A triple bottom line approach to optimising odour removal from a residential water supply

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63

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A triple bottom line approach to optimising odour removal from a residential water supply

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Abstract

Feedwater to Euroa Water Treatment Plant contains increasingly high levels of natural organic matter (NOM) which were determined to cause its strong earthy odour. A multidisciplinary approach was used to evaluate the coagulation process to better remove the taste and odour (T&O) causing organics from water supplied to the local towns. Such high levels of NOM require elevated doses of coagulant for removal, accounting for approximately 60% of the chemical costs. A need arose to reduce these operational costs. However, community expectations regarding T&O, and social and environmental impacts, are not typically considered in this process. The local water corporation, Goulburn Valley Water, undertook a case study involving a comparison of three coagulants to optimise the chemical coagulation process from a multidisciplinary (triple bottom line, TBL) perspective. The financial assessment incorporated operational costs and potential infrastructure requirements. The social assessment investigated the overall impacts on staff operating the water treatment plant and their broader community involvement. The environmental assessment focused on the impact on downstream infrastructure from changes in sludge volumes and wastewater quality, and third-party greenhouse gas emissions from chemical deliveries. From a TBL viewpoint, aluminium chlorohydrate was the most beneficial option.

Key words: coagulation, community expectations, optimisation, taste and odour, triple bottom line, water treatment

Highlights

- An increase in climate change-induced natural organic matter causes taste and odour issues.
- Optimisation of coagulation needed to reduce costs of elevated coagulant use.
- Coagulation process optimised via comparison of three coagulants.
- Triple bottom line assessment of social, environmental, and economic benefits.
- Aluminium chlorohydrate was the most beneficial option.

INTRODUCTION

Natural organic matter (NOM), a complex heterogeneous mixture of carbon-based compounds arising from the decomposition of plants, animals, microorganisms, and their waste products, is ubiquitous to

H₂Open Journal Vol 4 No 1
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water bodies worldwide. The presence of NOM can lead to problems in drinking water treatment as its concentration and properties can significantly affect the efficiency of the process. NOM can cause aesthetic problems with respect to taste, colour, and odour. It can act as a substrate for bacterial growth and lead to the formation of disinfection by-products, the concentrations of which are regulated.

An increase in dissolved organic carbon (DOC) concentrations over the past several decades has been reported in North America (SanClements *et al.* 2012), the United Kingdom (Sharp *et al.* 2006), northern Europe (Eikebrokk *et al.* 2004), and Japan (Imai *et al.* 2001). One possible factor which has been widely attributed as the cause for this is climate change (Whitehead *et al.* 2009). Average concentrations in the UK almost doubled over 1989–2003, and there were also strong seasonal variations in raw waters noted within the UK (Loganathan *et al.* 2020). In addition to DOC increases, changes in the ratios of NOM components have been observed in the UK (Sharp *et al.* 2006) and Australia (Mohiuddin *et al.* 2014). Water utilities in Australia (Mohiuddin *et al.* 2014), and many in the USA and UK, have experienced operational difficulties associated with these increased DOC levels when employing coagulation-based treatment (Sharp *et al.* 2006).

The residential supply of potable water is a primary activity undertaken by all water authorities. In this regard, water must not only be safe to drink from a technical perspective but also to meet residents' subjective (and often differing) expectations for taste, odour, perceived safety, regularity of supply, and cost. It is widely recognised that customers perceive drinking water characteristics such as taste, odour, turbidity, and colour as key measures of water quality (Doria 2010).

In Victoria, Australia, failure to meet these basic expectations can result in formal action such as reporting complaints to water utilities, or the Energy and Water Ombudsman of Victoria, or political authorities such as local representatives. Alternatively, informal action can include complaints expressed to family and friends, or the use of alternatives such as tank water or bottled water. From the perspective of water management, navigating this intersection between the technical qualities of potable water, customer expectations, social impacts, and cost requires the appraisal of these normally incommensurate metrics.

The economic regulator for the water sector in Victoria, the Essential Services Commission (ESC), changed its approach in 2016 by placing customer needs as central to the pricing process. This resulted in significant customer engagement being undertaken across the 54 towns serviced by Goulburn Valley Water (GVW), a regional water authority covering the North Central Victoria region. In addition to drinking water aesthetics, GVW noted that 14% of the customers surveyed indicated concerns with the price of water and sewerage services (Goulburn Valley Water 2017). This resulted in GVW implementing a 2% decrease per annum for service and volumetric charges between 2018 and 2023 which required a reduction in their expenditure focusing on the operational expenditure. Similarly, survey responses to open-ended questions showed that a large proportion of customers had concerns about the T&O of their drinking water (Goulburn Valley Water 2017).

In response, GVW undertook a case study to explore the improvement of T&O through chemical coagulation, a process that accounts for approximately 60% of GVW's water treatment chemical use. Although the financial aspects were a key reason for the case study, environmental and social aspects are also important to GVW. Therefore, a triple bottom line (TBL) assessment was used to identify the most beneficial coagulant for use.

The case study was based in Euroa which is situated in the Strathbogie Ranges in North Central Victoria, Australia. The water treatment plant (WTP) is gravity fed from Mountain Hut Reservoir which is in a predominantly forested area, and coagulated using aluminium sulphate (AS), caustic soda (CS), and a flocculation aid before entering a single sludge reactor clarifier. After clarification, the settled water is passed through two dual media filters and disinfected using chlorine gas, then pH corrected using CS. Water is stored in a 2.2 ML clear water storage (CWS) before entering the reticulation network. The Euroa WTP supplies drinking water to 4,120 people in the towns of Euroa and Violet Town. A schematic of the water treatment process is shown in Supplementary Figure S1.

