 2.1 shows the number of wineries in SA per production category that range from 5 tons of grapes to 75 000 tons per harvest crushed. The average winery ceushed between 1 - 100 tons of grapes. White wine production makes up more than 80% of the Cape wine production (SAWIS, 2013).

Table 2.1 Number of wineries in South Africa per production category in 2012 (SAWIS, 2013)

CATEGORY (Tons of grapes crushed)	NUMBER OF WINERIES
1 – 100	259
> 100 – 500	159
> 500 – 1 000	52
> 1 000 – 5 000	59
> 5 000 – 10 000	16
> 10 000	39

2.2.2 Composition of grape juice and wine

In Table 2.2 the composition of grape juice and wine are compared. There is almost no difference in the ingredients, but when wine is produced additional compounds are formed. Some of these compounds are only found in the sediment that has to be removed before bottling. Fermentable sugars are transformed to alcohol according to the variety and the ripeness of the grapes; this is the most important difference between grape juice and wine (Stevenson, 2007).

2.2.3 Winemaking processes

The fundamentals of winemaking have stayed the same since biblical times (Hands & Hugges, 2001). What has changed is our ability to maintain a sterile environment required to produce top quality wine (Halliday & Johnson, 1994). It is important to understand the winemaking processes when looking into the quality and quantity of wastewater produced at a winery. Typical steps of winemaking are illustrated in Figure 2.1 to show the differences between white and red winemaking.

Sulphur dioxide is added to the juice in the winemaking process to control micro-organism growth and to inhibit wild yeast that occurs naturally on the wine grapes (Sinha *et al*., 2012). Some other products that are used for wine treatment include: fining agents (egg white, tannin, gelatine, bentonite and casein) and filtration earths (Arvantitoyannis *et al*., 2005).

Before harvesting, random grape samples are taken in the vineyard and the pH, titratable acidity (TA) and sugar level are measured (Sinha *et al*., 2012). If certain requirements are met, the grapes are either harvested by hand or by using a harvesting machine and transported to the winery.

2.2.4 White wine production

At the winery the grapes are received in the receiving “hopper” then crushed and the stems are removed. Sulphur dioxide is added to the mash to prevent bacterial growth. The mash is then pumped through a mash cooler to the press and cooled to below 15°C (Stevenson, 2007). Cooling also inhibits the activity of micro-organisms. Enzymes may also be added to maximise the extraction of juice (Halliday & Johnson, 1994). The grapes are then pressed and the juice drains to a settling tank where the sediment can settle overnight. The clean juice is then racked to a fermentation tank, with cooling, where the juice is inoculated with cultured yeast which will enable easier regulation of yeast activity through temperature control (Sinha *et al*., 2012). Nutrient additives may also be provided for the yeast, depending on the composition of the must.

Table 2.2 Composition of fresh grape juice and wine *(Adapted from Stevenson, 2007)*

COMPONENT	GRAPE JUICE (Percentage by volume)	WINE (Percentage by volume)
Water	73.5	86
Carbohydrates	**25**	0.2
-Cellulose	*5*	-
-Sugar	*20*	-
Alcohol (Ethyl alcohol)	-	12
Glycerol	-	1
Organic acids	93	35
-Tartaric acid	*0.54*	*0.20*
-Malic	*0.25*	-
-Lactic acid	-	*0.15*
-Citric acid (plus traces of succinic and lactic)	*0.01*	-
-Succinic acid (plus traces of citric and malic)	-	*0.05*
Minerals	0.5	0.2
-Calcium	*0.025*	*0.02*
-Chloride	*0.01*	*0.01*
-Magnesium	*0.025*	*0.02*
-Potassium	*0.25*	*0.075*
-Phosphate	*0.05*	*0.05*
-Silicic acid	*0.005*	*0.005*
-Sulphate	*0.035*	*0.02*
-Others	*0.1*	*Traces*
Tannin and colour pigments	0.13	0.1
Nitrogenous matter	0.07	0.025
-Amino Acids	*0.05*	*0.01*
-Protein and other nitrogenous matter	*0.02*	*0.015*
Volatile acids (mostly Acetic acid)	-	0.045
Esters	-	0.025
Aldehydes	-	0.004
Higher Alcohols	-	0.001
Vitamins	Traces	Traces

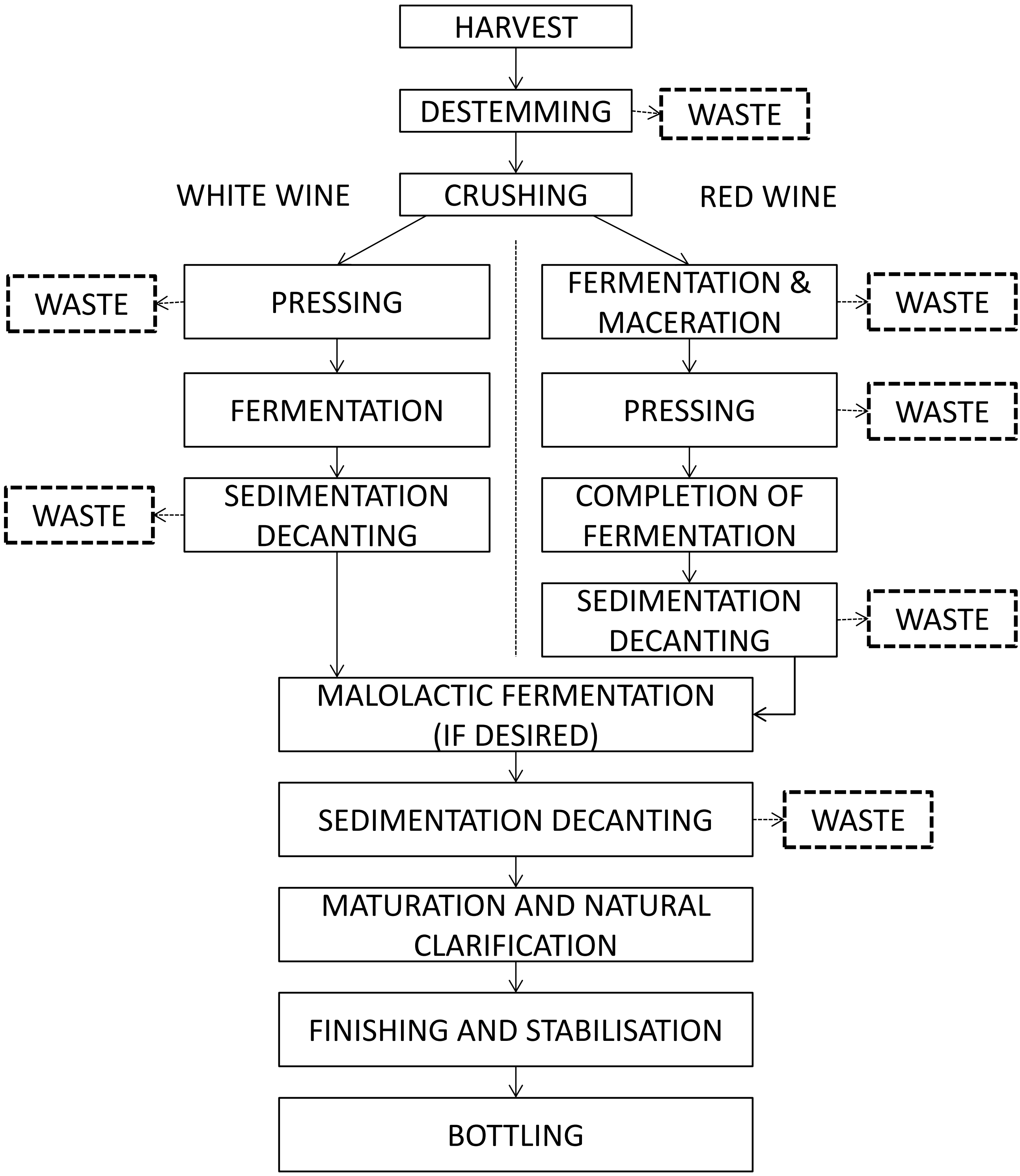

Figure 2.1 Diagram of organic waste generated in the winemaking process for red and white wine (Adapted from Arvanitoyannis *et al*., 2006; Devesa-Rey *et al*., 2011).

After fermentation the wine will look hazy, even though most of the dead yeast cells have settled at the bottom of the tank. The wine is then racked (drawn) from the lees (yeast sediment) to a clean stainless steel tank for fining (Woodard & Curran, 2006). Typically, sulphur is once again added at this stage (Sinha *et al*., 2012). Fining is used to clarify the wine by removing colloidal solids using special fining agents such as: egg white, tannin, gelatine, bentonite and casein (Woodard & Curran, 2006). The wine is then cold stabilised by cooling the wine to a very low temperature (-4°C). The tartaric crystals precipitate to the bottom and sides of the tank. The clean stable wine is then racked again to a clean tank and ready for bottling (Hands & Hughes, 2001).

2.2.5 Red wine production

The procedure for red winemaking is different to that of white winemaking (Stevenson, 2007). The grapes are harvested at similar levels of ripeness, and crushing and de-stemming occur in the same way. After the grapes are destemmed and crushed the mash is pumped to a stainless steel tank and inoculated with cultured yeast (Hands & Hughes, 2001). During fermentation the juice is pumped from the bottom of the tank (underneath the ‘skin cap’) to the top of the tank onto the skins, this will ensure an even temperature throughout the wine and extraction of colour and flavours from the skins. Pressing the grapes (now fermented skins) occurs after fermentation (Halliday & Johnson, 1994). The wine is then pumped to either a barrel or a tank where the second fermentation takes place. The second fermentation also known as malolactic fermentation (MLF), which ensures that the malic acid is transformed to lactic acid and the latter is a more stable acid of the two (Sinha *et al*., 2012). Wine style will determine if MLF will occurs in the barrel or in the tank since the barrel will add to complexity and creaminess of the wine (Halliday & Johnson, 1994).

Maturation in oak is a popular practice. The oak contributes to the aroma of the wine and the oak tannins add even more complexity (Gómez García-Carpintero *et al*., 2012). The wine is racked every few months to a clean tank and back to a clean washed barrel. This practice will remove any excess sediment and gives a gentle aeration to the wine (Sinha *et al*., 2012). Red wine does not undergo as strict fining as white because of the long periods in the oak barrel. The wine is filtered before bottling. Before bottling the bottling machine is washed and steamed thoroughly to ensure that no contaminants enter the wine to ensure that the wine will last up to 20 years in the bottle (Stevenson, 2007).

Figure 2.1 presents a schematic diagram of the major steps in winemaking and where waste is produced. All but one of the steps that produce the waste contributes directly to the wastewaters character. Destemming is the only step that does not produce waste in the form of lost brut production hence it is the only step that doesn’t contributes directly to the COD levels (Woodard & Curran, 2006).

2.2.6 Water use in a winery

Winemaking is seasonal and the most activities occur during the harvest period (Guglielmi *et al*., 2009). In the Southern Hemisphere harvest is from the end of January to the beginning of April

(Hands & Hughes, 2001). Throughout the year the water volume and pollution load vary in relation to the different processes taking place (Arienzo *et al*., 2009). Large volumes of polluted water are produced by winemaking and may vary from one winery to another depending on the production period and the unique style of winemaking of different wineries (Agustina *et al.,* 2007). A big difference can occur when comparing water use of different wineries due to several parameters including the type of tanks, processing equipment and various winemaking techniques (Walsdorff *et al*., 2004).

Table 2.3 describes the different periods and winemaking practices during the year that contributes to the volume and quality of winery wastewater. Generally pre-vintage (begin to mid Jan) is mainly used to clean the cellar and equipment in preparation for the harvest. It is essential to prevent growth of micro-organisms on the equipment that can lead to contamination of the juice (Mercado *et al*., 2006). Due to the regular/daily equipment cleaning during the harvesting period (end Jan – beginning April) there is a bigger demand for clean water (Rodriguez *et al., 2007)*. After harvesting, hygiene is still an immense priority, despite the decrease in the volume of clean water used (due to of activities in the cellar.) During the post-harvest period, it is possible that there may be days without water usage in the wine cellar (Ngamane, P., 2012, Assistant winemaker, Winery B, Stellenbosch, South Africa, personal communication, 11 December). In the winter months (rain season) it is important that the storm water and winery wastewater are separated to prevent the increase of water that needs to be treated. It is also vital that the storm water stays unpolluted (Walsdorff *et al*., 2004).

The water used to produce one litre of wine varies from different literature sources around the world. In Table 2.4 a summary is shown of estimates of global winery wastewater volumes according to the *Organisation internationale de la Vigne et du Vin* (OIV, 2011) of wine produced in 2010. It is clear that there is a significant difference between the respective estimates.

Furthermore, the wine industry in South Africa has grown by 44% since 1997, from 5.5 x 10^6 hL in 1997 up to 7.8 x 10^6 hL in 2010 (Fig 2.2). This is a significant increase in wine that goes hand in hand with volume of water used and wastewater generated for every litre of wine produced (SAWIS, 2013).

Table 2.3 Wine production periods in a winery for South Africa (Adapted from Resource management council of Australia and New Zealand, 1998)

PERIOD	MONTHS	ACTION IN WINERY
Pre- harvest	Beginning to mid-January	Caustic washing of tanks and equipment, non-caustic washing of equipment in preparation for vintage.
Early –harvest	Mid to end January	Wastewater production is rapidly increasing and can reach 40% of the maximum weekly flow. Harvest operations dominated by white wine production.
Peak-harvest	February and March	Wastewater generation is at its peak, Harvest operations are at a maximum.
Late-harvest	Beginning April	Wastewater production has decreased; harvest operations are dominated by red wine production.
Post-harvest	End April and May	Harvest operations have ceased. Caustic washing the tanks and equipment used during the harvest.
Non-harvest	June	Filtering of white wines in preparation for bottling. Filtering earth residues in waste water.
Non-harvest	July	Cleaning bottling equipment with caustic. Bottling wines.
Non-harvest	August, September and October	Put red wine to barrel and filtering of previous years reds. Water use is low.
Non-harvest	November, December and Beginning January	Cleaning bottling equipment with caustic. Bottling wines.

Table 2.4 Estimates of volumes of water used to produce wine

VOLUME OF WATER PER LITRE WINE PRODUCED USED	ESTIMATED VOLUME OF TOTAL WATER USED FOR THE WINE INDUSTRY WORLDWIDE	REFERENCE
5 – 8	1.3 – 2.1 x 10^9 hL	Mosse *et al*., (2011)
1 – 4	2.6 – 10.5 x 10^7 hL	Bolzonella *et al*., (2010)
0.97 - 1.25	2.5 – 3.3 x 10^7 hL	Lucas *et al*., (2010)

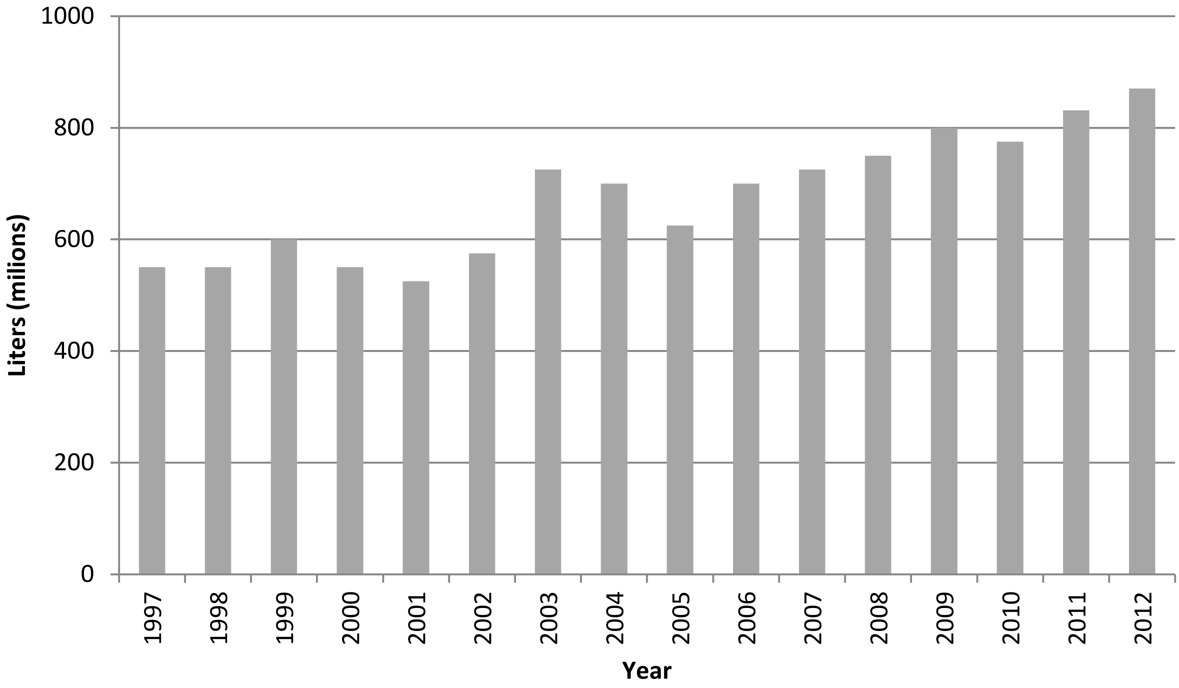

Figure 2.2 South African wine prodution volumes from 1997 to 2012 (SAWIS, 2013)

2.2.7 Winery wastewater composition

One of the biggest issues for the wine industry is the management of large volumes of wastewater (Bustamante *et al*., 2005). While wine production does not have a reputation as a polluting industry the wastewater volume worldwide is increasing and the wastewater has a high organic load, low pH, variable salinity and nutrient levels, all of which indicate that the wastewater has the potential to pose an environmental threat (Mosse *et al*., 2011).

The four biggest components contributing to wastewater pollution in a winery are:

- Sub-product residues: stems, skins, sludge, lees, tartar (Musee *et al., 2005)*;
- Loss brut production: must and wine occurred by spillage during winemaking activities (Mosse *et al., 2011);*
- Products used for wine treatment: fining agents and filtration earths (Pérez-Serradilla *et al., 2008)*;
- Cleaning and disinfection products (eg. Sodium hydroxide, potassium hydroxide) used: wash materials and equipment (Mahajan *et al*., 2010).

Winemaking generates different residues characterised by high concentrations of biodegradable compounds and suspended solids (Rodriguez *et al*., 2007). The residues consist of plant remains derived from the de-stemmed grapes, the sediments obtained during clarification, lees from pressing and lees which are obtained after different decanting processes (Arienzo *et al.,* 2009b). Table 2.5 shows the influence of the different steps in the winemaking process on the composition of wastewater. The main contributor to wastewater is from cleaning and the cooling processes and also contains wine must, grape pulp, skins, seeds and dead yeast from the alcoholic fermentation (Devesa-Rey *et al*., 2011).

An analysis into the average characteristics of wastewater showed that winery wastewater differed around the world and that different wineries in the same country had significant differences (Mosse *et al*., 2011). In Table 2.6 a summary of data for a few wineries is given, to illustrate the differences in wastewater characteristics in different studies. The variance in wastewater composition complicates the issue of finding a general solution for wastewater at different wineries (Andreottola *et al.,* 2009). To find the correct treatment and reuse efficiencies for wastewater it is important to understand the detailed composition of the wastewater (Bustamante *et al.,* 2005).

2.2.8 Organic compounds in winery wastewater

Most of the wastes generated in a winery (80 – 85%) are organic wastes (Ruggieri *et al*., 2009). Organic material in the winery wastewater is generated from the grapes and wine (Valderrama *et al.,* 2012). Figure 2.1 illustrates the points in the winemaking process where organic material contributes to the composition of winery wastewater. After pressing the grapes, (white and red) grape marc is produced that consist of grape skins and pips (Devesa-Rey *et al*., 2011). Despite the fact that the skins are kept separate from the wastewater system the residue on the floors of the winery and in the press will contribute to the high levels of COD and variation of pH (Van Schoor, 2005). Apart from this, lees will form on the bottom of the wine tank or barrels after fermentation of the grape juice. This sediment will also have an effect on the organic compounds and COD of the wastewater (Mosse *et al*., 2011). COD is used to measure the oxygen demand of the organic load present in the wastewater (Andreottola *et al*., 2009).

The difference in the composition of the organic material in wastewater is due to uncontrolled chemical reactions that takes place in the wastewater (Mosse *et al*., 2011). Organic acids (acetic, tartaric, malic, lactic and propionic), alcohols, esters and polyphenols play an important role in the composition of the winery wastewater (Mosse *et al*., 2012; Zhang *et al*., 2006). There is not a lot of research available on the organic components of winery wastewater but it is essential to characterise the organic composition of winery wastewater to establish the impacts the wastewater will have on the environment (Mosse *et al*., 2011; Bustamante *et al*., 2005).

2.2.9 Inorganic compounds in winery wastewater

The composition of the inorganic compounds in winery wastewaters are mainly (up to 76%) dependant on the components of the cleaning agents used in wineries (Table 2.5), except for potassium, which is present in high concentrations in grape juice (Mosse *et al*., 2011). Strong alkaline based cleaning agents that are good for tartrate removal includes caustic soda (NaOH) and caustic potash (KOH) (Sipowicz, 2007). Wineries that uses sodium based cleaning agents have problems with the salinity of the wastewater if used for irrigation. Inorganic ions present are predominantly potassium and sodium, with low levels of calcium and magnesium, although the concentrations of both organic and inorganic constituents vary with differences in winemaking operations over time, as well as between individual wineries (Mosse *et al*., 2012).

Different residues from the wine industry were analysed and found that winery and distillery wastewater has a low pH (mean values ranges from 3.8 to 6.8) and electrical conductivity and high organic matter content (Bustamante *et al*., 2007).

Table 2.5 Winery actions related to winery wastewater quantity and quality and the impact on the quality parameters (Adapted from Van Schoor, 2005).

WINERY ACTION	IMPACT ON WASTEWATER QUANTITY	IMPACT ON WASTEWATER QUALITY	IMPACT ON LEGAL WASTEWATER QUALITY PARAMETERS
CLEANING WATER			
Alkali washing and neutralisation	Up to 33%	Increase in Na, K, CO_2 and pH	Increase in EC, SAR, COD, variation in pH
Rinse water (tanks, floors, transfer lines, bottles, barrels etc.)	Up to 43 %	Increase in Na, P, Cl, COD	Increase in EC, SAR, COD, variation in pH
PROCESS WATER			
Filtration with filter aid	Up to 15 %	Various contaminants	Increase in COD and EC
Acidification and stabilisation of wine	Up to 3 %	H_2SO_4 or NaCl	Increase in COD and EC Decrease pH
Cooling tower waste	Up to 6%	Various salts	Increase COD and EC
OTHER SOURCES			
Laboratory practices	Up to 5-10%	Various salts, variation in pH, etc.	Increase COD and EC

EC – *electrical conductivity;* SAR- Sodium absorption ratio; COD- *Chemical oxygen demand*

Table 2.6 Summary of reported winery wastewater characteristics

PARAMETERS	UNIT	MIN	MAX	MEAN	REFERENCE
COD	mg.L^{-1}	340	49105	14426	[1-10]
BOD	mg.L^{-1}	181	22418	9574	[4,6,7,10]
pH	-	3.5	7.9	4.9	[2,4,6,8,9,10]
Total solids	mg.L^{-1}	190	18000	4151	[2,4,5,8]
EC	S.m^{-1}	1.2	7.2	4.16	[2,4,6,8]
Suspended solids	mg.L^{-1}	1000	5137	2845	[4,9,10]

For the reference: 1. Agustina *et al*., (2007); 2. Arienzo *et al*., (2009b); 3. Bolzonella *et al*., (2010); 4. Bustamante *et al*., (2005); 5. Eusebi *et al*., (2009); 6. Mahajan *et al*., (2010); 7. Rodriguez *et al*., (2007); 8. Rytwo *et al*., (2011); 9. Yang *et al*., (2011); 10. Zhang *et al*., (2006)

2.2.10 Why manage waste/wastewater?

In the past, the small volumes of winery wastewater that were produced by wineries had little effect on the immediate environment, but with the increasing wine production all around the world, winery wastewater is a rising concern for the contamination of soil and subsurface flow (Grismer *et al., 2003)*.

Research on the composition and volumes of winery wastewater is receiving more attention and the awareness of the effects of winery wastewater is assisting with the establishing and improving of winery wastewater treatment systems (Devesa-Rey *et al*., 2011). Moderate quantities of winery waste and wastewater that is exposed to soils can increase the organic material due to the high concentration of soluble organic carbon in winery wastewater, which will in turn, enhance the fertility of the soils (Bustamante *et al*., 2011). Unfortunately continuous exposure to the organic material can lead to organic overload that blocks the pores and lowers the quality of the soils immensely (Vries *et al*., 1972). The continuous addition of winery wastewater to soils can also contribute to high soil salinity that can lead to dispersion (Halliwell *et al*., 2001).

Disposal of grape marc, a complex lignocellulose material made up of the skin, stalks and seeds, has also been a problem for wineries. In total more than 20% of wine production is waste, comprising thousands of tons of marc (Arvanitoyannis *et al*., 2006). Untreated grape marc can lead to several environmental threats including foul odours and ground water pollution (Table 2.7). Decomposing grape marc is the perfect environment for flies and pest to flourish (Laos *et al*., 2004). Leachate from the marc contains tannins and other chemical compounds that could infiltrate surface soil and ground water leading to oxygen depletion (Arvanitoyannis *et al*., 2006). It is possible to use the marc in other industries (Kammerer *et al.,* 2005), however, this can be expensive and therefore other alternative solutions must be found (Ruggieri *et al*., 2009). The impact of winery wastewater on soil's biological and physiochemical properties has not been researched in depth (Mosse *et al.*, 2012). Table 2.7 shows the potential impacts of winery waste and wastewater on the environment.

2.2.11 Minimisation of water usage and pollution load

Before discussing the different treatment options it is important to understand that the minimisation of winery wastewater should be the goal of all wineries (Lee *et al*., 2011). The term 'zero discharge process' is used by Lee *et al.,* (2011)*,* referring to the substantial reduction of water and energy usages and ultimately to generate no waste during the production of food and beverages. Avoiding waste is the most cost effective and often the easiest principle to implement - better known as 'Prevention is Better Than Cure' (Chapman *et al*., 2001).

Not only is water a limited resource but can also contribute to the total cost of the final product. When the total cost of production water is calculated for the food and beverage industry it is vital not just to look at the cost of the volume used and the volume dispose but also to look at the potential loss in income when the product is dispose as effluent (Casani *et al.,* 2005).

Table 2.7: Potential environmental impacts of winery waste and wastewater (Adapted from **South Australia EPA, 2004)**

WINERY WASTEWATER COMPONENTS	INDICATORS	EFFECTS
Organic matter	BOD, TOC, COD	Reduces oxygen levels - death of fish and other aquatic organisms. Odors generated by anaerobic decomposition.
Alkalinity/acidity	pH	Death of aquatic organisms at extreme pH. Affects the solubility of heavy metals in the soil and availability and/or toxicity in waters affects crop growth.
Nutrients	N, P, K	Eutrophication or algal bloom. N as nitrate and nitrite in drinking water supply can be toxic to infants.
Salinity	EC, TDS	Impacts undesirable taste to water, toxic to aquatic organisms, affects water uptake by crops.
Sodicity	SAR, ESP	Affects soil structure resulting in surface crusting. Low infiltration and hydraulic conductivity.
Heavy metals	Cu, Ni, Pb, Zn, Hg etc.	Toxic to plants and animals
Solids	TSS	Can reduce light transmission in water, thus, compromising ecosystem health, smothers habitats, odor generated from anaerobic decomposition.

In Figure 2.3 the principles of a cleaner production are illustrated with the most preferred option, avoid the utmost important principle (Chapman *et al*., 2001).

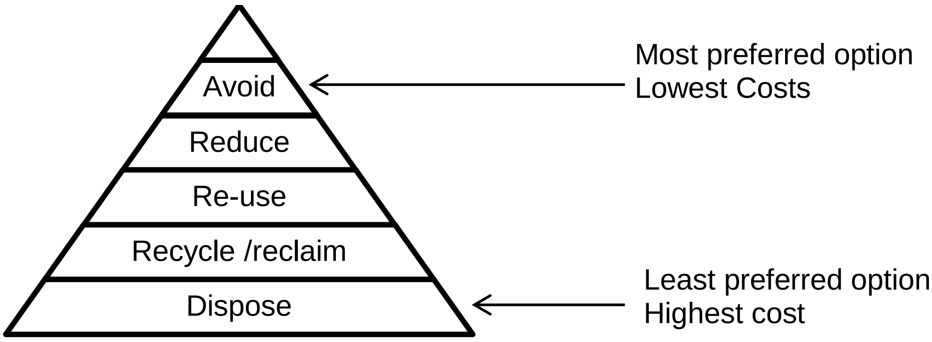

Figure 2.3 Hierarchy of cleaner production principles (Chapman *et al*., 2001).

Water management is a particular concern in the wine industry and there are practises that can be implemented to help reduce the wastewater volumes of wineries through the implementation of cleaner production practices (Van Schoor, 2005). In general a considerable volume of up to 30% can be reduced by simple changes with minimum capital input (Kirby *et al*., 2003). These changes include evaluation of water usage in controlled areas; improvement of planning and control of water use; the option to reuse water; water recycling after treatment and lastly the layout of the processing area can be improved (Klemeš *et al*., 2009). In particular the evaluation (water auditing) of water usage is important to all industries (Klemeš *et al.,* 2008). Wastewater auditing will not only help the winery to understand where the water is used but also indicate the place/process of largest usage. More importantly it will point out the areas of unnecessary waste (Klemeš *et al*., 2008).

In addition to these principles it is vital that the management is 100% committed - dividing responsibilities amongst employees aiding with the awareness of the employees (Klemeš *et al*., 2008). Wineries should implement cleaner production strategies to minimise their water usage (Chapman *et al*., 1996). Winewatch recommends that all staff of the winery involved should be included when a cleaner production strategy is developed (Anon, 2009). Overall it shows that smaller wineries with less staff have a better success rate when implementing this strategy (Anon, 2009). Researching literature for minimising of water usage practises showed that more research is being done on treatment rather than prevention. In Table 2.8, a summary is given of practises that should be efficient in lowering the volumes of water used (Walsdorff *et al.,* 2004). And Table 2.9 shows the different practises wineries can implement to reduce the pollution load of winery wastewater.

Primarily the elimination of salts (K, Ca, Na & Mg) used in the winery should be promoted to reduce the EC and no treatment would be necessary before irrigation of the wastewater. The use of non-sodium based cleaning chemicals is advised by Chapman (Champan *et al.*, 1996). Replacing disinfectants and cleaning agents with ozone will result in lowering the EC and COD (Van Schoor, 2005). The initial cleaning with caustic can also be substituted with a high pressure rinse or with heat/steam (Winewatch, 2009). When caustic is used for cleaning the aim should be to re-use it (Chapman *et al*., 1996).

Table 2.8 Water saving practices (Walsdorff *et al*., 2004; Chapman, 1996)

WATER SAVING PRACTICES	DESCRIPTION
Installation of water meter	Control water usage and identify water usage peaks
Use minimum water	Use no more water than needed for the job
High pressure water system	Less water required for more efficient cleaning
Nozzle on water pipes	Avoid wastage of water as a hose will not run when not required
Use of brushes and squeegee	Dry sweeping of floors before washing
Water awareness training	Developing of a cleaner production strategy

Table 2.9 Pollution load minimisation practises (Woodard & Curran, 2006; Chapman *et al*., 1996; Winewatch, 2009)

POLLUTION LOAD MIN PRACTICE	DESCRIPTION
Installing mesh sieves	Prevent organic matter in winery wastewater
Pomace animal feed / Fertiliser	Mixed with stems and other solids
Transfer lees and first rinse to separate tank	Prevent the lees and diluted lees from draining to the wastewater system
Ensure that conveyers, storage bins and tanks are not over filled	Reduce spillage
Grape seed oil	Edible oils can be extracted form grape seeds
Use fining agents that produce most compact lees	Reduce volume of lees
Install in-line screening organic matter	Reduce finer solids in wastewater
Recovery of tartrates	Use in cooking as cream of tartrate
Resettle lees	Remove as much as possible organic material
Keep transfers to a minimum	Reduce changes of spillage

2.2.12 Winery wastewater treatment

2.2.12.1 End use of winery wastewater

'What is the end use of winery wastewater?'- this is a very important question to ask before the necessary steps are taken to develop a suitable wastewater plan for a winery (Bustamante *et al.,* 2005). In 2004 Van Schoor did a study on the irrigation of winery wastewater, in South Africa, and it was found that more than 95% of wineries irrigated wastewater through a sprinkler system onto land.

In Table 2.10 the South African legal requirements are listed when winery wastewater is used as irrigation water in South Africa. The allowed volumes are given per day. It is also of high priority to do soil and crop analysis to determine the current conditions of the soils due to the irrigation of winery wastewater (Van Schoor, 2004).

In the past, land treatment of wastewater worked well for medium to small size wineries because of the low cost involved, but unfortunately if used on poorly drained soils, leachates can cause contamination of the ground waters (Arvanitoyannis *et al*., 2006; Christen *et al*., 2010). Christen *et* al. (2010) also believes that this can be a problem in the winter season because of rain contributing to the volumes of water that needs to be stored (Christen *et al.,* 2010).

Table 2.10 Requirements for winery wastewater irrigation (DWAF, 2004)

IRRIGATION VOLUME (m^3)	FAECAL COLIFORMS/ 100 ml	COD ($mg.L^{-1}$)	pH	SS ($mg.L^{-1}$)	SAR
< 2000	< 1000	75	<5.5 or >9	<25	< 5
< 500	< 100 000	400	<6 or >9		< 5
< 50	< 100 000	5000	<6 or > 9		< 5

Several treatment options are available for winery wastewater (*Mosse et al*., 2011). One of the constraining factors in the selection of a treatment process is the capital expenditure for the initial design and building of the system. There are a number of successful treatment systems available. However, not all of these are suitable for smaller wineries (Arvanitoyannis *et al.,* 2006). Furthermore with the financial pressure, the small wineries are intent on using low maintenance treatments that require minimum manpower (Andreottola *et al*., 2009). In South Africa, approximately 46% of wineries harvest less than 100 tons of grapes and can be classified as a small winery, therefore it is very important to do in depth research on treatment systems available for smaller wineries (SAWIS, 2013). The goal for winery wastewater treatment systems should be that it is viable for any size of winery.

The following criteria should be considered in selecting a winery wastewater treatment system:

1) Maximisation of removal efficiency of impurities;
2) Compatible for different organic loads;
3) Cost effectiveness;
4) Low maintenance;
5) Limited space requirement and
6) Ability to meet discharge requirements for winery effluent (Andreottola et al., 2009; Malandra *et al.,* 2003; Aybar *et al*., 2007; Mosse *et al*., 2011).

As a rule treatment technologies for winery wastewater can be separated into four groups:

1) Preliminary treatment (reduce or eliminating contaminant);
2) Primary treatment (Sedimentation or flocculation);

3) Secondary treatment (normally biological treatment), and
4) Advanced or specific treatment (Ozone + UV) (Klemeš *et al.*, 2009).

2.2.12.2 Physico-chemical treatments (primary treatment)

Physico-chemical treatment is used to screen/settle out large solids, bigger than 0.5 - 1.0 mm, including grape seeds, stalks and leaves present in the wastewater (Mosse *et al*., 2011). This step is uncomplicated and an efficient way to prevent other treatment equipment from getting blocked (Rytwo *et al*., 2011). It is also recommended by Van Schoor (2005) to follow the screening process with a settling period in a tank. The COD in wastewater will be lower when the contact time of the solids with the wastewater is kept to a minimum (Van Schoor, 2005).

