Challenges in the potable water industry due to changes in source water quality: case study of Midvaal Water Company, South Africa

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ABSTRACT

Midvaal Water Company treats hypertrophic water abstracted from the Vaal River to supply bulk wholesome potable water to their consumers in compliance with the South African National Standard (SANS) 241:2015 for drinking water. The facility incorporates conventional and advanced treatment processes. The aims of the study were to identify how the water treatment processes of the plant have changed over time in response to the varying water quality of the Vaal River, and to consider both current and future obstacles as well as possible solutions regarding water quality and treatment. Oxidation steps such as pre-chlorination, potassium permanganate addition, pre-ozonation and intermediate ozonation have either been applied in the past or are still operational. The dissolved air flotation plant accounts for almost 70% of total chlorophyll removal and the significance of this process was confirmed during a brief maintenance shutdown during 2015. Total chlorophyll concentrations of the source water have increased extensively since 1984, while turbidity levels have remained fairly constant but with spikes at times. The facility suffers from severe taste and odour episodes during warm periods due to the presence of methylisoborneol (MIB), released by Cyanophyceae, in the Vaal River. Concentrations of > 300 ng/L MIB have been recorded, whereas the odour threshold concentration for MIB ranges from 4 ng/L to 20 ng/L. The additional application of activated carbon to alleviate taste and odour problems has to be weighed against the cost implications for consumers, the correct type to be purchased for the organic molecules to be adsorbed, the interference of natural organic matter, and the formation of additional sludge mass, as well as the intensity and duration of taste and odour events. Midvaal remains a bulk potable water supplier and therefore has to consider the socio-economic status of their consumers where water pricing is concerned. The study ultimately emphasized the intrinsic value of protecting water resources.

Keywords: oxidation processes, dissolved air flotation, chlorophyll *a*, taste and odour

INTRODUCTION

The erstwhile Western Transvaal Regional Water Company was established in 1954 to address the drinking water needs of various mining companies at the time. The company is situated in the North West Province of South Africa on the banks of the Middle Vaal River, close to the small town of Stilfontein. The name was changed to Midvaal Water Company in 1998, with the new name derived from its location. Midvaal Water Company supplies bulk potable water to the local municipality, Vierfontein, and the mining industry in the surrounding area. The local municipality is the City of Matlosana Municipality which serves the towns of Klerksdorp, Orkney, Stilfontein and Hartbeesfontein (the KOSH area), which includes approximately 500 000 consumers. Vierfontein, in the Free State Province, has about 1 500 consumers. Anglogold Ashanti represents the majority of the mining industry in the area and is also responsible for the company Mine Waste Solutions which deals with tailing storage facilities reclamation. The 1 120 km long Vaal River originates in the Mpumalanga Province of South Africa and is both heavily used and polluted by the time it passes the treatment works close to Stilfontein. The hypertrophic water from the Vaal River serves as their only water source and is purified by means of various conventional (coagulation and flocculation, sedimentation, filtration and disinfection) and advanced treatment processes (dissolved air flotation (DAF) and ozonation) prior to distribution.

The first aim of this study was to identify the prior objectives, criteria and indicators of water treatment for Midvaal Water Company, and to show how the water treatment processes of the plant have changed over time to adapt to the varying water quality of the Vaal River. The second aim was to consider both current and future concerns and possible solutions regarding water quality and treatment.

METHODS

The study site is situated 14 km from Stilfontein, at 26°55’59.3” S and 26°47’51.8” E. Vaal River water quality data were available from 1984 and operational data were available from 2010. Water treatment at Midvaal Water Company currently consists of the following processes which have been implemented since 2007 (see Fig. 1 and Table 1):

1. Abstraction from source (Middle Vaal River) at intake tower
2. Pre-ozonation
3. Primary addition of water treatment chemicals for coagulation and flocculation.
   A combination of all or some of the following chemicals are used in this process depending on the water quality: lime, ferric chloride, polyelectrolyte and aluminium sulphate
4. Dissolved air flotation (DAF)
5. Intermediate ozonation
6. Secondary addition of water treatment chemicals (optional).
   A combination of all or some of the following chemicals are

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used in this process depending on the water quality: lime, ferric chloride, polyelectrolyte, aluminium sulphate and powdered activated carbon (PAC)

7. Sedimentation
8. Filtration
9. Disinfection by means of chlorine gas
10. Pump station for distribution of the final water to 11 reservoirs in the Klerksdorp, Orkney, Stilfontein and Hartbeesfontein (KOSH) area and Vierfontein

The following analytical activities were performed by Midvaal Water Company Scientific Services, which was established in the 1970s and has been an accredited SANAS Testing Laboratory since 2002 based on ISO 17025.The source water database dates back to 1984. Operational data have been captured on the Laboratory Information Management System (LIMS) since 2010:

• ph	Determined with an electrode since 1984
• Electrical conductivity	Determined with an electrode since 1984
• Turbidity	Determined with a turbidity meter since 1984
• Total chlorophyll	Determined by means of the Sartory (Swanepoel et al., 2008) extraction method since 1984
• Chlorophyll-*a*	Determined be means of an in-house extraction method since 2006
• Manganese	Determined since 1984 by means of atomic absorption spectros copy and inductively coupled plasma optical emission spectroscopy
• Iron	Determined since 1984 by means of atomic absorption spectroscopy and inductively coupled plasma optical emission spectroscopy
• Colour	Determined with a colorimeter since 1989
• Nitrate and nitrite	Determined by means of a colorimetric method since 1984
• Orthophosphate	Determined by means of a colorimetric method since 1984

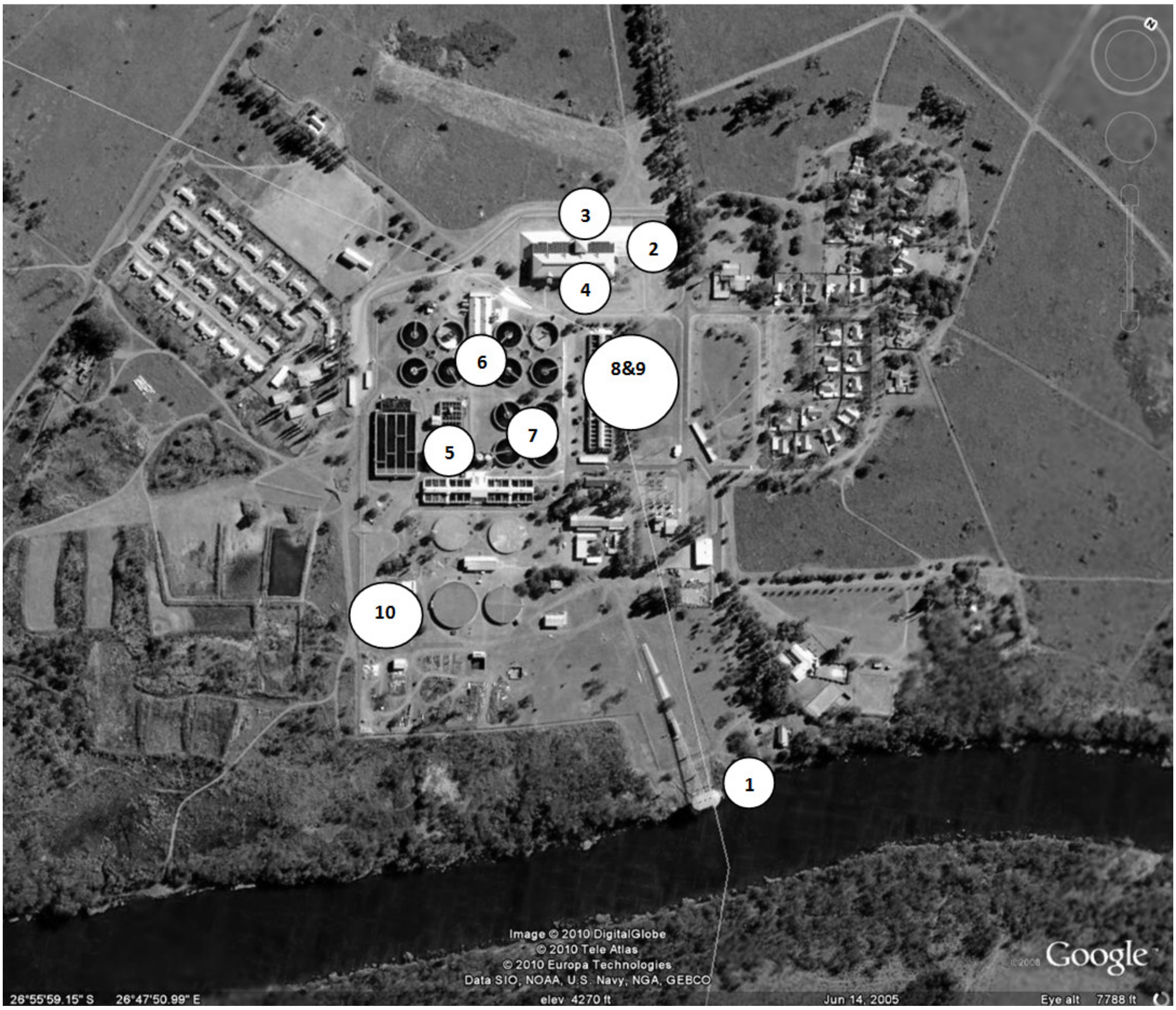

Figure 1

An aerial view of Midvaal Water Company. The treatment plant abstracts on average 130 ML /day, has a capacity to treat 320 ML /day and has a supply area that extends over more than a 1 000 km^2.

Samples are submitted to Rand Water Scientific Services for the analyses of geosmin and MIB when taste and odour problems occur. Rand Water makes use of the purge-and-trap system coupled to gas chromatography–mass spectrometry in order to determine these taste and odour compounds.

