Paper No: o7130

Case Study: Odour Risk Management at the WTP, One of Australia's Largest & Most Unique WWTPs

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ABSTRACT

The Western Treatment Plant (WTP) is one of Australia's largest and most unique wastewater treatment plants (WWTP) treating over 52% of Melbourne's sewage in a series of large lagoons. WTP has an existing, comprehensive Environmental Improvement Plan in place, which includes an ongoing focus on odour management in the context of a recently completed significant program of upgrade works that have resulted in an estimated reduction in odour emissions from the WTP site of about 90%. In this context, the purpose of the odour risk management project was to assess any ongoing residual odour impact risks for the plant and to identify any further odour mitigation approaches that may be available to appropriately manage this risk if required. Due to the scale and the unique nature of the facility, changes in odour emissions from any of the various sources may have a significant effect on off site odours, and reliably assessing the varying impact of these sources is much more complex than for other WWTPs.

For these reasons, the data collection and assessment phase of the project was more comprehensive than would normally be undertaken for an odour impact assessment, and integrated some unique and interesting new tools.

There were concerns that causality effects in AUSPLUME could result in overly conservative predictions. Therefore, the investigation also assessed the available odour dispersion models, (AUSPLUME, CALPUFF and TAPM) and their appropriateness for assessing odour impacts from this unusually large site. In particular, the predictions of AUSPLUME will be compared to the predictions of CALPUFF, community surveys and field olfactometry data to ascertain the relative accuracy of each model.

This paper will present the results of this investigation so far, including some interesting findings about the relationships between odour strength, perception (how humans interpret odour strength) and odour annoyance in the community.

INTRODUCTION

Melbourne Water Corporation engaged CH2M HILL to undertake an Odour Risk Management Investigation for Western Treatment Plant (WTP) in Melbourne. WTP is one of Australia's largest and most unique wastewater treatment plants (WWTPs), and receives incoming raw sewage from the Western Trunk Sewer (WTS). It treats over 52% of Melbourne's sewage in a process consisting of open carriers, covered anaerobic lagoons, aerobic lagoons, activated sludge plants and maturation ponds. There is also an ongoing need to dry and process digested sludge in open air drying pans.

To provide an indication of the scale of the plant, three main open carriers (Main Inlet, Main Southern and Main Eastern Carrier) with a combined length of approximately 12.5km convey an average dry weather flow (ADWF) of 485ML/day to three treatment lagoon systems – Lagoon 115E, Lagoon 55E and Lagoon 25W. Each lagoon system consists of a covered anaerobic zone, a transition zone, an aerobic zone and a series of facultative ponds. The surface areas of Lagoons 115E, 55E and 25W are 190hA, 280hA and 260hA respectively. Due to the scale of WTP, changes in the odour emission rates from various sources may have a significant effect on off site odours.

WTP has undergone substantial process and infrastructure upgrades over the last eight years as part of the Environment Improvement Project (EIP). These upgrade works included the retrofit of activated sludge treatment into the existing 55E and 25W Lagoon systems to increase the treatment capacity of these systems. As a result, the practice of direct application of raw sewage to land, which was responsible for large odour emissions from the WTP site, was abandoned. Additionally, the EIP also involved covering of anaerobic treatment areas for methane gas capture and odorous gas treatment. These upgrades are estimated to have reduced odour source emissions from WTP by approximately 90%.

Although significant improvements in odour performance have been achieved through the EIP, the possibility of further residential and recreational land development within close proximity to the plant may increase the likelihood of offensive odour impacts beyond the plant boundary in the future. The purpose of the odour risk management project was to identify whether further odour mitigation works are required at WTP, and to assess the risks of receiving odour complaints if mitigation works are not undertaken. Due to the large area of sources and the size of the infrastructure that would be required to cover and treat them, the cost to implement viable odour mitigation works would be much higher than for a more conventional plant and as a result, accurate assessment of odour impacts is critical.