Removal of salts also falls in this group with a number of treatments available shown in Table 11. The biggest concerns with these treatments are the high energy and maintenance costs, making it impossible in particular for smaller wineries to implement these. Secondly the by-product of this treatment, a highly concentrated brine, also requires disposal which adds to the feasibility of this treatment. However, evaporation ponds are an option for the brine, but have quite a large footprint (Ahmed e*t al.,* 2000). Ion exchange and reverse osmosis can be used for the removal of salts (Mosse *et al*., 2011). A high EC will have a negative effect on the soils physical, chemical and biological health if not managed correctly (Laurenson *et al*., 2012).

Biological treatment (Secondary treatment)

The high concentration of organic components that are readily biodegradable in winery wastewater often justifies the choice of a biological treatment (Andreottola *et al*., 2009). The COD removal efficiency of biological treatments is very high, ranging between 90 – 95%. The remaining COD (5 - 10%) that cannot be removed with a biological process or settling is due to the un-biodegradable fraction (Andreottola *et al*., 2009).

One of the greatest difficulties that biological treatment systems face is the distinctive wine processing style that contributes to the inconsistent nature of wastewater composition and quantities (Mosse *et al*., 2011). The fluctuation of the wastewater volume demands a system that can handle varying volumes and furthermore must be able to shut down and start-up again when needed (Zang *et al*., 2006). These difficulties pose problems because of the high start-up costs of a biological system and the disposal of the sludge for Aerobes systems (Christen *et al*., 2010).

Biological treatments can be divided into two processes: 1) Aerobic and 2) Anaerobic. This is a very broad division but is important because of different microbial activities that occur with varying levels of oxygen available (Mosse *et al.,* 2011).

Table 2.11 Physiochemical treatments for salt removal

TREATMENT	METHODOLOGY	RESULTS	ADVANTAGES	DISATVANTAGES	REFERENCE
Ion-exchange	Exchange of ions between solution and immobilized resin.	60% Concentration of Tartaric ion 64% maximum current efficiency	Reduce Na^{+},K^{+} levels Low energy require Waste – solid	Not proven for winery wastewater	Andres *et al*., (1997) Arvanitoyannis *et al*., (2006) Mosse *et al*., (2011)
Electro dialysis	Wastewater electrodialyse at 60°C and cooled at 5°C for 48h and re-electrodialysed.	Cold storage eliminates 80% Tartaric acid and 14% malic	Recover valuable products - Tartaric + Malic	Maximum impurities amount	Mosse *et al*., (2011) Andres *et al*., (1997) Arvanitoyannis *et al*., (2006)
Reverse osmosis	Membrane technology filtration that removes large molecules and ions.	Limited literature	Pre treatment require High energy input	Large wineries	Mosse *et al*., (2011)

Aerobic microbiological treatment technologies

Aerobic systems are commonly used in the wine industry to treat the wastewater (Arvanitoyannis *et al*., 2006). In 1914 the first Activated sludge system was developed and several versions of this process are still in use today (Arvanitoyannis *et al*., 2006), fundamentally they are still the same which simplifies troubleshooting (Mosse *et al*., 2011). An aerobic treatment systems relies on oxygen to facilitate microbial-mediated breakdown of organic matter present in wastewater. Heterotrophic microorganisms utilise the carbon as an energy source, typically converting it to biomass and CO_2 (Tchobanoglous *et al.,* 2004).

Some of the advantages of aerobic treatment include: easy management (Anreottola *et al*., 2009); high COD reduction (Mosse *et al*., 2011) and production of an odourless biologically product (Arvanitoyannis *et al*., 2006).

Table 2.12 illustrates the advantages and disadvantages for different aerobic treatments. The major disadvantages of aerobic treatment are the production of large volumes of sludge that require management (Mosse *et al*., 2011) and the process is highly affected by temperature (Arvanitoyannis *et al*., 2006). The treatment option that is the easiest to manage is the Aerated Pond, however, this treatment only shows good results if used on small volumes (Bolzonella *et al*., 2010). The Activated Sludge system reduces the COD intensely and is easier to manage than the aerated pond (Andreottola *et al*., 2009).

The biggest advantage of Aerobic treatment is the COD removal efficiency and in most cases up to 80-90% but this result in the production of large volumes of sludge (biomass) that requires management (Andreottola et al., 2009). Aerobic systems are compatible with different size wineries and suitable for smaller wineries.

Application of Aerobic treatment technologies to winery wastewater

In Spain a comparative study was done on conventional full scale activated sludge versus pilot scale membrane bioreactors (MBR). The MBR was continuously fed with real winery wastewater. Valderrama *et al.,* (2012) monitored the influent and effluent for six months till the specifications were met for agricultural and recreational uses. The MBR showed to be stable and flexible and that high removal efficiencies can be achieved.

A small winery's wastewater was treated using a sequencing batch reactor (SBR). The system could treat up to 15 000 hL wastewater a year and also included storage for the wastewater before treatment to aid as a buffer in seasonal times permitting the reactor to be fed daily. A significant reduction of up to 93% on the COD is just one of a few advantages of using this system. The system has also low maintenances cost and low start-up costs (Torrijos & Moletta, 1997)

Bolzonella *et al.* (2010) did a study on MBR in full scale at a winery producing COD loadings of up to 14 500 mg/L^{-1} per day to see if the system can cope with high organic loadings in

Table 2.12: Advantages and disadvantages of aerobic treatments used in the wine industry

TREATMENT	METHODOLOGY	COD REDUCTION	ADVANTAGES	DISADVANTAGES	REFERENCE
Aerated pond	Wastewater in a pond – aerated	91%	Easy management	Energy intensive Works best on small volumes	Bolzonella *et al*., (2010)
Activated sludge	Wastewater are aerated and treated with bacteria	98%	Easy management, High reduction of COD	Energy intensive Requires nutrients (N,P)	Andreottola *et al*., (2009)
Sequencing batch reactor	Fill and draw activated-sludge system – aerated	>90%	Low capital costs Simplified Automation	Periodic occurrence of bulking, difficulties with shock loading	Andreottola *et al., (*2009) Arvanitoyannis *et al*., (2006), Mosse *et al*., (2009)
Membrane bioreactor	Membrane used with activated sludge	>97%	Improved treated water quality, small footprint, rapid start up, possibility of direct re-use on-site, operation no difficulties with settling properties of sludge	High establishing costs for membrane, increase energy consumption, Membrane fouling, additional costs for membrane molecules	Andreottola *et al*., (2009) Bolzonela *et al*., (2010) Mosse *et al*., (2011)
Jet-loop activated sludge	Limited literature	94-98%	High mixing and turbulence without mechanical devices for aeration, low energy requirements	Limited literature	Andreottola *et al*., (2009) Mosse *et al*., (2011) Petruccioli *et al*., (2002)

harvest time. The average removal rate of COD was up to 95 % while producing a small amount of sludge.

A Jet-loop activated sludge reactor was used to treat various wineries wastewater with COD up to 12 000 mg/ L. The system was monitored throughout the year to observe the influence of the seasonal loading. Overall the COD efficiency was more than 90% and the system coped well with the fluctuation in load volume (Petruccioli *et al.,* 2002).

Anaerobic microbiological treatment technologies

Anaerobic digestion occurs in the absence of oxygen, relying on alternative metabolic pathways utilised by a consortium of different microorganisms (Arvanitoyannis *et al*., 2006). The processes involved in anaerobic digestion are: 1) hydrolysis, in which organic polymers (proteins, lipids, carbohydrates) are converted to organic monomers (amino acids, fatty acids, glycerol, sugars); 2) acidogenisis and acetogenesis, in which organic monomers are converted to acetate, carbon dioxide and hydrogen gas; and 3) methanogenesis, in which acetate, carbon dioxide and hydrogen gas are converted to methane (Tchobanoglous *et al*., 2004). An anaerobic digestion system can convert up to 95% of the organic matter to biogas and the remaining 1 - 3 % of the organic matter helps with cell growth and maintenance of the system (Britz & Robinson, 2009).

Anaerobic systems are widely used on winery wastewater with a high organic matter content (Mosse *et al*., 2011). Table 2.13 lists the advantages and disadvantages of the different anaerobic treatments that are available. Key advantages are that not only is energy requirements low for anaerobic systems (Andreottola *et al*., 2009) but it also produces biogas that can be use as an energy source (El-Fadel & Massoud, 2000), while low excess sludge production produced (Mosse *et al*., 2012).

The biggest weakness of this treatment is that it produces a variety of volatile fatty acids, which are responsible for malodour in winery wastewater (Bories *et al*., 2005). Odour emission can be controlled by the addition of nitrate salts to the wastewater, to act as an alternative electron acceptor and thus prevent the formation of volatile fatty acids (Bories et al., 2007). The latter process involves large quantities of nitrate salt that will decrease the final quality of the wastewater. The long start-up period for the system can also be seen as a disadvantage (Andreottola et al., 2009), typically an anaerobic system requires at least a 15 days start-up period after a shutdown (Moletta, 2005).

Application of Anaerobic treatment technologies to winery wastewater

Arnaud did a pilot scale test on an anaerobic rotating biological contractor with winery wastewater. The start-up time took one month for the biofilm to stabilise but after it stabilised the COD reduction rate was up to 80% when the temperature is obtained at 20°C and volume load of 2kg COD $m^{-3}d$ and at 37°C with volume load of 20-25kg COD $m^{-3}d$. (Arnaud, 2009).

Ronquest and Britz (1999) did a study on the efficiency of an upflow anaerobic sludge bed (UASB) when treating winery wastewater as well as the influence of pH and retention time on the

Table 2.13: Advantages and disadvantages of anaerobic treatments processes used in the wine industry

TREATMENT	METHODOLOGY	COD REDUCTION	ADVANTAGES	DISADVANTAGES	REFERENCE
Anaerobic sequence batch reactor	Fill and draw activated-sludge system - aerated	>98%	Biogas production and energy recovery, low sludge production	Batch feeing required	Andreottola *et al.,* (2009) Mosse *et al.,* (2011)
Upflow Anaerobic sludge Blanket	Granules, upflow velocity of wastewater	80-98%	High activity of granular sludge, good settle ability, low sludge production	High installation costs, accumulation of floating scum, Pre-treatment required and aerobic post-treatment	Andreottola *et al.,* (2009) Mosse *et al.,* (2011) Schmidt & Ahring, (1996)
Anaerobic Digestion	Covered anaerobic lagoon	65-95%	High biomass production, easy operation	Long start-up times, inability to treat high BOD or COD loads	Andreottola *et al*., (2009) Arvanitoyannis *et al*., (2006) Moletta (2005)

UASB. COD reductions of up to 93% were achieved when the organic loading rate (OLR) was 11.05 kgCOD.m^3d^{-1} and a hydraulic retention time (HRT) of 14h (Ronquest & Britz (1999).

Wetlands

Wetlands are created to manipulate natural processes to take advantage of biological processes in a controlled environment (Serrano *et al*., 2011). The use of wetlands as a means of wastewater treatment is appealing for moderate size wineries (Mosse *et al*., 2011). They have a good performance using pre-treatment for suspended solids removal and aeration, adapt well to influent fluctuations and are aesthetically pleasing (Andreottola *et al*., 2009). Aquatic plants, *Phragmites australis* and *Typha latifolia*, are used to take up large amounts of nutrients from the wastewater and filtration aid through the growth matrix of the plants (Mosse *et al*., 2011). The drawbacks of this treatment are that the climate conditions for the plants must be ideal, the requirement of wide areas due to large footprint of the plants, often located on valuable agricultural land and they require significant maintenance and skills (Andreottola *et al*., 2009). Serrano *et al.* (2011) found in their studies that constructed wetlands show rapid adaptation to low pH. Furthermore, that the variation in the performance and efficiency of constructed wetlands relies on the variables of surface loading rates and the temperature of the winery wastewater (Serrano *et al*., 2011).

The effectiveness of a wetland is dependent upon the volume of winery wastewater and the rate of delivery, but with a suitable design, wetlands can be operated effectively in almost any winery size (Mosse *et al*., 2011). There are typical three types of constructed wetlands: 1) horizontal surface flow, 2) vertical flow and 3) floating raft system. The most effective system is a combination of the horizontal and vertical flow system where the wastewater flows horizontally across the surface of the wetland and through a substrate. A floating raft system relies upon plants on a natural or synthetic floating medium, to remove organic material and other nutrients from the wastewater (Mosse et al., 2011).

Application of Wetlands treatment technology to winery wastewater

A study on a constructed wetlands with in Western Cape, South Africa was done in 2002 with distillery and winery wastewater. The diameters of the wetlands were 64m (long) x 4m (wide) x 1m (deep). The wastewater had an average COD of 14 000 mg/ L and showed reductions of up to 90%. The study also showed that winery wastewater that was treated with wetlands can be used for cash crop production (Mulidzi *et al.,* 2007).

Serrano *et al.* (2011) investigated a full scale hybrid constructed wetland (CW). This wetland consisted of a hydraulic up-flow (HUSB) digester and a vertical flow constructed wetland (VF) and three parallel subsurface horizontal flow (HF) wetlands. The HUSB was used for suspended solids removal. The system removed 86% TSS and 73% COD of the wastewater. The VF showed high removal rates in contrast with the HF. CW showed variation in efficiency with low pH (Serrano *et al*., 2011).

2.2.12.3 Combined treatment systems

Aerobic and Anaerobic treatments

Eusebi *et al*., (2009) used activated sludge to alternate the aerobic and anaerobic processes at a wastewater treatment plant in Italy. For this study municipal and pre-treated winery wastewater was co-treated. The existing total oxidative system was adapted to alternate cycles (AC) for 3 months. The system showed to cope very well with the fluctuation loads of the winery wastewater and improve the biological nitrogen removal. Furthermore was the energy savings of the AC application reduced up to 59% (Eusebi *et al*., 2009).

Biological and pre- and post-treatments

Ozonation is an extremely effective chemical oxidation method, and has been demonstrated to have numerous applications in wastewater treatment. Ozonation effectively reduces the polyphenol content of the winery wastewater, and reduce overall organic matter concentration when used in combination with UV-A irradiation. One major advantage of the application of ozone (undecomposed, pH<6) in the treatment of wastewater with a complex matrix, of polyphenols and other species, rest in the higher selectivity of molecular ozone towards polyphenols when compared to the reaction of these with radical species (Lucas *et al*., 2010).

Recent studies using a pilot scale bubble column reactor indicated that the operating pH also has significant impact on the level of organic removal from winery wastewater. A pH 10 influent reduced the concentration of aromatic compounds by approximately 75%, whereas influent pH values of 4 and 7 resulted in reductions of approximately 50% (Lucas *et al*., 2010). This treatment showed potential for the wine industry but unfortunately there are significant cost involve with this technology (Mosse et al., 2011).

A combined treatment of UASB and pre-and post-ozonation was tested by Sigge (2005). COD reductions of 17% was achieved when winery wastewater was pre-treated with ozone and UASB reduced the COD by 87% respectively. When the pre-treated wastewater was treated with the UASB the reduction was increased up to 92% with the biogas methane content increase up to 54%. On the whole the system was not affected by COD fluctuation loads. A post-treatment of ozone was also done on the wastewater reducing the COD in total up to 96% (Sigge, 2005).

2.3 Summary

Wine production is a growing industry all around the world with the demand for wine increasing and new wineries being established. Subsequently, this industry produces large volumes of wastewater that potentially pose a risk to the environment and thus require treatment.

It is clear from the literature that the volumes of water used in wineries vary, but also that the wastewater characteristics differ significantly. This is an indication that the winemaking practices (white, red, rosé or blends; types of press; bottling operations; filtering and barrel work to name a few) influence the wastewater characteristics. Contributing to this problem is that many wine makers see winemaking as an art and thus not overly concerned with water use and wastewater treatment.

Even though the characteristics of wastewater produced by wineries differ immensely from winery to winery, there are practices that wineries can implement to reduce the volume and the pollution load. The implementation of cleaner production practices offers a partial solution to wineries for minimising wastewater produced and also reducing the water usage. It goes without saying that this in return will potentially reduce cost by avoiding wastages. Apart from these principles it is vital that the management of the winery is effusively committed to aid in the awareness and motivation of their employees.

A number of studies have recently shown that there is a correlation between the winemaking practices and characteristics of the wastewater but further investigation is required to elucidate how specific winery practices influence the characteristics/composition of the winery wastewater.

More specific information on these practices and their effects will possibly encourage wineries to implement more efficient practices, thereby reducing water usage and pollution loads of winery wastewater.

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CHAPTER 3

INFLUENCE OF WINEMAKING PRACTICES ON WATER USAGE IN A WINERY

3.1 Summary

The water usage was determined while the winemaking practices were monitored at two wineries in the Stellenbosch Winelands District. This was done to identify the impact of the different winemaking activities on the water usage during two harvests and one post-harvest season. Firstly, this study showed that water usage is an essential part of the winemaking process and that there is a big demand for clean water during the harvest period when the grapes were processed (February – March). The demand for clean water decreased at both wineries during the course of the post-harvest period and steadily increases towards the end of the year again. Furthermore, it was found that certain winemaking practices including filtering with a bulk filter, washing of barrels and bottling mainly contributes to the water usage throughout the year. Activities that increase water usage during the harvests include the washing of the press and processing a combination of red and white grapes. Secondly it was noticed that there was a vast difference in the volumes of water used by the respective wineries. This could be an indication that the cleaner production strategy that was established 10 years ago at one of the wineries certainly has an impact on their water usage.

3.2 Introduction

The pressure on water resources is a global concern throughout all industries (Bustamante *et al*., 2011). The wine industry is no exception and uses vast amounts of water to produce their product (Bolzonella *et al.,* 2010). The increasing number of wineries and the demand for wine worldwide are contributing to this growing problem (Agustina *et al.,* 2007; Andreottola *et al*., 2009).

The basics of winemaking have not changed since the beginning of time but the pressure to produce high quality and good value wines has increased dramatically (Hands & Hugges, 2001). To ensure this, the demand for a sterile environment is increasing and consequently the demand for the availability of clean water (Holliday & Johnson, 1994).

Water is used in practically all the different steps of the winemaking process and therefore, produces wastewater from the receival of the grapes all the way to the final packaged product (Devesa-Rey *et al*., 2011). Water is for the most part used for cleaning - consequently producing large volumes of polluted wastewater that needs treatment before being re-used (Agustina *et al*., 2007). These volumes vary throughout the year in relation to the different processes taking place (Arienzo *et al*., 2009). Adding to this is the differences that can be noticed when comparing the water usage of different wineries due to several parameters including the type of tanks, processing equipment and various winemaking techniques (Walsdorf *et al*., 2004).

Small volumes of winery wastewater have little effect on the immediate environment, but with the increasing volumes produced, winery wastewater is a rising concern for the contamination of soil and subsurface flow, soil and the environment (Grismer *et al.,* 2003). For this reason the goal of all wineries should be the minimisation of water usage (Lee *et al*., 2011). This would not only lessen the pressure on water resources but would reduce the cost of the clean water used and also reduce the cost accompanying the treatment of the wastewater (Fillaudeau *et al.,* 2008). Chapman (1996) highlighted this by stating that avoidance of water use is the most important principle any winery can implement.

There are practices that can be implemented by wineries to help reduce the wastewater volumes by applying cleaner production principles (Van Schoor, 2005). Research has shown that a substantial volume of up to 30% can be reduced with simple changes, demanding no financial contribution (Kirby *et al.,* 2003). These changes include evaluation of water usage in controlled areas, improvement of planning and control of water use (Klemeš *et al*., 2008). Water auditing will not only point out the areas of unnecessary waste but also will help the winery to understand where the water is used (Klemeš *et al*., 2008). Therefore, the aim of this study was to compare the water usage and winemaking practices of two wineries (one which implemented a cleaner production strategy 10 years ago and the other systematically striving to improve its water usage) to determine the impact that certain winemaking practices have on the water usage.

3.3 Materials and methods

Research has shown that water usage for the production of wine varies considerably from winery to winery and country to country (Walsdorff *et al*., 2004; Mosse *et al*., 2011). This is due to the difference in winemaking practices and techniques from wineries. Therefore, the different wine production cycles were monitored to investigate the correlation between the range of winemaking practices and the volumes of clean water used.

To calculate the volume of water used per day it was essential to have water meter readings for two consecutive days noted at the same time of the day. Unfortunately with the nature of winemaking and the increased work load throughout the harvest it was not always possible for the responsible person to take the readings at the exact time and due to this there were days that no water meter readings were recorded. Resulting in days on which no water usage volumes could be calculated. Furthermore, during the 2012 harvest the water meter readings were noted daily (Monday to Friday), for this reason water usage volumes could only be calculated from Monday till Thursday. However, during the 2013 harvest readings were also taken on Saturday mornings to include the water usages for Fridays and also to have an indication of the water usage during the weekends.

The water usage of two wineries in the Stellenbosch winelands was monitored for 16 months (two harvests and one post-harvest season). These two wineries, Winery A- and Winery B are both medium sized wineries situated 8 km apart.

3.3.1 Geographical location of study sites

3.3.1.1 Winery A

The 150 ha of vineyards is situated high on the south western slopes of the Simonsberg Mountain. The average production per year is 900 – 1 000 tons or 500 000 L white and red wine, combined. This originates from 15 different grape varieties, namely: Chenin blanc, Chardonnay, Colombar, Gewürztraminer, Muscat D'Alexandri, Pinot blanc, Sauvignon blanc, Semillon and Weisser Reisling (all white) and Cabernet Sauvignon, Merlot, Pinotage, Pinot noir and Shiraz (red).

3.3.1.2 Winery B

Winery B is situated on the free draining North-eastern slopes of the Bottelary hills. There is a difference in altitude of some 250 m between the Northern and Southern vineyards. The estate is planted with 170 ha of 7 different grape cultivars. A yearly production of 540 000 L wine is made, from white (Chardonnay, Sauvignon blanc, Weisser Riesling) and red cultivars (Cabernet Sauvignon, Merlot, Pinotage, Shiraz).

3.3.2 Water meter readings

The water usage of Winery A and Winery B was monitored from 29 January 2012 to 28 March 2013. During the 2012 harvest (29 January – 29 March) the water meter readings and key winemaking activities were only noted daily by the cellar personnel from Monday to Friday. Therefore the water usages during the 2012 harvest were calculated daily for Monday to Thursday and the weekends included the Friday's water usages. In order to calculate the water usage for the whole week the water readings were also noted on Saturday mornings during the 2013 harvest at both wineries. Throughout the post-harvest season weekly water meter readings were noted to calculate the average water usage of the week up until week 50 of 2012.

The water meter readings and daily winery activities were noted by appointed personnel from the two respective wineries. In general the water meter readings were noted between 08:00 and 08:30 in the mornings. However, there were days when no readings were noted and therefore no water usage could be calculated for two consecutive days.

3.4 Results and discussions

3.4.1 Variation of water usage throughout the wine production cycle

3.4.1.1. Winery A – Harvest 2012

During the 2012 harvest at Winery A the water meter readings were taken, while the activities of the wineries were monitored. The harvest at Winery A started on the 30th of January and lasted till 28 March – processing 745 tons of grapes, using 1597 m^3 water with an average (indicated with X; Fig 3.1) of 35 m^3 per day. Forty percent of the grapes harvested were red, the rest being varieties for rosé and white wine. There is an immense difference in the winemaking techniques of red and white wine (Devesa-Rey *et al.,* 2001). The rosé winemaking technique is very similar to white wine winemaking and therefore the data for the Rosé production has been included under the white wine winemaking in further discussions.

Figure 3.1 summarises the water usage at Winery A for the 2012 harvest season. The first week of harvest (30 Jan – 5 Feb) had a high total water usage (217 m^3) and an average water usage of 38 m^3 per day, ranging from 35 m^3 to 44 m^3 (Fig 3.1; Table 3.1). Friday to Saturday (3 – 5 Feb) contributed 30% of the total water usage during this week resulting in the weekend with the second highest water usage (71 m^3) during the 2012 harvest. The reason for this could be due to the fact that Pinotage (red) grapes were processed on the 2nd February resulting in four hourly pump-overs during the week and weekend, which increased the cleaning demand. Adding to this was the high volume of Pinotage (rosé) grapes that was processed during the beginning of the week (30 Jan – 1 Feb) and the last day of the week (3 Feb) for the Rosé wine that needed to undergo flotation and racking, increasing the demand for cleaning. From Table 3.1 it can be seen that on the 30th January, white and red grapes were processed, compared to the 31st when only white grapes were processed. The water usage was higher for the latter by 26%. Figure 3.2 summarises the water usage for cleaning of equipment during the initial stages of white and red grape processing. Red grapes are destemmed and pumped directly to a stainless steel tank for fermentation in contrast to white grapes that are generally pressed on the same day when crushed and destemmed (Fig 3.1). For this reason less equipment is used in the initial stages of the red winemaking and therefore, less water is needed for cleaning. When white grapes are processed, the grapes are pressed after destemming and then the pressed juice is pumped to a stainless steel tank for settling overnight. The settled juice is racked during the following day and inoculated with yeast to start alcohol fermentation (Typical alcohol fermentation time of white wine 5 to 7 days at 12 -14 °C and red wine 5 to 7 days at 24 – 26 °C). In other words, when white grapes are processed more water is used for cleaning in the primary stages of the winemaking process, than for red grapes. This could be the reason for the higher water usage on the 31st January because of the higher volume of white grapes processed on this day. The rest of the week the water usage was marginally higher than the average of 34 m^3 for the season (Fig 3.1). The reason for this could be due to the filtering of older vintage (OV) wines that was done on these two days (1 – 2 Feb) (Table 3.1). At Winery A, a bulk filter is used that uses filtering powder to aid the filtration process. The filtration powder increases the intensity of the cleaning process due to the fact that more water is needed to clean the filter and the winery floors.

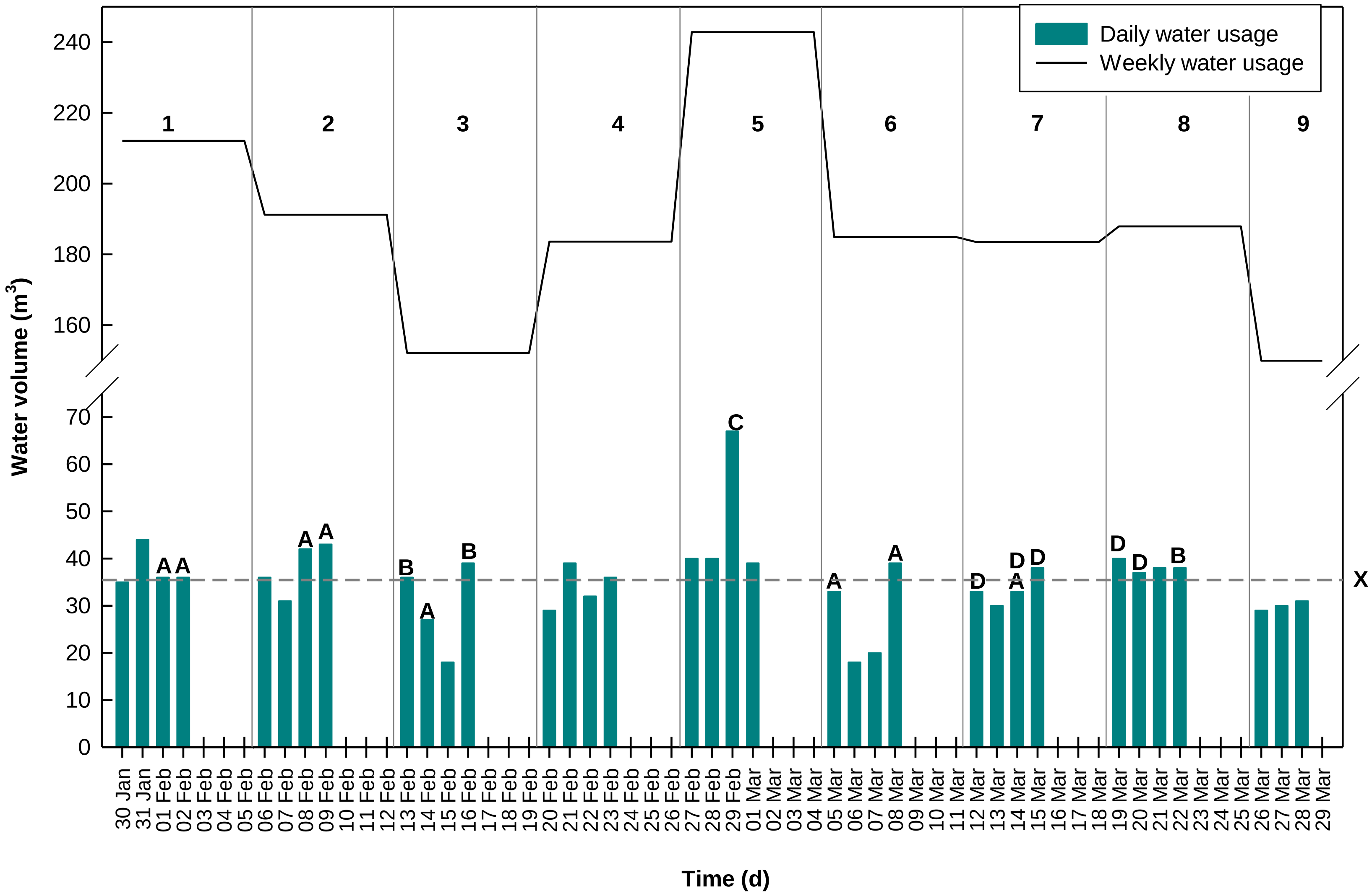

Figure 3.1 Daily and weekly water usages at Winery A for the 2012 harvest season. (Activities indicated with A: filter; B: bottle; C: high work load; D: barrel washing and X indicates the average daily water use)

Table 3.1 Daily mid week (Monday to Thursday) water usage of the winery and the associated winemaking activities during the 2012 harvest at Winery A (Bason, S., 2013).

DATE	WATER USAGE (m^3)	ACTIVITIES IN WINERY	DATE	WATER USAGE (m^3)	ACTIVITIES IN WINERY
30-Jan	35	HWR, flotation	29-Feb	67	Rack
31-Jan	44	HW, flotation	01-Mar	40	HR, rack, blend
01-Feb	36	HW, flotation, blend OV, filter OV	05-Mar	33	HR, filter, F barrels
02-Feb	36	HR, rack CV, rack OV, filter OV,	06-Mar	18	HW, press R
06-Feb	36	HW	07-Mar	20	HW, press R, rack
07-Feb	31	HW, rack	08-Mar	39	HWR, rack, filter
08-Feb	42	HW, rack, rack OV, filter OV	12-Mar	33	HR, E barrels
09-Feb	43	HW, rack, flotation, rack OV, filter OV	13-Mar	30	HR, rack,
13-Feb	36	HWR, F barrels, bottle	14-Mar	33	HR, rack, filter, E barrels
14-Feb	27	HR, F barrels, filter OV	15-Mar	38	HR, blend, E barrels
15-Feb	18	Rack, centrifuge	19-Mar	40	E barrels,
16-Feb	39	Centrifuge, rack OV, bottle	20-Mar	37	E barrels, F barrels, press R
20-Feb	30	HWR, rack	21-Mar	38	Rack
21-Feb	39	HWR, rack	22-Mar	38	HW, rack, bottle
22-Feb	32	HWR, rack	26-Mar	29	R press, cleaning
23-Feb	36	HWR, rack	27-Mar	30	HR, R press, F barrels, cleaning
27-Feb	40	HWR, blend	28-Mar	31	HR, Rack, R press
28-Feb	40	HW, press R, blend			

HW – white grapes harvested; HR – red grapes harvested; HWR – white and red grapes harvested; Press R – red fermenting grapes pressed; OV – older vintage; E barrels - emptied barrels; F Barrels – fill barrels; EF barrels – emptied and fill barrels

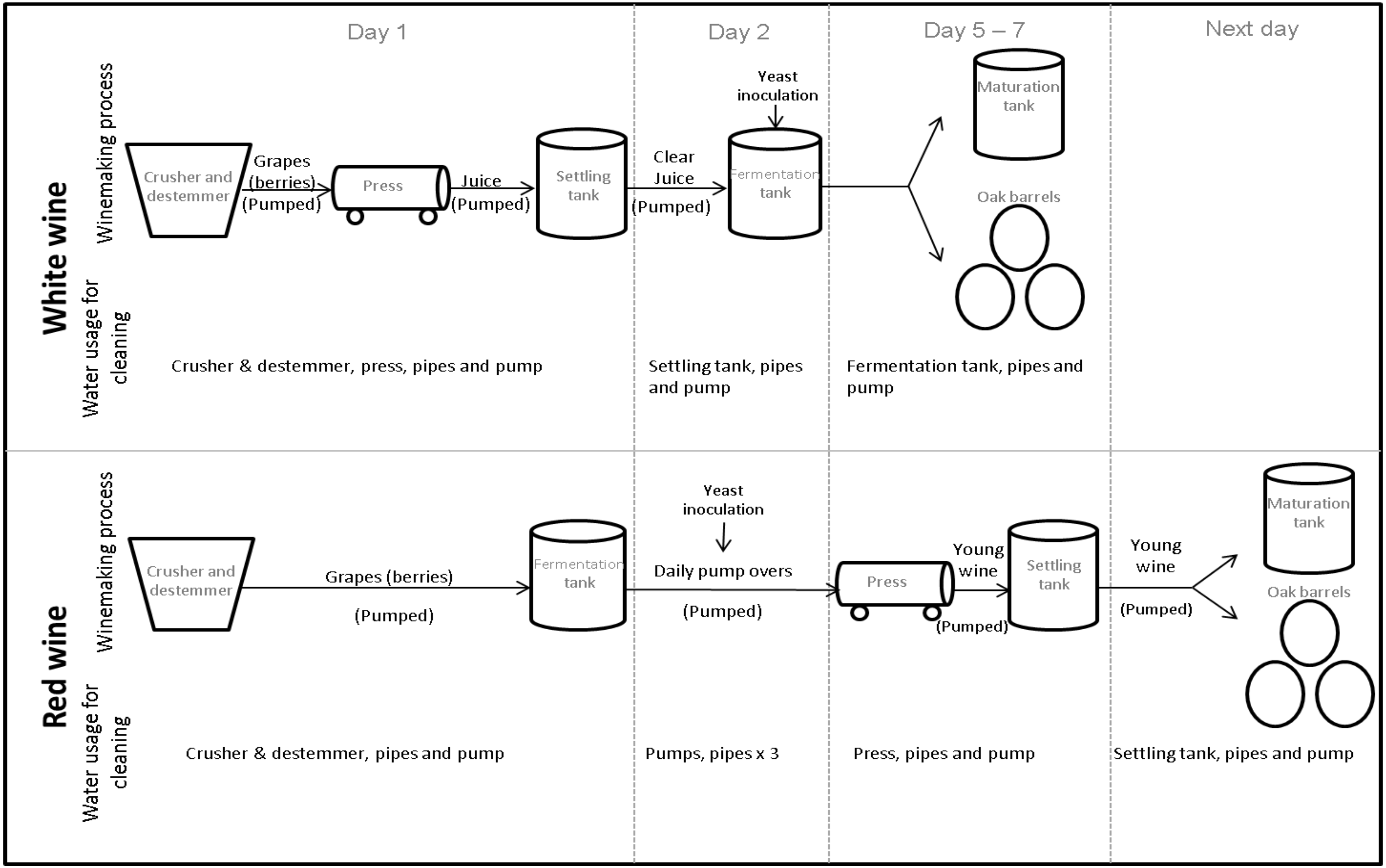

Figure 3.2 Water usages for cleaning of equipment during the initial stages of white and red grape processing.