H_2Open Journal Vol 4 No 1
doi: 10.2166/h2oj.2021.070

There have been few formal complaints made from Euroa with 0.44 complaints/100 people over 2004–2014. Despite the low numbers of formal complaints, informal discussions between residents and GVW staff show there is anecdotal evidence that there are some underlying T&O issues within the town. Some residents have stated that they maintain rainwater tanks for drinking due to the taste of water. Over time the DOC in the raw water has steadily increased, with DOC concentrations reaching 17 mg/L in 2020. The water sample was sourced from a mixture of storages with catchments predominantly forested with some mixed farming. DOC concentrations in the region are normally below 10 mg/L, thus from the perspective of GVW, levels of 17 mg/L were a significant issue.

This case study was designed to compare different chemical coagulants with respect to improved odour of the water, and to understand the overall financial, social, and environmental impacts of the use of each chemical.

METHODS

This project was completed in three parts. The first was to identify the causes of undesirable T&O, while the second was to assess the benefits of coagulation in improving water odour. The third part was to identify the most beneficial coagulant by considering the environmental, social, and financial aspects using a TBL assessment.

Identification of tastes and odours

An investigation into the T&O issues within the Euroa reticulation system was completed using a Taste and Odour Panel which used a modified version of flavour profile analysis according to Bartels & Burlingame (1986). The panel was made up of 20 GVW staff and operated over 12 months. Samples of water were taken from the outlet of the CWS and from within the Euroa and Violet Town reticulation networks. A control sample was taken from the reticulated water within the main GVW office building where the Taste and Odour Panel members were based.

One-L samples of potable water were collected from GVW sampling locations and were tested at room temperature (18–23 °C) on the day of collection. Approximately 30 mL of each sample was transferred to a tasting glass and covered with a watch glass. Each sample was labelled with a non-identifiable tag to control for pre-conceived biases about the T&O of the water based on its source location. The panel members were asked to smell the samples first and then to taste them. All results were recorded on the pro-forma (Supplementary Figure S2). Each week the order of the samples was changed to remove any potential bias associated with a particular sample. All data collected were recorded removing any personal identification.

Where the panel identified specific odours, the identified odour was cross-referenced with known odour-causing chemicals as per Suffet *et al.* (1999). Once identified, these compounds were analysed with respect to their odour detection thresholds (ODTs).

Taste and odour improvement using coagulation

Following the identification of the key T&O compounds, jar testing was completed using AS, aluminium chlorohydrate (ACH), and ferric sulphate (FS) as coagulants. CS was used to pH correct AS- and FS-treated water based on the alkalinity consumed by the coagulant. The method followed is detailed by Murray & Mosse (2015). A four-jar Platypus jar testing system with 2 L beakers was used. It was set to operate at 120 rpm for 2 min to replicate the flash mixing conditions at Euroa WTP, and 30 rpm for 20 min to replicate flocculation time and allow flocs (clumps) to form. The flocs were allowed to settle for 20 min. After settlement water was drawn from 5 cm below the surface.

H2Open Journal Vol 4 No 1
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The pH, turbidity, true colour and UVA (UV absorbance at 254 nm, a measure of the aromatic nature of the NOM) were determined with GVW standard instruments using manufacturer's instructions. DOC (an independent NATA accredited laboratory-measured DOC). These data were used to identify the most effective dose as indicated by the lowest turbidity, DOC, colour, and UVA.

After the jar testing, the most effective coagulant dose, that is, resulting in least odour, was determined using the taste and odour testing panel and compared against the odour from the WTP and the raw water. As the water was not considered potable following the jar tests, the panel members were asked to assess only the odour.

TBL assessment

The GVW TBL assessment tool was used to compare the alternative coagulation chemicals and the optimal dose of AS as the current plant operation's coagulant. The assessment boundary was drawn around the operations over which GVW had a direct influence, and economic, social, and environmental assessments were conducted. A workshop was organised using three key GVW staff members. Each item was assessed a rating between −4 (major negative impact) and +4 (major positive impact) where levels were designated as a neutral impact for 0, through minimal, minor, moderate to major impact. The rating was achieved through discussion and consensus. The total score was then aggregated for each assessment, weighted (35% for financial and social assessments and 30% for the environmental assessment), and ranked. A sensitivity analysis was used to test initial TBL assessment outcomes by increasing the weightings to 50% in order to favour the economic, environmental, or social aspect.

The financial assessment considered the cost of the chemicals, landfill disposal costs, and the potential impact on the existing infrastructure program.

The environmental assessment considered the impacts on landfill utilisation through the generation of sludge, and the potential carbon emissions of heavy vehicles based on the volumes of coagulation chemicals required to be delivered and the volumes of sludge being disposed of to landfill.

The social assessment took into consideration how improved odour of the treated water will impact on the community and GVW staff. This included the safety and wellbeing of the operator.

RESULTS AND DISCUSSION

Taste and odour identification

A Chi-squared test for independence was used to determine the relationship between the water source and the reported T&Os. It was determined that panel members were able to distinguish between samples taken from Euroa and the main office building, with the main odours reported being earthy/musty and chlorinous. Conversely, the panel members were unable to distinguish different tastes at each of the locations. Hence, odour became the primary focus of this study.

Analysis of the odour panel results showed that of all the CWS samples, 60 of the 111 odours detected by the panel were classified as having a chlorinous or chemical odour. In the reticulation systems of Euroa and Violet Town, these chlorinous or chemical odours decreased to 36 of 117 odour detections and 26 of 92 odour detections, respectively. The free chlorine residual at the entry point to the reticulation system ranged between 0.69 and 1.09 mg/L which is above the odour threshold of 0.6 mg/L for chlorine (National Health and Medical Research Council (NHMRC) 2011).