For these reasons, the data collection and assessment phase of the project was more comprehensive than would normally be undertaken for an odour impact assessment, and the following unique and interesting new tools and approaches were used to determine the odour risk posed by WTP:

- The use of field olfactometry, using a Nasal Ranger, to measure ambient odour levels from major sources and their potential offsite impacts.
- Dispersion modelling of major sources to back calculate emission rates that corresponded to the measured odour impact using field olfactometry.
- Comparison of these odour emissions rates with the measured and calculated emission rates.
- Establishing the accuracy and reliability of using surrogate gases that could be readily measured to ascertain odour levels from sources with diurnal and seasonal odour emissions.
- Confirmation of the log linear relationship between odour strength and perceived odour intensity.
- Objective and subjective community odour surveys over several weeks for three different seasons to ascertain odour intensity and perceptions in the community at these times.

By collecting this wide range of data it is possible to cost effectively establish seasonal and diurnal odour variation and to correlate and validate assumptions and emissions used, so that more accurate dispersion modelling and impact assessments could be undertaken. It also ensured that conclusions could be validated in a number of ways providing more assurance of the need to undertake further odour mitigation works.

There were concerns that causality effects in AUSPLUME could result in overly conservative predictions of the risk of odour complaints. Therefore, the investigation also assessed the available odour dispersion models, (AUSPLUME, CALPUFF and TAPM) and their appropriateness for assessing odour impacts from this unusually large site and modelling domain. In particular the predictions of AUSPLUME will be compared to the predictions of CALPUFF, community surveys and field olfactometry (Nasal Ranger) data to ascertain the relative accuracy of each model.

Details of the data collection and assessment phase of the works undertaken at WTP are outlined below. Ultimately, a year's worth of odour sampling results, Nasal Ranger monitoring data and community survey results will be used to determine the odour risk posed by WTP.

DATA COLLECTION

In order to accurately assess the odour impacts from WTP, a large amount of data was collected to determine the odour emissions from the plant and the impact of these emissions on the surrounding community.

Odour impact assessment for wastewater treatment plants generally relies heavily on the results of odour sampling. In the case of WTP, the following data collection was undertaken, and will be discussed below:

- Odour sampling to determine odour concentration
- Nasal Ranger monitoring program to determine odour concentration and intensity
- Details of past odour complaints
- Community survey to determine how odour from WTP is perceived by existing residents

Odour Sampling

Odour sampling using a standard sized isolation flux hood was undertaken at WTP in Autumn 2006. Additional sampling is to be undertaken to represent odour emissions in Spring 2006 and Summer 2007.

H_2S measurements were taken concurrently with odour samples at a number of locations, to determine whether a correlation existed between odour and H_2S levels. H_2S levels were measured on site from the sampling bag as odour samples were collected, and then in the laboratory prior to olfactometry assessment of odour concentration for each sample. **Figure 1** illustrates the correlation between H_2S and odour for H_2S measurements taken on site and in the laboratory (results shown were from samples taken in the open raw sewage carriers over several days at various times). This figure illustrates good correlation between H_2S and odour for the primary sources at WTP and suggests that H_2S measurement is a good surrogate for determining odour concentration for these sources. Therefore continuous H_2S monitoring was used to determine diurnal and seasonal odour profiles at WTP for these sources. Also comparison of the diurnal H_2S profiles with odour sampling data for the carriers enabled us to determine that the odour emissions from all quiescent (non turbulent) zones were consistent with the H_2S profiles. Initial investigation of odour results for the carriers on their own appeared quite different.