During the second week of harvest (6 – 12 Feb) the weekly average and total water usage were measured at 38 m^3 and 192 m^3, respectively, with the highest volume used on 9th February (43 m^3) (Fig 3.1; Table 3.1). During this week only white grapes were processed in the winery. On the first two days of this week (6 – 7 Feb) the water usage was lower than on the last two days (8 – 9 Feb) (Table 3.1). During the latter two days, more wine movements (including racking of fermented tanks) were done resulting in more tanks being cleaned, thus using more water. Also, on these two days filtering was done, again contributing to the water usage (Fig 3.1; Table 3.1). The water usage (40 m^3) for the weekend following week two decrease from the first weekend (71 m^3). This could be due to smaller volumes of red grapes processed resulting in less pump overs during this weekend.

The average water usage measured in week 3 (13 – 19 Feb) was a moderate 30 m^3 per day varying from as low as 18 m^3 on 15th February to a high of 39 m^3 on the 16th February resulting in the lowest weekly water usage of this harvest (152 m^3) (Fig 3.1; Table 3.1). During this week grapes were processed on only two of the four monitored days and this could be the reason for the moderate usage over the entire week. The 13th was the first day that red (75%) and white (25 %) grapes were processed on the same day, resulting in a higher water usage (36 m^3) (Fig 3.1; Table 3.1). Wine was also bottled on the 13th, contributing to the water usage (Fig 3.1). During the bottling process the bottles are washed before being filled with wine and therefore potentially increasing the water usage (Basson, S., 2012). Wine was also bottled on the 16th February (Fig 3.1; Table 3.1), reflected by the higher water usage. Other than on the 13th, no grapes were processed on the 16th February and the small volume of white grapes (6 tons) harvested on the 13th could be the reason for the small difference in the water usage of the two days (Table 3.1). Therefore it could be said that the using of the centrifuge, racking of older vintages and bottling activities uses more water than harvesting of red and white grapes on the same day, filling barrels and bottling. The 14th – 15th February no wine was bottled and the slightly lower water usage could be due to the small volume (10 000 L) of wine that was filtered on the 14th (indicated with A Fig 3.1) and the fact that no grapes were processed on the 15th (Fig 3.1; Table 3.1). The water usage during the third weekend was the lowest (32 m^3) for the 2012 harvest. The grapes processed during this week was noticeably lower than the two previous weeks and could be the result of the decrease in water usage during the weekend.

Figure 3.1 shows that the fourth week (20 – 26 Feb) of harvest had a total water usage of 185 m^3 and the daily water usage fluctuated slightly from below 30 m^3 to almost 40 m^3 per day (Fig 3.1; Table 3.1). Fig 3.1 also shows an increase in the weekly water usage from week 3 to week 4 - this could be due to the increase in water usage during the weekends. Week four to seven could be seen as the peak harvest time due to the volumes of grapes processed and the work load during this period and therefore more work was done over the weekends increasing the weekly water usage. Every day of this week a combination of red and white grapes where processed and wine was racked, but the quantities varied. On the 21st February the highest volume of white grapes was processed (17 tons) and it was also the day with the highest water usage during this week (39 m^3). The following two days (22 and 23rd) the volumes of white grapes processed decreased slightly resulting in slightly lower daily water usages (Table 3.1). Whereas on the 20th the smallest volume (12 tons) of white grapes was harvested with the lowest water usage measured (30 m^3) for this week (Table 3.2). A slight increase in water usage from the previous weekend (32 m^3) to the weekend following week four (48 m^3) could be due to the increase in red grapes harvest during this week increasing the pump overs (Fig 3.1). White grapes were also processed on the Thursday (23 Feb) and Friday (24 Feb) resulting in more racking activities of the white juice during the weekend increasing the need for cleaning.

Table 3.2 A summary of grapes processed during the fourth week of the 2012 harvest at Winery A.

DATE	GRAPES PROCESSED (t)	RED GRAPES (t)	WHITE GRAPES (t)	TOTAL WATER USAGE (m^3)
20 Feb	14	2	12	30
21 Feb	19	2	17	39
22 Feb	23	10	13	32
23 Feb	32	17	16	36

During the fifth week (27 Feb – 4 Mar) the total weekly water usage (243 m^3) was the highest with an average of 46 m^3 per day (Fig 3.1; Table 3.1). Week five's weekend water usage (56 m^3) was the third highest during this harvest. This week represented the peak of harvest in terms of the increase in work load. During this week, a number of red tanks were pressed and the Rosé blend was made. The Pinotage Rosé blend is the biggest blend (in volume) made by Winery A. Therefore, the tanks that were used for the making of the blend were cleaned after use and contributed to the water usage. The 29th February was the day with the highest water usage (67 m^3) during the 2012 harvest and this could be due to the majority of Rosé blend that was made, thereby increasing the workload of this day and the volumes of water used for cleaning (Fig 3.1; Table 3.1). On Saturday 3 March 9.8 tons of red grapes were processed increasing the water usage during the weekend to 56 m^3 (Fig 3.1).

The water usage fluctuated during week six (5 – 11 Mar) between 18 and 39 m^3 per day and the total water usage was 186 m^3 (Fig 3.1; Table 3.1). On the two days (5 and 8 March) with the higher water usage, filtration of wine was done and this could be the reason for the increase in water usage (indicated with A on Fig 3.1; Table 3.1). White grapes were harvested on 6th – 7th March, thereby theoretically increasing the water usage because of the intense cleaning needed at the end of the day. But the volumes of grapes harvested on the 6th and 7th were considerably lower (7.5 and 6.5 tons) when compared with the tons of white grapes harvested on the 8th March (40 tons) therefore, the possible lower water usage on the 6th and 7th. The weekend following week six (9 – 11 Mar) was the weekend with the highest water (76m^3) usage during the 2012 harvest. The Friday to Sunday (9 – 11 March) contributed to 44% (76m^3) of the weekly water usage (184 m^3) possibly due to the high volume of white grapes that was processed on the 8th – 9th Mar. The high volume of settled white juice was flocculated, racked and inoculated in the proceeding days increasing the cleaning demand

(Fig 3.1; Table 3.3). The high volumes of white grapes processed on Thursday (27.0 tons) and Friday (23.5 tons) could be the reason of the high water usage (76 m^3) during the weekend following week 6 (Fig 3.1). As mentioned previously an increase in the workload can be expected during the following weekend if white grapes are processed on the last two days of the working week.

Week seven (12 – 18 Mar) had moderate total water usage (184 m^3) ranging from 30 to 38 m^3 per day (Fig 3.1; Table 3.1). During the majority of these days barrels were emptied and cleaned (12, 14 and 15th), contributing to the water usage (barrel work is indicated by D on Fig 3.1). Generally, when barrels are emptied they are washed with a high pressure system on the same day which results in the increased water usage. During this week, on the 13th March no barrel work was done - possibly the reason for the slightly lower water usage. The slight increase in the water usage from the 14th to 15th March could be due to the increase in the tonnage of grapes that were processed on these days (23, 27 and 33 tons, respectively of red grapes were processed). Adding to the water use is the fact that wine was also filtered on the 14th (indicated by A on Fig 3.1). The decrease in water usage during the weekend following week seven could be due to no white grapes harvested at the end of the working week. Even though the water usage (50 m^3) is noticeably lower than the previous weekend it was just below the average (51 m^3) water usage over weekends. The pump-overs of red wine most likely contributed to the water usage during this weekend.

During week eight (19 – 25 Mar) the average water usage was noticeably higher than the previous week, ranging between 37 and 40 m^3 per day resulting in a slightly higher total water usage of 190 m^3 (Fig 3.1; Table 3.1). Firstly, the high volume of red grapes that were processed during week seven, was fermenting at this stage and routine pump-overs were done four times a day to ensure maximum colour extraction from the skins (Table 3.1). After the pump-overs the equipment and floors were washed, this can most likely be the reason for the higher water usages. Secondly, on the 19th and 20th barrels were emptied and washed, increasing the water usage (indicated by D on Fig 3.1, Table 3.1). Lastly, Table 3.1 shows that on the 22nd wine was also bottled, adding to a higher water usage than normal, Fig 3.1. The water usage (37 m^3) during this weekend was noticeably lower than the previous four weekends (Fig 3.1). This could be due to the low volumes of grapes processed during week.

Week nine (26 – 29 Mar) showed a decrease in the total water usage (152 m^3) ranging from 29 to 31 m^3 per day (Fig 3.1; Table 3.1). The 26th was the only day that no processing of grapes took place and most likely the reason for the slightly lower (29 m^3) water usage than the rest of the week. Activities recorded on this day include pressing of red fermented tanks and cleaning of the winery. The last two days of the week red grapes were pressed increasing the water usage slightly (Table 3.1). A slight decrease in water usage can be noticed when the water usage of the 27th and 28th March is compared to the water usage of days earlier in the harvest (31 Jan, 1, 3, 6, 7, 8, 9 and 14 Feb) when only white grapes were pressed (37 m^3). This could possibly be due to the fact that on the days that a higher volume of white grapes were pressed the crusher and destemmer was also used and cleaned compared to the 27th and 28th March when no grapes where processed lowering the cleaning activities on these days.

3.4.1.2 Winery A – Post-harvest 2012

Figure 3.3 shows the weekly water usage of Winery A during the 2012 post-harvest season, which was monitored from week 14 up until week 50 when the winery closed for the summer holidays and no water meter readings were taken. Total water usage was 2 465 m^3 with an average (Fig 3.3) of 64.4 m^3 per week. The water usage was measured weekly on Friday mornings and therefore, the reading represents the water usage for the entire week. This was done to investigate the influence of weekly winemaking activities on the water usage. This post-harvest period can be sub-divided in five sub-periods (A to E on Fig 3.3 and Fig 3.5).

Sub-period A (week 14 to 21) was considered post-harvest although grapes were still processed on a few occasions during this period, but these were low volumes, and there were several weeks during which no grapes were harvested (Table 3.3). During the post-harvest sub-period A, the total water usage was 850 m^3, ranging from 69 m^3 in week 17 to a high of 166 m^3 in week 15 (Fig 3.3; Table 3.3). This was the sub-period with the highest water usage. The first two weeks (week 14 and 15) of this period had water usages which were considerably higher than during the rest of sub-period (A), with 150 and 166 m^3, respectively. A small volume of grapes (2.5 tons) were only processed on one day during these two weeks – which would not explain the high overall water usage. The main contributing factor during these two weeks was most likely the major “end of harvest” cleaning and the fact that the cellar was preparing for a hygiene audit, scheduled for the end of week 15. Apart from this, a number of red wine tanks were still fermenting, therefore pump-overs were still done, also adding to the water usage (Table 3.3).

A noticeable decrease in water usage during week 16 to 18 was observed with water usage ranging between 69 and 85 m^3 (Fig 3.3, Table 3.3). During all three of these weeks, only small volumes of grapes (an average of 5 tons) were processed on at least one day of each week (Table 3.3). Week 16 was the only week of these three, during which white and red grapes were processed on the same day and this took place on two consecutive days, resulting in an increased demand for cleaning water. Figure 3.3 indicates an increase in the water usage for week 19 and 20 with values of 106 and 114 m^3, respectively (Table 3.3). The three wines (total of 32 000 L) that were bottled throughout week 20 not only increased the water usage during week 20 but most likely also contributed to the high water usage during week 19. Wine must undergo stabilisation (fining) and filtration to ensure that the insoluble matter suspended in the wine is removed, before it

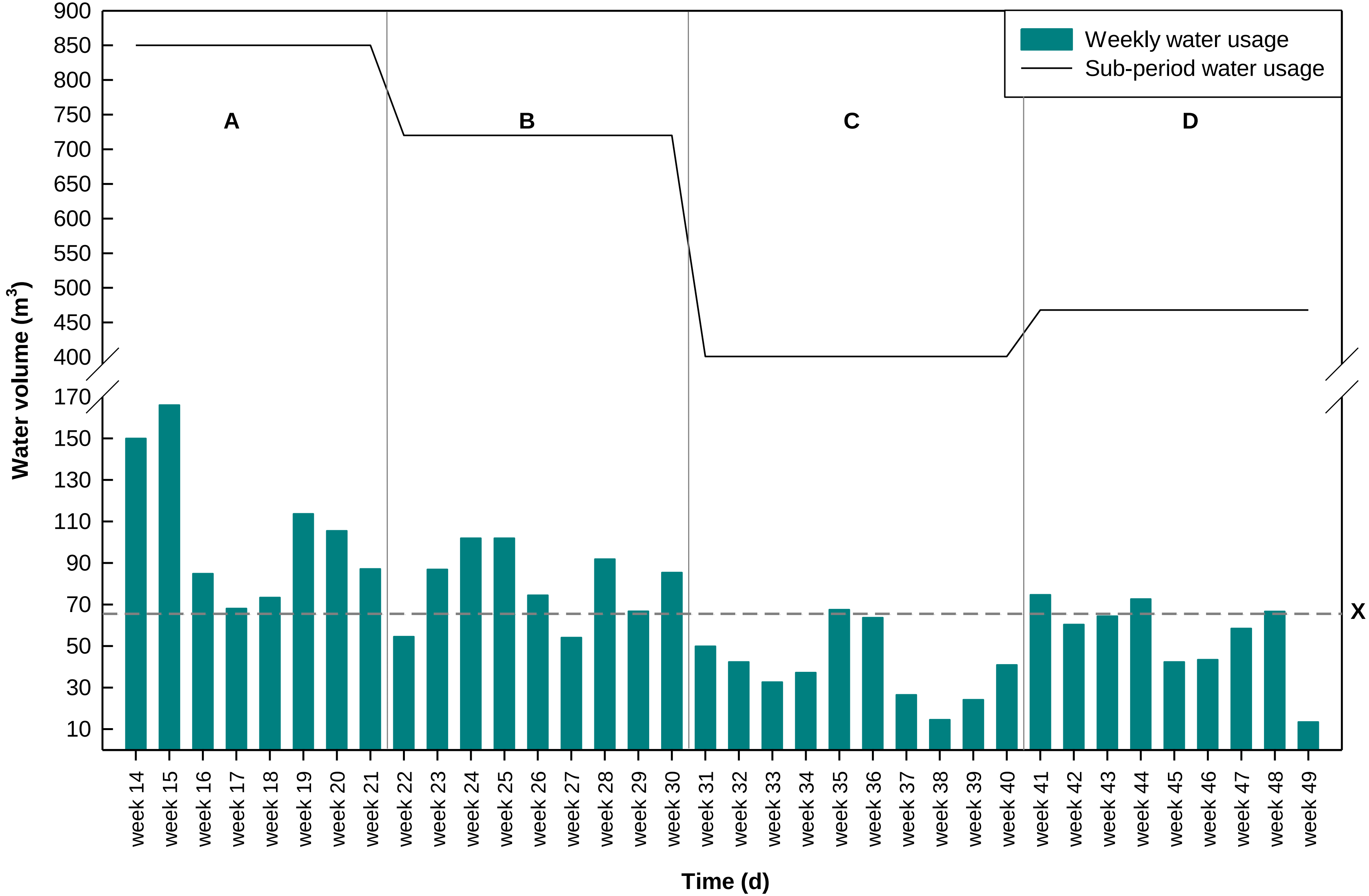

Figure 3.3 Weekly water usages at Winery A for the 2012 post-harvest season. (X indicates the average weekly water usage).

Table 3.3 Weekly water usage of the winery and the associatedwinemaking activities during the 2012 post-harvest at Winery A (Bason, S., 2013).

DATE	WATER USAGE (m^3)	ACTIVITIES IN WINERY	DATE	WATER USAGE (m^3)	ACTIVITIES IN WINERY
Week 14	150	HR, filter, bottle, blending, cleaning	Week 32	42	Rack, bottle, F barrels
Week 15	166	F barrels, R press, cleaning	Week 33	33	Bottling, rack, E barrels, cleaning
Week 16	85	HRW, blend, cleaning	Week 34	37	Rack, E barrels
Week 17	69	HW, press R, filter, F barrels	Week 35	68	Rack, EF barrels, cleaning
Week 18	73	HW, bottle, F barrels, press W	Week 36	64	Rack, filter, EF barrels, cleaning
Week 19	114	Bottle, filter, rack, cleaning	Week 37	27	Rack, filter, bottle, blend, cleaning
Week 20	106	Rack, bottle, blend, F barrels	Week 38	15	Rack, filter, bottle, F barrels
Week 21	87	HL, EF barrels	Week 39	24	Rack, filter, F barrels, cleaning
Week 22	55	EF barrels, filter, cleaning	Week 40	41	No records available
Week 23	87	Filter, blend	Week 41	75	Rack, filter, bottle, F barrels
Week 24	102	Bottle, blend, filled barrels with water	Week 42	60	Rack, filter, blend, EF barrels
Week 25	102	Rack, bottle, F barrels, filled barrels with water	Week 43	64	Rack, blend, F barrels
Week 26	75	Rack, filter, bottle, F barrels	Week 44	73	Rack, filter, blend, E barrels
Week 27	54	Rack, bottle, EF barrels	Week 45	42	Rack, filter, bottle
Week 28	92	Rack, E barrels	Week 46	44	Rack, filter, bottle
Week 29	67	Rack, filter, bottle, EF barrels	Week 47	59	Rack, filter, bottle
Week 30	86	Rack, filter, bottle, EF barrels	Week 48	67	Rack, filter, bottle
Week 31	50	Rack, filter, bottle, EF barrels	Week 49	14	Bottle

HW – white grapes harvested; HR – red grapes harvested; HWR – white and red grapes harvested; HL – late harvest; Press R – red fermenting grapes pressed; OV – older vintage; E barrels - emptied barrels; F Barrels – fill barrels; EF barrels – emptied and fill barrels

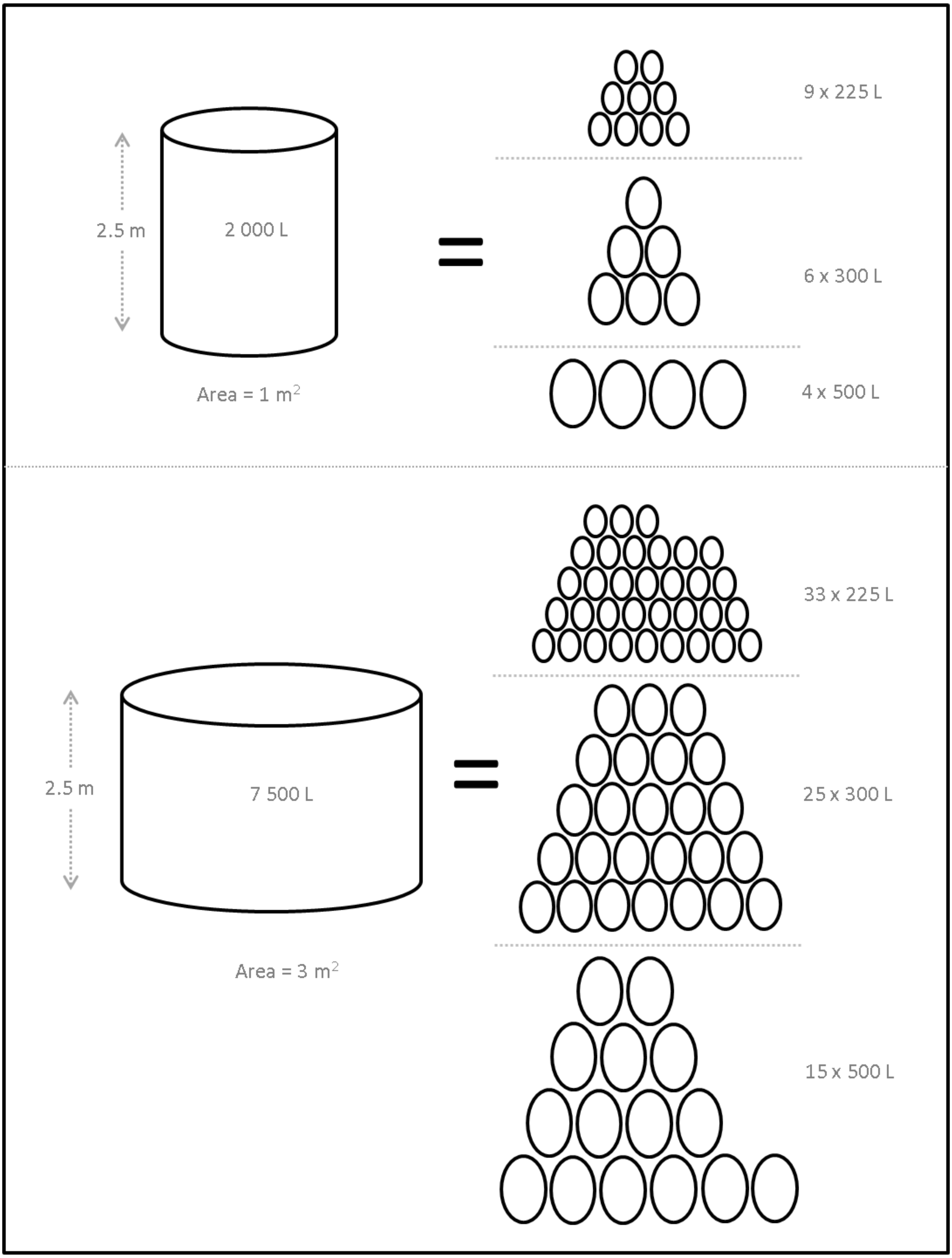

Figure 3.4 Schematic illustration of the different surface areas for different vessels

can be bottled (Woodard & Curran, 2006). These processes will most likely increase the water usage due to the preparation of the filter and the cleaning of the machinery after use.

A reduction to a moderate 87 m^3 in the water usage for week 21 was observed (Fig 3.3; Table 3.3). During week 21 the last grapes for 2012 were harvested and processed (Table 3.3), and the volume of grapes was very small (4 tons), therefore probably not influencing the total water usage significantly. During this week, 15 tanks were cleaned with caustic and citric acid and a small batch of wine was racked from the barrels adding to the water usage. A stock take was done in the winery on the 21st May - consequently the lack of water use on this day probably contributed to the decrease in average water usage for the week.

During the second sub-period (B) of the post-harvest (week 22 – week 30) the weekly water usage was moderate, ranging between 54 and 102 m^3 per week resulting in a total water usage of 720 m^3 (Fig 3.3; Table 3.3). Mainly barrel work was done during these weeks, filling and empting of the wine, from and into the barrels (Table 3.3). As a rule after the wine was racked from the barrels (taken out of the barrel), they are washed with a high-pressure system to ensure the barrels are free of all the lees and tartaric crystals formed during maturation (Basson, S., 2013), consequently increasing the water usage. The highest number of barrels were emptied and cleaned during week 28 and 30 (Table 3.3). These wines were then filtered, also contributing to the water usage.

Week 24 and 25 had the highest water usage (102 m^3 per week) during this period (Fig 3.3). The reason for this could be due to the new barrels that were filled with water (Table 3.3). Generally at Winery A, new wine barrels are filled with water to ensure that the wood swells and eliminate any possibilities of leaking. If there was a visible leak the barrels were refilled with water until the leaks sealed themselves. This practice undoubtedly increases the water usage of the winery.

During the mentioned two weeks a number of new barrels were prepared for filling with wine. Adding to the high water usage was the other winemaking activities taking place in the winery during this week including bottling, racking, and blending (Table 3.3).

The lowest water usages during sub-period B were in week 22 and 27 with values of 54 and 55 m^3 per week, respectively (Fig 3.3; Table 3.3). During these two weeks the work load was lower than the rest of this period (B) and the volume of wine that was racked from barrels was considerably lower. This could be an indication that the volume of the batches of wine that are processed, influences the volume of water used for cleaning. Figure 3.4 illustrates the influence of different barrel sizes on the water usage for cleaning. A higher number of smaller barrels being used for a specific volume of wine, invariably results in a higher volume of water used for cleaning due to a higher number of barrels used for the same volume of wine used in bigger volume barrels.

The 3rd sub-period (C) (week 31 to week 40) had a noticeable lower total water usage (401 m^3) ranging between 15 and 68 m^3 per week (Fig 3.3; Table 3.3). During this time the work load and volumes had decreased considerably compared to week 14. Generally, after alcoholic fermentation winemaking involves the maturation of the wine to develop structure and complexity. As a rule wine is matured in either oak barrels or in stainless steel tanks on the lees (Bason, S., 2013). In most cases while the wine is matured it is racked every three or four months to adjust the sulphur and to aerate the wine (Basson, S., 2013). With the first racking after the malolactic fermentation (possibly in week 14 – 21) the settled lees at the bottom of the vessel (tank or barrel) is thick and therefore increases the intensity of cleaning and water usage. The racking of the wine involves that the lees is separated from the wine and as a result the wine remaining produces less sediment thereafter. This will ensure that at the next racking (possibly in week 31 – 34) the amount of lees at the bottom of the tank will be less and consequently this simplifies the cleaning of the vessels after this racking. For this reason, each subsequent racking has a smaller influence on cleaning and thus water usages.

Wine was bottled during six of the 10 weeks of sub-period C (Table 3.3). Figure 3.5 shows the volume of wine bottled, overlaid on the water usage data. Generally, Winery A prepare (racking, blending, filtering) their wine for bottling during the preceding weeks, increasing the volume of the clean water used for cleaning after these operations. The bottling during this period and sub-period D are indicated by A, B and C, while A^1, B^1 and C^1 represents the preparation periods for each of these bottling periods (bottlings during sub-period A and the beginning of sub-period B were not included due to too many other non-bottling activities that took place while preparing for bottling and bottling). It can be seen from Fig 3.5 that there is an increase in the water usage at point A^1, B^1 and C^1 in the preparation of the blends compared to the slight decrease in water usage during the weeks of the actual bottling (Fig 3.5).

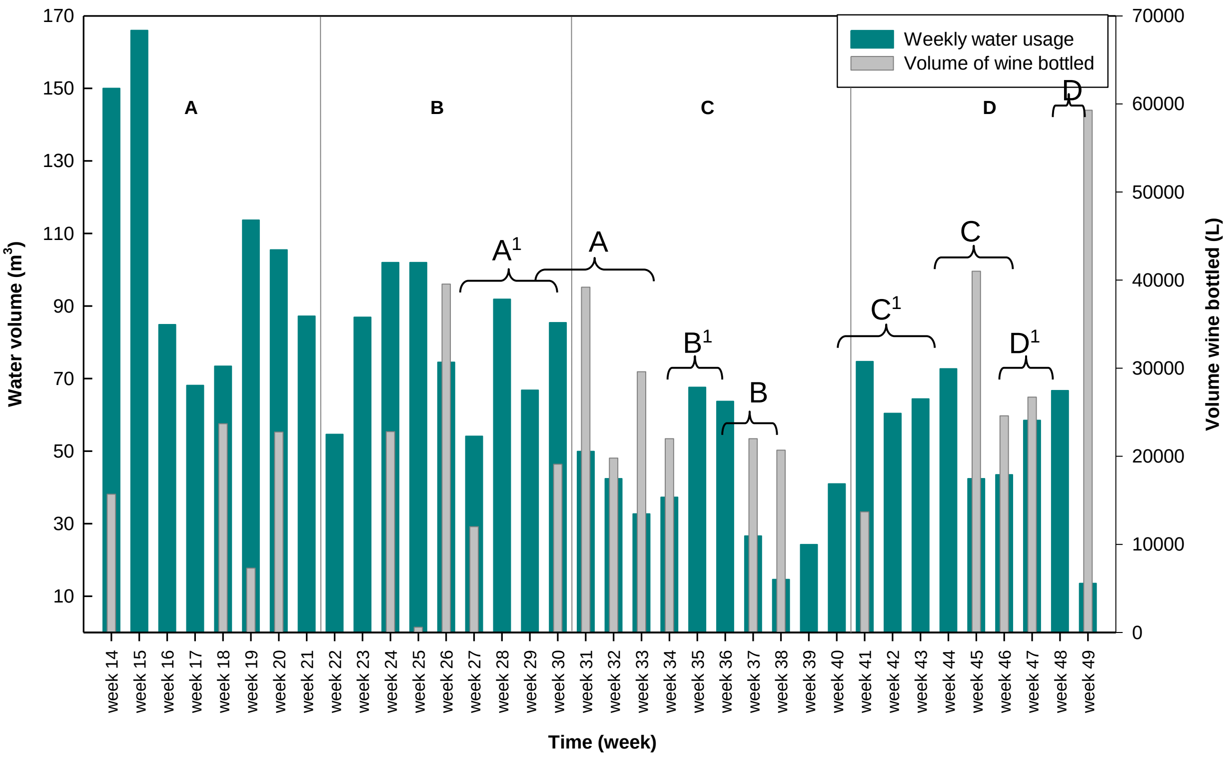

Figure 3.5 Weekly water usage and volume of wine bottled for the 2012 post-harvest period at winery A.

During the last sub-period (D) of the post-harvest season at Winery A (week 41 - 49) the water usage was moderate between 14 and 75 m^3 increasing the total water usage slightly (498 m^3) (Fig 3.3 and Fig 3.5; Table 3.3). The water usage had a steady increase from 61 m^3 in week 42 to 73 m^3 during week 44. This could be as a result of the preparation of the blends for the bottling's that started in week 45 and lasted till week 47 (C and C_1) . From week 41 to 44 wines were racked, blended and filtered, potentially increasing the water usage (Table 3.4). During week 46 to 48 a steady increase in the water usage can also be noticed, leading up to bottling of a large volume of wine in week 49 (D and D_1 on Fig 3.5).

3.4.1.3 Winery A – Harvest 2013

The 2013 harvest was the second harvest monitored at Winery A during this study. This harvest was monitored from the 28th January until 28th March 2013 (Fig 3.6; Table 3.4). The total harvest was 835 tons of which 48% were red and 52% were white grapes (compared to 745 tons, 40% red and 60% rosé and white in 2012), using 1 720 m^3 water with an average (indicated with X; Fig 3.6) of 39 m^3 per day. The water usage was monitored daily to investigate the correlation between winemaking practices and the volume of clean water used.

During the first week of harvest at Winery A (28 Jan – 3 Feb) the water usage rapidly increased from 23 to 59 m^3 and a total water usage of 220 m^3 for the week were recorded (Fig 3.6; Table 3.4). Pinotage grapes (46 tons), for making of the Rosé blend, and white grapes (140 tons) were also harvested during this week. After initial moderate water usage of 23 m^3 on 28 January the water usage almost doubled before the end of the week (Fig 3.6; Table 3.4). This increase could most likely be attributed to two reasons. Firstly, the flotation method was use for more effective and faster sedimentation of the solids in the fresh juice (Table 3.4). Due to the gelatine that is used in this process, a film is left behind in the tank increasing the intensity of cleaning, therefore, increasing the water usage. Secondly the work load and volumes of grapes processed increase during the week from no grapes on the 28th, 46 tons on the 29th; 54 tons on the 30th and lastly 69 tons on the 31st January. The Friday to Sunday (1 – 3 Feb) contributed to 27% (60m^3) of the weekly water usage (220 m^3) possibly due to the high volume of white grapes that was processed on the 31st Jan – 1st Feb. The high volume of settled white juice was racked and inoculated in the proceeding days increasing the cleaning demand (Fig 3.6; Table 3.4). The water usage (60 m^3) of the weekend following the first week was the highest of all the weekends during the 2013 harvest however, slightly lower than the highest (76 m^3) water use over weekends from the 2012 harvest (Fig 3.1; Fig 3.6). The higher water usage during this weekend could be due to the high volume of Rosé produced during this week and the increased workload during the weekend and the red fermenting tanks that needed pump-overs.

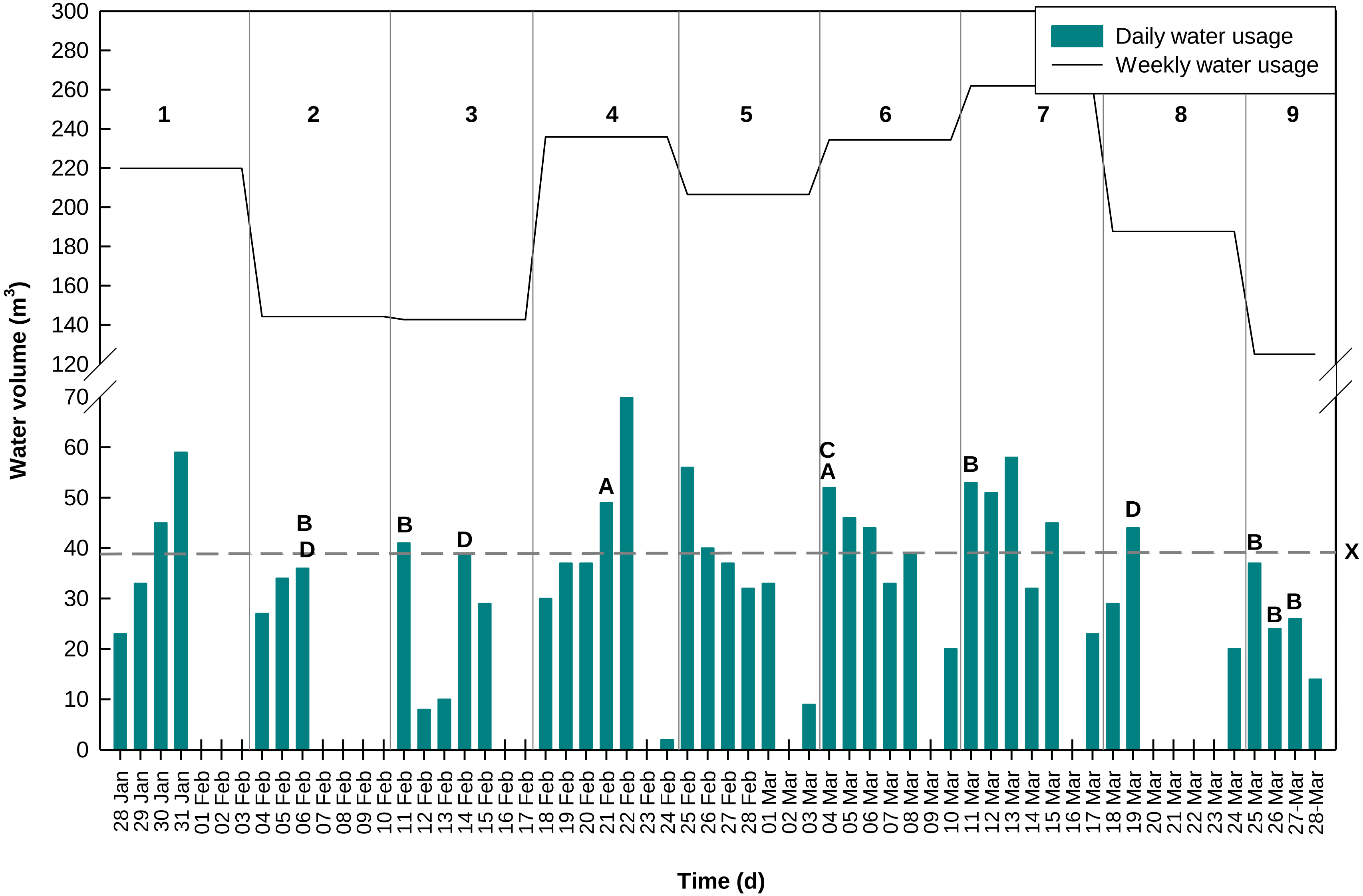

Figure 3.6 Daily and weekly water usages at Winery A for the 2013 harvest season. (Activities indicated with A: filter; B: bottle; C: high work load; D: barrel washing and X indicates the average daily water use)

Table 3.4 Daily and week (Monday to Friday) water usage of the winery and the associated winemaking activities during the 2013 harvest at Winery A (Bason, S., 2013

DATE	WATER USAGE (m^3)	ACTIVITIES IN WINERY
28-Jan	23	Cleaning
29-Jan	33	HWR, rack, flotation
30-Jan	45	HWR, rack, flotation
31-Jan	59	HW, flotation
04-Feb	27	HW
05-Feb	34	HW, rack
06-Feb	36	HW, rack, E barrels, rack OV, bottle
11-Feb	41	Bottle, cleaning
12-Feb	8	Press R, cleaning
13-Feb	10	Rack OV, E barrels OV, F barrels OV
14-Feb	39	Rack OV, E barrels OV
18-Feb	30	HW, E barrels, Rack OV
19-Feb	37	HW
20-Feb	37	HW
21-Feb	49	HR, rack, filter
22-Feb	79	HW, rack
24-Feb	2	Weekend
25-Feb	56	HWR, press R, floatation
26-Feb	40	HW, rack , flotation
27-Feb	37	HW, rack
28-Feb	32	Rack, press R
01-Mar	33	HR, rack, blend
03-Mar	9	Weekend
04-Mar	52	HW, rack, filter, press R
05-Mar	46	HWR, rack , press R
06-Mar	44	HWR, rack
07-Mar	33	HR, rack, F barrels
08-Mar	39	HR
10-Mar	20	Weekend
11-Mar	53	HR, rack CV, press R, bottle
12-Mar	51	HR
13-Mar	58	HW
14-Mar	32	HR, rack, rack OV
15-Mar	45	HR, rack, press R, F barrels
17-Mar	23	Weekend
18-Mar	29	HR, press R
19-Mar	44	HR, press, E barrel
24-Mar	20	Weekend
25-Mar	37	HR, rack, bottle
26-Mar	24	
27-Mar	26	HWR, bottle
28-Mar	14	HR, press R

HW – white grapes harvested; HR – red grapes harvested; HWR – white and red grapes harvested; Press R – red fermenting grapes pressed; OV – older vintage; E barrels - emptied barrels; F Barrels – fill barrels; EF barrels – emptied and fill barrels

A slight decrease in the total water usage (145 m^3) can be seen during the second week of harvest (4 – 10 Feb) with daily water usage ranging between 27 and 36 m^3 (Fig 3.6; Table 3.4). The tons of grapes processed during this week (63 tons in total) were lower than the previous week (186 tons), and this could be the reason for the decrease in water usage compared to week 1. On 6 February barrels were emptied and cleaned with the high pressure system possibly adding to the slightly higher water usage (Fig 3.6; Table 3.4). Apart from this, wine was also bottled on the 6th February adding to the cleaning water used (Fig 3.6; Table 3.4). The reason for the lower water usage during the second weekend including Thursday (8 – 10 Feb) of the harvest compared to the first weekend (1 – 3 Feb) could be due to the noticeably lower volumes of white grapes (8 tons) processed during the last days of the second week in compassion to 91 tons in the first week. As mentioned previously, white grape processing requires more cleaning water than red. A slight decrease in water usage during the weekend can be noticed from the first (60 m^3) to second (48 m^3) weekend. This could be due to no pump-overs required during this weekend.