The other key odours reported were earthy/musty and no odours with the earthy/musty odours being consistently detected from the CWS through to the reticulation system. The greater number of perceptions of chlorine odours seen for the WTP samples was attributed to the fact that chlorine

H₂Open Journal Vol 4 No 1
doi: 10.2166/h2oj.2021.070

tends to mask earthy/musty odours (Water Research Foundation 2014). Geosmin and 2-methylisoborneol (MIB) are well known to cause earthy/musty odours (Zamyadi *et al.* 2015) and were, therefore, investigated over 12 months. These results showed few detections above the odour detection threshold, and as they were not sustained, geosmin and MIB were not considered the underlying cause of the earthy/musty odours.

In order to target the water treatment process for odour improvement, the association of water quality parameters with the number of the odours detected was determined using Pearson's correlation to identify any significant relationships (where $p < 0.05$) between the odours detected and the free chlorine residual. These correlations suggested some relationships between the identified odours and indicators of NOM. The key raw water parameter which had a significant correlation was specific UV absorbance (SUVA), which is the UV absorbance at 254 nm divided by DOC concentration. There was a decrease in the number of samples with chlorinous or earthy/musty odours detected as the SUVA value increased. Pearson's correlation coefficients for both odours detected were significant ($r\ (18)_{chlorine} = 0.69$, $p = 0.02$ and $r\ (18)_{earthy/musty} = -0.66$, $p = 0.03$). SUVA can be used to indicate the nature of NOM with respect to the hydrophobicity, aromaticity, and molecular weight (Matilainen *et al.* 2010). It also indicates the removal of NOM through coagulation. This indicates that as the SUVA increased, NOM was more readily removed through coagulation and reduced the number of odours detected.

Pearson's correlation coefficients for relationships between the free chlorine at the inlet and outlet of the CWS and the number of detections of earthy/musty and chlorinous odours were determined (Table 1).

As expected, the level of free chlorine residual at the point of disinfection directly correlated to the number of chlorine odours detected by the panel. However, the chlorine residual at the outlet of the CWS did not correlate with the chlorinous odours, despite the free chlorine residual consistently being above the aesthetic limit. Interestingly, it did relate to the number of earthy/musty odours seen in the reticulation system.

An investigation by the Water Research Foundation (2014) stated that chlorine could mask earthy/musty odours. This can be problematic because if the free chlorine is not controlled effectively, the earthy/musty odours can recur with time. The disinfection chlorine dose rate is high (~3 mg/L) at the Euroa WTP to allow for sufficient disinfection while maintaining a suitable chlorine residual within the reticulation system. This indicates that the free chlorine is initially masking the earthy/musty odours and then dissipating as the water passes through the system causing a re-release of these odours.

Based on the outcomes of Pearson's correlations between the number of the perceived odours and indicators of NOM it was determined that the underlying odours in the water are due to the presence of NOM; therefore the chemical coagulation step was investigated with the aim of removing the causative organics.

Odour improvement using coagulation

Coagulation with FS and ACH was compared with AS, which is currently used, for organics removal. FS and ACH were trialled as alternative coagulants as they traditionally have higher efficacy for DOC

Table 1 | Pearson's correlation coefficient determined between free chlorine residual and the number of odour detections

Correlation	Pearson's correlation coefficient (r)	Significance (p)	Degrees of freedom
Chlorine odours – free chlorine inlet	0.60	0.04	19
Chlorine odours – free chlorine outlet	0.49	0.09	19
Earthy/musty odours – free chlorine inlet	0.78	0.01	19
Earthy/musty odours – free chlorine outlet	0.69	0.02	19

H$_2$Open Journal Vol 4 No 1
doi: 10.2166/h2oj.2021.070

removal than AS (Matilainen *et al.* 2010). UVA and DOC were used as measures of effectiveness for organics removal. Jar testing was completed to mimic the existing plant conditions, with odour testing performed to determine odour improvement. Jar tests were completed according to Murray & Mosse (2015) which included guidance on setting the initial chemical doses and the amount of alkalinity consumed for each chemical to provide an estimate for the pH correction. The chemical dose rates were then narrowed until the turbidity, colour, and UVA were within GVW acceptable range. These parameters were then used to identify the 'best dose'. The average, minimum, and maximum chemical doses for the most effective treatments for organics removal in terms of DOC are shown in Figure 1.

The FS jar test results show a greater average DOC removal than obtained in the WTP and the AS jar tests, and the DOC removals for FS were consistent. The ACH gave slightly higher removals than the WTP but had a high standard deviation. The DOC removals for the AS and WTP were consistent; however, the WTP showed a greater range than the AS despite the similar average. This is likely due to the clarifier being exposed to the weather, which can potentially impact its operation.

Following jar testing, odour testing of the jar-tested samples was completed in a similar manner to that discussed. The only key point of difference was that none of the jar-tested water was tasted as it was not considered to be safe for drinking. As the jar-tested samples had not been subjected to the addition of chlorine, the treated water from the Euroa CWS was used as a control. The strong chlorinous odour of this sample provided a key point of difference between the samples and was readily detectable by the panel.

The Chi-squared test for independence was used, and three null hypotheses (H_0) were developed to test. This test was used as it takes account of the different sample sizes from each jar test. Each of the null hypotheses and the Chi-squared result is shown in Table 2.

Using the null hypotheses shown in Table 2, the panel members demonstrated that they could distinguish between the final water and the settled water samples, which was expected as the final waters had been disinfected using chlorine. However, the panel data show that they were unable to distinguish between the different coagulants used or between the jar test and the WTP samples. This indicates that the odour detected by the panel was independent of the coagulant used.