Statistica (Version 13) software was used to determine differences between the different datasets. The Shapiro Wilks test for normality was used to determine if the datasets were distributed parametrically. The data did not meet the assumptions of normality in the distribution of all variables. Therefore the Kruskal-Wallis ANOVA (non-parametric data) for comparing multiple independent samples was used to determine differences between the different periods of treatment changes. This software package was also used to determine descriptive statistics for all variables as well as to create the scatterplots.

RESULTS

How the water treatment processes at Midvaal Water Company have changed to adapt to the varying water quality of the Vaal River

Water treatment concerns for Midvaal Water Company: Water quality of the source water

Table 1 indicates how the water treatment processes of the plant have been changed over time in order to address treatment problems encountered due to varying source water quality over a timeline of 53 years. To summarise changes in source water quality, the data available from 1984 until the end of 2014 were grouped into 4 time periods which match significant changes in water treatment:

Group 1: 1984–1991
Group 2: 1992–1996
Group 3: 1997–2006
Group 4: 2007–2014

The mean manganese concentrations declined over time (Fig. 2). This decrease may be ascribed to the enforcement of the National Environmental Management Act of 1998 (Act No. 107 of 1998) (RSA, 1998a) as well as the National Water Act of 1998 (Act No. 36 of 1998) (RSA, 1998b). Interventions by mining companies to comply with regulations resulted in diminishing pollution of underground water that feeds the source. Since 2007 the manganese concentration has no longer posed any concerns to the treatment process.

The turbidity of the source water fluctuates continuously (Fig. 2), and it is the extreme and unexpected spikes that are cause for concern, considering that a maximum value of 1 226 NTU has been recorded (Fig. 3).The water source is a river and rainfall patterns in the catchment, influenced by the effects of climate change, will in future continue to contribute to unpredictable spikes in turbidity levels.

As seen in Fig. 2 and Fig. 3, the total chlorophyll concentrations remain on the increase and subsequently result in an increase in pH levels as carbon dioxide is consumed by more algal cells during photosynthesis.

The mean orthophosphate concentration shows a gradual increase from Group 2 (1992–2006) to Group 3 (1997–2006) to Group 4 (2007–2014) (Fig. 2). The mean nitrate and nitrite concentrations show an increase between Group 3 (1997–2006) and Group 4 (2007–2014) (Fig. 2). Therefore these nutrients will continue to sustain algal growth in the source water.

It appears from Fig. 3 that the presence of algae and the subsequent total chlorophyll concentrations will continue to increase in future, increasing the risk for colour, taste and odour episodes. Higher algal concentrations in the source water, as well as increased spikes in turbidity levels, will ultimately put more pressure on the existing treatment processes, similar to when the DAF process was temporarily out of order from 14 February 2015 to 6 March 2015.

Hudson (2015) conducted a study from January 2010 to December 2011 and determined an average geosmin concentration of 4.083 ng/L (< 5 ng/L) for the Middle Vaal River.

TABLE 1
A summary of the water treatment process train at Midvaal Water Company from 1954–2015

Process	Plant 1954	Plant 1978	Plant 1980	Plant 1985	Plant 1992	Plant 1997	Plant 2007-2015	Treatment objective
Abstraction	✓	✓	✓	✓	✓	✓	✓	
Pre-chlorination		✓	✓	✓				Removal of algal related problems e.g. colour and filter capacity
Pre-ozonation				✓	✓		✓	Improve colour & oxidise manganese, iron and total chlorophyll (1985–1997) Enhance algal removal by DAF (2007)
Primary addition of chemicals	✓	✓	✓	✓	✓	✓	✓	Coagulation and flocculation to remove turbidity/suspended matter
$KMnO_4$ oxidation			✓	✓				Manganese removal
Dissolved air flotation						✓	✓	Separation and removal of light particulate matter and algae
Intermediate ozonation						✓	✓	Manganese & iron removal, colour, taste and odour improvement
Secondary addition of chemicals						✓	✓	Flocculation of particulate matter/solids after the oxidation step
Sedimentation	✓	✓	✓	✓	✓	✓	✓	Separation of solids from water
Filtration	✓	✓	✓	✓	✓	✓	✓	Removal of remaining particulate matter and removal of micro-organisms which might pose a health risk
Disinfection	✓	✓	✓	✓	✓	✓	✓	Pathogen removal

Studies by Morrison (2009) and Hudson (2015) stated that Chlorophyceae and Bacillariophyceae are the dominant algal classes in the Middle Vaal River. *Planktothrix sp.* is usually identified in the raw water during taste and odour episodes. The MIB concentrations indicated in Table 2 confirms that taste and odour problems mostly occur during the months of January, February and March, and also indicates an increase in the frequency of taste and odour problems.

Water quality and the use of oxidants

The treatment processes including oxidants have varied over time to adapt to the ever-changing quality of the source water as well as to ensure optimal, cost-effective operations (Table 1).