From Figure 3.6 it can be seen that the 3rd week (11- 17 Feb) had fluctuations in the daily volumes of water used in the winery but the total weekly water usage stayed relatively unchanged (142 m^3). This week started with a high water usage of 41 m^3 on the 11th and decreased the following two days to below 10 m^3 and then increased rapidly again on the 14th (Table 3.4). No grapes were processed during this week (Table 3.4). The high water usage on the 11th could be attributed to bottling of wine (Table 3.4) that took place on this day increasing the water used for cleaning (Fig 3.6). The decrease in water usage during the next day (12th Feb) could possibly be due to the fact that there were limited activities in the winery, with only one tank of red grapes being pressed and a few cleaning activities taking place (Table 3.4). On the 13th the water usage stayed low, with only a small volume older vintage (OV) wine being racked from the barrels and then returned to the barrels after they had been cleaned (Table 3.4). As discussed in the previous section (Post-harvest 2012) it is most likely that the number of barrels cleaned, influenced the volume of clean water used. The smaller amount of barrels used in 2013 camparred to 2012, resulted in a smaller surface area to clean and therefore a smaller volume of water is needed for cleaning. The last day (14th) of this week saw the water volume increase again to almost 40m^3 (Table 3.4). During this day a larger batch of wine was racked from the barrels and therefore more barrels were cleaned with the high-pressure system increasing the water usage (Fig 3.6). The water usage during the weekend (16 – 17 Feb) was the lowest (44m^3) since the beginning of the 2013 harvest (Fig 3.6). This could be due to the fact that no grapes were processed during this week resulting in a lower work load during the weekend.

During the fourth week (18 – 24 Feb) of the 2013 harvest the water usage started with a moderate 30 m^3 on the 18th and steadily increased over the next 3 days to 49 m^3 on the 21st and then rapidly increased to just below 80 m^3 on the 22nd with a weekly total of 236 m^3 (Fig 3. 6; Table 3.4). On the 18th of February the water usage was moderate and the racking of barrels most likely attributed to the volume of 30 m^3 water used for cleaning and the high tonnage (40 tons) of grapes harvested could possibly also add to the volumes used (Table 3.4). During the next two days (19 – 20 Feb) the water usage increased slightly to 37 m^3 (Fig 3.6; Table 3.4). On the 18th, 39 tons of white grapes were processed and had to be racked and inoculated on the 19th possibly increasing the water usage. Moderate volumes of grapes were also processed on these two days (19th and 20th Feb) contributing to the water usage (Fig 3.6). The increase on the 21st of February could be due to wine that was filtered (Fig 3.6; Table 3.4). The initial setup of the bulk filter requires a substantial amount of water before the wine is filtered, and this possibly increased the water usage (Basson, S., 2013). On the 22nd of February the water usage was the highest during the 2013 harvest (Fig 3.6) even though the volume of grapes harvested on this day was very low with only two tanks racked. The high water use can most likely be attributed to the practise of filling barrels with water (to achieve wood swelling) in preparation of the barrel filling of wine scheduled for the following week. The weekend following the fourth week was the weekend with the lowest water usage (2m^3) during the 2013 harvest at Winery A. When taking this week's activities in consideration it would have been suspected that that water usage during this weekend would have been higher. It is also possible that the work and cleaning ethics changed since the 2012 harvest resulting a lower water usage during 2013 however.

During the next three weeks (week 5 to 7) the weekly water usage increased gradually to week 7 when the highest weekly water usage was measured at 260 m^3 with the daily water usage on average higher than the rest of the harvest with an average of 43 m^3 per day ranging from 32 – 58 m^3 (Fig 3.6; Table 3.4). These three weeks could be considered as the peak of the harvest with the highest work load and more than 40 % of the grapes being processed in these weeks. During these three weeks there was only one day on which no grapes were processed, and this coincided with the lowest water usage for the week of 32 m^3 on 14th Mar (Fig 3.6; Table 3.4). Throughout these three week 350 tons were processed and other activities (included processing of grapes, racking of vessels and filtering) that occurred during this period and possibly contributed to the water usage and lastly bottling (Fig 3.6). On the 4th March, additional to the 17 tons of white grapes that was processed, nine tanks were also filtered. This contributed to the higher (52 m^3) than average the water usage (Fig 3.6; Table 3.4). Comparing the water usage from the 4th and the 5th March - the main difference was the nine tanks that were filtered on the 4th and a small volume of red grapes were processed compared to three tanks racked on the 5th. From week five onwards white grapes were processed in the beginning of the week ensuring that the rackings and inoculations took place before the weekends decreasing the workload over the weekends. For this reason the water usage during the weekends of week five onwards considerably lower (9, 20 and 23 m^3) than those of the first three weeks of the 2013 harvest ranging between 44 to 60 m^3 per weekend. Activities that occur on weekends include pump-overs of the red fermenting tanks and pressing of red fermenting tanks if necessary. Generally, no grapes were processed and no wine was bottled over weekends, with only the most essential activities being performed (Basson, S., 2013). The three weekends during this time had an increase in the water usage (9 m^3; 20m^3; 23 m^3). This could bet due to the high volumes of red grapes processed during this weeks and therefore increasing the workload during the weekends.

Week eight (18 – 24 Mar) had a slight decrease in the weekly water usage (190 m^3) and had moderate to high water usage ranging from 29 and 44 m^3 could be noticed (Fig 3.6; Table 3.4). The 21st March (Thursday) was a public holiday and the person responsible for the water meter readings was on leave, therefore there were only three readings taken for this week. On the 18th and 19th red grapes were processed. Although the tons of grapes processed on the 18th (31 tons) were five times more than on the 19th (6 tons), the difference is not reflected in the water usage on these days (29 vs. 44 m^3, respectively). This was most likely a result of the large volume of wine that was racked from barrels on the 19th which resulted in a higher demand for clean water to wash the barrels (Fig 3.6; Table 3.4). The weekend water usage could not be calculated for the weekend following week 8 due to lack of water meter readings taken during this week.

During week nine (25 – 28 Mar) the total water usage was low, ranging from 14 to 37 m^3 (Fig 3.6; Table 3.4). On the 25th the water usage was the highest during this week, and this could be due to the bottling that took place on this day (Fig 3.6; Table 3.4). During the rest of this week the work load and grapes processed decreased gradually. This could be the reason for the lower water usage on the 26th and 27th even though bottling occur.

3.4.1.4 Winery B – Harvest 2012

During the 2012 harvest the water usage of the winery was monitored and the results were compared with the daily winery activities to observe the influence of winemaking practices on the water usage. However, unfortunately the water meter also measures the water used by the guest house, restaurant and the tasting room therefore, the water meter readings are only indications of the influence of the winery activities on the water usage. The 2012 harvest at Winery B started on the 2nd of February (Thursday) and ended on 29 March lasting 9 weeks in total (Fig 3.7; Table 3.5). Winery Bharvested 376 tons of grapes of which 73% were red and 27 % were white grapes, using 875 m^3 water with an average (Fig 3.7) of 19.7 m^3 per day.

Figure 3.7 summarises the water usage at Winery B for the 2012 harvest season. The first week of the harvest at Winery B (2 – 5 Feb) had only one water usage reading taken, due to the fact that no reading was taken on Saturdays during the 2012 harvest but the weekly water usage was measured at a low 50 m^3, thus predicting that the average daily water usages would also have been low (Fig 3.7; Table 3.5). The water usage for the 2nd of February was a low 10 m^3 for the day (Table 3.5). This was the first day of harvesting and a small volume (3 tons) of white grapes were processed and wine was bottled (Table 3.5). No activities other than this took place on this day therefore the water was only used for the bottling and cleaning of the processing cellar at the end of the day. The water usage calculated for the weekends during the 2012 harvests include the water usage of the Friday before the weekend due to lack of water meter readings on the Satudays. The high (40m^3) water usage during the weekend following the first weekend most likely was due to the white grapes

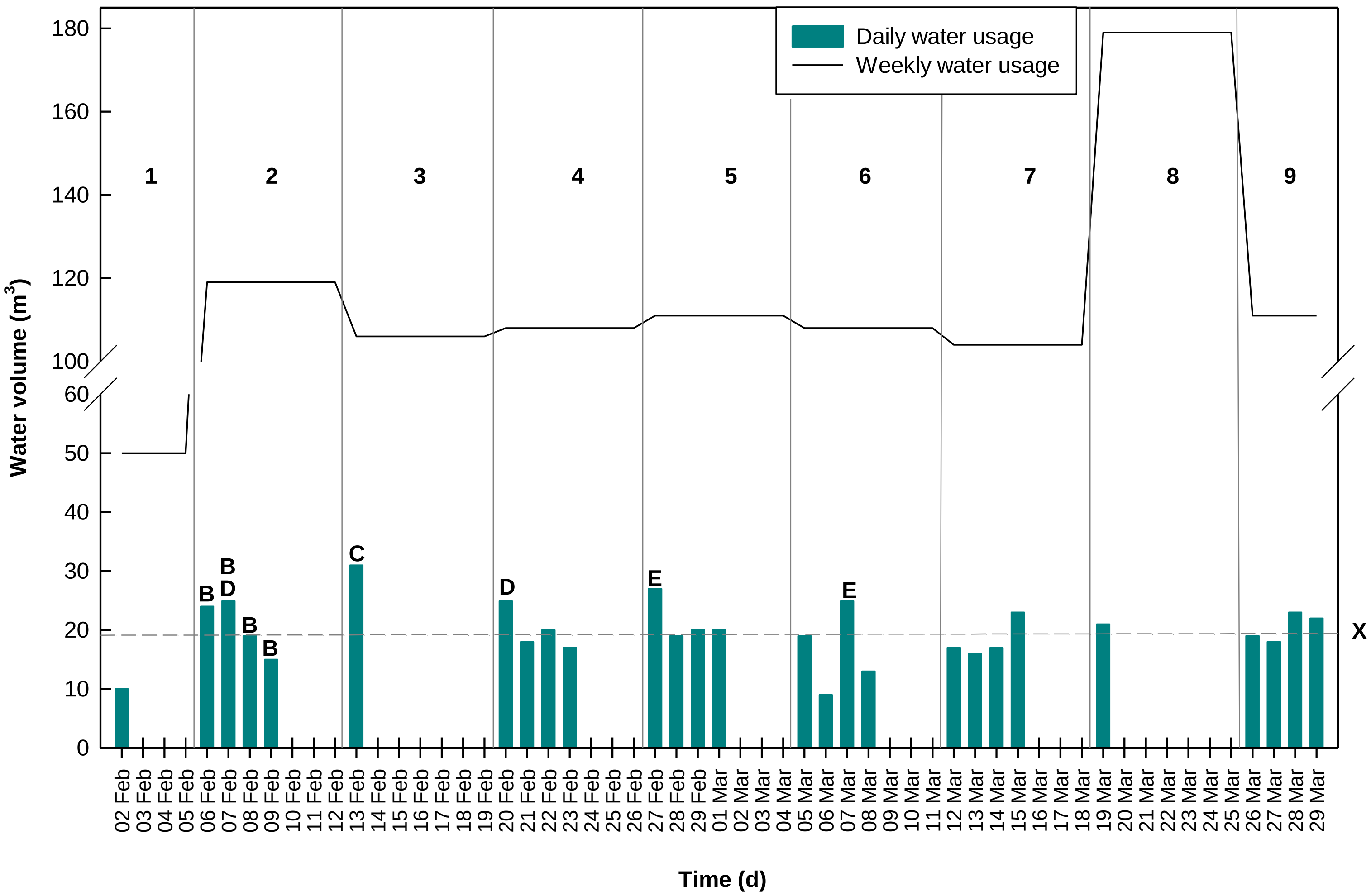

Figure 3.7 Daily and weekly water usage at Winery B for the 2012 harvest season. (Activities indicated with B: bottle; C: high work load; D: barrel washing'; E: white and red grapes processed on the same day and X indicates the average daily water use)

Table 3.5 Daily (mid week Monday to Thursday) Water usage of the winery and the associated winemaking activities during the 2012 harvest at Winery B (Ngamane, P., 2013).

DATE	WATER USAGE (m^3)	ACTIVITIES IN WINERY	DATE	WATER USAGE (m^3)	ACTIVITIES IN WINERY
02-Feb	10	HW, bottle OV	07-Mar	25	HWR, rack, cleaning
06-Feb	24	HW, rack, blend OV, bottle OV	08-Mar	13	HR, press R
07-Feb	25	HW, No press W, E barrels, bottle OV, rack OV,	12-Mar	17	HR, caustic tanks
08-Feb	19	Press W, bottle OV, load bulk	13-Mar	16	HW, rack, filter
09-Feb	15	Bottle OV, load bulk	14-Mar	17	HWR, rack
13-Feb	31	HW, rack, rack OV	15-Mar	23	HR, press R, rack, blend
20-Feb	25	Rack, E barrels OV	19-Mar	21	HR, rack, press R
21-Feb	18	HW	20-Mar	-	HR, press R, rack
22-Feb	20	HW, rack OV, blend OV	21-Mar	-	Rack
23-Feb	17	Press W , blend OV	22-Mar	-	HR, press R, rack
27-Feb	27	HWR, rack	23-Mar	-	HR, press R, rack
28-Feb	19	HW, rack, load bulk	24-Mar	-	Press R, rack
29-Feb	20	HW, rack	26-Mar	19	HR
01-Mar	20	HW, rack, F barrels	27-Mar	18	Press R
05-Mar	19	HR, rack	28-Mar	23	HR, rack
06-Mar	9	HR, rack, F barrels	29-Mar	22	HR, press R, rack, blend, cleaning

HW – white grapes harvested; HR – red grapes harvested; HWR – white and red grapes harvested; Press R – red fermenting grapes pressed; OV – older vintage; E barrels - emptied barrels; F barrels – fill barrels; EF barrels – emptied and fill barrels

processed on the Friday (3 Feb) resulting in increased cleaning on the Friday and cleaning on the weekend due to racking of the white juice processed on the Thursday (2 Feb) and Friday (3 Feb).

During the second week (6 – 12 Feb) of harvest 120 m^3 of water was used an increase in the weekly water usage can be noticed. The daily water usage started with a high value of almost 25 m^3 and then steadily decreased to 15 m^3 (Fig 3.7; Table 3.5). Throughout this week, wine was bottled and prepared for future bottling while 28 tons of white grapes were processed (Fig 3.7; Table 3.5). As a rule the bottling of wine uses more clean water to ensure that the bottles were washed before filling and for the cleaning of the emptied tanks. This most likely contributed to the high water usages on the 6th – 8th February. Furthermore, wine from a number of barrels was racked on the 7th and together with the cleaning of the barrels with the high pressure cleaning system, contributed to the water usage (Fig 3.7). The following day (8th Feb) white grapes were pressed that had been processed on the 7th and thus, the cleaning of the press contributed to the water usage on the 8th (Fig 3.7; Table 3.5). The last monitored day (9th) of this week had the lowest water usage of the week (Fig 3.7; Table 3.5), most likely due to the fact that no grapes were processed (Table 3.5). When the water usage from the Monday (6 Feb) to Thursday (9 Feb) is deducted from the total water usage of week 2 it shows that the water usage for the last 3 days (Friday and the weekend) was 36 m^3. It is possible to say that the activities (processing 11.5 tons of white grapes) would produce the same volume wastewater than other days that only white grapes were processed. Even though the weekend following week two's water usage decrease slightly (36 m^3) from the first weekend (40 m^3) it still representative of the white grapes that was processed on the days preceding the weekend (9 and 10 Feb).

Figure 3.7 shows that only one water usage value was measured during week 3 (13 – 19 Feb) and this was also the highest daily value of the 2012 harvest adding to a total of 109 m^3 of the week. During this week 3 measurements was taken however, they were not taken on three consecutive days therefore, only one water usage could have been calculated. On this day (13th Feb) 31 m^3 of water was used (Table 3.5). Activities that possibly contributed to the water usage were the processing of white grapes and racking of wines (Table 3.5). This was also the day with the highest volume (11 tons) of white grapes processed on one day during the 2012 harvest (on Fig 3.7). This could be the reason for the increase in water usage due to the small capacity of the press, therefore the press was used more than once and after each cycle was cleaned to ensure the optimum results.

During the rest of the week 19 tons of white grapes were processed and racking of the settled white juice were done over the weekend. When the weekly water usage was taken into consideration the average daily (Tuesday – Saturday) water usage could be calculated as 12.5 m^3 per day compared to the previous weeks daily average water usage of 17.1 m^3. The main difference between the second and third week were the bottling activities that took place in the second week, resulting in the higher (120 m^3) water usage in week 2.

Due to a lack of water meter reading during week three, a weekend water usage could not calculated for the third weekend. However, it is possible to say that a decrease from the previous weekend's water usage would be expected due to the lower volumes of white grapes harvested on the days preceding the weekend.

During week 4 of the 2012 harvest at Winery B, (20 – 26 Feb) the daily water usage was moderate ranging from 17 to 25 m^3 per day resulting in a total of 108 m^3 for the week (Fig 3.7; Table 3.5). The 20th started with a high water usage (25 m^3) and this could possibly be due to the barrels that were racked and cleaned (Table 3.5) with the high-pressure system Fig 3.7). As mentioned in the above section the washing of barrels increases the water usage. The 21st – 22nd February were the only two days, during this week that grapes were processed, contributing to the water usage (Table 3.5). A slightly lower water usage was noticed on the 23rd most likely due to the fact that no grapes were processed and therefore decreasing the amount of cleaning (Fig 3.7; Table 3.5). Even though no grapes were processed on the 23rd, white grapes were pressed which were destemmed the previous day, adding to the water usage (Fig 3.7; Table 3.5). The water usage during this weekend (24 – 26 Feb) was the lowest (28 m^3) since the beginning of the 2012 harvest. This could be due to the decrease in the tonnage of white grapes that was processed during the end of the week (3.9 tons) compared to the first (5.3 tons), second (17.5 tons) and the third (8 tons) weeks. The lower tonnages of white grapes processed closer to the weekend results in a decrease in the work load over the weekend and therefore, decreased water usage.

Table 3.5 shows that during the fifth week (27 Feb – 4 Mar), a combination of white and red grapes were processed on the same day. The water usage during this week started with a high volume of 27 m^3 on the 27th decreasing to more moderate values (19 – 20 m^3) for the rest of the week and the weekly water usage stayed constant compared to the two previous weeks (111 m^3) (Fig 3.7; Table 3.5). The higher than usual water usage on the 27th could be due to the red and white grapes that were harvested on the same day, requiring more cleaning at the end of the day (Fig 3.7). Over the next three days (28th Feb – 1st Mar) only small volumes (2.7, 1.9 and 1.1 tons) respectively of white grapes were processed, including racking of the previous day's settled juice (Table 3.5). These general practices and low volumes of grapes could be the reason for the moderate (19 – 20 m^3) use of water on these days (Fig 3.7) compared to 13 Feb when 11.3 tons of white grapes were processed. The smaller volumes of white grapes also resulted in low water usage (24 m^3) during the weekend that followed. This was due to a smaller demand for cleaning of the equipment used. The water usage of the weekend following week five is a reflection of the low work load during this weekend. Even though white grapes were processed on the days preceding (1 and 2 March) the weekend no red grapes were processed compared to week four.

During week 6 (5 – 11 Mar) the daily water usage fluctuated between 9 m^3 on the 6th to a high of 25 m^3 on the 7th contributing to a weekly water usage of 108 m^3 (Fig 3.7; Table 3.5). On the 5th March a small volume (4.6 tons) of red grapes were processed and a number of tanks were racked, resulting in a moderate water usage (19 m^3) (Fig 3.7; Table 3.5). On the 5th, 6th and 8th March only red grapes were processed, resulted in low to moderate water usages (Fig 3.7; Table 3.5). When red grapes are processed the grapes are crushed and destemmend and then pumped directly into a stainless steel tank for fermentation. Therefore, less cleaning takes place on the 1st day compared to white grapes where the press is also used (Fig 3.3). The high water usage on the 7th was most likely attributed to the processing of a combination of white and red grapes increasing the demand for cleaning (Fig 3.7). The weekend after the sixth week the water usage was higher than the previous 2 weekends (Fig 3.7). This was most likely due to the red grapes that were processed on the Saturday (10 Mar). As a norm grapes are only processed on weekdays at Winery B, but sometimes weekend harvesting is required when large volumes of the correct ripeness of grapes cannot all be harvested during the week.

The seventh week (12 – 18 Mar) of the 2012 harvest had water usage that was moderate with a slight increase towards the end of the week with values ranging from 16 to 23 m^3 and a weekly water usage of 104 m^3 (Fig 3.7; Table 3.5). On the 13th March only four tons of white grapes were processed compared to the 22 and 32 tons of red grapes processed on the 12th and 14th, respectively. This again clearly illustrate that red grape processing initially uses less water than white grapes processing (Fig 3.2), as larger tonnages (22 and 32 tons) of red grapes resulted in similar water usage (17 m^3) for a low tonnage of white grapes (4 tons – 16 m^3). Even though wine was filtered on the 13th the water usage remained low, most likely due to membrane filtration that is used by Winery B and requires less clean water for cleaning (Ngamane, P., 2012). The increase in the water usage on the 15th was most likely due to two reasons (Fig 3.7; Table 3.5). Firstly, a number of red fermenting tanks were pressed and therefore increased the demand for water to clean the press after use. And lastly, a blend was made on the 13th that involved a number of tanks being used, resulting in more tanks than usual to be cleaned. The weekend following week seven had a water usage of 31 m^3. This is most likely due to the high volume of red grapes processed during the preceeding week resulting is an increase in pump-overs.

Only one value (21 m^3) for the daily water usage was taken during week 8 (19 – 25 Mar) (Fig 3.7; Table 3.5). This was due to a public holiday on the 21 March and no other water meter readings being taken either. The weekly water usage was measured at 179 m^3. This was the highest weekly water usage during this Winery B harvest. The average daily water usage for this week (Tuesday 20th – Saturday 24th) was thus 32 m^3. Red grapes (31 tons) were processed during this week and other activities including racking, pressing of red tanks and filtering (Table 3.5) also took place. These activities are all activities that results in moderate water usage however, when the number of times these activities are undertaken increase, the water usage will also increase. During this week nine red fermenting tanks were pressed and 60 tons of red grapes were processed. Monday the 19th had a high water usage of 21 m^3 including activities such as processing of red grapes, racking and pressing of red fermenters (Table 3.5), all of which require in high water usage. It was also noted that on Friday 23 March the Manor House of the estates swimming pool was cleaned and re-filled, accounting for approximately 70 m^3 of water. This was most likely the main contributor for the high water usage during this week.

During the ninth week (26 Mar – 1 Apr) of harvest the weekly water usage was 111 m^3 and the daily water usage was moderate to high ranging from 19 to 22 m^3 (Fig 3.7; Table 3.5). This was the last week of the 2012 harvest in which grapes were processed (Table 3.5). Red grapes were processed during this week, except on the 27th, when no grapes were harvested (Table 3.5). On this day a number of red fermenting tanks were pressed, increasing the water usage slightly (Fig 3.7). The 29th March was the last day of harvesting and a thorough cleaning of the processing cellar started increasing the demand for clean water and therefore adding to the water usage.

3.4.1.5 Winery B – Post-harvest 2012

During the post-harvest period (week 14 – 49), the water usage was determined, while the activities of the winery were monitored (Fig 3.8). This was done to investigate the correlation between the post-harvest activities and the water usage. During this period the winery was closed for several these weeks (week 32 – 34 and week 43 – 44) consequently, no water was used in the winery and only maintenance was done. However, as the water meter used to measure the water use also measures water used by the guest house, restaurant and tasting room, there was always water being used. The average weekly usage by the non-winery activities was 22 m^3 per week (indicated on with Y, Fig 3.8). Total water usage was 1 670 m^3 with an average (indicated with X on Fig 3.8) of 25.7 m^3 per week. The post-harvest season was divided into four sub-periods (A – D) for discussion purposes.

The first sub-period ‘A’ started the week after harvest, and spanned weeks 14 to 21 with a total water usage of 526 m^3 (Fig 3.8). This was the sub-period with the highest water usage during the post-harvest period (Fig 3.8). After an initial high water usage (108 m^3) during week 14 the water usage decreased to more moderate volumes ranging from 41 to 84 m^3 per week (Fig 3.8; Table 3.6). During the weeks after harvest (week 14 – 15) intense cleaning of the winery was done contributing to the higher water usages (Fig 3.8; Table 3.6). Mostly during this sub-period wine was racked after the completion of the second fermentation (malolactic fermentation (MLF) (Table 3.6). The lees formed from MLF is thicker compared to the lees of wine later in the wine production cycle due to repetitive racking’s resulting in a reduction in the amount of sediment in the wine. As a consequence of the thick lees, the intensity of cleaning and demand for clean water was noticeably higher during sub-period A compared to than the following two sub-periods (B and C). During week 20 no barrels were emptied and this was most likely the reason for the decrease in water usage (Fig 3.8; Table 3.6). The increase in water usage (52 m^3) during week 21 could be due to the blend that was prepared during this week (Fig 3.8; Table 3.6). A number of vessels were used when preparing the blend, thereby increasing the surface area for cleaning and therefore a higher demand for clean water.

During the second sub-period ‘B’ of the post-harvest season at Winery B (week 22 – 34) the water usage was low to extremely low ranging between 13 and 44 m^3 per week (Fig 3.8; Table 3.6). Mainly rackings and blending of wine was done throughout this period (Table 3.6). In most cases the wines had undergone their first rackings during the first sub-period 'A’ and therefore the lees was

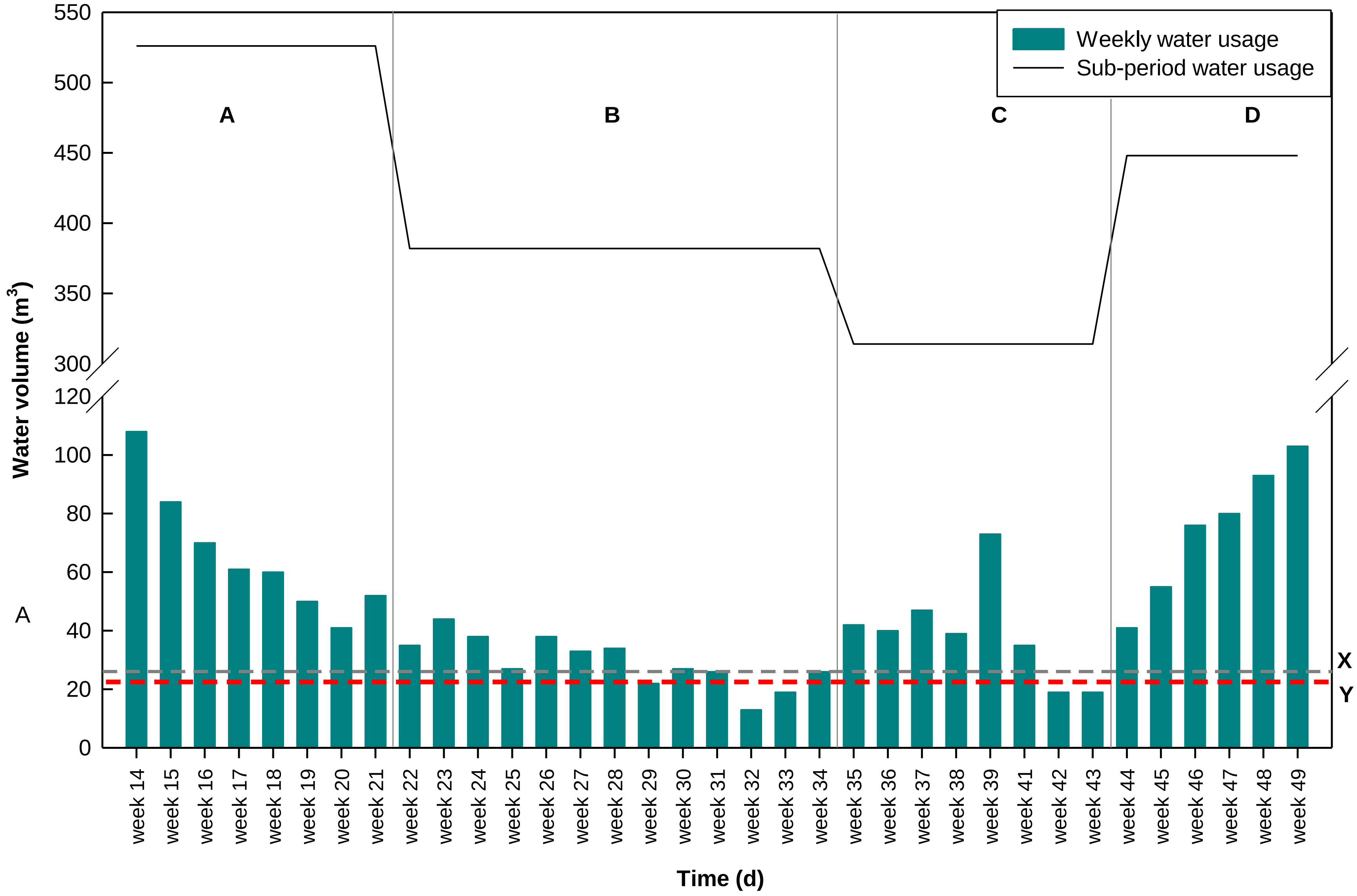

Figure 3.8 Weekly water usage at Winery B for the 2012 post-harvest season. (X indicating average weekly water usage).

Table 3.6 Weekly water usage of the winery and the associated winemaking activities during the 2012 post-harvest at Winery B (Ngamane, P., 2013).

DATE	WATER USAGE (m^3)	ACTIVITIES IN WINERY	DATE	WATER USAGE (m^3)	ACTIVITIES IN WINERY
Week 14	108	Rack, post-harvest activities	Week 32	13	no cellar work with water
Week 15	84	Rack, cleaning	Week 33	19	
Week 16	70	Rack, EF barrels	Week 34	26	
Week 17	61	Rack, EF barrels	Week 35	42	Rack, blend, EF barrels
Week 18	60	Rack, EF barrels	Week 36	40	Rack, blend, filter, EF barrels,
Week 19	50	Rack, EF barrels	Week 37	47	Rack, filter, F barrels, bottle
Week 20	41	Rack	Week 38	39	Rack, E barrels
Week 21	52	Rack, blend, E barrels	Week 39	73	Rack, EF barrels
Week 22	35	Rack, F barrels	Week 40	39	Rack, EF barrels
Week 23	44	Rack, EF barrels,	Week 41	35	Rack, EF barrels
Week 24	38	Bottle, EF barrels	Week 42	19	no cellar work with water
Week 25	27	EF barrels	Week 43	19	
Week 26	38	Blend, EF barrels	Week 44	41	F barrels
Week 27	33	Rack, EF barrels,	Week 45	55	Rack, EF barrels
Week 28	34	Rack	Week 46	76	Blend, filter
Week 29	22	Rack	Week 47	80	Filter, bottle
Week 30	27	Rack	Week 48	93	EF barrels
Week 31	26	Rack, high pressure the walls	Week 49	103	Rack EF barrels, bottle

E barrels - emptied barrels; F Barrels – fill barrels; EF barrels – emptied and fill barrels thinner and easier to clean, thus using less water and therefore lowering the water usage. The low water usage during weeks 28 – 31 could possibly be due to the fact that no barrel work was done during these weeks (Fig 3.8; Table 3.6). The last three weeks (week 32 -34) of this sub-period no water was used by the winery (Table 3.6).

The third sub-period 'C' (week 35 – 43) during the post-harvest season the water usage was moderate ranging between 35 and 73 m^3 per week with a total water usage of 353 m^3 (Table 3.6). During this period, mainly blending and fining was done for wine that was to be bottled in the last quarter of the year (Table 3.6). Barrel work was done during the majority of the weeks except in week 37 which was also the week in this sub-period with the highest water usage (47 m^3) (Fig 3.8; Table 3.6). The increase in water usage during week 37 was most likely due to the bottling that took place. The number of batches of wine racked from the barrels during this sub-period (35 – 42) varied immensely and reflects in the water usages throughout the different weeks. A sum of nine different batches of wine was racked from the barrels throughout weeks 35 and 36 showing an increase in the water usage (Fig 3.8). During week 38 only 3 batches of wine were racked and in week 39 with the lowest water usage just one batch of wine was racked. The following weeks (40 and 41) two batches were racked per week increasing the water usage slightly (Fig 3.8). During the last two weeks of sub-period C, no water was used by the winery.

The water usage increased from 41 to 103 m^3 during the last sub-period D (week 44 – 49) of the year with a total water usage of 448 m^3 (Fig 3.8; Table 3.6). This increase could be attributed to two main reasons. Firstly, the work load increased slightly towards the end of the year to ensure all the necessary wine is bottled and out of the cellar in preparation for the 2013 harvest. Secondly, the increasing visits of tourists to the wine farm in the South African summer season could be contributing to the water usage of the tasting room and the restaurant (Shultz, C., 2012). The increase in water usage from week 44 to 45 was due to the racking and blending of the largest single volume red blend from Winery B, the Cabernet Sauvignon Shiraz (Fig 3.8; Table 3.6). This blend consisted of 134 barrels and all the barrels were emptied and washed during this week increasing the demand for clean water. During week 46 and 47 a number of tanks were filtered and prepared for bottling in week 47 increasing the water usage. Week 48 shows the continued increase of water usage towards the end of the year attributed to activities such as emptying of barrels (3 batches) and filling of barrels (2 batches) (Fig 3.8). The last monitored week for the year was the second highest water usage during the post-harvest season. A number of tanks were racked and wine was bottled increasing the water usage (Fig 3.8; Table 3.6).