However, when comparing the observed values against the expected values, calculated as a part of the Chi-squared test, several observations of note were observed. In particular, the number of no odours observed when using ACH was greater than expected (25 and 20, respectively). The number of earthy/musty odours observed was less than expected (25 and 20, respectively). These results indicate that the use of ACH rather than AS would improve the odours of the final water at Euroa WTP.

TBL assessment

TBL assessment is a common tool used by businesses to measure the overall sustainability of a project or as a tool for self-evaluation (Marques *et al.* 2015). The TBL encompasses the financial, social, and environmental aspects of the project or process being assessed (Slaper & Hall 2011). In the water sector, financial performance as a measure of commercial viability was used during the 'economic reform era' of the 1980 and 1990s. Changes in economic regulation resulted in transformation in the governance of the urban water sector (Infrastructure Partnerships Australia 2015). Since this period, the sector's overall sustainability was reviewed and the use of a multi-criteria assessment became common (Adams *et al.* 2014). A TBL assessment was completed using GVW's TBL tool to assess the benefits of each of the coagulants in comparison with the operational conditions used at the Euroa WTP. For each item assessed, a rating was given between −4 (major negative impact) and +4 (major positive impact); where the impact was neutral or negligible, the rating was given as 0.

H2Open Journal Vol 4 No 1
doi: 10.2166/h2oj.2021.070

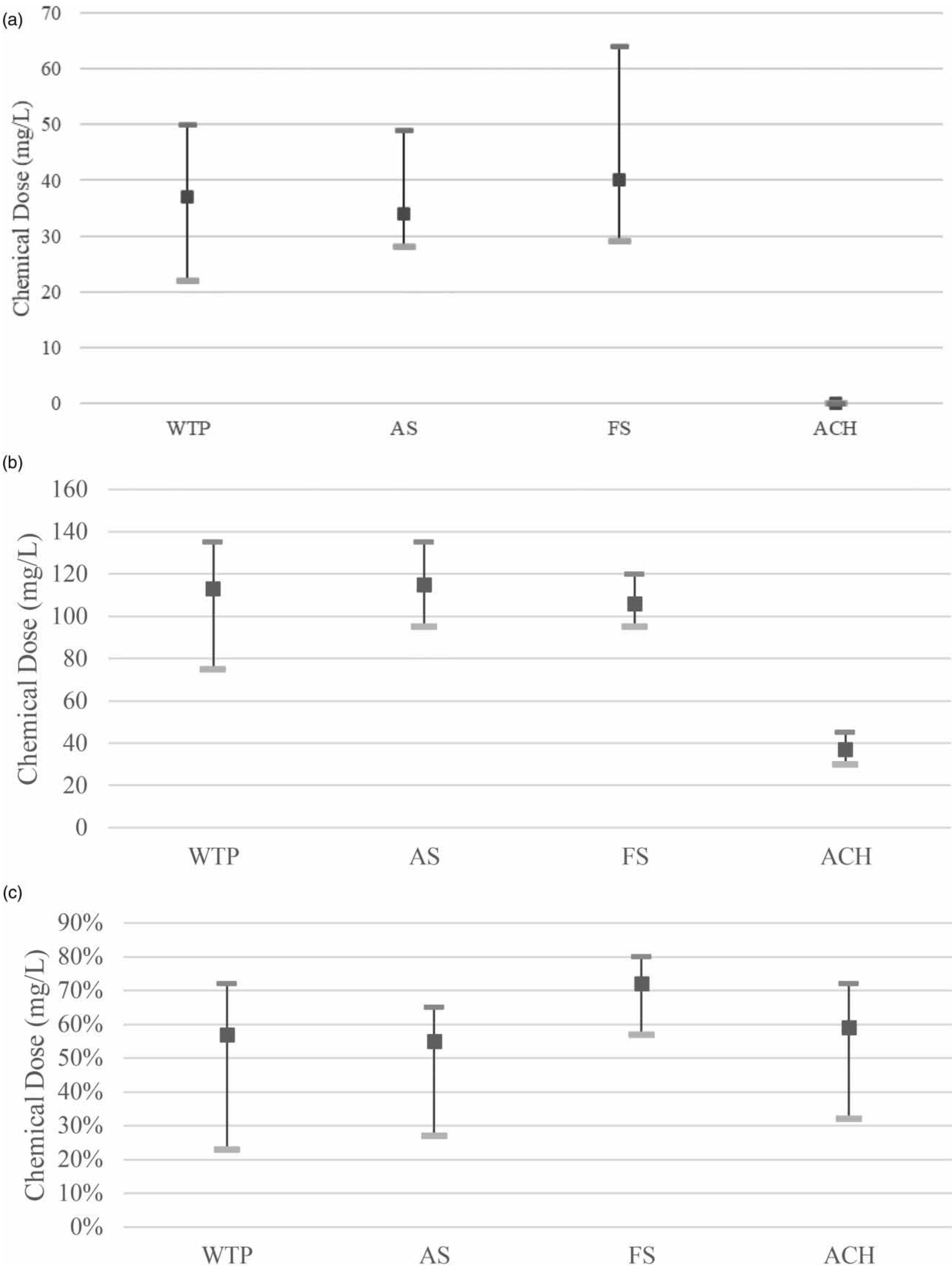

Figure 1 | Average, maximum, and minimum (a) coagulant, (b) CS dose rates, and (c) DOC removal rates.