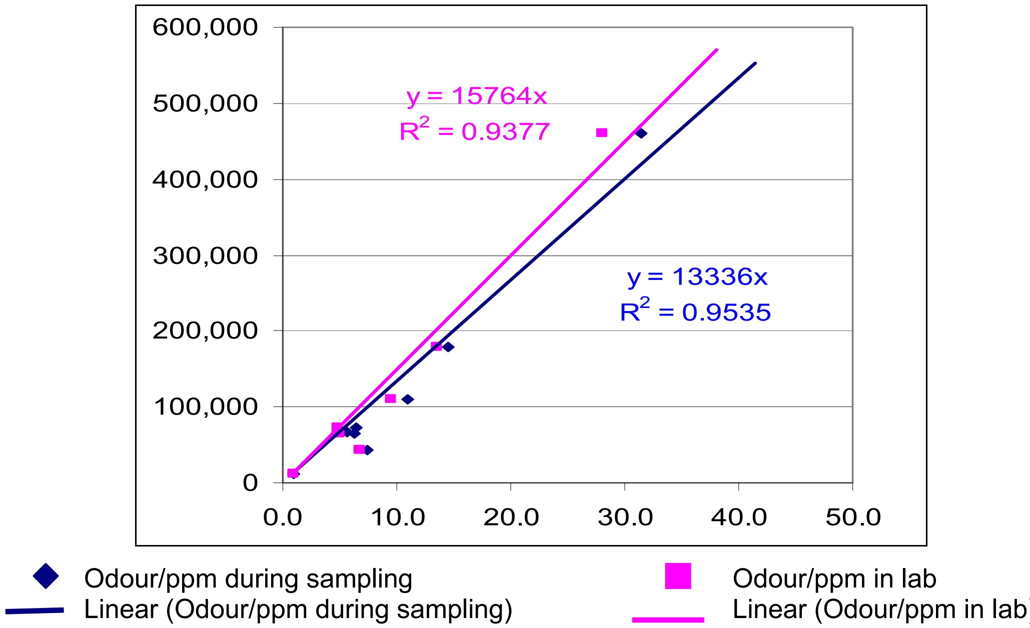

Figure 1 Correlation between Odour and H_2S

Logged H_2S data was therefore used in conjunction with odour samples to develop diurnal odour profiles from primary odour sources at the plant where H_2S was thought to be the main constituent and where there is significant variation in odour levels over a 24 hour period.

The odour emissions from the carriers, and anaerobic zones and transition zones of the lagoon systems were also affected by temperature, due to greater biological activity in warmer months increasing H_2S emission rates. The diurnal H_2S profile where the WTS discharges into the open carriers at WTP was found to be very similar to that in carriers 7km downstream. Therefore, it was assumed that the seasonal variation that occurs in the carriers, anaerobic zones and transition zones was consistent to that measured in the WTS. The seasonal effects of emissions from the process units at WTP, due mostly to raw sewage temperature variations, will be confirmed upon collection of a year's worth of sampling data.

H_2S measurements were also used to determine the deterioration of samples that occurred between the time of collection and the time of analysis in the laboratory. Deterioration ranged from 3-25% and did not appear to correlate with the time between sampling and analysis.

As WTP consists of very large area sources, changes in odour emission rates can have a significant effect on offsite odour impacts, both in reality and as predicted using odour dispersion modelling. Therefore, it is important to ensure that odour sampling data is collected over a period of time that is long enough to capture seasonal variation in emission rates and spatial effects. At WTP, H_2S is a representative surrogate gas for odour, and diurnal H_2S

profiles can be a useful tool for ensuring that peak odour levels are captured for inclusion in odour dispersion modelling. Further odour samples will be collected during Spring 2006 and Summer 2007, and odour emission rates reviewed as required. During all area source sampling, care was taken to ensure that enough samples were collected from large sources to ensure good representation of each source. This was particularly important as some sources demonstrated a marked difference in emission rate from one end to the other.

Nasal Ranger Monitoring

A Nasal Ranger monitoring program was implemented by Melbourne Water in Autumn 2006, and will be supplemented with additional programs in Spring 2006 and Summer 2007. The Spring and Summer monitoring programs will be conducted at the same time as community surveys to determine how the level of odour from WTP can be perceived by the community.

Melbourne Water personnel recorded the following details at fifteen locations around the perimeter of WTP twice daily for a total of ten days in an eight-week period for each program:

- Date and Time
- Wind direction
- Wind velocity
- Weather conditions (including cloud cover and precipitation)
- Odour strength (measured using a Nasal Ranger)
- Description of Odour character
- Odour intensity – on a scale from 0 to 6, ranging from very weak to extremely strong
- Hedonic tone – on a scale ranging from 1 to (-3) from pleasant to nauseating

Field olfactometry provides a dynamic response to odour assessment and in the event that Melbourne Water receives an odour complaint regarding WTP, Nasal Ranger measurements at the plant boundary upwind of the complaint will be undertaken. The aim of this monitoring will be to confirm the source of the odour at the plant, and indicate the strength/intensity/character of odour that can cause a response in the community.