Consumer complaints in the late 1970s about brown stains on bathtubs as well as on laundry treated with household bleach lead to the discovery of high and fluctuating concentrations of

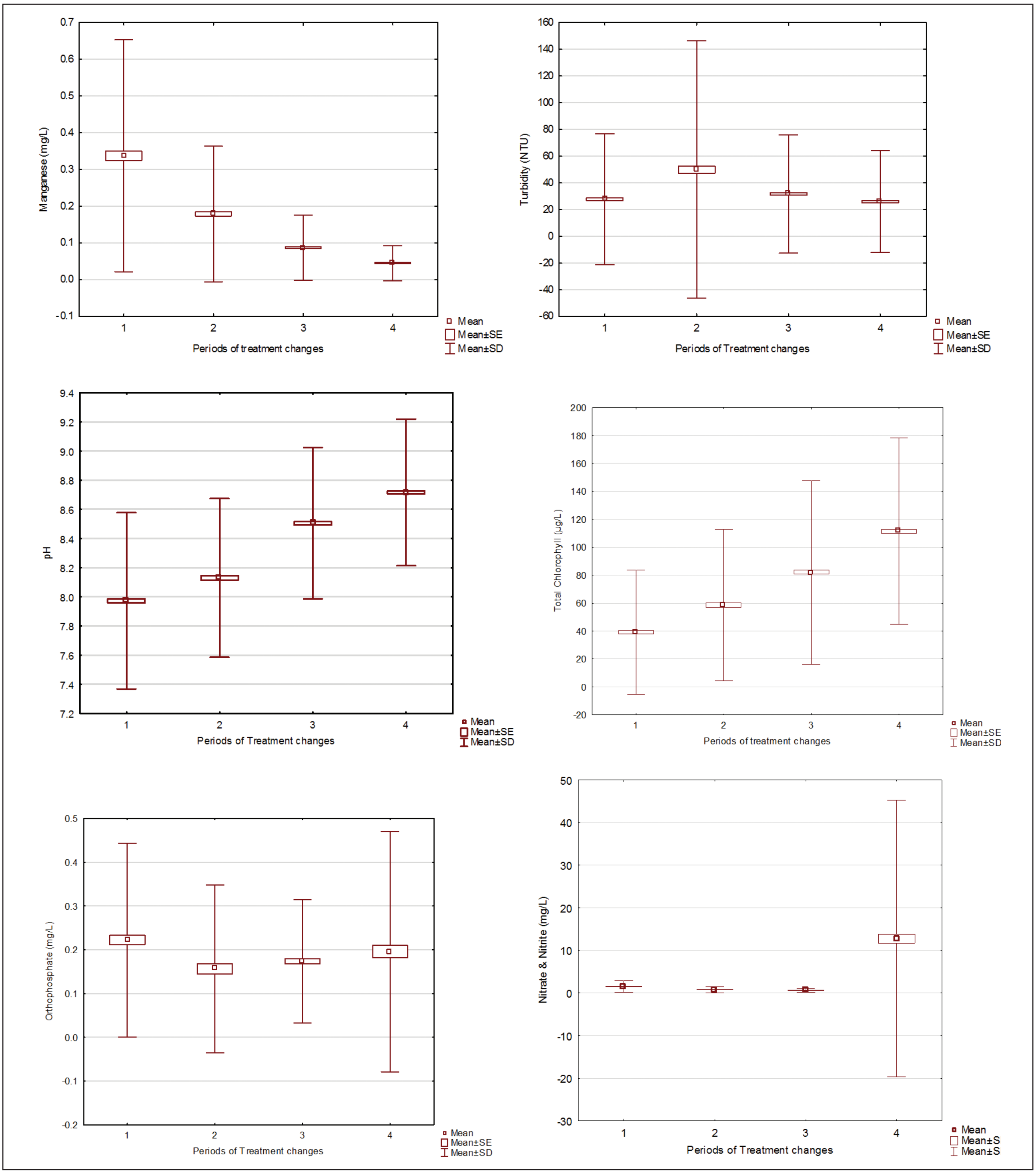

Figure 2

Box and whisker plots that compare means, standard errors (SE) and standard deviations (SD) for manganese, turbidity, pH, total chlorophyll, orthophosphate and nitrate and nitrite values of the source water from 1984 till the end of 2014 for Group 1 (1984–1991), Group 2 (1992–1996), Group 3 (1997–2006) and Group 4 (2007–2014) dissolved manganese in the source water. The average manganese concentration in the source water from 1984–1992 was 0.34 mg/L (±0.3), which ranged from a minimum of 0.01 mg/L to a maximum of 2.84 mg/L. De-stratification of the source water during windy conditions resulted in isolated peak manganese concentrations ranging from 4 mg/L to 8 mg/L at times. An oxidation step using potassium permanganate was implemented from **1980–1992** for the removal of manganese and ± 1.2 mg/L was dosed with other water treatment chemicals after pre-chlorination and the addition of lime. Manganese concentrations below ± 1.5 mg/L could successfully be removed with the potassium permanganate. For higher concentrations, the required dose resulted in the treated product having a brown/purplish colour; structures that came into contact with it were stained and a manganous oxide layer formed on filter sand. The manganese was bound in tough organic complexes and a more powerful oxidation was required.

