OPTIMISING PAC DOSING TO REMOVE MIB AND GEOSMIN IN FOUR ADELAIDE METROPOLITAN WATER TREATMENT PLANTS

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ABSTRACT

A procedure for predicting the minimum powdered activated carbon (PAC) dose to remove the earthy-musty taste and odour compounds 2-methylisoborneol (MIB) and geosmin from the inlet waters to four Adelaide metropolitan water treatment plants (WTP's) was successfully tested.

The equilibrium capacity and kinetics of MIB and geosmin removal was determined for the inlet water of four WTP's with one PAC. These results were used with the Homogeneous Surface Diffusion Model (HSDM) to predict MIB and geosmin removal in batch kinetic tests. Based on HSDM predictions PAC dose tables were constructed for each water. These tables allow the WTP operator to determine the minimum PAC dose required to reduce the influent concentration of MIB and geosmin to a desired effluent concentration that will not cause any taste and odour problems. Laboratory jar tests showed the PAC dose tables to be accurate, however increases in raw water turbidity were found to reduce the accuracy of the predictions.

KEY WORDS

Activated carbon, adsorption, MIB, geosmin

1.0 INTRODUCTION

During the warmer months of the year, between October and March, the incidence of blue-green algal blooms in the source waters of four Adelaide water treatment plants can result in the release of MIB and geosmin. To supply aesthetically pleasing water to the customer these compounds need to be removed in the water treatment process. Earthy-musty tastes and odours attributable to MIB and geosmin can be noticed at very low concentrations.

Conventional water treatment practices (coagulation - flocculation - sedimentation - filtration) will not remove MIB and geosmin. The addition of powdered activated carbon to the water treatment process is the most common method used for the removal of taste and odour compounds. One of the major challenges when using PAC is knowing how much to add. Overdosing with PAC will waste money while underdosing will result in taste and odour problems in the distribution system, with the likely consequences being customer complaints and dissatisfaction. The following factors have an impact on the amount of PAC to be dosed.

(i) Contact time. An increase in contact time will increase the amount removed.

(ii) Type of PAC. Some PAC's perform better than others in the removal of MIB and geosmin. Geosmin is much easier to remove than MIB.

(iii) Water quality. Changes in concentration and character of natural organic matter (NOM) can affect PAC performance. An increase in turbidity appears to reduce PAC performance if the PAC is dosed during coagulation, as the PAC can become incorporated into the floc during flocculation.

The aim of the work presented here was to produce a table that would allow the WTP operator to

determine the minimum PAC dose to remove MIB and geosmin.

The inlet waters used in this study were taken from the Anstey Hill, Happy Valley, Hope Valley and Myponga WTP's. The first three plants listed employ a conventional water treatment process. Myponga WTP uses a dissolved air flotation process. Apart from Anstey Hill WTP, water supplied to the WTP's is pumped from the adjoining reservoir. At the time of this study Anstey Hill WTP was receiving water from the River Murray via the Mannum to Adelaide pipeline. This water is chlorinated prior to the WTP as several towns are supplied with water from the pipeline.

To determine the amount of MIB and geosmin remaining after a given reaction time equilibrium capacity and batch kinetic experiments were completed for each compound in the four inlet waters. These results were used with the Homogeneous Surface Diffusion Model (HSDM) to predict MIB and geosmin removal in batch kinetic tests. The HSDM was found to successfully predict the kinetics of MIB and geosmin removal in each of the waters for a range of initial concentrations and PAC doses tested. HSDM predictions were then used to construct PAC dose tables to determine the minimum PAC dose required to remove MIB and geosmin in the water treatment process. These tables were successfully tested by conducting jar tests in the laboratory utilising WTP conditions. The accuracy of the predictions were, however found to decrease as the raw water turbidity increased.

A limitation of the predictions is that they can only be applied to the PAC and the raw water tested. Further work is being carried out to determine what effect changes in raw water character have on predictions.

2.0 MATERIALS AND METHODS

2.1 Water Samples

Raw waters obtained from each of the water treatment plants were split into two samples, one was filtered through a 0.2 μm cartridge filter for equilibrium and kinetics experiments while the unfiltered portion was kept for jar tests. All waters were stored at 4 ^{o}C until used.