Financial assessment

The cost of treatment was assessed with regard to the chemical costs. This was determined on an annual basis using an average annual production rate of 710 mL. The chemical prices were sourced

H_2Open Journal Vol 4 No 1
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Table 2 | Chi-squared statistic and the null hypotheses based on odours detected

Null hypothesis	Chi-squared value (X^2)	Significance	Null hypothesis accepted?
The odour of the data sample type of chemical used is independent of the odour in the jar test samples.	7.46	0.49	Yes
The odours of the data samples from the WTP are independent of the odour of the data sample from the jar test samples.	8.36	0.08	Yes
The odours of the data samples from the final water samples (Euroa and Shepparton) are independent of the odour of the data sample from the jar test samples.	182.41	<0.00001	No

from the GVW chemical contract. The annual estimated chemical costs and any potential savings are shown in Table 3.

Therefore, based on the chemical costs, using FS would increase the chemical costs by approximately $9,796, whereas the use of ACH would decrease the annual costs by approximately $6,345. The optimisation of AS coagulation would lead to approximately $3,380 in savings.

With respect to the existing infrastructure program, the only project that would be impacted by any of the proposed situations is a planned upgrade to the sludge handling system. Following jar testing, the volumes of the sludge formed from the floc were measured using a 1 L Imhoff cone (Table 4). As the density of the floc produced from ACH was too low to settle sufficiently, these jar tests were repeated using the addition of a polymer to assist the settleability of the floc. Following the addition of polymer, floc was still observed in suspension after an hour. Similarly, AS sludge density was also too low for full settlement to occur, even after 1 h of settling time. Conversely, the FS floc settled quickly and was dense and easy to measure. Overall, these results were as expected based on industry knowledge, with FS producing large volumes of dense sludge and ACH producing low volumes of low-density sludge.

The use of FS would increase the amount of sludge produced, and the planned upgrade may not be sufficient. Conversely, the use of ACH would not produce as much sludge, and therefore, the planned upgrade project could be deferred.

Through consensus and discussion, both the operational costs and the infrastructure program impacts were given a rating as shown in Figure 2, in which the base case was rated as zero.

Therefore financially, ACH is considered the most advantageous coagulant, with FS considered to have the least financial benefit.

Table 3 | Annual estimated chemical costs and associated savings (Australian dollars)

	Base case – current situation	AS	FS	ACH
Annual cost	53,096	49,717	62,894	46,753
Estimated annual savings ($/year)	0	3,380	−9,796	6,345

Table 4 | Measured sludge volumes shown in cm^3/2 L jar

Sample number	AS	FS	ACH	ACH with 0.4 mg/L polymer added
1	60	95	20	30
2	90	100	70	50

H2Open Journal Vol 4 No 1
doi: 10.2166/h2oj.2021.070

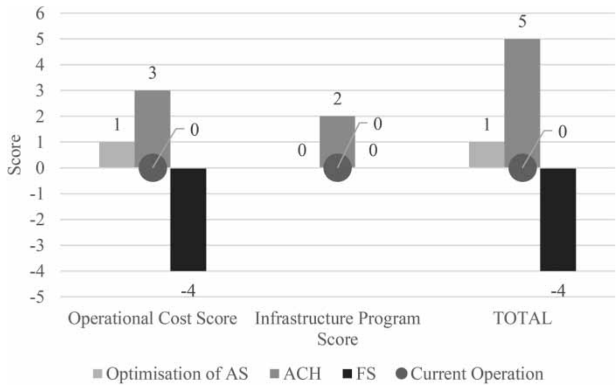

Figure 2 | The combined financial assessment based on the impacts of each coagulant.

Environmental assessment

At present, all wastewater from the treatment process is managed within two sludge lagoons, with the supernatant being returned to the head of the WTP. When the lagoons are at capacity, they are decanted, and the sludge is left to dry. Once dry, the sludge is dug out and disposed of to landfill. This is currently completed annually. The volume of sludge produced that would potentially end up as landfill was assessed as an environmental impact. Additionally, based on the volume of chemicals required for coagulation to be delivered to site, the potential greenhouse gas emissions resulting from the delivery tankers were assessed based on the work by Seo *et al.* (2016).

WTP sludge is considered to be a prescribed waste by the Environment Protection Authority of Victoria due to its aluminium content which has very little potential for beneficial reuse (Environment Protection Authority Victoria 2009). In most cases, the waste sludge is disposed of to landfill. Similarly, ferric-based sludge is also considered as a prescribed waste by the EPA with disposal to landfill the most common method of management.

Based on the sludge production (Table 4), and the expected volumes to be disposed to landfills, the assessment showed that ACH coagulation was the most attractive. FS coagulation was shown to be the least attractive, and optimised AS coagulation was considered as having a slight benefit over the base case.

Changing the coagulant would have environmental impact upstream due to the production of the chemicals and the subsequent need to deliver them to the site. The number of deliveries for each coagulant and the associated pH correction requirements was determined based on the production of 710 mL finished water per year and a chemical delivery volume of 10,000 L. The number of deliveries and volumes of coagulation chemicals required per annum are shown in Table 5.