3.4.1.6 Winery B – Harvest 2013

The 2013 harvest was the second harvest at Winery B to be monitored during this study. This harvest started on the 30th of January 2013, 4 days earlier than 2012 and lasted 9 weeks in total, until the 2nd of April 2013. The first water meter reading was monitored during the second week of the 2013 harvest but for discussion purposes will be indicated as week one in Fig 3.9. The water meter also

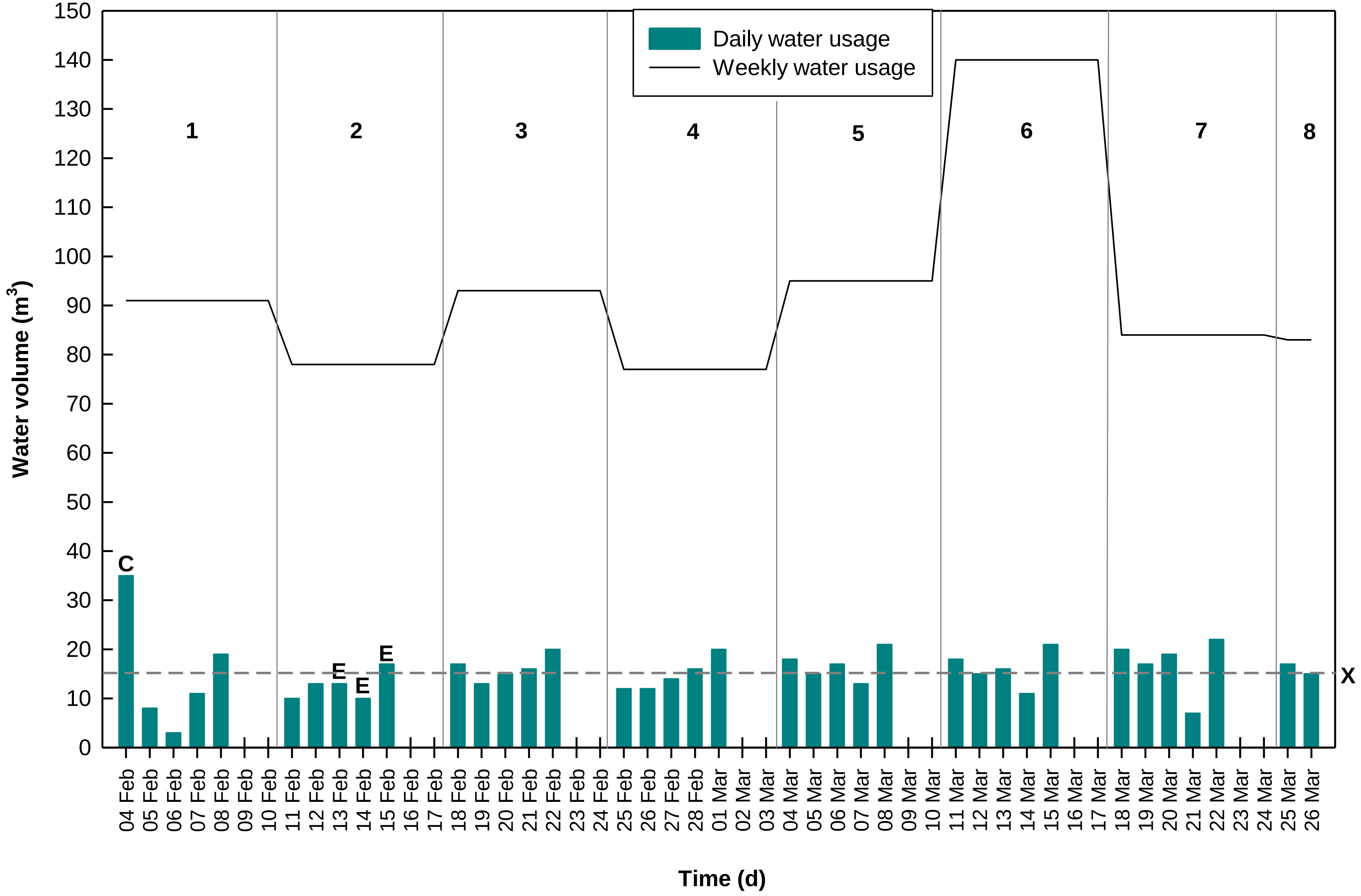

Figure 3.9 Daily and weekly water usages at Winery B for the 2013 harvest season. (Activities indicated with C: high work load; E: white and red grapes processed on the same day and X: average daily water use).

Table 3.7 Daily midweek (Monday to Friday) water usage of the winery and the associated winemaking activities during the 2013 harvest at Winery B (Ngamane, P., 2013).

DATE	WATER USAGE (m^3)	ACTIVITIES IN WINERY	DATE	WATER USAGE (m^3)	ACTIVITIES IN WINERY
04-Feb	35	HW, rack	04-Mar	18	HR, R press
05-Feb	8	HW	05-Mar	15	HR, R press
06-Feb	3	Rack, E barrels	06-Mar	17	HR, rack
07-Feb	11	HW, rack	07-Mar	13	Rack, F barrels
08-Feb	19	HW, F barrels	08-Mar	21	HR, rack, F barrels
11-Feb	10	Rack OV, bottle	11-Mar	18	HR, rack
12-Feb	13	Rack OV, F barrels	12-Mar	15	HR
13-Feb	13	HWR, F barrels	13-Mar	16	HR, R press
14-Feb	10	HWR	14-Mar	11	HR, R press, rack
15-Feb	17	HWR, routine cleaning	15-Mar	21	HR, R press
18-Feb	17	R Press, rack	18-Mar	20	HR, R press, rack
19-Feb	13	HWR, F barrels	19-Mar	17	HR, R press, rack
20-Feb	15	HWR, rack	20-Mar	19	HR, R press, rack
21-Feb	16	HW, rack	21-Mar	7	Rack
22-Feb	20	HW, F barrels	22-Mar	22	HR, F barrels
25-Feb	12	Rack	25-Mar	17	R press
26-Feb	12	HW, F barrels	26-Mar	15	Rack, R press
27-Feb	14	HW, R press, F barrels	01-Apr	14	Rack, R press
28-Feb	16	HW, rack, blend	02-Apr	15	R press
01-Mar	20	HR, R press			

HW – white grapes harvested; HR – red grapes harvested; HWR – white and red grapes harvested; Press R – red fermenting grapes pressed; OV – older vintage; E barrels - emptied barrels; F Barrels – fill barrels; EF barrels – emptied and fill barrels

measures the water used by the guest house, restaurant and the tasting room which average around 22 m^3 per week. The total grapes processed in 2013 were 430 tons of which 82% were red and 18% were white (compared to 376 tons, 73% red and 27 % white in 2012) using 658 m^3 water with an average (Fig 3.9) of 15.5 m^3 per day. An in-depth discussion will follow.

During the first week (4 – 10 Feb) the initial water usage was high (35 m^3) and then rapidly decreased, before increasing again and ending the week with a moderate volume of 19 m^3 (Fig 3.9). The weekly water usage was 91 m^3. The volumes ranged from below 5 to 35 m^3 per day (Fig 3.9; Table 3.7). The high volume of water used on the 4th can most likely be attributed to the 12 tons of white grapes processed on this day (Fig 3.9), increasing the water used for cleaning of the press. On the 5th, a much smaller volume of grapes (2.2 tons) was processed resulting in a reduction of the water usage (Fig 3.9). Also, no additional cellar work was done on this day. The low water usage on 6th was probably due to the fact that no grapes were processed and only a few barrels were racked and cleaned (Fig 3.9, Table 3.7). The water usage on the 8th increased to 19 m^3 and this could most likely be due to the additional cleaning done on Fridays. The water usage for the weekend following the first week was relatively low (15 m^3) taking in consideration that on the two days preceding the weekend high volumes (14 tons) of white grapes were processed. This could be due to the awareness of water usage in the winery after the 2012 water usage study.

The second week (11 – 17 Feb) of the harvest had water usage that was low, with a slight increase towards the end of the week, with values ranging from 10 to 17 m^3 per day during this week resulting in a total water usage of 78 m^3 (Fig 3.9; Table 3.7). The 11th of February was the only Monday during the 2013 harvest that the water usage was below 12 m^3 (Fig 3.9). No grapes were processed on this day and the water was mainly used during bottling (Table 3.7). During the last three days of this week (13 – 15 Feb), a combination of red and white grapes were processed (Fig 3.9). The ratio of white to red grapes was very small, influencing the water usage only slightly. The increase on the 15th could possibly be due to the cleaning that was done on this Friday. The water usage for the weekend after the second week stayed constant compared to the first weekend even though the volume of white grapes processed decreased (with 45%). However on the two days preceding the weekend 20 tons of red grapes were processed increasing the work load in terms of pump-overs during the weekend.

Throughout the rest (week 3 – 8) of the harvest the water usage was 10 and 20 m^3 per day with week 6 registering with the highest water usage (140m^3) during this harvest. During week 6, 43 % of the grapes were processed. This week was also the only week during this harvest that grapes were processed on a Saturday (16 Mar), significantly adding to the weekly and weekend water usage. Normally processing of grapes only happens on 5 days of the week but during this week huge amounts were processed daily (average 30.9 ton) for six days resulting in processing 185 tons in total increasing the total water usage of the week. Adding to this was the increase ine pump overs of red wine during this weekend (16 – 17 Mar). Figure 3.9 shows that the water usage was only on one occasion (21st March, week 7) lower than 10 m^3 (Table 3.7). This could be a result of the fact that no grapes were processed on this day and only one tank of wine was racked decreasing the demand for clean water (Table 3.7). Throughout the 2013 harvest it can be seen that the water usage was the highest on Fridays (Fig 3.9). This could most likely be the result of the routine cleaning that was done on Fridays. The water usage was only slightly lower than 20 m^3 on the first two Fridays – this could be due to the lower work load in the beginning of the harvest, requiring less cleaning.

3.4.2 Comparison of seasons and wineries

3.4.2.1 2012 Harvest vs 2013 Harvest - Winery A

During the 2012 harvest at Winery A the average daily and weekly water usage was 27 m^3 and 177 m^3 respectively with the total water usage throughout this period being 1 597 m^3. The total tonnage for this harvest was 745 tons (40% red and 60% white grapes). During the 2012 harvest it was observed that mainly three practices influenced the high water usage of the winery. These practices are indicated on Figure 3.1 and include filtering of wine with a bulk filter (Fig 3.1), bottling wines (Fig 3.1) and barrel emptying and cleaning (Fig 3.1). Lastly, it appears that Mondays often had a higher water usage due to the extra cleaning work, which was neglected over weekends. During the first two weeks of harvest the average water usage was higher, most likely due to the Rosé wine that was made including the flotation and centrifuging processes.

The total water usage for the 2012 post-harvest period at Winery A was 2 465 m^3 (week 14 to week 50) with a weekly average of 67 m^3. During the post-harvest period it was observed that mainly 3 activities or periods influenced the high water usage of the winery. Firstly, in the beginning of the first sub-period (A), during this time the last stages of the harvest were processed (pressing of last fermenting tanks) and an in-depth cleaning of the cellar was done after the harvest. These two practices both involve the extensive use of water. Adding to this was the processing of a few small batches of grapes during sub-period A, most likely resulting in a slightly higher weekly water usage than the other three sub-periods (Fig 3.3) especially when the Late Harvest grapes (white grapes) were processed. Secondly, the racking of the red wine after MLF had a big influence on the water usages during sub-period B due to the initial thick lees that accumulated at the bottom of the wine tanks and had to be washed out – requiring more water. And lastly Fig 3.5 shows the influence of preparing and fining the wine to be bottled, which increases the water usage. This generally occurs in the week prior to bottling (Fig 3.5).

Table 3.8 A summary of the highest and lowest water usage, total water usage, tons harvested and water usage per ton of grapes harvest for Winery A and Winery B during the study period.

	WATER USAGE			GRAPES HERVESTED	WATER USAGE PER TON GRAPES
	HIGHEST (m^3)	**LOWEST (m^3)**	**TOTAL VOLUME (m^3)**	**TOTAL TONS (t)**	**AVE WATER/TON (m^3t^{-1})**
Winery A					
Harvest 2012	67	17	1 597	745	2.14
Post-harvest 212	166	14	2 465		
Harvest 2013	79	8	1 720	835	2.05
Winery B					
Harvest 2012	31	9	875*	376	2.5
Post-harvest 212	108	13	1 670		
Harvest 2013	35	3	658	430	1.5

* excluding volume of water used for cleaning of swimming pool

The average daily water usage for the 2013 harvest at Winery A was 28 m^3, weekly water usage 191 m^3 and the total volume of water used during this harvest was 1 720 m^3 (Table 3.8). On one occasion the daily water usage was more than 60 m^3 during the fourth week (Fig 3.6; Table 3.4). While the lowest water usage (<10 m^3) was in the third week (12th Feb) (Fig 3.6; Table 3.4). The water usage (1 720 m^3) of the 2013 harvest was slightly higher (7%) than the 2012 harvest (1 597 m^3) with an increase of 12% in grapes processed (Basson, S., 2013). The increase of the water usage could be due to the increase in grapes processed. Adding to this, the following practices most likely also contributed to the water usage and are indicated on Fig 3.6, including barrel washing. During 2012 the high pressure system was only used for barrel washing and in the 3rd quarter of 2012 the system was installed throughout the winery to be used for all cleaning purposes. Therefore, the 2013 harvest was the first harvest that the high pressure system was used for cleaning throughout the winery. This could be the reason for the slightly smaller increase (7%) in water usage compared to the 12% increase in volume of grapes processed. This could be due to smaller amounts of water needed to clean with the high pressure system. This is also reflected in the lower calculated average water used for a ton during and 2013 (2.05 $m^3.t^{-1}$) compared to 2012 (2.14 $m^3.t^{-1}$) (Table 3.8).

3.4.2.2 2012 Harvest vs 2013 Harvest – Winery B

During the 2012 harvest at Winery B the average daily and weekly water usage was 18 m^3 and 97 m^3, respectively with the total water usage throughout this period being 875 m^3. On only one day during the harvest was the water usage more than 30 m^3 (13 Feb) (Fig 3.7; Table 3.5). The lowest water used (9 m^3) was in the sixth week (Fig 3.7; Table 3.5). During the 2012 harvest it was observed that a few practices influence the higher than average water usages of the winery. These practices are indicated on Figure 3.7 and include processing big volumes of white grapes (Fig 3.7), tending to initially use more water on the first day of processing than days when a combination of red and white (Fig 3.7) and when, only red grapes were processed. The days that only red grapes were processed generally show lower water usage. Lastly, cleaning of barrels also contributed to the increase in water usage (on Fig 3.7).

The average weekly water usage for the post-harvest season at Winery B was 47.7 m^3 (Fig 3.8) and the total volume of water used 1 670 m^3 (week 14 – week 50). It was observed that sub-period B (Fig 3.7) had the lowest average weekly water usage during this season. This could be due to the decrease in visits to the wine estate and restaurant during the South African winter decreasing the water usage. The increased water usage during the other 3 (A, C and D) sub-periods could possibly be due to a few specific activities that took place. During the sub-period A (Fig 3.8) of the post-harvest the average weekly water usage was the highest most likely due to the intense cleaning after the harvest and the racking of the wines that was finished with MLF. During the second last sub-period C (Fig 3.8) the water usages most likely increased due to the preparation of the wine that was bottled in the last sub-period D (Fig 3.8). And lastly, the increase in water usage during the last sub-period (D) could be attributed to two reasons. Firstly, the increase in work load before the next harvest and secondly the increase in visits to the wine estate and restaurant during the South African summer could potentially increase the total water usage of the estate.

During the 2013 harvest at Winery B the average daily and weekly water usage was 13 m^3 and 82 m^3 respectively with the total water usage throughout this period being 658 m^3. The highest volume of water (35 m^3) was used during the first day of harvest (4 Feb) and the lowest (3 m^3) was also in the first week (Fig 3.9; Table 3.7). The total water usage was 25% lower (Table 3.8) compared to the 2012 harvest with an increase of 14% in grapes processed (Ngamane, P., 2013). When Figure 3.9 is studied it can be seen that on Mondays and Fridays the most water was used possibly because of more cleaning that was done.

Table 3.8 shows the difference in the water used and tons processed between the two harvests at Winery B. During the 2013 harvest at Winery B the water usage decreased noticeably from the 2012 harvest, while the tonnage increased by 10% (Schultz, C., 2013). During the 2013 harvest there were 14 days that the water usage was under 15 m^3 per day compared to the 3 days in 2012 and only four days that the water usage exceeded 20 m^3 compared to the 10 days in 2012 (Table 3.5; Table 3.7).

3.4.2.3 2012 Harvest vs 2013 Harvest - Winery A and B

The difference in tons processed at Winery A and Winery B could be argued to have an effect on the water usage, but when the average water usage per tons processed are calculated in Table 3.8 it shows that Winery B uses noticeably less water per ton of grapes than Winery A during the 2013 harvest. Apart from this, Table 3.8 also indicates that the increase in tonnage processed does not mean an increase in water usage. On the contrary the water usage per tons processed decrease slightly from the 2012 to the 2013 harvest at Winery B despite an increase in tons processed (Table 3.8).

The low water usage at Winery B is a result of the implementation of a cleaner production strategy in 2003 which has been constantly re-evaluated since then (Shultz, C., 2013). This together with the awareness of the water used during the 2012 harvest resulted in even lower water usage during the 2013 harvest at Winery B.

The number of different varieties could also influence the water usage of a winery. Winery A produces wine from 15 different varieties compared to Winery B, which only uses seven. This plays a role when the grapes are processed. At Winery A there a number of days that the processing of red and white grape on the same day is taking place compared to Winery B. Generally white grapes ripen a few weeks before the red grape varieties but at Winery A not only do they process Pinotage (an early ripening red variety) but they also produce Rosé wine from the Pinotage grapes, thus harvesting even earlier. This results in a bigger demand for cleaning due to the risk of contaminating the white juice with the red colour. This can happen when equipment (pipes, pumps or press) was used to pump red juice or wine, therefore it is necessary to thoroughly clean, most likely with caustic, further increasing the water usage. During both harvests at Winery B the majority of the white grapes were processed before the red grapes was processed.

Winery B have recently re-coated the entire winery's floor ensuring cleaning to be more efficient (Fig 3.10). The surface of the floor is smooth and sweeping the grapes skin and spilled lees is done with more success, reducing the amount of clean water needed to rinse the floor. Winery A's is a much older winery and even though some of the floors have been repaired in the past, the tanks are too close to each other therefore it is not possible for a staff member to clean the floors underneath the tanks first before rinsing. This result in more water needed to clean.

Figure 3.10 Recoated floors of Winery B: A) processing cellar; B) barrel cellar.

3.5 Conclusions

When the data from Winery A and Winery B was studied it is evident that water plays an integral role in the day to day activities in a winery. Water was used throughout the entire wine production cycle during the year. The harvest period contributes up to 40% (Winery A) and 30% (Winery B) of the yearly water usage. The majority of winemaking activities had a direct influence on the volumes of water used and a smaller number of activities had an indirect influence.

In this study it was identified that Winery B used a smaller volume of water on a daily basis and per tonnage during harvest than at the Winery A (Table 3.8). The lower water usage of Winery B indicates that their strategy towards cleaner production is helping in reducing the water usage of the winery. There are mainly four practices that Winery B uses that improve their water use efficiency. The first and most important practice is the implementation of a cleaner production strategy. This ensures that all the winery employees are constantly striving to use less water and increases awareness. Adding to this is the commitment of the management at Winery B to reduce the water usage from year to year.

The second practice that was indicated by this study, to help reduce the water usage at Winery B, is membrane filtration rather than bulk filtration with filtering aid (DE). The membrane filter decreases the volume of water needed for preparing the filter before use and cleaning after the wine has been filtered. The membrane filter is used on all of Winery B's wines.

Another practice that showed to decrease the demand of clean water is the dry sweeping of the floors and the inside of the tanks before washing with water. This ensures a smaller volume of water needed to wash the floors and tanks. Lastly, the water saving nozzles fitted on all the hosepipes throughout the winery. Not only does this increase the pressure of the water emerging from the pipe but also ensures that no water is wasted when the pipes are not in use. These nozzles are checked regularly to increase the effectiveness.

However, there are also a number of changes that involve long term planning and that will most probably involve capital input. When the grape processing data of the two wineries was compared it can be noticed that Winery B rarely processed white and red grapes in the same week or even more specifically on the same day. This helps to lower the demand for cleaning and therefore uses less water. The ideal would be if a winery can make wine from different varieties that ripen at different stages. This is not always possible at larger wineries due to the fact that their product list is generally more extensive than specialist wineries such as Winery B.

The winery floors at Winery B were re-coated with an epoxy coating. The smooth surfaces of the floors decrease the cleaning intensity and reduced the volume of water needed to wash the floors. The financial implication of this application can be high and not always viable for all wineries.

Not only is there an increase in the demand for clean water when wine is bottled but the increase in water usage prior to the bottling is obvious. The different steps that wine undergoes to be ready for bottling, involves racking, fining and filtering. Extra attention should be paid to the planning and timing of these practices and where possible should be done longer in advance before bottling to reduce the high demands of water on certain days.

Adding to the planning, where possible the winemaker should try to decrease the cleaning requirements on Monday by doing the necessary cleaning tasks over the weekend to ensure less cleaning activities on Mondays. This study also showed that a high pressure cleaning system decreased the demand of clean water needed for cleaning.

Lastly, it is highly recommended that all the personnel of the wineries should be involved in the strategies to reduce water usage.

Therefore, it is possible to say that certain activities can make a noticeable difference in the water usage of wineries during the harvest and post-harvest season. These activities include using brushes and squeegees for sweeping of the floors before washing; washing equipment directly after use; cross flow membrane filtration rather than conventional bulk filtration and using a water safety nozzle on the water pipes to avoid wastage of water as a hose will not run when not required. Implementation of these practices can significantly reduce a wineries water use.

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CHAPTER 4

INFLUENCE OF WINEMAKING PRACTICES ON THE CHEMICAL CHARACTERISTICS OF WINERY WASTEWATER

4.1 Summary

Raw and treated winery wastewater was monitored from two wineries during a period of 15 months, including two harvests and one post-harvest season. Firstly the effect of the winemaking practises on the raw wastewater characteristics was investigated. Secondly the efficiency of an existing constructed wetland in treating the wastewater and the subsequent chemical characteristics of the treated wastewater were evaluated. Not only was it discovered that there was a variation in the chemical characteristics of the two wineries raw wastewater, but also a major difference when comparing the two harvests of the respective wineries. Chemical oxygen demand (COD) values as high as 14 724 $mg.L^{-1}$ was measured from winery A during the 2012 harvest whereas winery B only measured 6 614 $mg.L^{-1}$ as the highest value. This indicated that certain winemaking practises could influence the chemical characteristics of the raw wastewater. Both wineries also showed a decrease in the COD concentrations from the 2012 harvest to the 2013 harvest, confirming that awareness plays a part in the cleaner production. The overall pH of winery B was also lower than winery A, possibly because of the cleaning chemicals that were used possibly also increasing the COD of the raw wastewater. The decrease in the raw wastewater COD over this period showed promising results when a cleaner production plan is established and managed.

4.2 Introduction

Winemaking is a major agricultural activity around the world and produced 252.9 x 10^6 hL wine in 2012, with South Africa one of the top eight wine producing countries of the world (OIV 2014). South Africa is a growing wine producing country and the wine industry has grown by 42% since 1997 from 5.5 x 10^6 hL in 1997 up to 8.7 x 10^6 hL in 2012 (SAWIS, 2013).

Winemaking is seasonal and the most activities occur during the harvest period typically Jan to April in South Africa (Guglielmi *et al*., 2009). Throughout the year the pollution load varies in relation to the different processes taking place (Arienzo *et al*., 2009) producing large volumes of polluted wastewater. Winemaking generates different residues characterised by high concentrations of biodegradable compounds and suspended solids (Rodriquez *et al*., 2007). The four biggest contributors to the pollution of the wastewater are 1) product residues (skins, stems sludge, tartar); 2) loss brut production (must and wine due to spillage and from washing of equipement); 3) products used for wine treatment (fining agents and filtration earths) and lastly 4) cleaning products (NaOH and KOH).

An analysis into the average characteristics of winery wastewater showed that there are noticeable differences in wastewater generated around the world ranging from 340 to 49 105 mg.L

$^{-1}$ COD (Bustamante *et al*., 2005; Mosse *et al*., 2011). Furthermore, wastewater also differs from one winery to another regarding the volume and composition and therefore it is vital for detailed characterisation of the wastewater to fully understand the problem before managing it (Mosse *et al*., 2011)

The variance in winery wastewater composition complicates the issue to find a general solution for the wastewater treatment at different wineries (Andreottola *et al*., 2009). Chapman *et al.,* (1996) suggested that the most cost effective manner to treat winery wastewater is by avoiding and minimising the waste generated. Adding to this, implementing cleaner production strategies to reduce the organic material in the generated wastewater, including practices such as installing mesh sieves, use of fining agents that produce the most compact lees and keeping wine transfers to the minimum to name a few (Chapman *et al*., 1996).

The different influences of the various winemaking practises were investigated to establish whether cleaner production practises have a positive effect on the chemical characteristics of winery wastewater. In addition to this a study was done to investigate the influence of the size of a wetland in changing the characteristics of the wastewater through treatment.

4.3 Materials and methods

In the Stellenbosch winelands, winery wastewater was collected from two wineries at Winery A and Winery B (the same as in the 3rd chapter), both of which use existing constructed wetland treatment systems. They are both medium size wineries situated approximately 8 km apart.

Winery A, consisting of 150 ha of vineyards, situated high up on the south-western slopes of the Simonsberg Mountain.

Winery B is situated on the free draining North-eastern slopes of the Bottelary hills. There is a difference in altitude of some 250 m between the Northern and Southern vineyards.

4.3.1 Wastewater treatment systems

4.3.1.1 Winery A

The winery's raw wastewater exits the cellar at 'A' (Figure 4.1) where a mechanical screen separates the grape pips and skins from the water and by gravity flows to a pit (B). The pit (B) has a volume of 15 m^3 and collects the wastewater before being pumped on a daily basis or when full to a Delta separator (C and D). The Delta separator consists of two parts: C - the pH is checked and adjusted daily with lime (CaO) and Urea ($CO(NH_2)_2$) before entering D. The undissolved lime and filter powder settles to the bottom of the Delta separator before the winery wastewater flows by gravity through three 10 m^3 bioreactors (E). The bioreactors serve to aerate the wastewater and lower the COD partially. After the biological oxidation, the water again flows by gravity into two settling tanks (F) of 5 m^3 each. In the settling tanks, (F), 6 m^3 sewage are added into the wastewater every day. The settling tank stage gives the bacterial biomass chance to settle out before the water enters the wetlands. The first section of the wetland consists of two 60 x 5 x 0.5 m units (G). After the wastewater has passed through the first wetland, it accumulates in a tank (H) from where it is pumped to an additional smaller wetland (I) (20 x 3 x 0.5 m). The final point of the system is at (J), where the water accumulates before the "treated wastewater" is pumped into a dam. The dam water is used at a later stage for irrigation of the vineyards.

Figure 4.1 Aerial photo of the constructed wetland next to the Winery A, AfriGIS(PTY) LtdGeoEye (2013).

4.3.1.2 Winery B

Winery B strives to work as conservatively as possible with water and an effort is made to minimise the pollution load of the wastewater that leaves the cellar. Winery B has a number of practices in place to minimise or prevent any grape skins and pips from entering the wastewater system. The philosophy is that the sooner solid organic material is separated from the wastewater the less polluted it will be and the easier to treat (Shultz, C., 2012).

The wastewater that leaves the winery (Point A, Fig 4.2) enters a pipeline (B) together with the grey and sewage water from the restaurant, two houses and the estate offices to accumulate at (C). In an effort to increase the microbial load, the grey and sewage water are added to the winery's wastewater. When the pit (C_{1}, Fig 4.3) is full, the wastewater is pumped to a screening station (C_2). This station allows the water to flow over a 2 mm screen into a 20 m^3 pit to enable settling of organic material in the wastewater. When this 20 m^3 pit is full the wastewater flows through six exit points to six different pits (C_3), in the wetlands. At this point, the wastewater flows over a few layers of 30 mm stone chips to maximize the area for biofilm growth, and so increasing the contact area for micro-organisms before it flows into the 65 ha wetland. The treated wastewater leaves the wetlands at (E) into the irrigation dam that is used for irrigation of the vineyards.

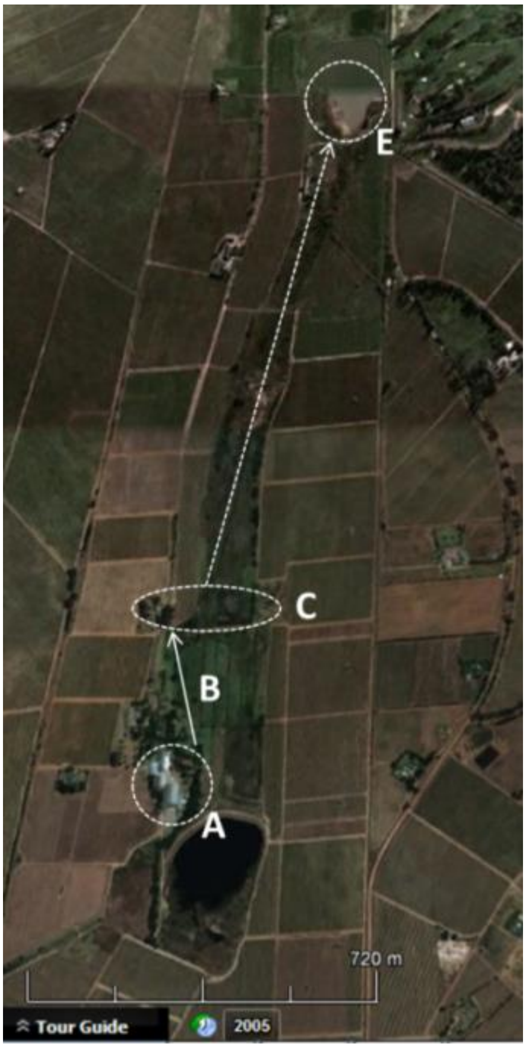

Figure 4.2 Aerial photo of the constructed wetland from the exit point at the Winery B, AfriGIS(PTY) Ltd GeoEye (2013).

Figure 4.3 Enlarge aerial photo of point C from Figure 4.2, Winery B, AfriGIS(PTY) Ltd GeoEye (2013).

4.3.2. Sample collection

The sampling was done from January 2012 until the end of April 2013. During this period two harvests (2012 & 2013) were monitored, as well as the post-harvest season after the 2012 harvest. During harvest (end January until end March) the raw winery wastewater was characterised by daily samples taken from the wineries on weekdays (Monday to Friday). At Winery A, the raw (unsettled) wastewater grab sample was obtained at point B (Fig 4.1), every weekday at the same time. The pit is the collection point for the wastewater produced in the winery and is pumped out every day at the same time or when it reached its full capacity. At Winery B the raw (unsettled) wastewater samples were collected four times a day (weekdays) at the wastewater exit point of the winery (A) and combined to form a composite sample for that specific day.

The pH of the raw wastewater samples was measured directly after the samples were taken at the particular wineries and stored at 2 – 4°C until collection. The daily samples were collected from the wineries every morning at 08:00, transported to the laboratory and stored at 2 – 4°C for 3 hours. The sedimentation of the organic material (grape skins and pips) happened during this interval in the refrigerator, to simulate what happens with the wastewater at the winery when it undergoes screening before treatment. The wastewater used for the analysis was drawn from the settled raw samples, to make certain that no solid organic material was present. This also ensured that the duplicate samples for the COD correlated with each other.

During the post-harvest (Apr 2012 to middle Jan 2013) period, the composite wastewater sample was analysed only on a weekly basis. The daily samples of 100 mL were collected in the same manner as during harvest, except that they were frozen at -18°C until analysed. Once a month, these frozen samples were collected from the winery, transported to the laboratory, and analysed. The day before analysis the samples were left overnight in a refrigerator (5 °C) to thaw. Daily samples of a week, once thawed, were pooled to form a weekly composite sample. The same chemical characterisation, as done during harvest, was done on these composite samples, except that the pH was only measured after pooling the thawed samples.

To determine the efficiency of the wetlands in terms of COD and the influence on the pH, samples were taken of the treated water on a weekly basis. The samples were collected from the exit point of the Winery A wetland (point J – Fig 4.1) and the point where the treated water enters the holding dam at Winery B (point E – Fig 4.2). These grab 'treated wastewater' samples were collected and analysed once weekly from February 2012 until April 2013. During the post-harvest period the treated wastewater samples were frozen at the wineries, directly after sampling, at - 18°C. These samples were then analised on a monthly basis similar to the raw wastewater samles.

The following chemical parameters were analysed: COD and pH according to methods defined in 'The Standard methods for the examination of water and wastewater 20th Edition' (APHA 1998). The soluble COD was measured colorimetrically using a DR 2000 spectrophotometer. All COD analyses were done in duplicate. The average of the two samples were used/

4.3 Results and discussions

4.3.1 Variation of wastewater chemical characteristics throughout the wine production cycle

4.3.1.1 Winery A – Harvest 2012

COD

During the 2012 harvest, the wastewater COD was determined, while the activities of the winery were monitored. A comparison was made between the COD results and the daily activities, to determine the influences of the winemaking practices on the COD of the raw wastewater. Harvest started on 30 January 2012 and the last recorded date of harvesting was 28 March 2012 – processing 745 tons of grapes during this time. Forty percent of the grapes harvested were red, the rest being varieties for rosé and white wine. There is an immense difference in the winemaking techniques of red and white wine. The rosé wine-making technique is very similar to white wine wine-making and therefore the data for the Rosé production has been included under the white wine-making in further discussions. During harvest the fresh sample was collected daily from the wineries every morning at 08:00 and transported to the laboratory and stored at 2 - 4°C for 3 hours till analysed.

Figure 4.4 shows the daily COD concentration and pH of raw and treated wastewater at Winery A during the 2012 harvest. Values recorded on specific dates are the characteristics of the wastewater generated by the cellar activities on the preceding day

During the first week of harvest at Winery A (30 Jan – 5 Feb) the raw wastewater had a moderate COD of between 6 139 and 8 920 mg.L^{-1} (Fig 4.4; Table 4.1). For making a Rosé blend, mainly Pinotage grapes were harvested during this week. After an initial wastewater COD of 7 808 mg.L^{-1}, the COD dropped to 6 139 mg.L^{-1} and then increased throughout the week. This increase in COD can most likely be attributed to two reasons. Firstly, the flotation method that was used for the first time (to decrease the clarification time of the grape juice). Due to the use of gelatine in this process, a film is left behind in the tank, which is more difficult to clean, thereby adding to the organic material and subsequently a higher COD in the wastewater. Secondly, from 1 – 2 February (Table 4.1), wine from a previous vintage was racked and filtered, thereby contributing to an increase in the COD (Fig 4.4; Table 4.1).

Treated wastewater COD at the end of week 1 was 1 300 mg.L^{-1}. According to the COD value, it could be confirmed that the quality of the wastewater complied with irrigation requirements. For kikuyu irrigation up to 50 m^3 per day the COD was within the beneficial irrigation limits (< 5 000 mg.L^{-1} (DWAF, 2004).