2.2 Powdered Activated Carbon

Picactif 1100 PAC was supplied from PICA. It is a coconut based steam activated carbon with a surface area of 1241 m^2/g and an average particle diameter of 23 μm. The PAC was dried in an oven at 105 ^{o}C 24 hours prior to use.

2.3 Analysis

Geosmin. This was analysed using Solid Phase Microextraction -Gas Chromatography / Mass Spectrometry (SPME - GC/MS).

MIB. ^{14}C-labelled MIB was analysed using a liquid scintillation counter. Samples were mixed with a scintillation cocktail in scintillation vials and the resulting fluorescence was measured.

2.4 Equilibrium Isotherms

Raw water was added to clean dry pyrex bottles to a level just below the top to obtain minimum headspace. MIB or geosmin was added followed by PAC. The bottle was sealed and agitated for 3 days.

2.5 Kinetics

MIB or geosmin was added to a constantly stirred raw water sample. After 15 minutes of mixing a sample was taken to determine the initial concentration. PAC was added with samples taken at

predetermined intervals over the following four hours. Samples were pressure filtered though 0.45 μm disposable filters to remove the PAC.

2.6 Jar Tests

The jar test conditions were set up to simulate conditions at the four WTP's. For all raw waters except that from Myponga WTP PAC and alum were dosed during the rapid mix stage where samples were mixed at maximum velocity (160 rpm) for 1 minute. For Myponga raw water the PAC was dosed 40 minutes prior to alum dosing. Polyelectrolyte was added at the beginning of the flocculation stage. The flocculation speed, time and sedimentation time were determined by the operating conditions at the water treatment plants.

3.0 RESULTS AND DISCUSSION

3.1 Raw water character

The differences in the raw water character of the four waters are shown in Table 1.

Table 1: ***Raw water characteristics.***

Raw water Source	UV Absorbance (254 nm)	DOC (mgL^{-1})	SUVA ($Lm^{-1}mg^{-1}$)	Colour (HU)	Colour/ DOC ($HUmg^{-1}L$)	Turbidity (NTU)	Average Molecular Weight
Hope Valley	**0.179**	**6.1**	**2.9**	**17**	**2.8**	**6**	**1203**
Happy Valley	**0.143**	**4.6**	**3.1**	**16**	**3.5**	**5.5**	**1733**
Myponga	**0.438**	**10**	**4.4**	**67**	**6.7**	**2.3**	**2091**
Anstey Hill	**0.087**	**4.2**	**2.1**	**4**	**1**	**60**	**1114**

Some insight into the nature of the background natural organic matter can be obtained from Table 1. The low specific UV absorbance (SUVA) of Anstey Hill, Happy Valley and Hope Valley raw water shows that the DOC of these waters is composed of largely non-humic relatively hydrophilic compounds. The higher SUVA value of Myponga raw water indicates the DOC is composed largely of aquatic humics and would be relatively hydrophobic, and of high molecular weight compared with the other waters that have a lower SUVA value (Edzwald 1993). The higher colour and UV absorbance of Myponga raw water indicate that the DOC is more highly conjugated and aromatic in nature than the other raw water DOC's. Anstey Hill raw water has a lower UV absorbance and colour due to the breakdown of UV absorbing compounds by chlorination.

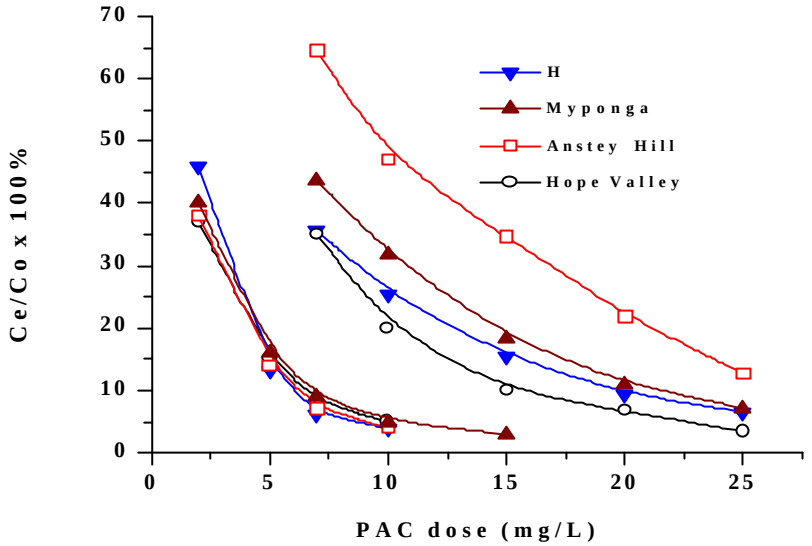
3.2 Equilibrium Capacity

Previous PAC adsorption studies by Knappe (1996) for atrazine, and later Gillogly *et al.* (1998) for MIB in natural water have shown that for trace quantities of these compounds, the percent remaining at equilibrium is independent of initial concentration and is a function of PAC dose over a limited low concentration range.