The CO_2 emitted for each delivery was determined based on 600 g of CO_2 emitted per km driven with a full tanker load and 500 g of CO_2 emitted per km driven with an empty tanker (Seo *et al.* 2016). Chemical manufacture is completed on the outskirts of Western Melbourne, and the coagulation chemicals are delivered approximately 180 km to Euroa WTP. This figure was used to determine

Table 5 | Annual chemical volume requirements and annual delivery requirements

	Base case – current situation	AS	FS	ACH
Coagulant (L/year)	66,619	64,361	47,115	19,849
CS (L/year)	14,766	13,433	13,048	1,602
Deliveries required coagulant	7	7	5	2
Deliveries required CS	2	2	2	1

H$_2$Open Journal Vol 4 No 1
doi: 10.2166/h2oj.2021.070

the CO_2 emissions assuming a full load to Euroa and an empty tanker returning to Melbourne. Based on the number of deliveries required (Table 5), the total volume of emissions for each coagulant and CS was determined (Supplementary Figure S3). The CO_2 emissions from the delivery of the dry sludge to landfill disposal were also calculated, but were negligible compared with those for chemical delivery after taking the sludge volumes and close proximity of the landfill site to the WTP into account. The data shown in Supplementary Figure S3 are an estimation only as there is limited information regarding heavy vehicle carbon emissions in Australia. The total carbon emissions from a vehicle are dependent upon many factors, including vehicle weight, fuel quality, and how the vehicle is being driven. The study by Seo *et al.* (2016) simulated these factors and gave a good basis for this estimation. From this, ACH would lead to the least carbon emissions associated with chemical delivery.

The factors associated with the environmental impact are the disposal of waste sludge to landfill (not including transport emissions). The volume of carbon emissions for chemical delivery was combined into the overall environmental assessment (Figure 3).

These results show that the coagulant with the greatest environmental benefit is ACH, due to the need for less coagulant and thus fewer chemical deliveries. Additionally, the volume of sludge produced would be significantly less, likely resulting in less waste being sent to landfill.

Social assessment

The impacts on the community and GVW staff were assessed based on the impacts of the use of the alternative coagulants. Consideration was given to the WTP operators' daily tasks, occupational health and safety, and the ease of operation at the WTP. The impact of changing coagulants on the improved quality of water that customers would receive at their taps was considered.

Poor taste and odours are regularly cited as the key reason consumers choose alternative drinking water sources (Doria 2010). In Euroa, reports from GVW employees suggest that some customers maintain a rainwater tank for drinking water, due to concern regarding the taste and odour of their reticulated water. This situation is not unusual, with 24.3% of residents in regional and rural Australia reporting that rainwater is their main drinking water source despite having potable reticulated water (Sinclair *et al.* 2005). The Federal Government's guidance on the use of rainwater tanks published in 2010 (EnHealth 2010) indicates that although rainwater tanks generally have a higher bacterial count (measured as Heterotrophic Plate Count), if they are well maintained they pose minimal health risk. However, within the same document, it is stated that householders have a poor record of maintaining rainwater tanks. Consequently, the long-term health risk associated with drinking tank water was higher than comparison with reticulated water (EnHealth 2010). Therefore, based on the

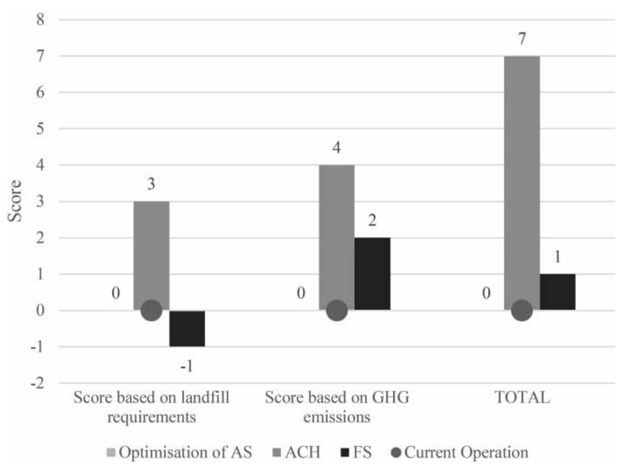

Figure 3 | Overall score for the environmental assessment.

H$_2$Open Journal Vol 4 No 1
doi: 10.2166/h2oj.2021.070

odour detections following jar testing, it could be proposed that by changing the coagulant to ACH and improving the taste and odour of the treated water, there is potential for the number of people maintaining rainwater tanks for drinking to be reduced, so the risk posed to their health through drinking rainwater would also be reduced.

GVW sees itself as a community-centric organisation with employees also being customers living in the community. This integration within the community leads to significant informal and word-of-mouth feedback, which is forwarded to the organisation's relevant work group. Research into employee motivation finds that recognition and praise improve self-esteem, which can improve employees' performance (Fulop & Linstead 2009). Therefore, by improving the T&O of drinking water from the Euroa WTP, knowing that it is a customer's measure of the level of service provided (Doria 2010), employees' overall work satisfaction may potentially improve. A brief informal discussion with the Taste and Odour Panel members indicated pride in the improved customer satisfaction resulting from the improvement of T&O in water from the Euroa WTP. Thus, increased treatment results have beneficial ripple effects for workforce morale and organisation culture.

Without the contribution of the WTP operator, there would be no improvements seen within the community. As a result, consideration of how a change in coagulant would impact the operators was undertaken. Items taken into account were:

- jar testing requirements above and beyond the current GVW minimum requirements of monthly or when the water quality requires it,
- interaction with hazardous chemicals during delivery, and
- overall ease of operation at the WTP.

The ACH dose rates would decrease the operators' interaction with coagulation and pH correction chemicals currently used on site. ACH is not considered a dangerous material, and the use of ACH removes the pre-coagulation pH correction requirement. The number of deliveries would be reduced, and therefore, the interaction with the chemical would be reduced. There would likely be an increased requirement to the jar test, as the floc produced by ACH has a low density and does not settle easily. As the clarifier at Euroa requires a sludge blanket to operate, there are some potential issues around the compatibility of the floc produced by the ACH. Some further solids may be required to improve the settling within the clarifier to use ACH at Euroa.