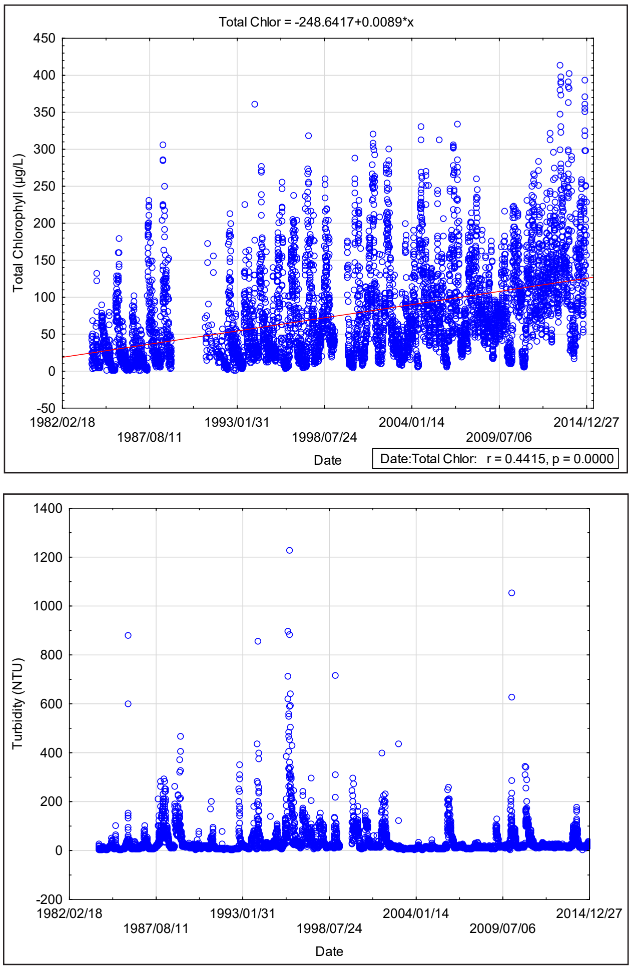

Figure 3

Scatter plots for total chlorophyll concentrations in the source water, which increased significantly (r = 0.4415 and n = 6268) and for turbidity levels (r = −0.0445 and n = 7 830), showing extremely high turbidity spikes at times

TABLE 2
A summary of geosmin and MIB concentrations in the source water from 2004 when Midvaal Water Company began to experience taste and odour incidents

Date	Geosmin (ng/L)	MIB (ng/L)
2004/01/23	36.4	51.9
2012/01/09	<6	255
2012/01/10	<6	335
2012/01/25	19	325
2012/02/09	<6	27
2012/03/02	<6	125
2012/03/05	<6	130
2013/02/04	5.8	20
2015/01/19	<5	245
2015/02/02	<5	28

A pre-chlorination step was implemented from **1978–1992** to alleviate colour problems and filter blockages caused by high total chlorophyll concentrations in the source water. The total chlorophyll concentrations in the source water increased progressively (see Fig. 3) as maximum total chlorophyll concentrations of 132 µg/L, 179 µg/L, 230 µg/L and 305 µg/L were recorded in 1984, 1985, 1987 and 1988, respectively. The pre-chlorination dosages ranged from 1.5 mg/L to 5 mg/L at the time and were positioned after the source water abstraction and prior to the addition of other water treatment chemicals.

In order to try to address these problems with manganese and high chlorophyll concentrations it was decided to add an advanced treatment process in the form of pre-ozonation. The configuration of the plant allowed for a pre-chlorination line (east) and a pre-ozonation line (west) to be separated from the point of abstraction up to the filtration process. A pre-ozonation step was implemented from **1985–1997** as this powerful oxidant could improve the colour of the water and also address the manganese, iron and total chlorophyll problems. Pre-ozone was dosed at ± 2.5 mg/L with a contact time of 4 min. The effectiveness of these two oxidants was compared from **1985–1992,** as far as the removal of total chlorophyll, manganese and iron were concerned. The effect of the pre-chlorination was found to be different for each algal species and, as the algal composition of the source water varies seasonally, the effectiveness of pre-chlorination was therefore inconsistent and unreliable. The colour removal also showed limited success. Ozone clearly proved to be more effective and the decision was made to terminate pre-chlorination and utilise pre-ozonation only, as from **1992–1997** (Krüger et al., 2006).

Water quality and the combined use of oxidants and dissolved air flotation

A dissolved air flotation (DAF) plant was implemented in **1997** as a first treatment step to address the high algal load present in the Vaal River and the inability of conventional water treatment methods to remove algae effectively. The pre-ozonation was redirected to an intermediate ozonation step, after DAF and prior to sedimentation. Intermediate ozonation dosages of ±1.8 mg/L to 2.5 mg/L together with the DAF resulted in favourable removal of total chlorophyll, iron, manganese, micro-organisms and colour. The removal of taste and odour compounds, mainly MIB, has however not been desirable at these ozone dosages but a significant saving in other water treatment chemicals (± 30%) was achieved by the application of DAF and intermediate ozone. The ferric chloride and chlorine demand decreased because less suspended matter had to be flocculated during the sedimentation process and some disinfection had already taken place with ozonation. The disinfection demand after filtration was collectively reduced by both pre-ozonation and intermediate ozonation as ozone is a more powerful oxidant than chlorine; however ozone fails to provide a residual disinfectant concentration which is possible with the use of chlorine.