In the four waters tested this was found to be the case for MIB and geosmin adsorption over the range of initial concentrations (Co) tested. The equilibrium data was analysed as outlined by Knappe (1996) by plotting percent remaining at equilibrium (Ce/Co x 100 %) versus PAC dose (Cc), as shown in Figure 1. Using this type of plot a summary of MIB and geosmin adsorption at equilibrium can be obtained.

Results show that the capacity of the PAC is greater for geosmin than for MIB and that the differences in background NOM had no affect on the equilibrium capacity of the PAC for geosmin. The differences in background NOM had an impact on MIB adsorption, with the capacity varying from water to water. The capacity of the PAC for MIB was greater in Myponga raw water compared with Anstey Hill raw water, even though the DOC was twice that of Anstey Hill raw water. The lower capacity of the PAC for MIB in Anstey Hill raw water is most likely due to competition between MIB and chlorination by-products for adsorption sites.

Figure 1: ***Percent remaining of MIB and geosmin at equilibrium as a function of PAC dose.***



3.3 Predicting MIB and geosmin removal using the HSDM

Parameters that describe the equilibrium capacity and kinetics need to be determined before the kinetics of adsorption of MIB and geosmin can be predicted using the HSDM. The relationship between the amount of MIB/geosmin (adsorbate) adsorbed at equilibrium and the amount remaining in solution can be described by the Freundlich equation ($\mathbf{qe = K.Ce^{1/n}}$). The Freundlich constants **1/n** and **K** can be determined by constructing a log-log plot of qe versus Ce (Figure 2). The Freundlich constant 1/n is equal to the slope of the linear portion of the isotherm while log K is equal to the y intercept. The isotherms shown in Figure 2 were constructed from Ce/Co x 100% versus PAC dose plots for Anstey Hill from Figure 1. The equilibrium solution concentration (Ce), and the amount adsorbed onto the PAC at equilibrium (qe), were calculated from the knowledge that for a given PAC dose a known percentage of MIB and geosmin will remain in solution at equilibrium.

The HSDM was used to determine the kinetics of MIB and geosmin removal. This model requires that the liquid film mass transfer coefficient (kf), that describes the diffusion of the adsorbate through the thin liquid layer surrounding the carbon particle, and the surface diffusion coefficient (Ds) that describes the diffusion of the adsorbate inside the carbon particle, are known. These cannot be directly measured and were determined using a search program that solves the HSDM for Ds and kf by minimising the difference between the HSDM solution and experimental batch kinetic data using a Levenberg-Marquardt numerical algorithm (Traegner and Suidan 1989). Having obtained a satisfactory fit, a program written by Traegner and Suidan (1989) was used to determine MIB and

geosmin removal under different conditions. A full explanation of the HSDM is given elsewhere (Najm *et al*., (1991); Traegner and Suidan 1989).

Figure 2: ***Equilibrium Isotherms for MIB and geosmin removal in Anstey Hill WTP influent water.***