The second week (6 Feb – 12 Feb) showed noticeable COD variations, ranging from 3 887 to 8 537 mg L^{-1} (Fig 4.4; Table 4.1). One of the five days had a COD concentration below 5 000 mg L^{-1}. February 5th was a Sunday, and generally minimal cellar activities occur on Sundays. In contrast with the non-harvest season, harvest might require work performed on any day of the

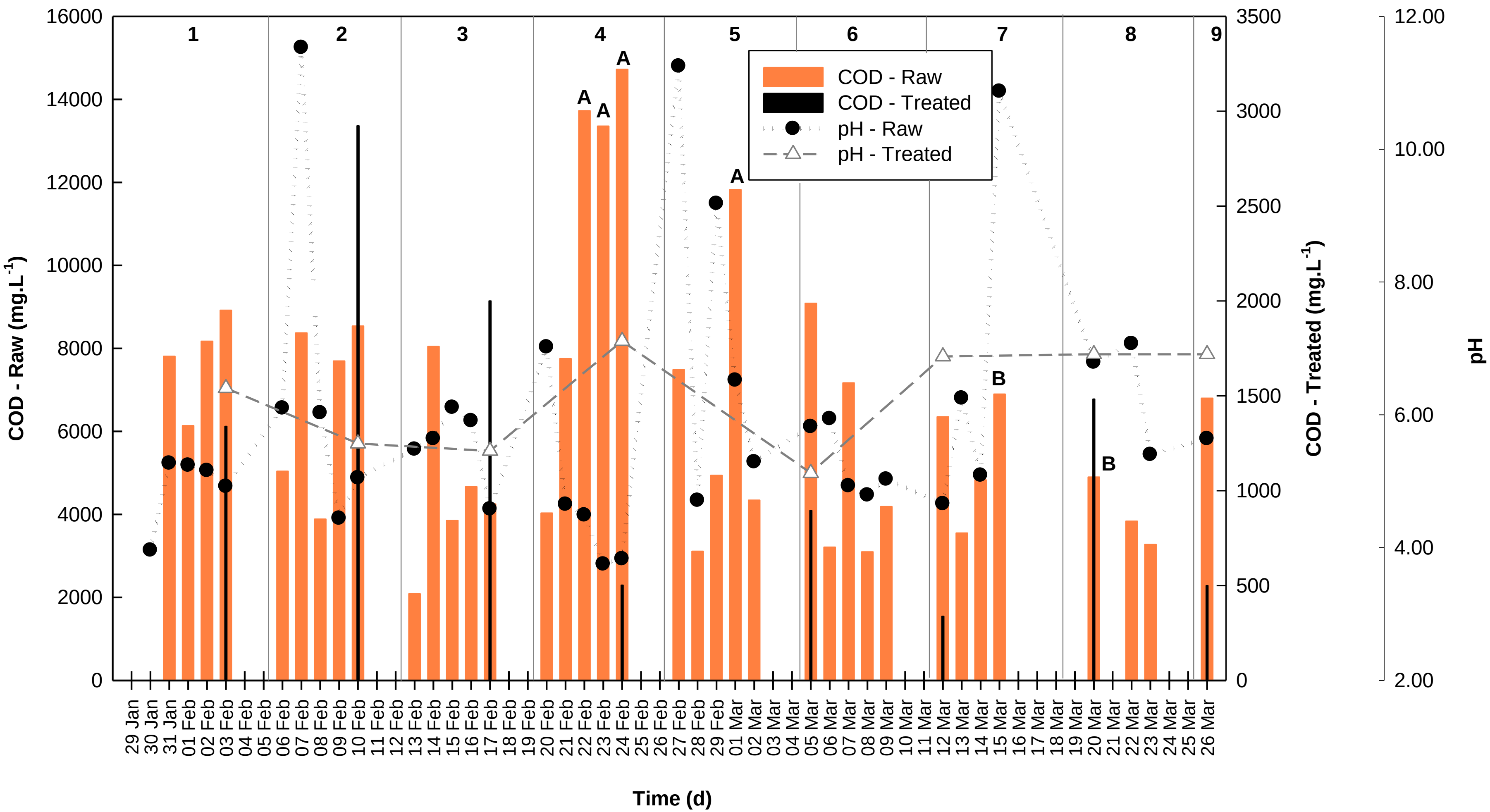

Figure 4.4 Results of daily COD concentrations and pH of raw and treated wastewater from Winery A for the 2012 harvest. Values recorded on specific dates are the characteristics of the wastewater generated by the cellar activities on the preceding day. (Activities indicated with A: filter; B: barrel washing)

Table 4.1 Daily COD concentrations of raw wastewater and the associated activities in the winery during the 2012 harvest at Winery A (Bason, S., 2013).

DATE	COD (mg.L^{-1})	ACTIVITIES IN WINERY	DATE	COD (mg.L^{-1})	ACTIVITIES IN WINERY
31-Jan	7 808	HW, flotation	27-Feb	7 488	HWR, blend, cleaning
01-Feb	6 139	HW, flotation, blend OV, filter OV	28-Feb	3 114	HW, press R, blend
02-Feb	8 175	HR, rack CV, rack OV, filter OV, rack OV	29 Feb	4 942	Rack, cleaning
03-Feb	8 920	HW, flotation, rack OV, ,bottle OV	01-Mar	11 826	HR, rack, blend
06-Feb	5 040	HW	02-Mar	4 345	Blend, rack
07-Feb	8 372	HW, rack, cleaning	05-Mar	9 087	HR, filter, F barrels
08-Feb	3 887	HW, rack, rack OV, filter OV	06-Mar	3 212	HW, press R
09-Feb	7 696	HW, rack, flotation, rack OV, filter OV	07-Mar	7 170	HW, press R, rack
10-Feb	8 537	Rack, rack OV, filter OV	08-Mar	3 100	HWR, rack, filter
13-Feb	2 087	HWR, F barrels, bottle	09-Mar	4 190	HWR, rack, filter, F barrels
14-Feb	8 046	HR, F barrels, filter OV	12-Mar	6 350	HR, E barrels
15-Feb	3 857	Rack CV, centrifuge, bottle OV	13-Mar	3 553	HR, rack,
16-Feb	4 665	Centrifuge, rack OV	14-Mar	4 832	HR, rack, filter, E barrels
17-Feb	4 251	Rack CV, press R, rack OV, filter OV	15-Mar	6 900	HR, blend, E barrels, cleaning
20-Feb	4 032	HWR, rack	16 Mar	-	Rack
21-Feb	7 754	HWR, rack	20-Mar	4 660	E barrels, F barrels, press R
22-Feb	13 725	HWR, rack	22-Mar	3 839	HW, rack, bottle
23-Feb	13 356	HWR, rack	23-Mar	3 280	Rack
24-Feb	14 724	HW, rack	26-Mar	6 873	Press R

HW – white grapes harvested; HR – red grapes harvested; HWR – white and red grapes harvested; Press R – red fermenting grapes pressed; OV – older vintage; E barrels - emptied barrels; F Barrels –fill barrels; EF barrels – emptied and fill barrels

week, as grapes and grape juice are a natural product and need processing as quickly as possible, to minimise the decrease of quality and spoilage (Hui *et al*., 2006).

On weekends, only the most essential processes are performed to ensure a good quality product. In other words, less water will be used on weekends as only skeleton staff performed the crucial operations, resulting in more concentrated levels of COD in the wastewater. This could be the reason why the COD concentration on the 6th was moderate to high (5 040 $mg.L^{-1}$). The rapid increase in COD after the 8th could be a result of previous vintages being racked and filtered on 8 - 10 February. The reason for this might be that the lees of older wine is more concentrated due to the sedimentation that accumulates during the year and all the excess organic material that leaches from the wine into the lees (Fillaudeau *et al*., 2008). Lees is the residue that has accumulated at the bottom of a wine storage vessel during storage or after treatment (Pérea-Serradilla *et al*., 2008).

The treated wastewater showed (Fig 4.4) a dramatic increase from the previous week to just below 3 000 $mg.L^{-1}$. This could be because of the initial shock of the sudden increase in high COD wastewater volume to the constructed wetland. According to the COD value, it could be confirmed that the quality of the wastewater did comply with irrigation requirements. For kikuyu irrigation up to 50 m^3 per day the COD was within the beneficial irrigation limits (< 5 000 $mg.L^{-1}$) (DWAF, 2004).

The third week (13 – 19 February) had raw wastewater starting with a low COD (2 087 $mg.L^{-1}$) on the 13th, but with a sudden increase to 8 046 $mg.L^{-1}$ on the following day (Fig 4.4; Table 4.1). The COD concentration was lower over the last 3 days of this week, with an average of below 4 500 $mg.L^{-1}$. The 13th was the 1st day that red and white grapes were processed on the same day but due to the high water usage of 35.8 m^3 for this day the raw wastewater COD was low (2 087 $mg.L^{-1}$). On the 14th the same volume of grapes were processed but the water usage was noticeably lower (26 m^3) resulting in the higher COD concentration (8 046 $mg.L^{-1}$) of the wastewater possibly due to the higher concentration of organic material in the smaller volume of water. The below average COD concentration for the specific week (3 857 $mg.L^{-1}$) on the 15th, could possibly be explained by the fact that only red grapes were processed on the 14th. When red grapes are processed after de-stemming, they are pumped straight to the stainless steel tank where they will undergo fermentation, in contrast with white grapes that are pressed before fermentation - therefore the lower impact of the red grape processing on the COD due to the press not having to be cleaned. On the 15th and 16th, no grapes were processed but other winemaking activities such as centrifuging of the Rosé wine, bottling and racking took place, resulting in below average CODs (Table 4.1). The 17th showed a decrease in COD even though older vintages wine was racked and filtered. This could be due to the small volumes of wines that was worked on, on this day.

Even though the treated wastewater COD concentration (1 923 $mg.L^{-1}$) on Friday 17th February was 31% lower than the previous week it was still under the 5 000 $mg.L^{-1}$ legal limit for irrigation of less than 50 m^3 per day (DWAF, 2004). The decrease in the COD concentration could possibly be the result of the wetland acclimatising to the COD levels and volumes from the beginning of harvest.

During the 4th week (20 – 26 Feb) the raw wastewater started off with a moderate COD concentration of 4 032 $mg.L^{-1}$ on Monday 20th February, due to a decrease in work load on Sunday 19th. During the rest of the week, the highest values of the 2012 harvest were measured (Fig 4.4), with concentrations ranging from 7 754 up to 14 724 $mg.L^{-1}$. This was the first week in which red and white grapes were harvested simultaneously on four consecutive days (Table 4.1), and the workload thus increased dramatically, resulting in more intensive cleaning to maintain a hygienic environment. During this week, nine tanks were also racked after the first fermentation (Fig 4.4). The accumulated lees after the initial alcohol fermentation is thick and spillages can easily increase the COD (Fillaudeau *et al*., 2008) of the generated wastewater. The average COD of wine lees is 76 000 $mg.L^{-1}$ (Boires *et al*., 2006) therefore a small volume (in this case of spilled thick, lees from the tank that needs to be washed out) could have a vast influence on the raw COD of winery wastewater. This resulted in three consecutive days on which the wastewater COD was above 12 000 $mg.L^{-1}$.

The treated wastewater COD concentration, however, was very low (502 $mg.L^{-1}$) at the end of week 4 (Friday 24 February) (Fig 4.4). This value is lower than the DWAF legal limit of 5 000 $mg.L^{-1}$ for irrigation of less than 50 m^3 per day (DWAF, 2004) and was much lower than that of the three previous weeks. This could be due to the stabilisation of the water volume used and pollution load after four weeks and the initial shock of the increase wastewater volumes.

Week 5 (27 – 4 Mar) started off with the wastewater having a moderate COD of 7 488 $mg.L^{-1}$ with a noticeable decrease in COD on both the following two days (28th and 29th Feb), but increased to 11 826 $mg.L^{-1}$ on 1st March (Fig 4.4; Table 4.1). During this week, the largest volumes of blended wine were prepared (Table 4.1). Since the wines used to prepare the blends were racked during week 4, the influence on COD was observed then, as less lees and organic material had to be cleaned during week five. On the 29th, the majority of this blend was made, thereby increasing the workload of the day and the amount of tanks cleaned, resulting in the higher COD of the wastewater (> 10 000 $mg.L^{-1}$) on 1st March. A on Figure 4.4 indicates the influence of the first rackings after the alcoholic fermentation on the COD of the raw wastewater.

Unfortunately, the winery personnel did not take a treated wastewater sample during week 4. Also from week 5, the treated wastewater samples were taken on Mondays instead of Fridays for the rest of this study. The treated wastewater sample that was taken in the beginning of week 6 represents the treated wastewater COD concentration of week 5 and was just below 1 000 $mg.L^{-3}$. This is quite impressive as both of week 4 and 5's high COD wastewater has now been into the wetland. This COD concentration is low enough for irrigation under 50 m^3 per day (DWAF, 2004).

During the sixth week of harvest (5 – 11 March) the raw wastewater initially had a high COD concentration of 9 087 $mg.L^{-1}$ on 5th March, as a result of work done on Sunday 4th March (Fig 4.4; Table 4.1). This high COD could be a result of the cellar work that was performed on Sunday, 4th March. On Sundays only the most essential winemaking work was done and therefore less water was used, most likely resulting in higher COD concentrations of the wastewater generated. The following days the COD concentration decrease to a more moderate concentration ranging between

3 212 and 7 170 mg.L^{-1}. The increase in COD in the wastewater from the 6th to 7th can most likely be attributed to the fact that white grapes were processed as well as a number of red fermenting tanks being pressed (Table 4.1). Pressing of grapes generally increases the COD concentration in the wastewater because of organic load increases when the press is cleaned after use. Therefore, the more tanks that are pressed the higher the organic load and thus COD concentration.

Treated wastewater COD at the end of week 6 was 400 mg.L^{-1}. According to the COD value, it could be confirmed that the quality of the wastewater complied with irrigation requirements. For vineyard irrigation up to 50 m^3 per day the COD was within the beneficial irrigation limits (< 5 000 mg.L^{-1} (DWAF, 2004).

Figure 4.4 shows that throughout week 7 and 8 the raw wastewater COD concentrations were on an average 5 200 mg.L^{-1}, with no values exceeding 10 000 mg.L^{-1}. During week 7 only red grapes were harvested (Table 4.1), resulting in a moderate COD concentration. On the 14thMarch, barrels were emptied and washed, possibly adding to the higher COD concentrations (Fig 4.4). The residual lees that is found in the barrel, after the wine has been pumped out, pollutes the wastewater when the barrel is washed. The COD concentration for the 16th was not available nevertheless from Table 4.1 it is possible to predict that the organic load in the wastewater generated would have been high because a number of red wine tanks that has just finished with their MLF fermentation were racked. The accumulated lees, after a red wine has been through MLF fermentation is thick and spillages can easily increase the COD (Fillaudeau *et al*., 2008). During week 8 only two weekdays (working days) values for COD were measured, due to a number of public holidays (19th and 21st March) during this week. On these days (20th, 22nd and 23rd March), the average COD was below 4 000 mg.L^{-1}.

Week sevenths treated wastewater COD concentration was almost triple the value (1 500 mg.L^{-1}) compared to week sixths, as can be seen in Figure 4.4 (20 March). This could be a result of the high workload during the preceding weeks.

Fig 4.4 shows that starting with the weekends from mid harvest (week 5) the average COD concentrations of the raw wastewater generated on Sundays were often high, possibly due to the low water usage during weekend resulting in a more concentrated organic load in die wastewater (Fig 4.4).

pH

During the 2012 harvest at Winery A the pH for the raw wastewater ranged between 3.75 and 11.53 (Fig 4.4; Table 4.2). According to literature winery wastewater pH usually ranges between 3.5 and 7.8 (Bustamante *et al*., 2005). Therefore, only the peaks exceeding this range will be discussed (the pH during this season never dropped below 3.5). There were only four occurrences where the pH exceeded 7.8. The reason for the high pH on the 7th, 27th & 29th of February and 15th March is most likely due to the cleaning regimes implemented on those days, using large amounts of Potassium Hydroxide (KOH). This occasional high pH is of concern, as it was higher than the 9.00 pH legal limit for irrigation of more than 50 m^3 for per day (DWAF, 2004). Therefore, is necessary that the raw wastewater pH is treated before irrigation.

The treated wastewater pH had a mean of 6.35 (Table 4.4). The pH of the treated wastewater was only once lower than the legal limit value of 6.00 on 5th March (Fig 4.4). This could be due to the increase in the wastewater volumes and pollution load from the previous two weeks. After treatment the water accumulates in a holding dam before irrigation and therefore the pH most probably will equilibrate before irrigation. The pH values monitored for the raw and treated wastewater for the 2012 harvest are summarised in Table 4.2.

Table 4.2 Summary of the highest, lowest and average pH values for the raw and treated wastewater from Winery A for the 2012 harvest.

	RAW WASTEWATER pH	TREATED WASTEWATER pH
Mean	4.73	6.35
Highest	11.53	7.60
Lowest	3.75	5.81

4.3.1.2 Winery A – Post-harvest 2012

COD

Figure 4.5 shows the COD concentrations of raw and treated wastewater at Winery A during the post-harvest season of 2012 (week 19 – 49). After the harvest, the weekly COD concentration of the wastewater was analysed, to determine the influences of the winemaking practices on the COD of the wastewater. Even though the last grapes, for the Winery A, Edelspatz Noble Late Harvest, were harvested in week 21 this period was considered post-harvest, since 99.5% of the harvest was completed by the beginning of week 14 and eight weeks had passed. Unfortunately, the winery personnel did not take a wastewater sample from 27 March to the beginning of week 19.

During week 20 the raw wastewater had a high value of 12 705 $mg.L^{-1}$ (Fig 4.5; Table 4.3). Mainly racking and blending eight tanks of wine could have contributed to the high COD concentrations. The lees from the racked wines can increase the wastewater COD either by spillages or when the tanks of the racked wines are cleaned. During this week bottling (Table 4.3) was also done but bottling has a very low impact on the COD concentrations of winery wastewater (Bolzonella, D., 2013) (Fig 4.5).

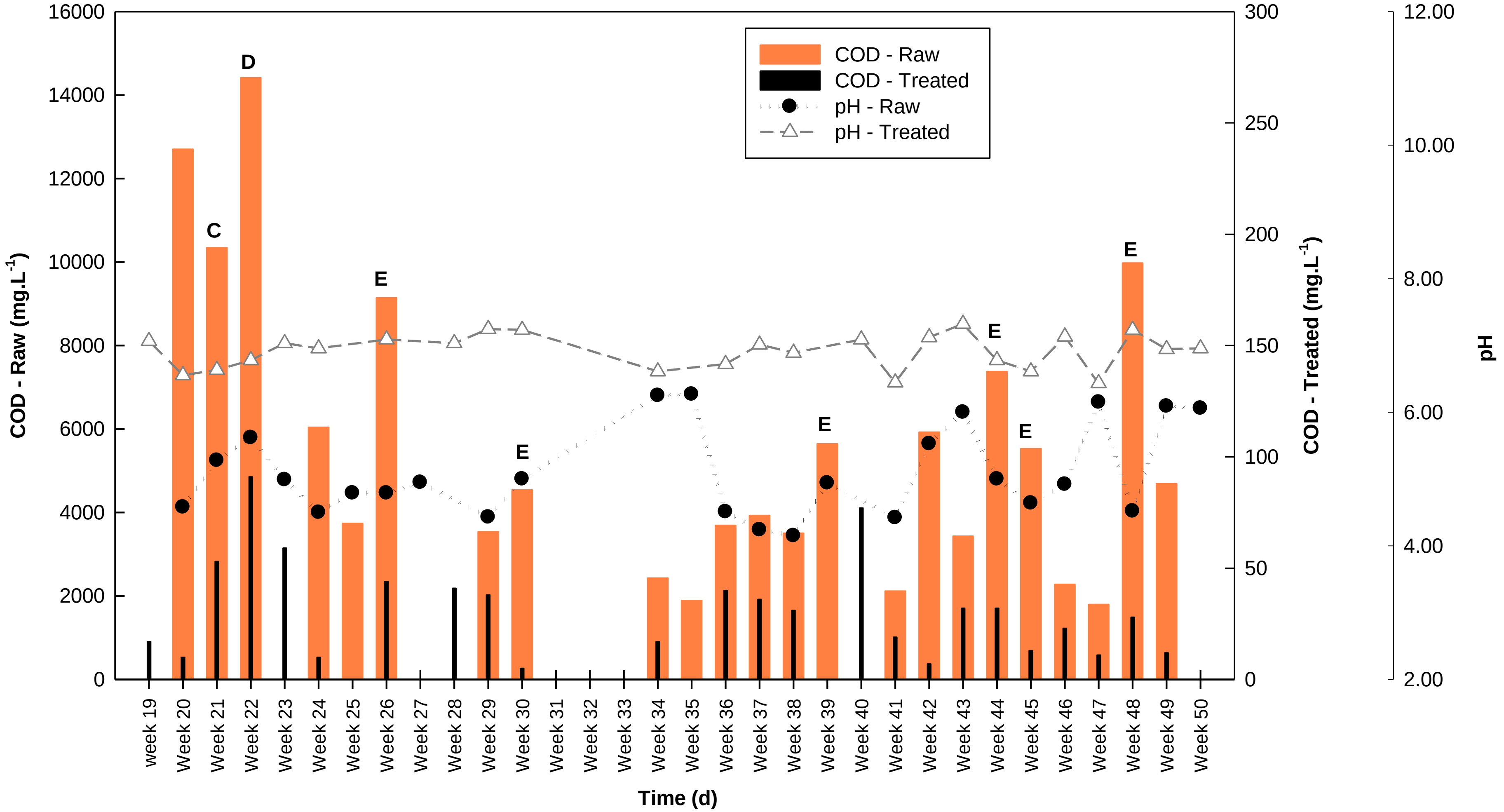

Figure 4.5 Results of weekly COD concentration and pH of raw and treated wastewater from Winery A for the 2012 post-harvest. . (Activities indicated with C: processing of Late harvest grapes; D: no activities recorded; E: increased work load)

Table 4.3 Weekly average COD concentrations of raw wastewater and the associated activities in the winery for the 2012 Post-harvest season at Winery A (Bason, S., 2013).

DATE	COD (mg.L^{-1})	ACTIVITIES IN WINERY	DATE	COD (mg.L^{-1})	ACTIVITIES IN WINERY
Week 19			Week 35	1 895	Rack, EF barrels, cleaning
Week 20	12 705	Rack, bottle, blend, F barrels	Week 36	3 694	Rack, filter, EF barrels, cleaning
Week 21	10 341	Late harvest, EF barrels	Week 37	3 931	Rack, filter, bottle, blend, cleaning
Week 22	14 418		Week 38	3 505	Rack, filter, bottle, F barrels
Week 23		Filter, blend	Week 39	5 648	Rack, filter, F barrels, cleaning
Week 24	6 043	Bottle, blend	Week 40		
Week 25	3 740	Rack	Week 41	2 117	Rack, filter, bottle, F barrels
Week 26	9 148	Rack, filter, bottle, F barrels	Week 42	5 927	Rack, filter, blend, EF barrels
Week 27		Rack, bottle, EF barrels	Week 43	3 436	Rack, blend, F barrels
Week 28		Rack, E barrels	Week 44	7 376	Rack, filter, blend, E barrels
Week 29	3 542	Rack, filter, bottle, EF barrels	Week 45	5 528	Rack, filter, bottle
Week 30	4 541	Rack, filter, bottle, EF barrels	Week 46	2 282	Rack, filter, bottle
Week 31		Rack, filter, bottle, EF barrels	Week 47	1 810	Rack, filter, bottle
Week 32		Rack, bottle, F barrels	Week 48	9 977	Rack, filter, bottle
Week 34	2 430	Rack, E barrels	Week 49	4 690	Bottle

CV- current vintage; OV – older vintage; E barrels - emptied barrels; F Barrels –fill barrels; EF barrels – emptied and fill barrel

The treated wastewater COD at the end of week 20 was 25 mg.L^{-1} (Fig 4.5). This value was an indication that the high COD wastewaters of the harvest had been treated successfully by the wetlands. According to DWAF's legal limit the COD concentration should be under 5 000 mg.L^{-1} for irrigation of up to 50 m^{3} per day and for that reason the wastewater was suitable for irrigation if only the COD levels were taken in consideration (DWAF, 2004).

Week 21 raw wastewater had an average COD concentration of 10 341 mg.L^{-1}. During this week the grapes for the production of the Winery A Noble Late Harvest Wine were harvested (Table 4.3). The 3.85 t of grapes that were processed were most likely the reason for the high COD concentrations during this week (Fig 4.5). Adding to the high COD levels were the fifteen red wine tanks that were racked and cleaned. Lastly, barrels were emptied, washed and re-filled during this week, also contributing to the raw wastewater COD.

The COD of the treated wastewater showed an increase from the previous week but the value was still below the legal limit (5 000 mg.L^{-1}) for irrigation according to DWAF (2004). The reason for the increase could possibly be the increased COD of the raw wastewater entering the wetlands since week 20.

Figure 4.5 illustrates a steep increase, in the raw wastewater COD during week 22, of 39% from the previous week to more than 14 000 mg.L^{-1} (Fig 4.5; Table 4.3). Not only was the highest COD concentration measured during this week, but it was also the last time the raw wastewater COD was higher than 12 000 mg.L^{-1}. Unfortunately, the winery personnel did not record their activities for this week in their logbook (Fig 4.5), but the high COD concentration indicates that the activities most likely included racking of the fermented Late Harvest wine and barrel work.

It can also be seen from Figure 4.5 that the treated wastewater COD concentration increased slightly to 91 mg.L^{-1} and the concentration was suitable for irrigation according DWAFs legal requirements for irrigation of winery wastewater (DWAF, 2004).

No samples for the raw wastewater were taken during week 23 because the winery personnel responsible for the sample taking resigned and the responsibilities were not clear concerning the wastewater samples to the new laboratory technician. The activities recorded during this week (Table 4.3) indicate that the COD concentration of the wastewater could have been moderate to high because of the filtration activities. Filtration earths that were used in the filtration method at Winery A consist primarily of Diatomaceous earth (DE). The microscopic matrix of DE ensures the high absorbent qualities and DE can absorb water in reasonably large volumes (Rutherford & Coons, 2007). The residue from filtration therefore influences the wastewater COD due to the fact that DE absorbed the wine, lees and cleaning water with high COD concentration and then increases the organic material in the wastewater gathered in the holding pit (indicated with B on Fig 4.1). There was a slight decrease in the COD of the treated wastewater (Fig 4.5).

During week 24 the raw wastewater had a moderate COD of 6 043 mg.L^{-1} (Fig 4.5). Mainly bottling was done during this week and blending of a number of tanks (Table 4.3). The bottling had little effect on the COD of the wastewater. When wine is blended the pumping can cause spillage of wine and lees, and the cleaning of the tanks, pumps and pipes could again have contributed to the moderate COD. The treated wastewater COD in the beginning of this week was very low with a value of below 25 $mg.L^{-1}$ (Fig 4.5). This could possibly be a result of the increase in rainfall from week 23 to week 24 (Rowswell, D., 2013).

Figure 4.5 shows a decrease in the raw wastewater COD from week 24 to week 25. During this week, only a small amount of winery work was done with only a few tanks being racked (Table 4.3). This could be the reason for the lower COD values for the raw wastewater. Again no treated wastewater sample was available but the COD concentration was most likely below 50 $mg.L^{-1}$ when the COD (6 043 $mg.L^{-1}$) of the raw wastewater of week 24 was taken in consideration.

In the 26th week the raw wastewater COD was again higher than in the previous weeks, with a value of 9 148 $mg.L^{-1}$ (Fig 4.5; Table 4.3). During this week five tanks were racked and filtered, possibly contributing to the increased COD of the wastewater generated (Fig 4.5). The COD of the treated wastewater was higher than the previous measurement, but still reasonably low and could be used for irrigation according to DWAF legal requirements for irrigation (Fig 4.5) (DWAF, 2004).

During week 27 and 28 the personnel at Winery A responsible for collecting the wastewater were on an informational workshop and therefore no values are available for these two weeks as no sampling was done. According to activities that took place during these two weeks the COD concentrations were possibly moderate ranging between 2 000 and 4 000 $mg.L^{-1}$ (Fig 4.5; Table 4.3). The treated wastewater was measured for week 28 and a COD value of 44 $mg.L^{-1}$ was measured (Fig 4.5).

The raw wastewater COD for week 29 was measured at 3 542 $mg.L^{-1}$ (Fig 4.5; Table 4.3). During this week a small batch of wine in barrels was emptied and refilled again. This small batch, therefore, had a low impact on the COD of the raw wastewater. The COD of the treated wastewater remained relatively constant from the previous week at below 50 $mg.L^{-1}$ (Fig 4.5). This could possibly be due to the moderate COD of the raw wastewater from the previous weeks.

It can be seen from Figure 4.5 that the measured value for the raw wastewater COD for week 30 was 4 541 $mg.L^{-1}$. This slight increase from the previous week can most likely be attributed to a small increase in the workload from week 29 to week 30. The same winemaking practices (rack, filter bottle and EF barrels) took place, but with a slight increase in the volumes (Fig 4.5). From Figure 4.5 it is also possible to see that the treated wastewater COD for week 30 was the lowest for the post-harvest period – and also for the whole study period. The highest rainfall for 2012 in the Winery A region was measures between mid-July (week 30) and the end of Aug (week 35) (Rowswell, D., 2013). The constructed wetland is situated in a natural environment hence the rainfall will have a direct influence on the quality and quantity of the water in the wetland, mainly by diluting the COD of the water leaving the wetland.

Week 31 – 34 the personnel responsible for sampling were on leave therefore no analysis on the wastewater (both raw and treated) was done.

Over the next ten weeks (34 till 43) the raw wastewater COD was moderate with an average of 3 600 $mg.L^{-1}$ (Fig 4.5; Table 4.3). During this period, the raw wastewater COD was only above 4 000 $mg.L^{-1}$on two occasions (week 39 and 42). Throughout this period the workload was much lower than during the rest of the post-harvest season, and this ultimately had a smaller influence on the raw wastewater COD. A combination of a slight increase in the work load (Fig 4.5) and the low water usage, during week 39, might be the reason for the higher COD of the raw wastewater. This possibly resulted in the increase in the COD for the treated wastewater (week 36 to 38) in the following week (week 40). The moderate to low COD (2 117 $mg.L^{-1}$) of the raw waste water of week 41 could possibly be the reason for the low COD of the treated wastewater for week 42. Week 42 had a high raw wastewater COD due to a big batch of wine in barrels were emptied and cleaned that possibly led to the higher COD concentration possibly explaining why the COD of the treated wastewater increased during week 43.

During week 44 the raw wastewater COD was 7 376 $mg.L^{-1}$ (Table 4.3; Fig 4.5). The steep increase in COD from week 43 could most likely be attributed to the drastic increase in work load (Fig 4.5) during this week. A number of high volume tanks were racked and larger volumes of wine were emptied from the barrels which added to the COD concentration because of wine spillage, cleaning of the tanks and the barrels with the high-pressure cleaning system. The treated wastewater was still at a fairly low level of under 50 $mg.L^{-1}$ (Fig 4.5).

From week 45 till week 48 the raw wastewater COD ranged from 1 810 (week 47) to just below 10 000 $mg.L^{-1}$ in week 48 (Fig 4.5; Table 4.3). During these weeks the same winemaking practices such as racking, filter and bottling were done, but the volumes of the wine batches differ, resulting in different COD concentrations in the wastewater generated. Week 47 had the lowest raw wastewater COD value of 1 810 $mg.L^{-1}$ (Fig 4.5) and was also the week that the smallest number of tanks with the smallest volume of wine was racked and filtered. Week 45 had the highest number of tanks that were filtered (raw wastewater COD 5 528 $mg.L^{-1}$) and week 48 had the highest number of tanks that were racked and (raw wastewater COD 9 977 $mg.L^{-1}$) (Fig 4.5; Table 4.3) which also reflects in the COD concentrations, respectively (Fig 4.5). The treated wastewater COD remained at a low level during this period (week 45 to week 48) (Fig 4.5).

Week 49 was the last monitored week for the year of 2012. The measured values for the raw wastewater was a moderate 4 690 $mg.L^{-1}$ (Table 4.3). During this week only bottling occurred, which usually has a low impact on the raw wastewater COD.

pH

During the post-harvest season in 2012 at Winery A the raw wastewater pH ranged between 4.00 and 6.27 (Fig 4.5). The reason that there were no peaks outside this range could be because the weekly composite sample masks the few days with a pH value exceeding the given ranges.

The treated wastewater pH ranged between 6.99 and 7.79 (Table 4.4). For kikuyu irrigation up to 50 m^3, the pH was within the beneficial irrigation limits of 6.00 to 9.00 and the treated wastewater complied with irrigation requirements taking only pH in consideration (DWAF, 2004). This is an indication that the wetlands rectify the pH sufficiently to use the treated wastewater for irrigation. Table 4.4 summarised the pH values for the post-harvest season for the raw and treated wastewater.

Table 4.4 Summary of the highest, lowest and average pH values for the raw and treated wastewater from Winery A for the Post- harvest season.

	RAW WASTEWATER pH	**TREATED WASTEWATER pH**
Mean	4.75	7.36
Highest	6.27	7.79
Lowest	4.15	6.99

4.3.1.3 Winery A – Harvest 2013

COD

The 2013 harvest was the second harvest monitored at Winery A during this study. This harvest started on 29 January 2013 and lasted until 6 April 2013 (Fig 4.6; Table 4.5). The total of 835 tons was harvested, of which 48% were red and 52% were white grapes. As discussed earlier values for COD of raw wastewater recorded on specific dates are the characteristics of the wastewater generated by the cellar activities on the preceding day.

In the first week (28 Jan – 3 Feb) of the 2013 harvest the raw wastewater COD ranged from 5 117 to 11 705 mg.L^{-1} (Fig 4.6; Table 4.5). The week started with a moderate 5 500 mg.L^{-1} on 30 Jan (Table 4.5) followed with a steep increase to 11 705 mg.L^{-1} on the following day. The COD then decreased to a moderate 5 117 mg.L^{-1} on 1st February. During this first week of harvest, primarily Pinotage grapes were harvested for the Rosé wine. The steep increase in COD on 31January could be due to the 20% increase in volume of grapes processed this day (indicated with F, Fig 4.6). The higher amount of grapes harvested also resulted in more tanks being used, and in this instance, the press was also used an additional time to process the grapes for the Rosé. Therefore, the double cleaning of the press could also account for the increase in COD of the raw wastewater. Also contributing to the COD levels during this week was the flotation method that was used during the harvest. As mentioned in the discussion of the 2012 harvest the gelatine used in this process, leaves a film behind in the tank, which is more difficult to clean, thereby adding to the organic material and subsequently a higher COD in the wastewater

The treated wastewater COD, leaving the wetlands, was very low in the first week with a value of 22 mg.L^{-1} on 1st February (Fig 4.6). According to the COD value, it could be confirmed that the quality of the wastewater complied with irrigation requirements, for up to 50 m^{3} per day (< 5 000 mg.L^{-1} (DWAF, 2004).