The use of FS as a coagulant would not necessarily change the current situation with respect to interaction and contact with chemicals. There would be fewer coagulant deliveries (both FS and CS), which would be beneficial to the operator as FS is considered a hazardous material due to its corrosivity and is considered to be more hazardous than AS. The high-density floc resulting from coagulation using FS is compatible with the current clarifier design leading to easier operation. This ease of operation would also result in the need to do fewer jar tests as FS and the WTP compatibility would mean a broader range of FS dose rates resulting in a satisfactory floc and resultant sludge blanket. This means that the current GVW requirements of monthly jar tests would be sufficient.

The optimisation of AS coagulation would have a limited impact on the operator compared with the base case for site operation, chemical deliveries, and management of the sludge handling facilities. However, in order to optimise the AS dose, more jar testing would be required which would increase the operator workload and time requirements. With the rapid changes seen in raw water quality at Euroa WTP, there would likely be a need to complete jar tests weekly compared with the current GVW practice of monthly as a minimum.

The combined results from the impacts of improved odour on the community and GVW staff, and the change in coagulant would have on the WTP operation and the subsequent impact on the WTP operator, are shown in Figure 4.

H2Open Journal Vol 4 No 1
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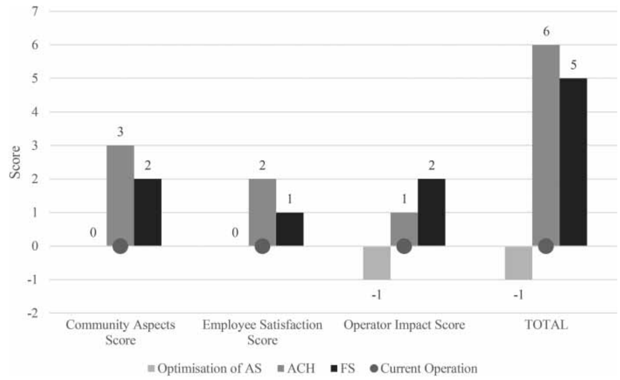

Figure 4 | Summary of the findings from the social impact assessment.

Overall, ACH was shown to be the most socially beneficial coagulant. In terms of impact on the operator, FS was rated to be the most beneficial due to the ease of operation, and the lower requirement for interaction leads to its high rating, despite FS being a more dangerous chemical.

Outcomes of the TBL assessment

Using the weightings in the 'TBL assessment' section, the outcomes from the financial, social, and environmental aspects were combined into a single value in relation to the base case of current operation (Figure 5).

The results show that after considering all criteria, ACH is the most attractive option.

Sensitivity analysis was used to test the initial TBL assessment outcomes by increasing the weighting to 50% to favour the economic, social, or environmental aspects. The remaining two aspects were reduced to 25% (Figure 6).

The sensitivity analysis results further support the original findings from the TBL assessment showing that for Euroa WTP, ACH coagulation is the most attractive option financially, socially, and environmentally.

CONCLUSIONS

The following conclusions were made from this study:

- The predominant odours determined from the Euroa system resulted from NOM within the raw water.

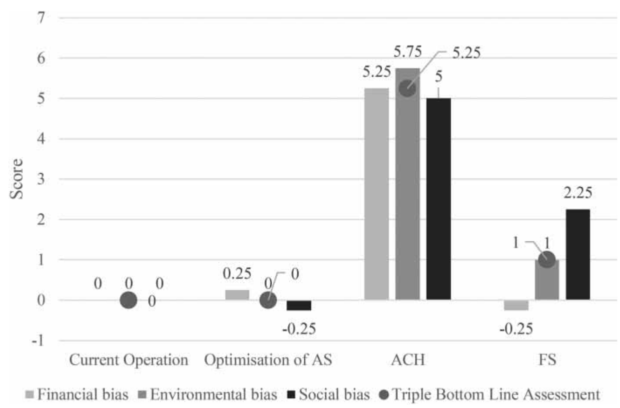

Figure 5 | Summary of the outputs from the economic, environmental, and social assessment.

H_2Open Journal Vol 4 No 1
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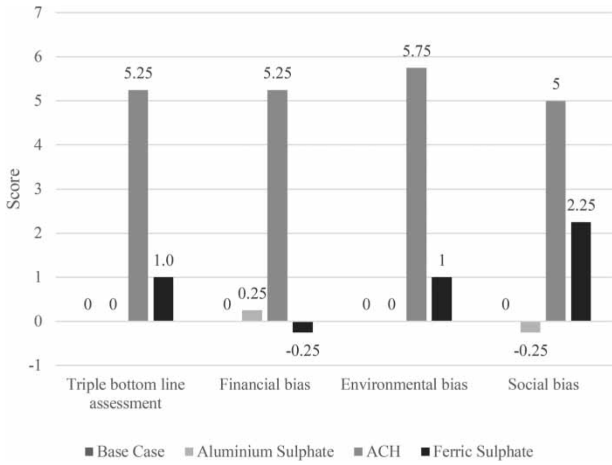

Figure 6 | Outcomes of the sensitivity analysis.

- Targeting coagulation for organics removal can improve the odour of the water.
- For the Euroa system, ACH provided the best outcome when taking into consideration social, economic, and environmental benefits.
- Although FS provides an effective solution to the problem of NOM in the system, its financial and environmental costs make it less attractive than ACH.
- Within the Euroa system, optimisation for organic removal provides minimal benefit for the current operation.

From a water management perspective, this case provides one contextualised expression of how a multidisciplinary approach is needed in making decisions about the best treatment options for NOM, particularly given current global trends of its increasing levels in source waters. Factors of water quality, customer expectation, social and environmental impact, and financial cost are all interrelated and impact each other. These need to be incorporated by water managers, through the wider incorporation of customer complaint data, the potential inclusion of community members on Taste and Odour Panels, and TBL assessment in addition to the current focus on technical water quality and monetary cost.