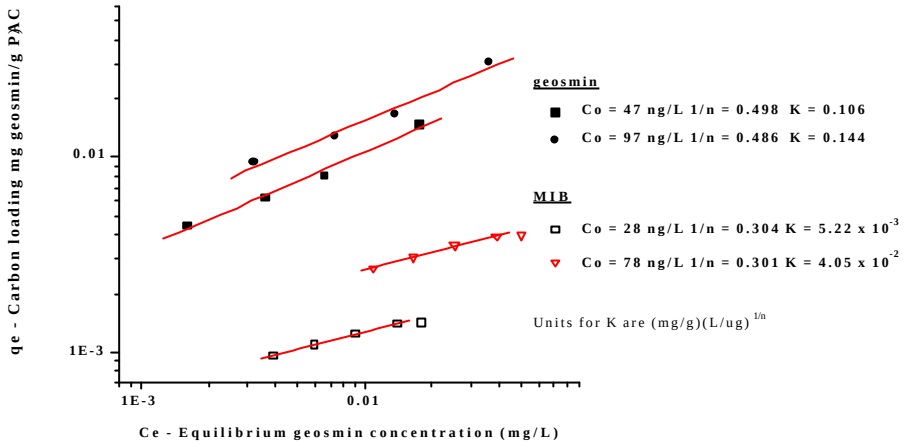
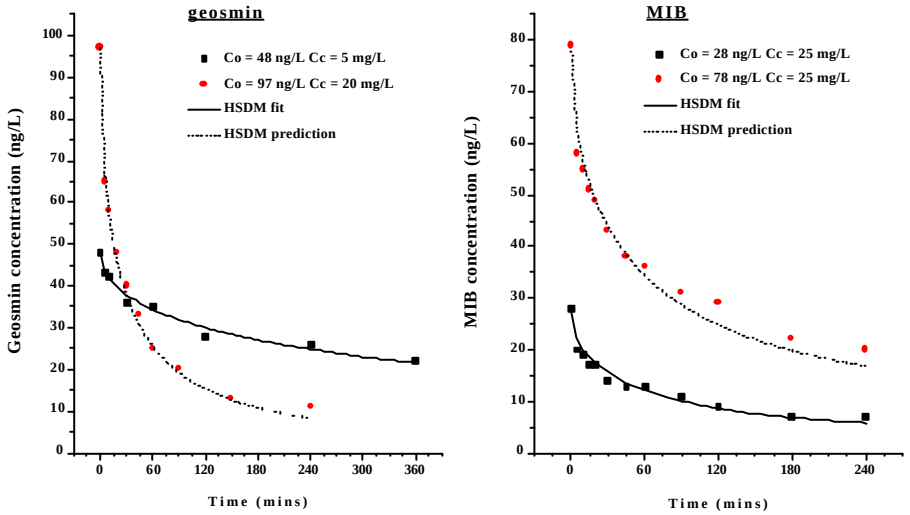


Figure 3: ***HSDM fit to batch kinetic data (bold line) and how this data predicts MIB and geosmin removal for other conditions (broken line).***



3.4 Jar Tests

Figure 4 shows that the removal of MIB and geosmin was successfully predicted during the flocculation of Hope Valley raw water, however the prediction was not as successful with Anstey Hill raw water (Figure 5). The lower than expected removals were attributed to the flocculation of the turbidity. This was the major physical difference between the two waters and would affect the structure of the floc formed during flocculation.

The floc that formed while treating Anstey Hill raw water was larger and denser than that formed while treating Hope Valley raw water. These characteristics would greatly increase the chances of the PAC becoming incorporated into the floc resulting in a reduction of MIB and geosmin removal. Jar tests on Anstey Hill and Happy Valley inlet waters sampled after changes in raw water turbidity show that the accuracy of the predictions varied as the raw water turbidity changed (Figures 5 and 6).

The accuracy of the predictions improved as the raw water turbidity decreased. Increased MIB and geosmin removal was most likely a result of there being less material flocculated, hence less PAC was getting bound up in the floc. In terms of PAC dosing more PAC is going to be required as the turbidity increases. For example, an increase in the turbidity of Anstey Hill raw water from 5 NTU to 61 NTU would increase the PAC dose to treat 40 ng/L of MIB or geosmin with a contact time of 50 minutes by 10 and 5 mg/L respectively. If the accuracy of the predictions need to be within 3 ng/L of the desired effluent MIB and geosmin concentration then even with a high turbidity of 61 NTU the PAC dose tables can be used if influent MIB and geosmin concentrations are below 20 and 27 ng/L.

The point at which turbidity begins to impact on HSDM predictions appears to be between 6 and 26 NTU. Figure 6 also shows that data for Hope Valley raw water can be used to predict MIB and geosmin removals in Happy Valley. This is not surprising as both waters are of similar quality due to both reservoirs being topped up with River Murray water over the summer.