The wind speed and direction, as well as details of odours detected during Autumn 2006 Nasal Ranger monitoring were analysed to determine which process areas caused odours at the WTP boundary. These results were then compared with other odour and H_2S data to determine the major sources of odour at the plant at that time that emit beyond the plant boundary.

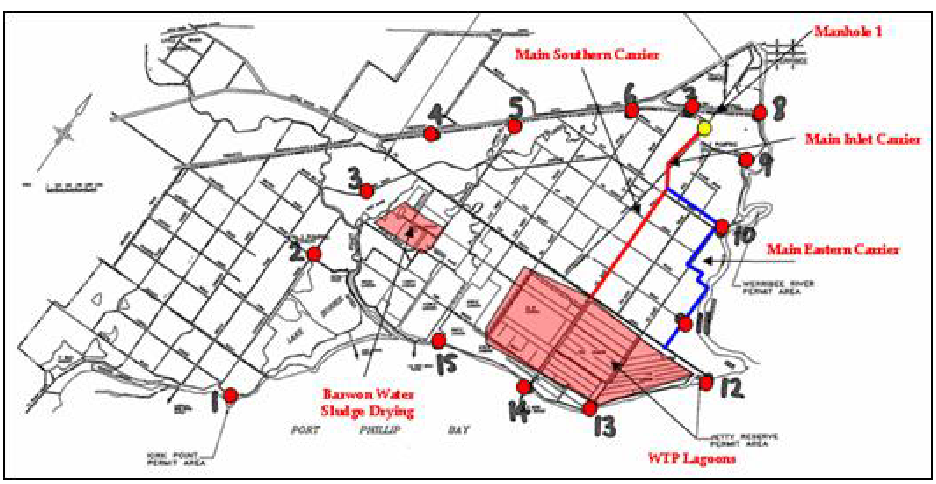

Figure 2 WTP Nasal Ranger Sampling Locations and Major Odour Sources

Figure 2 shows the remaining major odour sources at WTP (post implementation of the EIP) and the locations where Nasal Ranger monitoring was undertaken. As can be seen above, the lagoons and the Main Eastern Carrier are very close to the plant boundary. Under appropriate meteorological conditions (generally when wind direction is from west to southwest), odours at Locations 9-14 odours were assumed to be attributable to the lagoons and carriers. Odours logged at Locations 2-4 were assumed attributable to current sludge drying operations under appropriate meteorological conditions (generally when wind is from the east or southeast).

The Nasal Ranger monitoring results have also been used to correlate odour concentrations predicted by AUSPLUME modelling.

In addition to Nasal Ranger monitoring, odour intensities were assigned to various process units at the plant by odour technologists from CH2M HILL during a site visit in March 2006. At other WWTPs, it has been demonstrated (Schultz et al., 2002) that $\log_{10}$ of the odour concentration ($\log_{10}$OU) determined by sampling correlates with the odour intensity perceived on site. In order to determine if this correlation was applicable at WTP, the perceived odour intensity was plotted against the $\log_{10}$OU for the top 13 remaining odour sources at WTP, based on sampling undertaken in 2006. It is noted that all these top 13 sources were zones of lagoons and carriers on site. This plot is shown in **Figure 3**, and indicates that the correlation is consistent for sources at WTP.