A case study was conducted by Morrison (2009) from October 2007 to September 2008 to determine the influence of ozone on water purification processes. The average total chlorophyll concentration of the source water during the study was 104 µg/L, reduced to 32 µg/L after DAF (69% removal) and further reduced to 27 µg/L after intermediate ozonation (an additional 5% removal). The average manganese and iron concentrations of the source water during the study were 0.05 mg/L and 0.02 mg/L, respectively, and even though there was no cause for concern the manganese and iron concentration averages as well as concentration ranges decreased after the intermediate ozonation process.

Dissolved air flotation is an advanced water treatment process whereby small air bubbles are introduced to the water after the primary addition of water treatment chemicals for coagulation and flocculation (Table 3). The air bubbles attach to the flocs (containing organic material and algae) and rise to the water surface where the froth is collected and removed. Heavier particles settle to the bottom of the flotation units as sludge.

A pre-ozonation step, prior to the DAF, was implemented in **2007**. Pre-ozone is currently dosed at a range from 1 mg/L to 1.5 mg/L with a contact time of 2 min in order to enhance the DAF, and intermediate ozone dosages of 2.5 mg/L with a contact time of 4 min are maintained. Pre-ozonation enhances the DAF process by inactivating algal cells and does not necessarily reduce total chlorophyll concentrations of the source water immediately, as was confirmed by Morrison et al. (2012).

Temporary shutdown of the DAF and the effects thereof

The DAF process together with the pre-ozonation process was out of operation from 14 February 2015 up to 6 March 2015 due to maintenance on the DAF plant. During this period flocculated material had to be removed in the conventional clarifiers by means of settling. The effect was evident in the higher turbidity levels in the four Midvaal reservoirs as well as the final water (Fig. 4). The turbidity of the final water did however comply with the limit of ≤1 NTU during the DAF shutdown, but more pressure was placed on the other treatment processes during this period. Higher turbidity levels added to other treatment problems on the plant, e.g., shorter filter runs, increased backwashing, the generation of larger volumes of wastewater and a higher demand for water treatment chemicals and energy. The usage of chlorine gas increased by about 30% during the DAF shutdown whiles the requirement for flocculants increased by 15%. In spite of the additional chemical additions, the average turbidity of the final water 3 months before the DAF shutdown could not be maintained (Fig. 4). Figure 5 shows improved total chlorophyll removal in 3 Midvaal reservoirs as well as the final water after maintenance had been completed.

Operational monitoring at Midvaal Water Company: Water quality of the various processes

Midvaal Water Company uses pH, electrical conductivity, turbidity and total chlorophyll as operational indicators to monitor the effectiveness of the various treatment processes. The average total chlorophyll concentrations after pre-ozonation, before flotation and after chemical dosing are higher than the average total chlorophyll concentration of the source water (Table 4). This could possibly be the result of lyses of algal cell material due to damaged algal cell walls combined with a reaction between the source water and the ozone and chemicals. It is also difficult to ensure that samples are always homogenous and representative of the source water. In water treatment the desired outcome is often not immediately evident as the cumulative effects are only visible right at the end of the treatment train.

TABLE 3
Design specifications of the DAF plant (Midvaal Water Company, 2014)

Parameter	Specification
Design	Modular, 5 x 50 ML/day units
Capacity	250 ML/day
Retention time	± 1 h
Recycle stream	7 to 10% v/v
Bubble size	0.5 mm
Pressure vessels	500 kPa
Sludge concentration	1.5 to 2%
Flocculation method	Serpentine channels; adjustable outlets
Air:water ratio	1:1

The SANS 241: 2015 (SABS, 2015) requires the pH to range from ≥ 5 to ≤ 9.7 pH units, electrical conductivity at 25°C to be ≤ 170 mS/m and turbidity to be ≤ 1 NTU and ≤ 5 NTU for operational and aesthetic risks, respectively. Midvaal aims for the pH to range from 7.8 to 8.1 pH units, as the efficacy of chlorine as a disinfectant decreases when pH increases above pH 8.0. The average electrical conductivity (60 mS/m) and turbidity (0.5 NTU) of the final water, as indicated in Table 4, comply with the national limits. Even though there is no national limit for total chlorophyll, Midvaal has an internal limit of ≤ 1.0 µg/L in the final water which was also met with an average of 0.55 µg/L according to Table 4.