Figure 4 – ***Comparison of MIB and geosmin removal during flocculation with Hope Valley raw water with that predicated by the HSDM.***

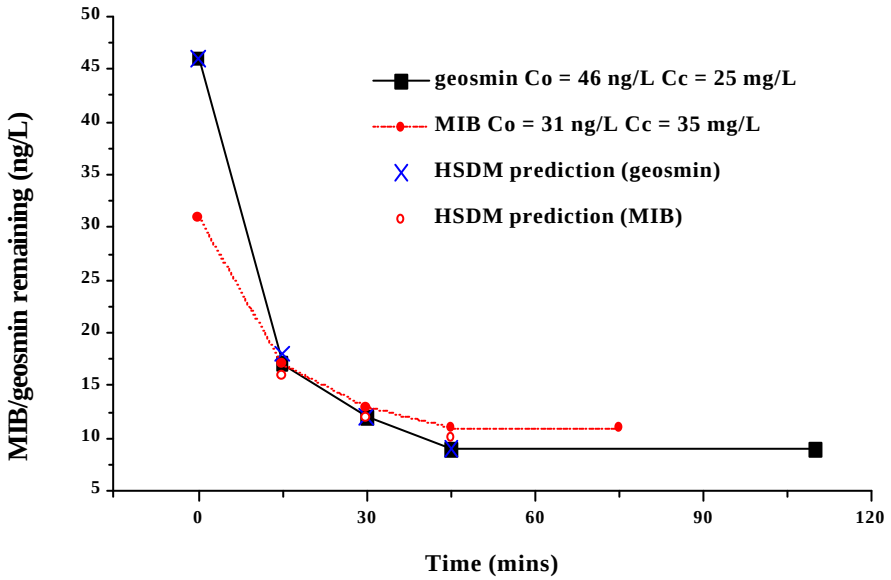


Figure 5 – ***Effect of turbidity on HSDM predictions for geosmin removal during flocculation with Anstey Hill raw water***

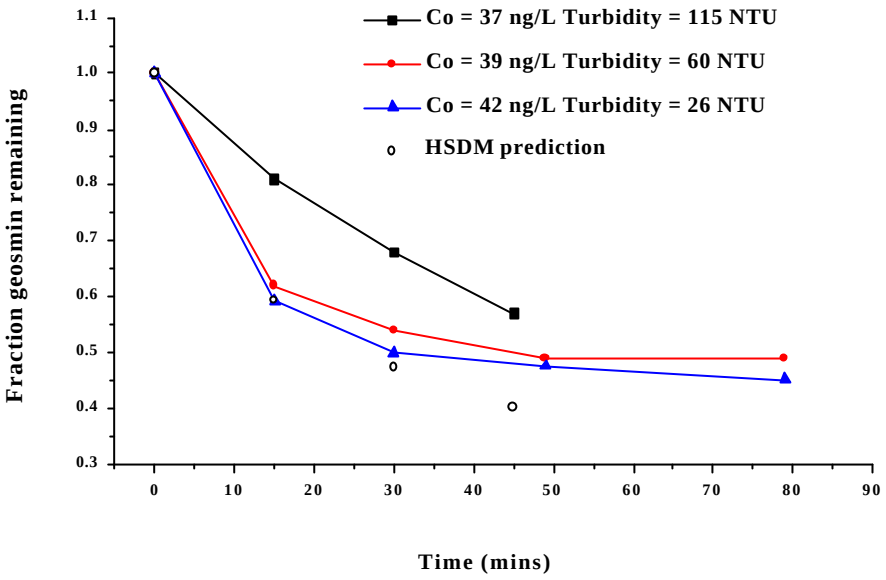
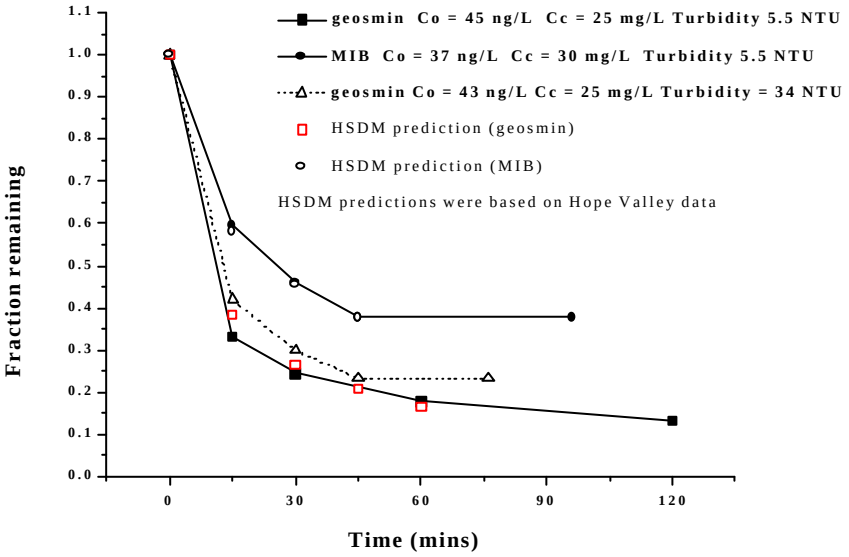