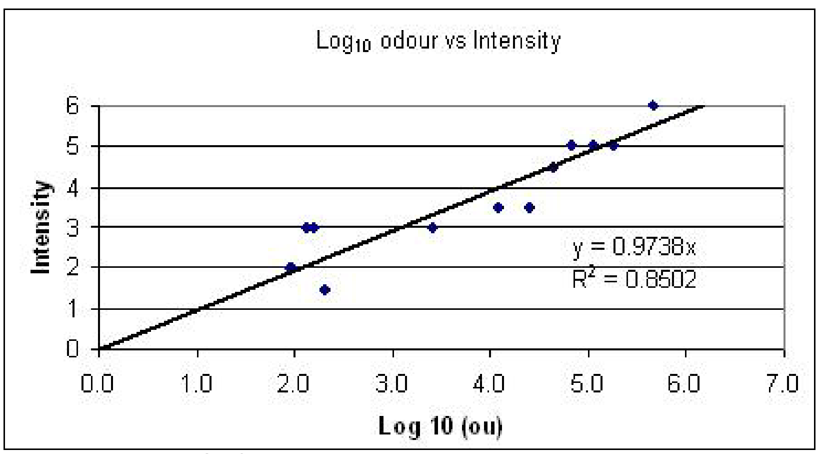

Figure 3 **Odour intensity vs $\log_{10}$OU for top 13 odour sources at WTP (based on odour concentrations derived during 2006 sampling)**

Confirmation of the $\log_{10}$ linear relationship between odour concentration and intensity for lagoons and carriers at WTP provided a level of verification of odour results and was used to establish an understanding of odours characteristics when determining odour criteria for the risk evaluation. The relationship is similar in perception to noise audibility (the decibel scale).

Complaints Data

Analysis of complaints data provided an indication of the actual odour impact of WTP on the surrounding community. Both Melbourne Water and the EPA Victoria (EPAV) provided historical data for WTP. The complaints are classified as “not likely”, “likely” or “confirmed” based on investigation by each authority. To investigate a complaint, the wind direction at the time of the complaint is determined. If this indicates that WTP could be the source of odour, an inspection of the plant is then undertaken to find the odour source. CH2M HILL analysed likely and confirmed complaints data from 2001 until 2005 and the odour sources at WTP that were closest to the origin of the complaint were identified. The origin of the odour complaint, its distance from WTP and other odour sources in its vicinity were also considered to determine whether it was likely that the odours causing complaints were attributable to WTP.

Based on analysis of the complaints data, it was concluded that a key consideration for assessing odour complaints is the potential for high sensitivity to small changes in the existing local community (eg. new residents moving into the area). This indicates that, should new developments occur within closer proximity to WTP than is currently the case, new residents may be more sensitive to odours from WTP as they are not acclimatised to them, and as such may be more likely to make odour complaints.

Community Surveys

Like complaints data, community surveys are a useful tool for determining the odour impact of a facility on the surrounding community. A community survey was undertaken in Summer 2004, Winter 2006, and additional surveys will be conducted in Spring 2006 and Summer 2007 to coincide with Nasal Ranger monitoring. By undertaking surveying and monitoring simultaneously, the odour concentration and intensity that generates a response from the community can be established.

To date, community surveys and Nasal Ranger monitoring have not been undertaken concurrently. However, the Winter 2006 community survey found that 85% of respondents said that where they lived, the air was always or usually clean. Whether respondents believed odours were attributed to WTP appeared to depend on whether there were other odour causing activities in their immediate vicinity. For example, in some areas most respondents attributed odours to surrounding agricultural activities rather than WTP. This indicates that the community's perception of the origin of odours is impacted by their proximity to both WTP and other odour sources. The community survey indicated that the surrounding residents are aware of odours and some do attribute these to WTP, although this does not necessarily result in odour complaints.

ASSESSMENT OF DATA USING ODOUR DISPERSION MODELLING

An assessment of odour dispersion modelling programs applicable to WTP was undertaken. The modelling programs assessed were AUSPLUME, CALPUFF and TAPM.

Initial odour modelling of WTP was conducted using AUSPLUME in conjunction with the data collected above to estimate the overall odour impact from WTP, both under current operating conditions and upon implementation of a number of odour improvement strategies. Results of AUSPLUME modelling were correlated against findings from the Nasal Ranger survey to establish whether odour emissions determined during sampling were representative of the odours from particular sources. AUSPLUME modelling results were also compared with available community survey results.

Assessment of Modelling Program

AUSPLUME, CALPUFF and TAPM were assessed regarding their suitability at WTP.