DISCUSSION

Algal assemblages and spikes in turbidity levels seem to be the greatest water quality concerns for Midvaal Water Company. Unacceptably high pH levels (Fig. 2), which affect treatment processes and influence scaling properties of the final water, are attributed to the excessive algal activity and are intensified during periods of low rainfall. Untreated or partially treated sewage effluents and over-fertilised agricultural runoff contribute to the nutrient load of the Vaal River. Due to this nutrient enrichment, the only source of drinking water for consumers in this area of supply is a hypertrophic water body. However, nutrient concentrations do not appear to be a cause for concern as such, but result in high algal activity which confirms the presence of nutrients. Increasing total chlorophyll concentrations also hold a threat for taste, odour and colour problems. The abundance of Cyanophyceae species and higher microcystin levels in the source water of the Rand Water Barrage (Hudson, 2015) pose a risk for Midvaal Water Company as the point of abstraction is situated downstream of Rand Water Barrage. Not only is Midvaal at risk for taste and odour problems but consumers will perceive the drinking water as unsafe. SANS 241: 2015 regulates that water services institutions shall use a risk-based management approach to ensure that safe drinking water is produced at all times and that public health is protected.

Conventional water treatment processes are simply not adequate to supply safe and healthy drinking water anymore when the source water is heavily polluted. DAF and ozonation are absolutely essential water treatment processes at Midvaal Water Company. This was confirmed by elevated total chlorophyll

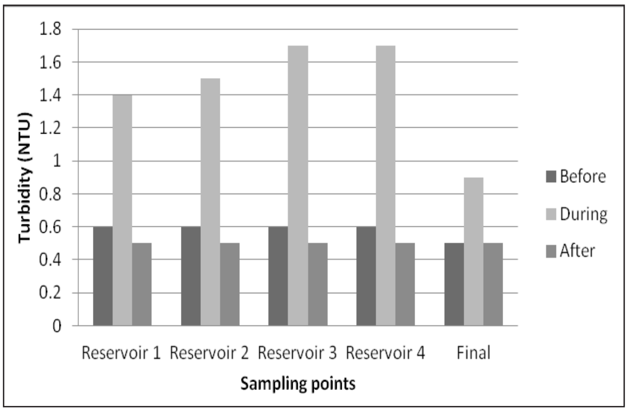

Figure 4

The average turbidity levels 3 months before, during and 3 months after the DAF shutdown for 4 Midvaal reservoirs, and for the final water

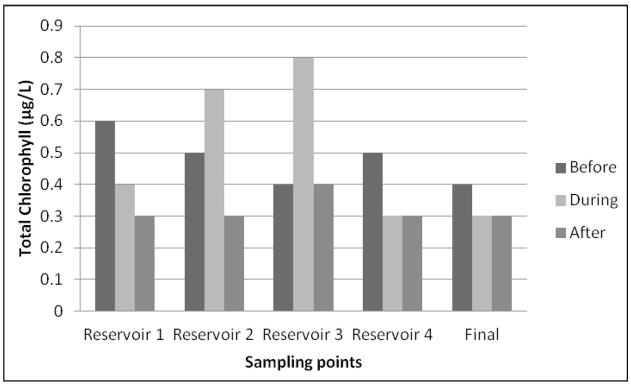

Figure 5

The average total chlorophyll concentrations 3 months before, during and 3 months after the DAF shutdown for 4 Midvaal reservoirs, and for the final water

TABLE 4
The average concentrations for pH, electrical conductivity, turbidity, total chlorophyll, manganese, iron and colour indicate the effectiveness of the various water treatment steps from 2010–2014(± standard deviation)

Processes/ Sampling points	pH	Electrical conductivity (mS/m)	Turbidity (NTU)	Total chlorophyll (μg/L)	Manganese (mg/L)	Iron (mg/L)	Colour (mg/L)
Source	8.76 (±0.53)	57 (±15)	30 (±44)	127 (±72)	0.04 (±0.04)	0.12 (±0.29)	119 (±96)
After pre-ozonation	8.82 (±0.49)	58 (±14)	30 (±42)	122 (±72)	-	-	-
Before flotation	8.80 (±0.48)	58 (±14)	32 (±43)	145 (±70)	-	-	-
After chemical dosing	8.94 (±0.46)	59 (±13)	33 (±42)	138 (±79)	-	-	-
After flotation	8.82 (±0.45)	59 (±14)	12 (±25)	39.86 (±35.97)	-	-	-
After intermediate ozonation	8.61 (±0.49)	61 (±13)	14 (±24)	39.48 (±31.40)	0.03 (±0.04)	0.05 (±0.09)	-
After settling	8.55 (±0.47)	60 (±13)	3.3 (±4.0)	15.33 (±42.67)	-	-	-
After filtration	8.17 (±0.43)	62 (±17)	0.6 (±0.9)	1.64 (±4.5)	-	-	-
Storage	8.20 (±0.39)	60 (±13)	0.5 (±0.9)	0.81 (±5.1)	-	-	-
Final after pump station	8.23 (±0.39)	60 (±13)	0.5 (±0.2)	0.55 (±0.6)	0.02 (±0.02)	0.03 (±0.03)	2.65 (±0.8)

concentrations and turbidity levels when the DAF was temporarily out of operation (Figs 4 and 5). Pantelić et al. (2013) emphasized the importance of removing cyanobacteria without cell lysis and subsequent release of intracellular metabolites, thereby confirming the value of a DAF process at Midvaal Water Company. The difference in colour of the final water is also noticeable during ozone plant shutdowns. The water treatment processes of the Midvaal plant have adapted successfully to the varying water quality of their source water, as compliance with SANS 241: 2015 (SABS, 2015) proves. Climate change has, however, resulted in dry periods being experienced regularly during recent years, as well as occasional floods causing spikes in turbidity levels and, together with the increase in total chlorophyll concentrations, Midvaal would most probably be required to consider additional treatment processes to ensure continued compliance with the required standard.