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CONFLICT OF INTEREST

None.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

H$_2$Open Journal Vol 4 No 1
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REFERENCES

Adams, C. A., Muir, S. & Hoque, Z. 2014 Measurement of sustainability performance in the public sector. *Sustainability Accounting Management Policy Journal* **5** (1), 46–67.

Bartels, J. H. M. & Burlingame, G. A. 1986 Flavor profile analysis: taste and odor control of the future. *Journal of the American Water Works Association* **78** (3), 50–55.

Doria, M. F. 2010 Factors influencing public perception of drinking water quality. *Water Policy* **12** (1), 1–9.

Eikebrokk, B., Vogt, R. D. & Liltved, H. 2004 NOM increase in Northern European source waters: discussion of possible causes and impacts on coagulation/contact filtration processes. *Water Science and Technology, Water Supply* **4** (4), 47–54.

EnHealth 2010 Guidance on the use of rainwater tanks. Commonwealth of Australia, Canberra ACT.

Environment Protection Authority of Victoria 2009 *Environment Protection (Industrial Waste Resource) Regulations*. Environment Protection Authority of Victoria, Melbourne, Victoria, Australia.

Fulop, L. & Linstead, S. 2009 Motivation and meaning. In: *Management and Organization* (Linstead, S., Fulop, L. & Lilley, S., eds). Palgrave McMillan, London, UK, pp. 411–472.

Goulburn Valley Water 2017 *2018–2023 Price Submission*. Goulburn Valley Water, Shepparton, Victoria, Australia.

Imai, A., Fukushima, T., Matsushige, K. & Hwan Kim, Y. 2001 Fractionation and characterization of dissolved organic matter in a shallow eutrophic lake, its inflowing rivers, and other organic matter sources. *Water Research* **35** (17), 4019–4028.

Infrastructure Partnerships Australia 2015 *Doing the Important, as Well as the Urgent*. Water Services Association of Australia. Melbourne, Victoria, Australia.

Loganathan, P., Gradzielski, M., Bustamante, H. & Vigneswaran, S. 2020 Progress, challenges, and opportunities in enhancing NOM flocculation using chemically modified chitosan: a review towards future development. *Environmental Science: Water Research & Technology* **6**, 45–51. doi:10.1039/C9EW00596J.

Marques, R. C., da Crux, N. F. & Pires, J. 2015 Measuring the sustainability of urban water services. *Environmental Science & Policy* **54**, 142–151.

Matilainen, A., Vepsalainen, M. & Sillanpaa, M. 2010 Natural organic matter removal by coagulation during drinking water treatment. *Advances in Colloid and Interface Science* **159** (2), 189–197.

Mohiuddin, A., Rajanayagam, C. & Kearney, C. 2014 Optimisation of non-ionic polymer to address production issues with high-colour low-turbidity raw water. *Water: Journal of Australian Water Association* **41** (8), 58–63.

Murray, B. & Mosse, P. 2015 *Practical Guide to the Optimisation of Chemical Dosing, Coagulation, Flocculation and Clarification*, 2nd edn. Water Industry Operators Association of Australia, Shepparton, Victoria, Australia.

National Health and Medical Research Council 2011 *Australian Drinking Water Guidelines*. National Health and Medical Research Council, Canberra, Australia.

SanClements, M. D., Oelsner, G. P., McKnight, D. M., Stoddard, J. L. & Nelson, S. J. 2012 New insights into the source of decadal increases of dissolved organic matter in acid-sensitive lakes of the northeastern United States. *Environmental Science and Technology* **46** (6), 3212–3219.

Seo, J., Park, J., Oh, Y. & Park, S. 2016 Estimation of total transport CO_2 emissions generated by medium and heavy duty vehicles in a sector of Korea. *Energies* **9** (8). Available from: http://www.mdpi.com/1996-1073/9/8/638/htm (accessed 3 April 2017).

Sharp, E. L., Simon, A., Parsons, S. A. & Jefferson, B. 2006 Seasonal variations in natural organic matter and its impact on coagulation in water treatment. *Science of the Total Environment* **363**, 183–194.

Sinclair, M. I., Leder, K. & Chapman, H. 2005 *Public Health Aspects of Rain Water Tanks in Urban Australia*. Co-operative Research Centre for Water Quality and Treatment, Salisbury, Australia.

Slaper, T. F. & Hall, T. J. 2011 The triple bottom line: what is it and how does it work. *Indiana Business Review Spring* **2011**, 4–8.

Suffet, I., Khiari, D. & Bruchet, A. 1999 The drinking water taste and odour wheel for the millenium: beyond geosmin and 2-methylisoborneol. *Water Science and Technology* **40** (6), 1–13.

Water Research Foundation 2014 *Advancing the Science of Water: WRF and Research on Taste and Odor in Drinking Water*. Available from: http://www.waterrf.org/resources/StateoftheScienceReports/TasteandOdorResearch.pdf (accessed 5 April 2017).

Whitehead, P. G., Wilby, R. L., Battarbee, R. W., Kernan, M. & Wade, A. I. 2009 A review of the potential impacts of climate change on surface water quality. *Hydrological Sciences Journal* **54** (1), 101–123. doi:10.1623/hysj.54.1.101.

Zamyadi, A., Henderson, R., Stuetz, R., Hofman, R., Ho, L. & Newcombe, G. 2015 Fate of geosmin and 2-methylisoborneol in full scale water treatment plants. *Water Research* **83**, 171–183.

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