AUSPLUME is a steady state Gaussian odour dispersion model that assumes that the odour plume moving from its source has a Gaussian profile. Steady state models assume constant meteorological conditions during each hour of the dispersion from source to receptor. The main limitations of AUSPLUME and other steady-state models with respect to modelling odour emissions are as follows:

- Causality effects – the model assumes that odour is transported in a straight line instantly to receptors that may be several hours in transport time away from the source;
- Does not account for low wind speed or calm conditions - AUSPLUME sets a minimum wind speed of 0.5 and overwrites data below this with this lower limit.
- Model assumes spatially uniform meteorological conditions;
- Model has no memory of previous hour's emissions; and
- Model is unsuitable for predicting impacts in areas of complex terrain.

Causality effects are especially relevant for a site like WTP where the sensitive receptors are quite a distance from the emitting sources and it is therefore anticipated that AUSPLUME will tend to over predict the actual odour impact. The assumption of spatially uniform meteorological conditions across the entire modelling domain may not be representative of conditions at WTP, where meteorological conditions are complex due to its proximity to Port Phillip Bay. Also, the spatially varying meteorology across the very large modelling domain could have significant impact on dispersion, which cannot be accurately represented by AUSPLUME.

Due to the shortcomings of AUSPLUME, CALPUFF modelling was considered for use at WTP. CALPUFF is a multi-layer, non-steady state Gaussian puff dispersion model. It simulates the dispersion of odours by representing emissions as a series of puffs emitted sequentially. The advantage of the puff modelling approach over the steady state Gaussian models such as AUSPLUME is that the progress and dispersion of each individual puff can be treated separately and can be made to account for local wind conditions and the way in which wind conditions at a particular place vary with time. This enables the model to account for a variety of effects such as spatial variability of meteorological conditions, causality effects and dispersion over a variety of spatially varying land surfaces, plume fumigation and low wind speed dispersion.

TAPM (The Air Pollution Model) is another non steady state model, developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), to aid in the assessment of projects where meteorological data are lacking. It is a prognostic model that predicts flows important to local scale meteorology, such as sea breezes and terrain induced flows, making it very useful in generating three-dimensional wind information to be used in other models, such as CALMET (used in CALPUFF modelling). TAPM is slower to run than CALPUFF and AUSPLUME and requires large data storage capacity. TAPM does not have a specific module for odour assessments, and thus it has not been widely used for odour assessments.

AUSPLUME odour dispersion modelling was undertaken to provide an initial prediction of the odour impact risk resulting from current and future operation at WTP. However, due to the concerns over AUSPLUME for this application and the potential to over predict impacts, it was also recommended that CALPUFF modelling be undertaken. CALPUFF modelling results would then be compared to Ausplume results and with the proposed odour design criteria for the site.

Correlation of AUSPLUME Modelling with Nasal Ranger Monitoring

AUSPLUME odour dispersion modelling was undertaken to predict the odour impact of WTP under current operation, and upon implementation of a number of odour control strategies, involving covering and treatment of foul air from a variety of different process units at WTP.

AUSPLUME modelling output for current plant operation was compared with results of the Nasal Ranger monitoring program to determine the correlation between odour strengths measured on site and odour concentrations predicted during modelling, and to determine the off site impacts of various sources on the plant.

The odour strengths measured using the Nasal Ranger provide a series of snap shot odour concentrations. This data was then compared with the 90th percentile odour concentrations from AUSPLUME modelling using an edited meteorological data set that only included similar wind speeds and directions to those during the Nasal Ranger survey at a similar time of year. The 90th percentile odour concentration was used because it is the lowest percentile available in AUSPLUME and also provides the best correlation. Upon analysis of the Nasal Ranger results under appropriate meteorological conditions, it was assumed that the odours detected at Locations 2 and 3 in **Figure 2** were a result of sludge drying operations, and that those from Locations 9-14 in **Figure 2** were a result of the lagoons and carriers combined.

The correlations between Nasal Ranger results and modelling are shown in **Table 1** below.