Powdered activated carbon (PAC) could be dosed at the secondary chemicals addition point and removed at the sedimentation stage. The application of activated carbon to alleviate taste and odour problems has to be weighed against the cost implications for the consumers, the correct type to be purchased for the organic molecules to be adsorbed, the interference of natural organic matter (NOM) and formation of additional sludge mass, as well as the intensity and duration of taste and odour episodes. Srinivasan and Sorial (2011) refers to the optimisation of GAC (granular activated carbon)/PAC adsorption but the sporadic and seasonal taste and odour events at Midvaal Water Company do not allow for frequent monitoring of geosmin and MIB concentrations present in the influent, and prevent proper research on the application of (GAC)/PAC adsorption, or any other advanced process, in this regard.

Advanced oxidation processes (AOPs) in drinking water are used to degrade primarily organic chemical contaminants, e.g., taste- and odour-causing compounds (Linden and Mohseni, 2014). Ozone and ultraviolet (UV) light constitute the main AOPs and are increasingly being used at a large scale for the degradation of contaminants in water and wastewater (Linden and Mohseni, 2014). Wang et al. (2015) compared UV/chlorine to UV/hydrogen peroxide (H_2O_2) at various pH concentrations, as UV/H_2O_2 is becoming more popular. Approximately 20% and 10% of spiked geosmin and MIB, respectively, were destroyed by UV exposure alone and when an AOP was applied, geosmin and MIB destruction was increased because of the additional hydroxyl radical oxidation (Wang et al., 2015). The UV/H_2O_2 process is used at the City of Cornwall Water Purification Plant (Ontario, Canada) for the control of seasonal taste and odour events that occur in late summer, but this process does also pose operational problems (Wang et al., 2015). Similar to GAC adsorption, presence of NOM in water can influence AOPs as well (Srinivasan and Sorial, 2011). According to Srinivasan and Sorial (2011), the capital and operating costs associated with these AOPs can be significantly high, especially at the higher dosages required for MIB/geosmin removal, and they could also result in the formation of disinfection by-products which could be of health or regulatory concerns. Zong et al. (2015) established that chlorination was an effective treatment option for removing microcystin but it is important for water suppliers to be aware of the secondary pollution of microcystin-associated disinfection by-products.

More research is required on the use of ultra-filtration for treatment of taste and odour problems at drinking water treatment plants, as very few research results were available on this advanced treatment process for this case study. Currently Midvaal Water Company should ensure that MIB/geosmin is not produced or intensified on-site. Srinivasan and Sorial (2011) stated that although some technologies are more effective and applicable than the others, a completely accepted technology that could be used in any drinking water treatment facility still does not exist. The odour threshold concentration for MIB/geosmin ranges from 4 ng/L to 20 ng/L (Srinivasan and Sorial, 2011) and the treatment of these taste and odour compounds is only required at Midvaal Water Company during increased concentrations called outbreaks.

The recommended process, or perhaps combination of technologies, would therefore be expected to deal with concentrations which have been recorded as greater than 300 ng/L MIB (Table 2) at times, and even if 80% removal of MIB could be achieved on a source water concentration of 150 ng/L this would still result in a MIB concentration which exceeds the odour threshold concentration. Srinivasan and Sorial (2011) stated that current practice most commonly followed is application of PAC during severe taste and odour outbreaks which is similar to the current situation at Midvaal Water Company. Srinivasan and Sorial (2011) also confirm the view of this case study when it concludes that it would not be economical or practical for water treatment facilities to install a technology exclusively for treatment of MIB/geosmin, but should rather optimise the technology they are currently using for MIB/geosmin treatment. Midvaal Water Company remains a bulk potable water supplier and therefore has to consider the socio-economic status of their consumers where water pricing is concerned, as any additional advanced treatment steps will increase costs. The availability of accurate information and communication with consumers during taste and odour episodes remains imperative for Midvaal Water Company as they have managed to supply wholesome drinking water for many years in spite of the ever increasing pollution of the source, the Vaal River.

CONCLUSION

The quality of the already hypertrophic source water seems to deteriorate continuously but until now Midvaal Water Company has managed to treat the water successfully, with ozone and dissolved air flotation being key processes. The need for more advanced and expensive processes does however seem to be inevitable in order to maintain final water quality in future, but to consider cost implications for consumers during challenging economic times remains a concern.

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