Figure 6 – ***Predicting MIB and geosmin removal during flocculation with Happy Valley raw water using HSDM data from Hope Valley raw water***



3.5 Determining PAC dose from PAC dosing tables

PAC dose tables have been constructed to make the process of determining the minimum PAC dose quick and easy. Successfully predicting the minimum PAC dose relies on the WTP operator knowing the influent MIB and geosmin concentration and the contact time between the PAC and the water in the flocculation stage of the treatment process. A concentration of 5-10 ng/L was chosen as the desired effluent concentration as at these low concentrations their presence would not be noticed by the majority of the population.

The following method is used to determine the PAC dose:

- Find out the influent geosmin concentration coming into the WTP, for example 30 ng/L.
- Determine the fraction remaining for desired effluent concentration. For the example above, this will be 0.167 for 5 ng/L and 0.333 for 10 ng/L.
- Assuming the contact time in the flocculators is 50 minutes. Find t = 50 minutes in the time column. Examine the fraction remaining for each PAC dose for this contact time. Find the fraction remaining that is closest to, but less than the desired fraction remaining. The column that this occurs in, is the PAC dose that should be used.

The PAC dose required to reduce 30 ng/L of geosmin to 10 ng/L is 17.5 mg/L. To reduce the same concentration a further 5 ng/L an extra 10 mg/L of PAC is needed.

Table 2: ***Prediction of PAC dose for the removal of geosmin from Hope Valley WTP water based on the influent geosmin concentration and PAC contact time.***

Influent Geosmin (ng/L)	Fraction remaining for desired effluent geosmin		Time (mins)	PAC Dose (mg/L)					
				15	17.5	20	22.5	25	27.5
	5 ng/L	10 ng/L		Fraction of geosmin remaining					
15	**0.333**	**0.667**	**0**	1.000	1.000	1.000	1.000	1.000	1.000
25	**0.200**	**0.400**	**50**	0.360	**0.305**	0.259	0.221	0.190	**0.164**
26	**0.192**	**0.385**	**55**	0.344	0.289	0.244	0.208	0.178	0.153
27	**0.185**	**0.370**	**60**	0.329	0.275	0.231	0.195	0.166	0.143
28	**0.179**	**0.357**	**65**	0.315	0.262	0.219	0.185	0.157	0.134
29	**0.172**	**0.345**	**70**	0.302	0.250	0.208	0.175	0.148	0.127
30	**0.167**	**0.333**	**75**	0.291	0.239	0.199	0.166	0.140	0.120

Predictions made for each of the WTP's show that MIB is much more difficult to remove than geosmin with approximately twice as much PAC needed to remove MIB compared with geosmin. An example of PAC doses required for one possible situation is shown in table 3.

Table 3: ***PAC dose required to reduce 40 ng/L of MIB or geosmin to 10 ng/L at each WTP given a contact time of 50 minutes.***

Raw water source	geosmin	MIB
	PAC dose (mg/L)	
Anstey Hill	22	42
Happy Valley	21	39
Hope Valley	21	39
Myponga	28	55

4.0 CONCLUSION

The HSDM was found to successfully predict the kinetics of MIB and geosmin removal in each of the waters for a range of initial concentrations and PAC doses tested. PAC dose tables were found to accurately predict MIB and geosmin removal in jar tests however turbidity was found to reduce the accuracy of predictions. Accuracy of predictions was found to decrease with increasing turbidity, however predictions to within 3 ng/L were obtained even with a high turbidity of 61 NTU providing MIB and geosmin concentrations were below 20 and 27 ng/L respectively. Compared with geosmin, MIB is more difficult to remove, requiring approximately twice the PAC dose to achieve equivalent removals with the PAC tested.

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