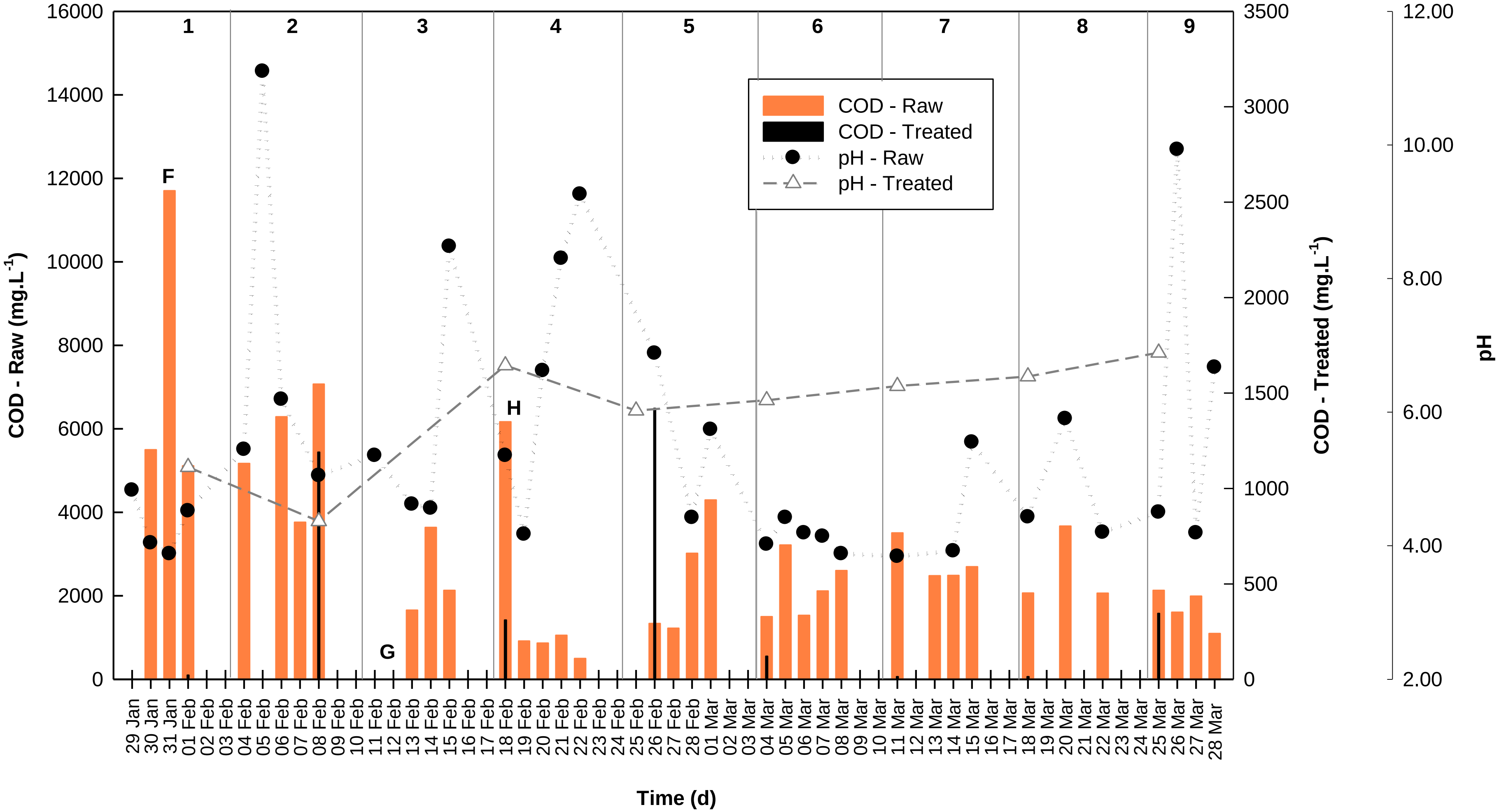

Figure 4.6 Results of daily COD concentrations and pH of raw and treated wastewater from Winery A for the 2013 harvest. Values recorded on specific dates are the characteristics of the wastewater generated by the cellar activities on the preceding day. (Activities indicated with F: high volume of grapes processed; G: cleaning of holding pit and H: low water usage).

Table 4.5 Daily COD concentrations of raw wastewater and the associated activities in the cellar during 2013 harvest at Winery A (Bason, S., 2013).

DATE	COD(mg.L^{-1})	ACTIVITIES IN WINERY	DATE	COD (mg.L^{-1})	ACTIVITIES IN WINERY
29-Jan		HWR, rack, flotation	01-Mar	4298	HR, rack , blend
30-Jan	5 500	HWR, rack, flotation	04-Mar	1 501	HW, rack , filter, press R
31-Jan	11 705	HW, flotation	05-Mar	3 218	HWR, rack , press R
01-Feb	5 117	HW, flotation	06-Mar	1 534	HWR, rack
04-Feb	5 171	HW,	07-Mar	2 117	HR, rack, F barrels
05-Feb		HW, rack	08-Mar	2 608	HR
06-Feb	6 291	HW, rack , E barrels, rack OV, bottle	11-Mar	3 510	HR, rack CV, press R, Bottle
07-Feb	3 764	HW, rack, bottle	13-Mar	2 484	HW
08-Feb	7 074	Bottle	14-Mar	2 489	HR, rack, rack OV
13-Feb	1 658	Rack OV, E barrels OV, F barrels OV	15-Mar	2 700	HR, rack, press R, F barrels
14-Feb	3 640	Rack OV, E barrels OV	18-Mar	2 068	HR, press R
15-Feb	2 133	HW, F barrels	20-Mar	3 672	HR
18-Feb	6 172	HW, E barrels , rack OV	22-Mar	2 066	HR, press R, F barrels
19-Feb	9 18	HW	25-Mar	2 133	HR, rack, bottle
20-Feb	869	HW	26-Mar	1 607	
21-Feb	1 058	HR, rack, filter CV	27-Mar	1 993	HWR, bottle
22-Feb	502	HW, rack	28-Mar	1 099	HR, press R
26-Feb	1 339	HW, rack , flotation	2-Apr	1 366	
27-Feb	1 226	HW, rack	03-Apr	4 290	Press R
28-Feb	3 019	Rack, press R	5-Apr	3 637	HR, press R

HW – white grapes harvested; HR – red grapes harvested; HWR – white and red grapes harvested; Press R – red fermenting grapes pressed; OV – older vintage; E barrels - emptied barrels; F Barrels –fill barrels; EF barrels – emptied and fill barrels

During the second week (4 – 10 Feb) the raw wastewater had a moderate COD of between 5 171and 7 074 mg.L^{-1} (Table 4.5). Only white grapes were harvested and processed during this week, thus explaining the COD levels of the raw wastewater, as white wine processing involves more cleaning in the early stages of processing due to the press usage on the day of harvesting. Unfortunately, the winery personnel did not collect a raw wastewater sample on the 5th however, the high volume of white grapes (30 tons) processed indicates that the COD most likely would have been high compared to the 13 tons that were processed on the 4th and 6th respectively resulting in a moderate COD of 5 171 and 6 291 mg.L^{-1}. The decrease in COD (3 764 mg.L^{-1}) on the 7th could possibly be due to the decrease in the volume (8 tons) of white grapes processed on this day.

A steep increase of the treated wastewater COD can be noticed from the first week (22 mg.L^{-1}) to 1 190 mg.L^{-1} on the 8th Feb (Fig 4.6). This could be due to the initial shock of the first high COD wastewaters entering the constructed wetland in the first week.

In week 3 (11 – 17 Feb) the raw wastewater COD was considerably lower than the previous two weeks (Fig 4.6). The values never exceeded 4 000 mg.L^{-1} during this week (Fig 4.6). On the 11th and 12th of February the pit (Fig 4.1), where the raw wastewater from the winery accumulates before the water enters the wetland treatment system, was thoroughly cleaned out, indicated with G on Fig 4.6. Cleaning out the pit resulted in a decrease of 65% in the average COD of the raw wastewater throughout the rest of the harvest with COD's of the wastewater ranging between 502 and 6 172 mg.L^{-1}. It is speculated that additional COD was leached out of this sediment into the wastewater entering the pit from the winery, thereby increasing the organic load in the raw wastewater being pumped to the Delta Separator (B; Fig 4.1). Raw wastewater samples are taken from this pit.

During the 4th week (18 – 24 February) the raw wastewater COD initially had a moderate COD (6 178 mg.L^{-1}) and then decreased to almost below 1 000 mg.L^{-1} for the rest of the week (Fig 4.6). The initial high raw wastewater COD of 6 172 mg.L^{-1} on the 18th was higher than average possibly because older vintages of wine were racked and filtered during the weekend of 16 and 17 February. Generally, the water usages during weekends are lower, and thus the COD is more concentrated in the wastewater (indicated at I in Figure 4.6). During the rest of the week the COD's were noticeably lower than the rest of the harvest, even though average to high amounts of grapes were processed (ranging from 15 tons on the 19th to 26 tons on the 21st) and harvest activities (pressing and pump overs) continued throughout the week. This was the first instance of several consecutive days having such low COD concentrations. This generally lower raw wastewater COD during "normal" operating conditions, again tends to suggest that the accumulated solids in the "pit" had previously contributed to the raw wastewater COD.

Figure 4.6 shows that from week 5 onwards the raw wastewater COD only exceeded 4 000 mg.L^{-1} on one occasion on 1 March. This was the day that the Rosé blend (consisting of nine tanks) were blended possibly increasing the COD. During the rest of the harvest period the COD ranged between 1 099 to 4 298 mg.L^{-1} (Fig 4.6; Table 4.5). Even though normal winemaking activities continued during this period, the COD was much lower than the average for the harvest. This is most likely also as a result of the wastewater pit, which was cleaned.

The highest COD values of the treated wastewater, for the 2013 harvest were measured in the beginning of week 5 (1 400 $mg.L^{-1}$). This high COD concentration of the treated wastewater could be due of the 44% increase in water usage form week 3 (142 m^3) to week 4 (205 m^3). As a result increasing the flow through the the wetland and potentially decrease the efficiency. During the whole 2013 harvest the treated wastewater COD concentrations never excided 5 000 $mg.L^{-1}$ and was suitable for irrigation according to the legal requirements of DWAF (DWAF, 2004).

pH

The pH for the raw wastewater during the 2013 harvest at Winery A ranged between 3.84 and 11.10 (Table 4.6). According to literature average winery wastewater pH ranges between 3.5 to 7.8 (Bustamante *et al*., 2005). The pH exceeded this range on five occurrences (5^{th}, 15^{th}, 21^{st}, 22^{nd} and 26^{th} March) (Fig 4.6). The high pH is most likely from the cleaning chemical Potassium Hydroxide (KOH) and the fact that the samples on these days was taken after the cleaning chemicals had been used.

The treated wastewater pH ranged from 5.13 to 7.40 (Table 4.6). The pH was on four occurrences lower than the recommended guideline pH of 6 for irrigation of wastewater less than 50 m^3 per day (DWAF, 2004). This could have been due to the volume of wastewater that increased dramatically in the first weeks of harvest and the wetland had to adjust to the pollution load. The pH values monitored for the raw and treated wastewater for the 2013 harvest are summarised in Table 4.6.

Table 4.6 Summary of the highest, lowest and average pH values for the raw and treated wastewater from Winery A for the 2013 harvest.

	RAW WASTEWATER pH	TREATED WASTEWATER pH
Mean	4.38	5.93
Highest	11.10	7.40
Lowest	3.84	5.13

4.3.1.4 Winery B – Harvest 2012

COD

During the 2012 harvest the COD of the winery B raw and treated wastewater was monitored and the results were compared to determine the influences of the winemaking practices on the COD of the wastewater. The 2012 harvest at Winery B started on the 2^{nd} of February (Thursday) and ended on 3 April lasting 10 weeks in total (Fig 4.7). Winery B harvested 380 tons of which 73% were red and 27 % were white grapes.

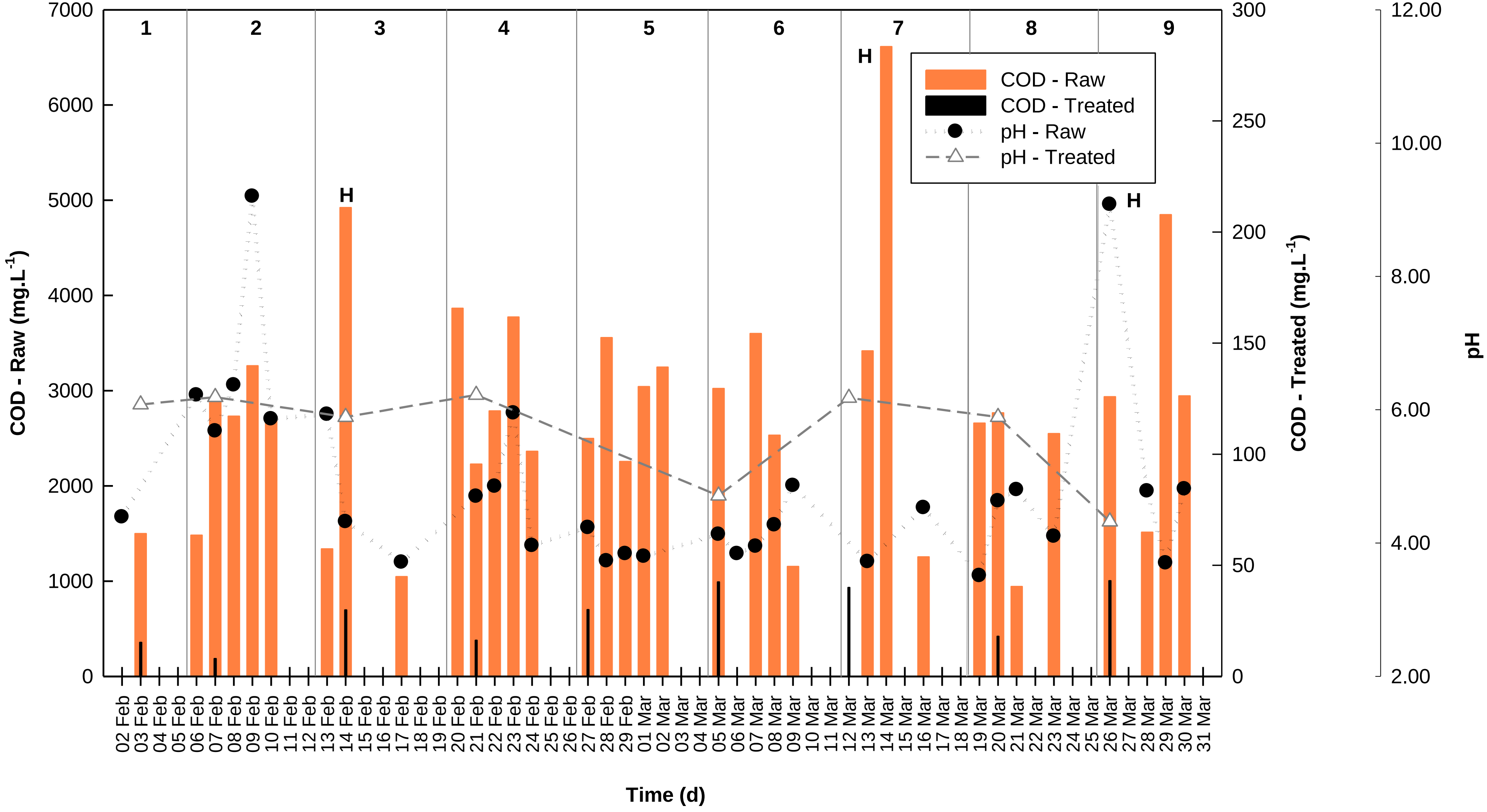

Figure 4.7 Results of daily COD concentrations and pH of raw and treated wastewater from Winery B for the 2012 harvest. (Activities indicated with H: low water usage)

Table 4.7 Daily COD concentrations of raw wastewater and the associated activities in the cellar during 2012 harvest at Winery B (Ngamane, P., 2013).

DATE	COD (mg.L^{-1})	ACTIVITIES IN WINERY	DATE	COD (mg.L^{-1})	ACTIVITIES IN WINERY
02-Feb		HW, bottle OV	03-Mar		Rack CV
03-Feb	1 500	HW, bottle OV	05-Mar	3 023	HR, rack
06-Feb	1 483	HW, rack, blend OV, bottle OV	06-Mar		HR, rack, barrels
07-Feb	2 878	HW, No press W, barrels, bottle OV, rack OV,	07-Mar	3 601	HWR, rack, cleaning
08-Feb	2 732	Press W, bottle OV, load bulk	08-Mar	2 532	HR, press R
09-Feb	3 261	Bottle OV, load Bulk	09-Mar	1154	HR, rack
10-Feb	2 727	HW, bottle OV	10-Mar		Rack, barrels
13-Feb	1 339	HW, rack, rack OV	12-Mar		HR, caustic tanks
14-Feb	4 923	Barrels, bottle OV	13-Mar	3 418	HWR, rack, filter
15-Feb		Barrels	14-Mar	6 614	HWR, rack
16-Feb			15-Mar		HR, press R, rack, blend
17-Feb	1 047	HW, rack, cleaning	16-Mar	1 255	HR, press R, rack, barrels
20-Feb	3 866	Rack, barrels OV	17-Mar		Rack
21-Feb	2 229	HW	20-Mar	2 767	HR, press R, rack
22-Feb	2 787	HW, rack OV, blend OV	21-Mar	944	Rack
23-Feb	3 774	Press W , blend OV	22-Mar		HR, press R, rack
24-Feb	2 364	HWR, rack, barrels	23-Mar	2 550	HR, press R, rack, barrels
27-Feb	2 499	HWR, rack	24-Mar		Press R, Rack
28-Feb	3 558	HW, rack, load bulk	26-Mar	2 937	HR
29 Feb	2 257	HW	27-Mar		Press R
01-Mar	3 043	HW, rack, barrels	28-Mar	1 514	HR, rack
02-Mar	3 248	HW, rack, barrels	29-Mar	4 849	HR, press R, rack, blend, cleaning

HW – white grapes harvested; HR – red grapes harvested; HWR – white and red grapes harvested; Press R – red fermenting grapes pressed; OV – older vintage; E barrels – emptied barrels; F Barrels –fill barrels; EF barrels – emptied and fill barrels

The 2012 harvest started on a Thursday and therefore the first water sample was only available on the Friday (3 Feb). During the first week two weeks of harvest (2 – 12 Feb), the raw wastewater COD was low with an average of 2 400 mg.L^{-1}, and COD values ranging from 1 483 to 3 261 mg.L^{-1} (Fig 4.7; Table 4.7). A slight increase in the raw COD is seen from the 6th to 7 February (Figure 4.7).This could be due to a number of reasons. White grapes were harvested, wine was bottled and barrel work was done on this day. As a rule, after the wine was racked from the barrels (taken out of the barrel) they were washed with a high-pressure system. This ensured that the lees and the tartaric crystals that were formed in the barrels were removed. The excess lees from barrels was first emptied by hand into a bucket, there was still a small percentage of the lees that had to be washed out with the high pressure system entering the wastewater system, thus contributed to the organic load in the wastewater. Furthermore, older vintage wine was also racked, thereby increasing the number of tanks that had to be cleaned. On the 8thFebruary no grapes were harvested but the processed white grapes from the previous day were pressed after having had 24h of skin contact in a stainless steel tank, therefore the press was not used or cleaned on the previous day. Cleaning of the press (9 Feb) could also be a reason for the increased raw wastewater COD (Fig 4.7) due to the increased amount of organic material. Lastly, during this period (week 1 – 2) wine from older vintages, was bottled on a daily basis. The wine that was bottled had been racked and filtered previously, hence the minimal influence on the raw wastewater COD during this period.

The third week (13– 19 Feb) of harvest had a few fluctuations (±1 000 – ±5 000) in the raw wastewater COD levels with a minimum value of 1 047 mg.L^{-1}, which was almost 5 times lower than that on the 14thof 4 923 mg.L^{-1}(Fig 4.7; Table4.7). This increase on the 14th could most likely be attributed to the racking and blending of wines from barrels. Added to the activities on the 14th, the volume of water used were also lower than usual, resulting in more concentrated COD's (Fig 4.7).

During week 4 (20 –26 Feb), the raw wastewater had a low COD with values between 2 229 and 3 774 mg.L^{-1} (Fig 4.7; Table 4.7). This was the first of three weeks in which the raw wastewater COD did not exceed 4 000mg.L^{-1}. On 20th February the COD was at the maximum for this week (3 866 mg.L^{-1}), then dropped for two days and increased again on 23rd February (Fig 4.7). On the 20th February barrel work was done and a number of tanks were racked, possibly contributing to the higher COD levels. The 24th February marked the first day that both red and white grapes were harvested together, showing little added effect on the COD. Harvesting white and red grapes on the same day generally means that white grapes are processed, followed immediately by the red grapes. There was thus no additional cleaning than when only white grapes were processed alone. The barrels that were filled on the 24th February also had little effect on the COD of the raw wastewater, as this process generally does not involve much spillage.

In week 5 (27 Feb – 4 Mar) the raw wastewater COD stayed low with values between 2 257 to 3 558 mg.L^{-1} (Fig 4.7; Table 4.7). The 27th February a low (2 499 mg.L^{-1}) COD was measured as a might be as a result of the high water usage on this day (Fig 4.7). A slight increase in the COD on 28th February could be due to the racking of white grape juice that was produced on the previous day from 10.8 tons of white grapes. As discussed earlier the racking of the white juice might have an effect on the COD levels in the raw wastewater. The slight decrease in the raw wastewater again on the 29th February could possibly be attributed to the small volume of white grapes that were processed and the low work load during this day. On the 1st – 2nd March barrels were racked and this could again explain the slightly higher COD levels.

The moderate levels of raw wastewater COD continued into week 6 (5 – 11 Mar) (Fig 4.7; Table 4.7). The COD concentrations ranged between 1 154 and 3 601 mg.L^{-1} (Fig 4.7; Table 4.7). On the 5th March only a small volume of red grapes were harvested together with a few tanks that were racked (Table 4.7), resulting in a moderate COD of 3 023 mg.L^{-1} (Fig 4.7). The slight elivation in the COD on 7th March could possibly be attributed to the increase in tonnage harvested and the low volume of water used on this day. Not only did the tonnage increase but white and red grapes were being processed simultaneously on this day. On 8th – 9th March no major cellar activities took place other than red grapes processing, resulting in lower COD levels. During red grape processing, the grapes are de-stemmed and pumped into a fermenting tank, which means only the crushing station, pipes and pump needs to be cleaned. Furthermore, red grape processing differs from white grapes processing in that red grape stay in the same tank for the duration of fermentation and only gets racked and pressed after the fermentation. This could be the reason for the low COD levels on the 9th.

During week 7 (12 – 18 Mar) the raw wastewater COD values ranged from 1 255 to 6 614 mg.L^{-1} (Fig 4.7; Table 4.7). The 14th March was the day with the highest raw wastewater COD concentration for the 2012 harvest. On the 13th and 14th both red and white grapes were processed. The difference of ±3 000 mg.L^{-1} between the two days might be due to the fact that less water was used on the 14th March, ensuring that the organic material was more concentrated and therefore had a higher COD (Fig 4.7). Furthermore, on the 14th March an additional 8.5 tons of grapes were harvested compared to the previous day. When comparing the COD of days on which only red grapes were harvested and only a small volume of water was used (13th & 14th Mar), it is evident that higher COD's resulted, than on days which water usage was lower (16th Mar) (Fig 4.7).

In the second last week of harvest (19 – 25 March) the average raw wastewater COD was mostly below the average of 2 711 mg.L^{-1} of the harvest (Fig 4.7). The COD ranged from 944 to 2 767 mg.L^{-1} (Table 4.7). During this period only red grapes were processed, therefore resulting in a lower organic load in the wastewater generated (Table 4.7)

During the last week of harvest (26 March – 1 April) the raw wastewater COD fluctuated, ranging from 1 514 to 4 849 mg.L^{-1} (Fig 4.7; Table 4.7). The high raw wastewater COD concentration on the 29th could be due to the intense cleaning of the winery after the last grapes of the season were processed. Adding to this is the low water usage of this day that contributes to the high organic loading in the wastewater generated (Fig 4.7)

Throughout the 2012 harvest the treated wastewater COD was below 50 mg.L^{-1} ranging from 8 to 43 mg.L^{-1} (Fig 4.7). The average reduction of the raw wastewater COD was 98% with a value of almost 10 times lower than the legal limit for irrigation up to 50 m^3 per day of 5 000 $mg.L^{-1}$ COD (DWAF, 2004). Therefore, this water was used for irrigation. It is possible to say that the size of the wetland is more than sufficient to treat the volume of wastewater produced by the winery during peak season (harvest) when the largest volumes of wastewater is produced.

pH

During the 2012 harvest at Winery B the pH of the raw wastewater ranged from 3.51 to 11.39 (Table 4.8; Fig 4.7). According to literature winery wastewater pH ranges between 3.5 and 7.8 pH (Bustamante *et al*., 2005). Therefore, only the peaks exceeding this range will be discussed. The pH exceeded 7.8 on only two occurrences during this period (9 Feb and 26 March) (Fig 4.7). The pH was measured in a composite sample that consisted of samples taken every 3 hours during a working day, and then combined. The increase of the pH on 9 February and 26 March could be because of the time of sampling and the specific practises that took place at the time of sampling. Even though the excess of the rinsing water used to rinse the caustic from the tanks were separated from the bulk of the wastewater there is still a small volume of caustic entering the wastewater increasing the pH.

The treated wastewater pH ranged from 5.09 to 6.80 (Fig 4.7; Table 4.8). According to DWAF the pH of treated winery wastewater must be between 6.0 and 8.5 when irrigating less than 50 m^3 per day (DWAF, 2004).

Table 4.8 Summary of the highest, lowest and average pH values for the raw and treated wastewater from Winery B for the 2012 harvest.

	RAW WASTEWATER pH	TREATED WASTEWATER pH
Mean	4.17	5.79
Highest	9.20	6.80
Lowest	3.51	5.09

4.3.1.5 Winery B – Post-harvest 2012

COD

During the 2012 post-harvest period (week 19 – 43) the weekly raw wastewater COD was measured to determine the influences that the different winemaking activities have on the COD of winery wastewaters. Figure 4.8 shows the raw and treated wastewater COD concentrations for the post-harvest season. During six of these weeks (week 31 – 34 & 42 – 43) no water was used in the winery and only maintenance work was done on the winery. Therefore, no water samples were taken as no wastewater was generated (Table 4.9).

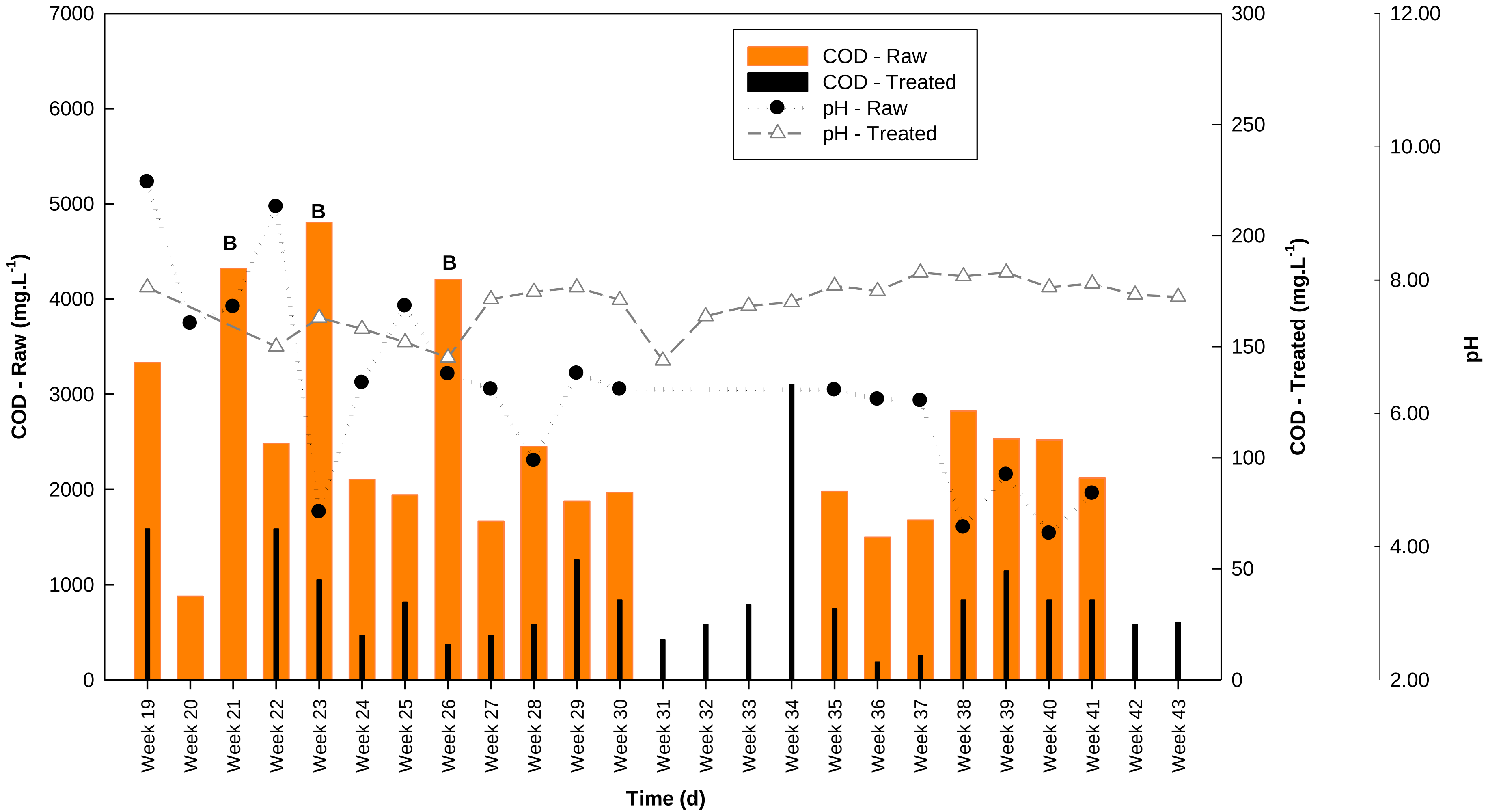

Figure 4.8 Results of weekly COD concentrations and pH of raw and treated wastewater from Winery B for the 2012 post-harvest period. (Activities indicated with B: Barrel washing).

Table 4.9 Weekly average COD concentration of the raw wastewater and associated activities in the cellar during 2012 post-harvest at Winery B with the average COD for the week (Ngamane, P., 2013).

DATE	COD (mg.L^{-1})	ACTIVITIES IN WINERY	DATE	COD (mg.L^{-1})	ACTIVITIES IN WINERY
Week 19	3 332	Rack, EF barrels	Week 32		
Week 20	880		Week 33	No cellar work with water	
Week 21	4 320	Rack, blend, E barrels	Week 34		
Week 22	2 484	Rack, F barrels	Week 35	1 980	Rack, blend, EF barrels
Week 23	4 806	Rack, EF barrels,	Week 36	1 500	Rack, blend, filter, EF barrels,
Week 24	2 106	Bottle, EF barrels	Week 37	1 679	Rack, filter, F barrels, bottle
Week 25	1 944	EF barrels	Week 38	2 824	Rack, E barrels
Week 26	4 207	Blend, EF barrels	Week 39	2 530	Rack, EF barrels
Week 27	1 666	Rack, EF barrels,	Week 40	2 522	Rack, EF barrels
Week 28	2 452	Rack	Week 41	2 120	Rack, EF barrels
Week 29	1 879	Rack	Week 42	No cellar work with water	
Week 30	1 968	Rack	Week 43		
Week 31		Rack, high-pressure the walls			

CV- current vintage; OV – older vintage; E barrels - emptied barrels; F Barrels –fill barrels; EF barrels – emptied and fill barrels

Week 19 starts off with a higher than post-harvest average (2 484 mg.L^{-1}) raw wastewater COD of 3 332 mg L^{-1} (Fig 4.8; Table 4.9). During this week a number of small batches of wine were racked from the barrels, thereby increasing the organic load of the wastewater.

The following week (week 20) the COD levels of the raw wastewater were at the lowest for the post-harvest season with 880 mg.L^{-1} (Fig 4.8; Table 4.9). During this week routine work was done (sulphur adjustment to the barrels and tanks) in the cellar, which did not involve any wine movement and therefore a minimum amount of water was necessary for cleaning, resulting in the low COD levels.

During week 21 the raw wastewater COD was a high of 4 320 mg.L^{-1} (Fig 4.8, Table 4.9). In the course of this week wine was racked from the barrels and the barrels were washed with warm water using a high-pressure cleaning system. As discussed during Winery B 2012 harvest section, this practice could be the reason for the high COD (Fig 4.8). This was also the week that the cellars biggest volume of red blend was racked from the barrels and pumped into clean tanks.

In week 22 the raw wastewater COD was 40% lower at 2 484 mg.L^{-1} (Fig 4.8; Table 4.9). During this week barrel work was done, but only consisted of barrel filling – thus very little cleaning was required, resulting in the lower COD's.

Figure 4.8 shows that in week 23 the raw wastewater COD was almost 4 806 mg.L^{-1}. Barrels were emptied during this week, which could explain the high COD concentrations due to cleaning activities (indicated with B on Fig 4.8). Even though the excess lees from barrels was first emptied by hand into a bucket, there was still a small percentage of the lees that had to be washed out with the high pressure system entering the wastewater system, thus contributed to the organic load in the wastewater as indicated. During the next two weeks (week 24 – 25), barrel work was also done but in smaller volumes, hence resulting in lower COD concentrations (Fig 4.8). In the 26th week the COD concentration was higher than average, at 4 207 mg.L^{-1} (Fig 4.8; Table 4.9). Barrels were also emptied during this week, thus requiring cleaning with the high-pressure system (indicated with B, Fig 4.9). Apart from the barrel work, white blends were also made during this week.

During week 27 the raw wastewater COD was lower at 1 666 mg.L^{-1} (Fig 4.8). Even though barrels were emptied during this week, a much smaller quantity of barrels were emptied, therefore having a smaller effect on the COD. In week 28, 29 and 30 no barrel work was done (Table 4.9). The only activity in these three weeks involved wine being racked from the stainless steel tanks, thus also resulting in lower than average raw wastewater COD's of 2 452 , 1 879 and 1 968 mg.L^{-1}.

In weeks 31 – 34 the only water usage occurred in week 31, when the cellar walls were cleaned with the high pressure hose, but the volumes were very low and thus no raw wastewater sampling occurred during the four weeks (Fig 4.8; Table 4.9).

Figure 4.8 shows that during weeks 35 – 37 the raw wastewater CODs were low ranging from 1 500 to 1 980 mg.L^{-1} (Fig 4.8; Table 4.9). During these weeks wine was racked from the barrels, which were cleaned with the high pressure system, but as this was not the first racking of these tanks, the lees was much less and subsequently did not have such a marked effect on the COD (Table 4.9).

During week 38 – 41 the raw wastewater CODs increased slightly ranging from 2 120 to 2 824 mg.L^{-1} (Fig 4.8; Table 4.9). Throughout these weeks, barrels were emptied and washed, again contributing to the higher COD's. In these cases it was the 2nd or 3rd racking of the wine, which could explain the smaller increases in COD, compared to the higher increases observed earlier in the year with the first rackings of the wines. Each successive racking 'produces' less lees than the previous racking, and therefore less lees can spill during rackings and hence the lower COD's.

The average COD levels of the treated wastewater for the 2012 post-harvest were low (41 mg.L^{-1}) and exceeded 100 mg.L^{-1} only once during week 34 (Fig 4.8). The average reduction of the raw wastewater COD was 98% and therefore could the water be used for irrigation according to DWAFs legal limit of 5 000 mg.L^{-1} for irrigation of less than 50 m^3 per day (DWAF, 2004).

pH

The pH of the raw wastewater for the post-harvest season at Winery B ranged between 4.20 and 9.47 (Table 4.10; Fig 4.8). According to literature, average winery wastewater pH ranges between 3.5 and 7.8 pH (Bustamante *et al*., 2005). During this period the pH exceeded these values on two occurrences, namely week 19 and 22 when cleaning of tanks could have been responsible for the higher pH (Fig 4.8). Caustic is often used and the sampling could have occurred close after the caustic usage.

The treated wastewater pH ranged between 7.31 and 8.5. These values met the specifications for irrigations of winery wastewater from DWAF of 6.00 – 9.00 pH when irrigating 50m^3 or less per day (DWAF, 2004). During the 2012 harvest the treated wastewater samples were taken from the mouth/end of the pipe delivering the treated wastewater to the storage/irrigation dam. However, during the post-harvest period, the end of the pipe was submerged in the dam and thus samples had to be taken from the dam itself (as close as possible to the end of the pipe). This could be the reason for the overall higher pH of the treated wastewater. A summary of the raw and treated wastewater pH monitored at Winery B during the post-harvest season is given in Table 4.10.

Table 4.10 Summary of the highest, lowest and average pH values for the raw and treated wastewater from Winery B for the Post- harvest season.

	RAW WASTEWATER pH	TREATED WASTEWATER pH
Mean	5.03	7.89
Highest	9.47	8.50
Lowest	4.20	7.31

4.3.1.6 Winery B – Harvest 2013

COD

The 2013 harvest was the second harvest monitored at Winery B during this study. The 2013 harvest started on the 30th of January 2013, and lasted 9 weeks in total, until the 2nd April 2013. The total tonnage of grapes processed in 2013 was 430 tons (82% red and 18% white grapes).

During the first week of the harvest (1 – 3 Feb) the first raw wastewater COD sample was taken on the day after harvesting began (31 Jan), resulting in a low COD of 2 184 $mg.L^{-1}$ (Fig 4.9; Table 4.11). The first day of harvest comprised only a small volume of white grapes, which were harvested and pressed.

During the second week (4 – 10 Feb) the raw wastewater COD fluctuated on a daily basis with values ranging from 842 to 5 219 $mg.L^{-1}$ (Fig 4.9; Table 4.11). On 4th February a COD of 5 219 $mg.L^{-1}$ was measured (the highest for the week), mainly due to the fact that almost 12 tons of white grapes were processed. This tonnage was the largest amount of white grapes processed on a single day during this harvest. The press used at Winery B is a 7.5 ton press and therefore needed to be used more than once on this day. After each cycle the press is cleaned out and rinsed before the next cycle. The drastic decrease in raw wastewater COD on 5th February (Fig 4.9) could be attributed to the low tonnage (2 tons) of white grapes processed, and the fact that the grape juice processed the previous day (4th) was only racked on the 6th, thus contributing to the COD levels for 6th February (Fig 4.9). Apart from the racking, a big batch of barrels were also emptied on the 6th, also possibly increasing the raw wastewater COD (Fig 4.9; Table 4.11). On the 7th February, 10 tons of white grapes were processed and a number of tanks were racked. Coupled to this, the fact than the water usage on the 7th was low (11 m^3), it was expected that the raw wastewater COD would be very high. The COD of the raw wastewater sample for the 7th was, however, very low at 842 $mg.L^{-1}$ (Table 4.11). The only plausible explanation is that the sampling was inaccurate on the occasion – possibly due to very high workload of the cellar personnel, and that the raw wastewater was not sampled four times per day as usual to make up the days composite sample.

Figure 4.9 shows that the raw wastewater COD during the 3rd week (11 – 17 Feb) had a mid-week peak with a decrease on the Friday (15th February). The COD concentrations ranged between 1 620 and 4 104 $mg.L^{-1}$ for this week (Fig 4.9). The increased COD on the 13th February can most likely be attributed to the combined processing of white and red grapes on the same day. Furthermore on the 14th and 15th a combination of red and white grapes were harvested. However, the COD on the 15th, which was remarkably lower than for the previous two days, can possibly be explained by the fact that the ratio of higher red to white grapes was higher on the 13th and 14th.

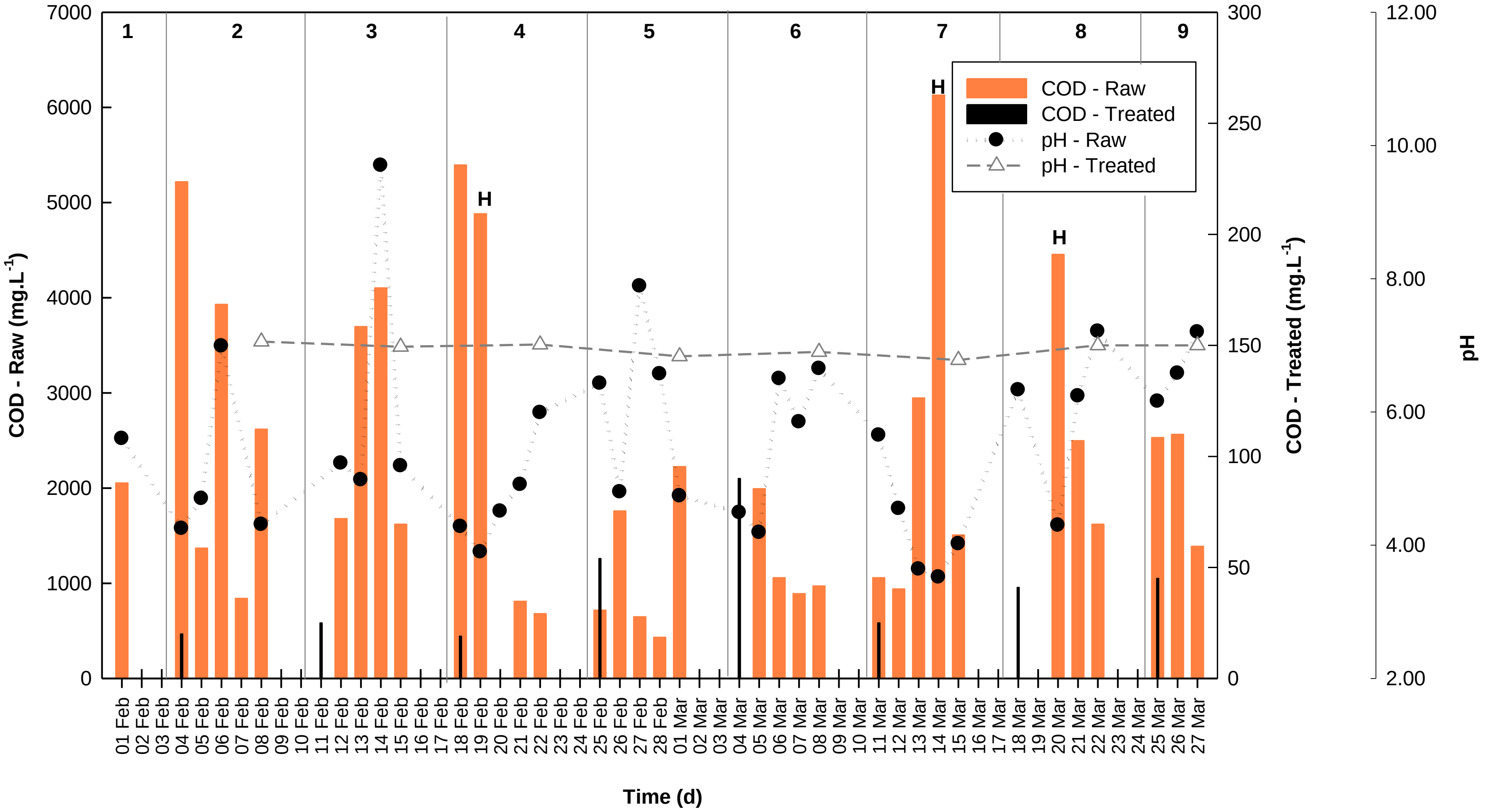

Figure 4.9 Results of daily COD concentrations and pH of raw and treated wastewater from Winery B for the 2013 harvest. (Activities indicated with H: low water usage).

Table 4.11 Daily COD concentration of raw wastewater and the associated activities in the cellar during 2013 harvest at Winery B (Ngamane, P., 2013).

DATE	COD (mg.L^{-1})	ACTIVITIES IN WINERY	DATE	COD (mg.L^{-1})	ACTIVITIES IN WINERY
01-Feb	2 184	HW, rack	05-Mar	1 993	HR, R press
04-Feb	5 219	HW, rack	06-Mar	1 058	HR, rack
05-Feb	1 369	HW	07-Mar	891	Rack, F barrels
06-Feb	3 931	Rack, E barrels	08-Mar	972	HR, rack, F barrels
07-Feb	842	HW, rack	11-Mar	1 058	hR, rack
08-Feb	2 619	HW, F barrels	12-Mar	940	HR
11-Feb		Rack, bottle	13-Mar	2 948	HR, R press
12-Feb	1 679	F barrels	14-Mar	6 129	HR, R press, rack
13-Feb	3 696	HWR, F barrels	15-Mar	1 507	HR, R press
14-Feb	4104	HWR	18-Mar		HR, R press, rack
15-Feb	1 620	HWR, routine cleaning	19-Mar	4 455	HR, R press, rack
18-Feb	5 395	R press, rack	20-Mar	551	HR, R press, rack
19-Feb	4 882	HWR, F barrels	21-Mar	2 498	Rack
20-Feb		HWR, rack	22-Mar	1 620	HR, F barrels
21-Feb	810	HW, rack	25-Mar	2 531	R press
22-Feb	680	HW, F barrels	26-Mar	2 565	Rack, R press
25-Feb	718	Rack	27-Mar	1 388	R press, F barrels
26-Feb	1 760	HW, F barrels	28-Mar		Rack, R press
27-Feb	648	HW, R press, F barrels	29-Mar		Rack, R press, F barrels
28-Feb	432	HW, rack, blend	01-Apr		Rack, R press
01-Mar	2 225	HR, R press	02-Apr	764	R press
04-Mar		HR, R press			

HW – white grapes harvested; HR – red grapes harvested; HWR – white and red grapes harvested; Press R – red fermenting grapes pressed; OV – older vintage; E barrels - emptied barrels; F Barrels –fill barrels; EF barrels – emptied and fill barrels

When the first two days (18 & 19 Feb) of week 4 (18 – 24 Feb) are compared to the last two days of week 4 it can be seen that the COD is considerably lower on the days (21st & 22nd Feb) on which only white grape were harvested (Fig 4.9). The workload on the18th (three red fermented tanks were pressed) and 19th (14, 700 tons processed) was noticeably higher than on the 21st and 22nd February. On the two days that only white grapes were processed (21st and 22nd) the water usage was higher and this would result in a more diluted COD of the raw wastewater generated (Fig 4.9).

Throughout week 5 and 6 (25 Feb – 10 Mar) the concentration of the raw wastewater COD never exceeded 2 200 mg.L^{-1} (Fig 4.9). The raw wastewater COD ranged from as low as 432 mg.L^{-1} on 25 February to 2 225 mg.L^{-1} on 1 March (Fig 4.9; Table 4.11) with an average of 1 200 mg.L^{-1}. During this period white and red grapes were never processed on the same day and the volumes of the white grapes processed were lower than in previous weeks. On the 25th of February and 7th of March no grapes were processed (Table 4.11), yet there was a difference in the raw wastewater COD of almost 20% on these two dates. The difference is most likely due to more tanks being racked on the 7th than on the 25th. The higher raw wastewater COD's on 1st and 5th March could be attributed, firstly to an increase in the amount of red grapes processed on these dates and secondly, red fermented tanks were also pressed on these days, increasing the organic load in the wastewater.

During week 7 (11-17 Mar) the COD for the raw wastewater was during two occasions higher than the average (2 230 mg.L^{-1}) for the 2013 harvest, ranging from 940 to 6 129 mg.L^{-1}(Fig 4.9; Table 4.11). The high raw wastewater COD on the 14th March could again be due to the high volumes of red grapes processed, and the higher work load in the winery during the peak period. Besides the latter, five red fermented tanks were pressed, adding to the COD load. Lastly, the water usage for the 14th March was lower than average resulting in a higher COD (indicated with H on Fig 4.9).

Over the last weeks (8 and 9) of the harvest there was only one day, (20th of March), on which the raw wastewater COD was higher than 4 000 mg.L^{-1}(Fig 4.9). On this day, red grapes where harvested, tanks were racked and red fermenting tanks were pressed (Table 4.11), and the water usage for the 20th March was lower than average resulting in a higher COD (indicated with H on Fig 4.9). All these activities have an influence on the resulting higher COD.

The average COD of the treated wastewater for the 2013 harvest period was lower than 100 mg.L^{-1}. This value is under the 5 000 mg.L^{-1} legal limit for irrigation of less than 50 m^3 per day (DWAF, 2004). Therefore the constructed wetland was reducing the COD efficiently enough for the treated wastewater to be used as irrigation water.

pH

During the 2013 harvest at Winery B the raw wastewater pH ranged from 3.52 to 9.70 (Table 4.12; Fig 4.9). The majority of these values fall in the range of 3.50 to 7.80, given in literature for average winery wastewater pH values (Bustamante *et al*., 2005). In Figure 4.9 it can be seen that on 14 February the pH peaked at a value of 9.70. The high pH on this day could be because of the time of sampling and the specific practises that took place at the time of sampling. Even though the excess rinsing water used to rinse the caustic from the tanks were separated from the bulk of the wastewater there is still a small volume of caustic entering the wastewater increasing the pH.

The treated wastewater pH ranged between 7.30 and 7.55 (Table 4.12). These values were within the legal limit for irrigation of winery wastewater by DWAF of pH 6.00 – 9.00 when less than 50 m^3 wastewater is used (Table 4.12). Therefore this water could be used for irrigation when only pH is taken in consideration.

Table 4.12 Summary of the highest, lowest and average pH values for the raw and treated wastewater from Winery B for the 2013 harvest.

	RAW WASTEWATER pH	TREATED WASTEWATER pH
Mean	4.47	7.45
Highest	9.70	7.55
Lowest	3.52	7.30

4.3.2 Comparison of seasons and wineries

4.3.2.1 2012 Harvest VS 2013 Harvest

During the 2012 harvest at Winery A it was observed that mainly 2 practices influenced the high COD loads of the wastewater generated. These practices are indicated on Fig 4.4 and include first rackings after fermentations (marked with A) and barrel emptying and cleaning (marked with B). The winemaking practices done on Sundays appeared also to influence the organic load in the wastewater resulting in higher COD concentrations. The average COD for the 2012 harvest was 6 488 mg.L^{-1} with the lowest on 13 February (2 087 mg.L^{-1}) and the highest on 24 February of 14 724 mg.L^{-1} (Table 4.13).

In Figure 4.5 ‘C’ indicates the influence of the processing of the grapes for the Noble Late Harvest on the COD concentrations of the raw wastewater at Winery A, during the post-harvest season of 2012. The sugar level of the grapes when harvested was between 40 – 44 °Balling which calculated to 440 g.L^{-1}. Since sugars are responsible for a large part of the organic load of wastewater it adds to the COD concentrations (Quale *et al.,* 2009). Tht high COD concentration indicated by ‘D’ relates to most likely due to activities including racking of the fermented late harvest wine and barrel work that was done. Unfortunately the winery personnel did not record their activities so this cannot be confirmed. ‘E’ indicates the weeks that filtration of more than 15 000 L of wine was done, and how the raw COD was influenced. As discussed previously the Diatomaceous Earths, used as a filtration aid, absorbs vast amounts of the wine or lees with a high COD level and as a result increases the organic load in the wastewater when the filtering equipment is washed. During the post-harvest season the average COD at Winery A was 5 596 mg.L^{-1} with a low of 1 810 mg.L^{-1} in week 47 and the highest COD in week 22 (14 418 mg.L^{-1}) (Table 4.13).

Table 4.13 A summary of the highest, lowest and average COD concentrations of the raw and treated wastewater COD for Winery A and Winery B during the study period January 2012 to beginning April 2013

	WINERY A COD (mg.L^{-1})			**WINERY B COD (mg.L^{-1})**		
Raw wastewater	**Average**	**Highest**	**Lowest**	**Average**	**Highest**	**Lowest**
Harvest 2012						
COD	6 488	14 724	2 087	2 711	6 614	944
pH	4.73	11.53	3.75	4.17	9.20	3.51
Post-harvest 212						
COD	5 596	14 418	1 810	2 484	4 806	880
pH	4.75	6.27	4.15	5.03	9.47	4.20
Harvest 2013						
COD	3 093	11 705	502	2 230	6 129	432
pH	4.38	11.10	3.84	4.47	9.70	3.52
Treated wastewater	**Average**	**Highest**	**Lowest**	**Average**	**Highest**	**Lowest**
Harvest 2012						
COD	1 245	2 923	338	29	43	8
pH	6.35	7.60	5.81	5.79	6.80	5.09
Post-harvest 2012						
COD	31	91	5	41	133	8
pH	7.36	7.79	6.99	7.89	8.50	7.31
Harvest 2013						
COD	430	1 420	14	40	90	19
pH	5.93	7.40	5.13	7.45	7.55	7.30

In the beginning of the 2013 harvest at Winery A the influence of harvesting and processing large amounts of grapes for the Pinotage blend are indicated with 'F' on Figure 4.6. The various practices used to process this wine increased the COD concentrations of the raw wastewater. Point G indicates the day that the holding pit was cleaned completely. This resulted in a decrease in the average raw wastewater COD throughout the rest of the harvest. Point H indicates the influence of low water usage on the raw wastewater COD. On Sunday 17th February, minimum work was done with low water usages consequently increasing the COD. The average COD during the 2013 harvest was 3 093 mg.L^{-1} with the highest measured concentration on 30th January (11 705 mg.L^{-1}) and the lowest of 502 mg.L^{-1} on the 21st February (Table 4.13). Overall, the average raw wastewater COD for winery A for the 2013 harvest was 3 093 mg.L^{-1} lower than that of the 2012 harvest.

During the 2012 harvest at Winery B, (H) in Figure 4.7 indicates the influence of low water usage on the COD concentrations. When a smaller volume of wastewater was generated the COD concentrations were more concentrated and consequently higher. Table 4.13 shows that Winery B in general had lower raw wastewater COD concentrations throughout the 2012 harvest with an average of 2 711 mg.L^{-1}, the highest of 6 614 mg.L^{-1} on 14 March and the lowest on 21 March (944 mg.L^{-1}) (Table 4.13).

'B' in Figure 4.8 represents the cleaning of barrels during the 2012 post-harvest season at Winery B. When the warm high-pressure system is used the COD increases because of the increase in organic material in the wastewater. The average raw and treated wastewater COD for the post-harvest was 2 484 mg.L^{-1} with the highest of 4 806 mg.L^{-1} in week 23 with the lowest being 880 mg.L^{-1} in week 20 (Table 4.13).

Throughout the 2013 harvest at Winery B, 'H' in Figure 4.9 represents the days that the water usage was low, with a high work load. Therefore the raw wastewater COD contrations were higher. The average raw wastewater COD concentration during this period was 2 230 mg.L^{-1} with the highest (6 129 mg.L^{-1}) on 14 March and the lowest (432 mg.L^{-1}) during the first week of harvest (Table 4.13). Overall the average raw wastewater COD during the 2013 Harvest decreased by 30% from the 2012 harvest.

4.3.2.2 Winery A VS Winery B

The difference in tons processed during the two harvests at Winery A and Winery B could be argued to have an effect on the COD concentration of the raw wastewater, but according to this study it is possible to say that the pollution load is not dependent on the volume of grapes processed by a winery. The smaller crop of Winery B possibly had no influence on the COD concentration of the raw wastewater. From Table 4.14 it was possible to see that the increase in tons harvested did not mean the increase in pollution load. On the contrary, Winery B had a decrease of 30 % in the raw wastewater COD concentration, even though the tonnage increase from 2012 (380 tons) to 2013 (437 tons). It is most likely that the pollution load is more dependent on the work ethics of the winery staff and the equipment that is use.

Winery B implemented a cleaner production strategy in 2003 which has been constantly re-evaluated since then (Shultz, C., 2013).

At Winery B all water drains in the winery are equipped with two mesh sieves to reduce organic material (grape skins and seeds) in the wastewater system (Fig 4.10 & 4.11). Generally wineries, including Winery A, use only one mesh filter in their drains. This often results in a "no mesh filter" scenario, when the mesh becomes blocked/clogged and is removed to be cleaned allowing large amounts of solids to enter the wastewater system. In contrast, when a blocked drain is cleaned at Winery B, the second sieve ensures that no grape skins and pips enter the wastewater system when cleaning the first mesh. Furthermore, Winery B also implemented a double mesh sieve system at the wastewater exit point for the winery. This ensures that if any organic material ends up in the wastewater system through the drains of the winery it will be removed before it enters the wastewater treatment system (Fig 4.12). Not only is the COD concentration of the raw wastewater lower, but treating the wastewater will use less resources.

Winery B also ensure that when a tank is cleaned that they collect most of the lees and rinse the tank with a small volume of water and then also collect the diluted lees. This diluted lees is added to the separate lees tank and when full, is sold to a recycling company that use the lees for tartaric acid extraction. Diluting the lees with water results in lower quality of the lees and therefore decreasing the selling price. However, it ensures lower organic levels in the wastewater keeping the COD levels to a minimum. At Winery A the thick lees will also be collected and sold to the recycling company but the first rinsing of the tank with water will go into the wastewater system rather than diluting the lees increasing the COD of the raw wastewater.

Winery B also recently re-coated the entire winery's floor, ensuring that cleaning is more efficient (Fig 4.13). The surface of the floor is smooth and sweeping the grapes skin and spilled lees is done with more success, reducing the contact time of the wastewater with organic material. Winery A's winery is a much older winery and even though some of the floors have been repaired in the

Figure 4.10 A) Double mesh sieves installed in the wastewater drains in Winery B floors. B) Single mesh sieve installed in the wastewater drains Winery A's winery floors.

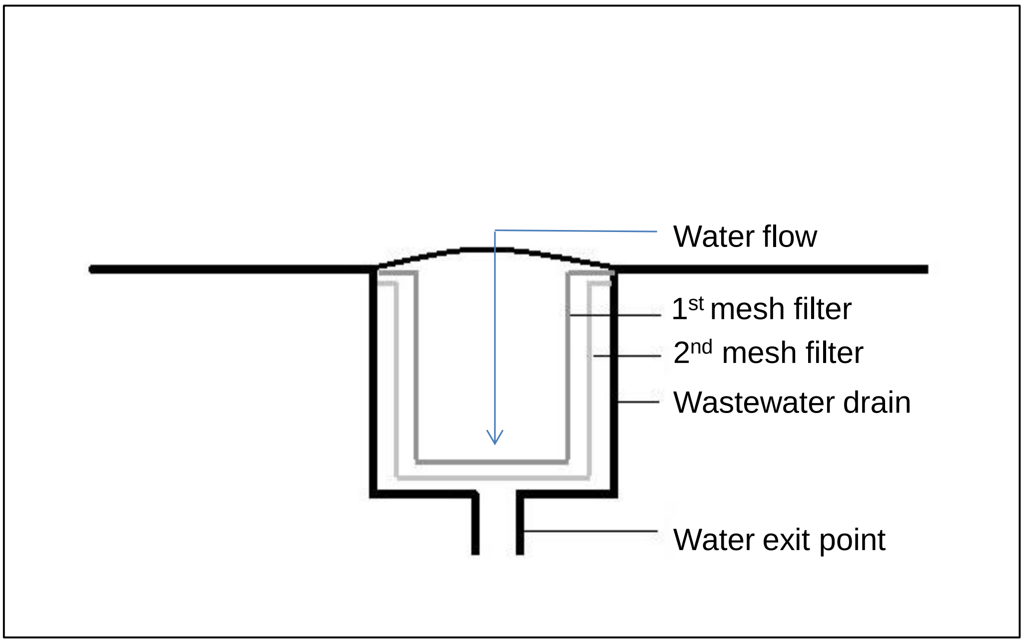

Figure 4.11 A schematic representation of the wastewater drain implemented with a double mesh sieve in Winery B floor.

Figure 4.1 Double mesh sieve at the wastewater exit point of Winery B.

past, the floors are worn out, causing puddles of wine and water to accumulate making it more difficult to clean and in turn increasing the COD levels.

Limited space at Winery A forced the winery to install tanks very close to one another limiting the usage of suitable sweepers to get the solids (grape skins and pips) out of the way before rinsing it off with water. When making wine in an older cellar the employees must be more aware of the cleaner practice strategies.

Winery B uses 'Hydrox' as a cleaning chemical. It is a concentrated oxidising peroxide acid used as a sanitiser and acid rinse. According to Ksibi (2006), hydrogen peroxide has also successfully been used for treating wastewater COD in the past. This could also attribute to the overall lower COD values of the raw wastewater. However, one of the disadvantages with using this chemical treatment comparing to biological and physical is the financial impact.

Figure 4.2 Recoated floors of Winery B: A) processing cellar; B) barrel cellar.

4.3.2.3 Comparison between Winery B and Winery A treated wastewater

The average treated wastewater COD concentrations are indicated in Table 4.14 measured during the 2012 harvest, 2012 post-harvest and the 2013 harvest for Winery A and Winery B.

During the 2012 harvest the average treated wastewater COD for Winery A was 1 245 $mg.L^{-1}$ (Table 4.14). There was a noticeable reduction in the average treated COD concentration for the 2013 harvest (Table 4.14). This reduction could be due to the reduction in COD concentration of the raw wastewater produced by the winery (Table 4.14). This shows that a drastic reduction in pollution load will increase the efficiency of the wetlands.

In Table 4.14 it can be seen that the treated wastewater COD concentration during this study at Winery B was always below the legal limit COD concentrations of 5 000 $mg.L^{-1}$ for irrigation by DWAF (DWAF, 2004). This is a good indication that the wetland is of an appropriate size to reduce the COD levels suitable for irrigation.

Table 4.14 A summary of the correlation between the tons harvested and the percentage COD reduction at Winery A and Winery B during the study period January 2012 to beginning April 2013

	TOTAL TONS HARVESTED (t)	AVERAGE RAW COD ($mg.L^{-1}$)	AVERAGE TREATED COD ($mg.L^{-1}$)	AVERAGE % COD REDUCED
Winery A				
Harvest 2012	745	6 488	1 245	80
Post-harvest 2012	-	5 596	31	99
Harvest 2013	835	3 093	4 30	86
Winery B				
Harvest 2012	376	2 711	29	98
Post-harvest 2012	-	2 484	41	98
Harvest 2013	430	2 230	40	98

4.4 Conclusions

From this study it was observed that both wineries showed a decrease in the COD of the raw wastewater produced. Over all Winery A showed a decrease for the average raw wastewater COD of 52% from 6 488 to 3 093 mg.L^{-1} during the 2013 harvest (Table 4.13).This decrease of COD can likely be attributed to a few reasons. Firstly during the 2012 harvest the older vintage wine was racked and filtered during harvest and during the 2013 harvest the work on older vintages was minimised. This shows that the lees and filtrate from older vintages has a large influence on the COD concentration of the raw wastewater. Secondly, the cleaning of the collection pit of the wastewater also decreased the average COD concentration during the 2013 harvest. The cleaning of this pit could be done more often, particularly during harvests when the pollution load is higher than in the rest of the year. Lastly, during the 2013 harvest the grapes ripened more evenly, compared to the 2012 harvest. This gives additional time between the receiving of the grapes and the different winemaking activities, providing the winemaking team with ample time to work and clean more efficiently reducing waste and organic material in the wastewater. Therefore, the cleaning of the press and tanks could be cleaned out thoroughly before washed with water and contributing to the COD levels.

Winery B also showed a decrease in raw wastewater COD concentration of 18% from 2 711 to 2 230 mg.L^{-1}during the 2013 harvest (Table 4.13). Although the decrease at Winery B was only 18%, the reduction was coming from a much lower COD (2 711 mg.L^{-1}) than was the case at Winery A (6 488 mg.L^{-1}). The reduction in COD from 2012 to 2013 could also be because less older vintage work was done during the 2013 harvest

The positive reduction of the raw wastewater COD concentrations for both wineries, throughout the 2013 harvest, indicates that cleaner production strategies and awareness plays an important role in the managing of wine wastewater. Therefore, it is import to highlight the practise that showed the most potential to reduce the pollution load during this study. These practises mainly decrease the organic load in the wastewater to ensure lower COD concentrations. Wineries could install mesh sieves in all the drains of the winery floor and in-line screening in the water treatment system to reduce the solids in the wastewater. Furthermore, will the transfer of the lees and the first rinsing to a separate container prevent the lees and diluted lees from draining to the wastewater system, before the vessel (stainless steel tank or oak barrel) is rinsed with ‘clean’ water. Lastly, to help reduce changes of spillage, it is helpful to keep wine transfers to the minimum.

To summarise, it is possible that certain winemaking practices influence the composition of the wastewater. Comparing the two wineries and the three different winemaking periods showed that:

- Cleaner production strategy
- Double mesh sieves

- Collecting of diluted lees
- Smooth clean floors
- Use of oxidising peroxide
- Regular cleaning of the sump/collection pit of the treatment plant most probably help wineries to lower the COD of the wastewater before the wastewater enters the treatment plant and over all lowering treatment costs.

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CHAPTER 5

GENERAL DISCUSSION AND CONCLUSIONS

5.1 Background

There is little doubt that one of the biggest concerns around the world is water scarcity. Over the last few years water has become a valued commodity not only in water scarce areas but also in areas where water is abundant. The latter is due to contamination of natural water sources. The wine industry does not have a reputation as a polluting industry, however, the increasing numbers of wineries and the demand for wine globally are adding to the production of wastewater. Wineries generate large volumes of wastewater during the winemaking process and mainly during the harvest period (January to April in South Africa). Cleaning during the harvest period is the main contributor and generates wastewater with a high organic load, low pH, variable salinity and nutrient levels - posing a threat to the direct environment if not treated correctly (Mosse *et al*., 2011).

Due to this increase in wastewater production it is important to develop strategies to reduce the volumes of wastewater produced, increase the quality of wastewater and optimise the volumes of water used during the winemaking process. The variance in wastewater composition and volumes produced during the different winemaking stages complicates the issue of finding general solutions for different wineries. The aim of all wineries is to find the most effective way to treat their wastewater. Avoiding waste is the most cost effective way and often easiest principle to implement – better known as ‘prevention (waste minimisation/cleaner production) is better than treatment’ (Champan *et al*., 2001).

5.2 Water usage in a winery

One of the aims of this study was to compare the water usage and winemaking practices of two wineries (one systematically striving to improve its water usage and the other having implemented a cleaner production strategy 10 years ago) to determine the impact of certain winemaking practices on the water usage. The water usage was monitored during two harvests and one post-harvest season. During this study it was evident that water plays a vital part in the winemaking process and that water is used throughout the winemaking process. It was also noticed that the biggest demand for water for both wineries was during the harvest period. The wineries used respectively between 30 and 40% of the total annual volume of ‘clean’ water during harvest and this demand decreased noticeably during the post-harvest season. It was also noticed that the demand for water again increased steadily towards the end of the year leading up to the next harvest. Adding to this increased usage was the different winemaking practices, including filtering with a bulk filter, washing barrels and bottling mainly contributing to the water usage throughout the year.

It was also evident that there was a vast difference in the volumes of water used by the two wineries. It was identified that Winery B used a smaller volume of water on a daily basis and per tonnage during harvest than Winery A during 2013. This could be a result of the cleaner production strategy helping to reduce the water usage at this winery. The four main factors contributing to their water efficiency are:

1. Implementing a cleaner production strategy and ensuring that all winery employees are constantly aware of using less water;
2. Using membrane filtration rather than bulk filtration to decrease the volume of water needed for preparing the filter before use and cleaning after the wine has been filtered;
3. Dry sweeping of the floors and the inside of the tanks before washing with water this ensure smaller volumes of water needed to wash the floors and tanks;
4. Using water saving nozzles on all the hosepipes, ensuring that no water is wasted when the pipes are not in use.

However, it is clear from this study that there are also a number of changes that can be implemented which will improve water use efficiency, but these will involve long term planning and capital input:

1. Processing white and red grapes separately helps lower the demand for cleaning and therefore uses less water;
2. Re-coating floors with an epoxy coating decreases the cleaning intensity and reduces the volume of water needed to wash the floors;
3. Using a high pressure cleaning system decreases the volume of clean water used for cleaning.

5.3 The chemical characteristics of winery wastewater

The second aim of this study was to investigate the influences of various winemaking practices on the chemical characteristics of winery wastewater. Firstly it was noticed that the different activities of the two wineries influenced the quality of the wastewater. This study showed that at Winery A during the 2012 harvest the first racking of the fermented white wines increased the COD of the raw wastewater. Large volumes of lees that are discarded into the wastewater when cleaning the used tanks increased the organic content in the wastewater, resulting in higher COD's. Adding to this was the amount of barrel work of older vintages that was done during harvest, again increasing the concentration of lees in wastewater. Lastly during the 2012 harvest it was noticed that working on Sundays also tended to increase the COD of the raw wastewater. This could be due to the low water usage on these days.

During the 2012 post-harvest at Winery A a small volume of Noble Late harvest grapes was processed increasing the COD of the raw wastewater. Since the sugar levels of the Noble grapes are higher than the average grapes processed during harvest it has a bigger influence on the organic load of the raw wastewater, increasing the COD.

During the second harvest at Winery A it was noticed that on the days that larger than average volumes of grapes were processed the COD concentration increased. This is most likely due to the larger amount of organic material ending up on the floor, while the same volume of water is used during cleaning. It was also noticed that the cleaning of the holding pit at the beginning of the 2013 harvest decreased the average COD of the raw wastewater. Therefore, it is highly recommended that the holding pit is cleaned annually before and after the harvest.

At Winery B it was noticed that mainly two practices influenced the raw wastewater quality during the whole study period. Firstly on the days that the water usage of the winery was low, it directly influenced the COD concentration of the raw wastewater. It is possible to say that when a small volume of wastewater was generated the COD concentrations were more concentrated and consequently higher. Secondly, barrel work also influenced the COD of the raw wastewater.

In general Winery B had over lower raw wastewater COD concentrations throughout this study compared to Winery A. Even though Winery B’s production increased during the 2013 harvest a decrease of 18% in the raw wastewater COD was noticed. Therefore, it is likely that the pollution load is more dependent on the work ethics of the winery staff and the equipment that is used.

Comparing the two wineries and the three different winemaking periods showed that:

1. Installing double mesh sieves in all the drains to minimise. The organic material entering the wastewater system;
2. The collection of lees and the diluted lees lowered. The organic load of the wastewater, thus lowering the COD of the raw wastewater;
3. Easy cleanable floors increase the cleaning efficiency of the organic material before water is used to rinsed the floors;
4. Limited space between the tanks at Winery A makes is more difficult for the personnel to remove the organic material from the floors before washing with water;
5. The use of a concentrated oxidising peroxide as a sanitiser will lower the overall COD of the wastewater;
6. Regular cleaning of the sump/collection pit of the treatment plant will decrease the average COD of the raw wastewater.

Both wineries showed decreases in the COD after treatment through the respective wetlands. However, Winery B’s treatment plant reduced the COD to much lower levels than of Winery A. Firstly, this could be due to the raw wastewater of Winery B having a lower COD than that of the Winery A. Secondly, the constructed wetland at Winery B is noticeably bigger than that of Winery A and adding to this, is the fact that a smaller volume of water is treated by the Winery

B wetland. This gives the water more contact time in the wetland thereby increasing its efficiency.

5.4 Concluding remarks

This study has successfully shown that the implementation of a cleaner production strategy is an important step in reducing the amount of water used by a winery, and also results in a lower organically loaded wastewater. Furthermore, this study has also shown that practices and activities in a cellar, both during the harvest and post-season, differ in their effect on the composition of the resulting wastewater. Thus, valuable information has been gained as to the activities in a cellar which use the most water or contribute most significantly to the organic load of the resulting wastewater.

Although the outcome of this study was successful in pointing out different winemaking practices to reduce the water usage and to improve the quality of the raw wastewater it would be helpful to have a clearer idea of the exact volume of water used for specific practices. This would be possible if a number of water meters were installed in the winery to measure the exact volume of water used by the specific process. It would also be beneficial if a dedicated study could be done on the effect of winemaking practices on the organic load, by monitoring the quality of wastewater at more comprehensively with specific practices (i.e. having someone on site performing these studies would significantly improve the correlations).