Table 1 Correlation of Nasal Ranger and 90th Percentile Modelling Results

Location No. (from NR Plan)	Odour Strength from Nasal Ranger monitoring (ou)			90th Percentile Modelling		Mass Odour Emission Rate (ou.m3/min)
	Min	Av	Max	Odour Strength (ou)	Ratio Modelling: Average NR	
Lagoons and Carriers						
9	2	2.4	4	20	8.3	604,424,364
10	2	2.3	4	40	17.4	
11	2	4.7	7	50	10.6	
12	4	5.5	7	40	7.3	
13	2	4	7	15	3.8	
14	4	4	4	15	3.8	
Range					**4 - 17**	
Sludge Drying Operations						
3	2	2.4	4	1	0.4	10,714,825
Range					**0.4**	

As can be seen, 90th percentile AUSPLUME modelling generally predicts emission rates approximately 4-17 times higher than those that were found during Nasal Ranger sampling for the lagoons and carriers.

As discussed earlier, a good correlation existed between the intensity of odours perceived on site from the lagoons and carriers and the odour concentrations measured during sampling, indicating that the sampled concentrations reflect reality.

When dealing with large area sources, changes in the odour emission rates used in modelling have a large effect on the predicted odour impact. Therefore, it is very important to ensure that the odour emission rates used in modelling are representative of the real odour impact. The correlation of odour concentrations measured using the Nasal Ranger with odour concentrations predicted using AUSPLUME was a useful method for determining whether the odour emission rates used for individual sources in modelling were representative of the true odour impact from the source. It was important that the meteorological data used for comparative modelling was reflective of conditions that resulted in the real life odour impact. Upon determining that a correlation exists between odour intensity and odour concentrations determined during sampling, this correlation could also be used to verify whether sampled odour concentrations were within the expected range based on odour intensity. In the case of WTP, the odour sampling program allows for the collection of samples over a year. As such, odour source emission rates used for modelling will be verified upon collection of additional odour samples in Spring 2006 and Summer 2006-07.

Comparison of AUSPLUME Modelling Results, Complaints Data and Community Survey Results

In order to determine the odour impact of WTP on existing residents, a community survey was undertaken in Winter 2006. Additional surveys will be conducted in Spring 2006 and Summer 2007, in conjunction with Nasal Ranger monitoring.

The community survey indicated that residents in the vicinity of the plant were aware of WTP as a source of odour, although this has not resulted in odour complaints attributable to WTP over the last 18 to 24 months. The odour concentrations predicted using AUSPLUME modelling was as high as 100ou in some areas close to WTP. However, in these locations, residents surveyed attributed odours to other agricultural activities in the area rather than WTP. This indicates that odours from the agricultural activities could be masking odours from WTP and that the AUSPLUME modelling could be over-predicting odours from WTP.

Without analysing complaints data or undertaking community surveys in the vicinity of WTP, and relying solely on AUSPLUME, the odour impact of WTP would appear much worse than is actually the case at present. Community surveys are a valuable tool for determining the perceived odour impact of a facility on the surrounding area.

CONCLUSION

Due to the large size of WTP, and the unique nature of the plant's configuration and treatment processes, it was necessary to undertake more comprehensive data collection and assessment to determine the odour impact of WTP on surrounding areas than would be conducted at smaller more conventional sewage treatment plants.

The data collection phase of the investigation is ongoing and will be undertaken over a year. It involves odour sampling, Nasal Ranger monitoring of odour strength and intensity, community surveys and analysis of historic odour complaints regarding WTP. By collecting this wide range of data, it was possible to cost effectively establish seasonal and diurnal odour variation and to correlate and validate assumptions and emissions used, so that more accurate dispersion modelling and impact assessments could be undertaken. It also ensured that conclusions could be validated in a number of ways providing more assurance of the necessity to undertake any further odour mitigation works.

During sampling it was found that a correlation existed between odour and H_2S, indicating that H_2S is a useful surrogate to monitor to determine diurnal and seasonal variation of odours from primary process units at WTP for input into odour dispersion modelling.

This study also illustrated that the $\log_{10}$ correlation between odour concentration and intensity is consistent at WTP for the lagoons and carriers. Applying this correlation to other sources at the site is a useful tool for determining whether the odour emissions measured during sampling are within the expected range, based on the intensity of the odour. Further support for these assessments was also provided by field measurement of odour strength during Nasal Ranger monitoring at the site and comparing this with the odour strengths predicted at the same locations using AUSPLUME modelling. Both these tools are useful for verifying the odour emission rates used in modelling and for comparing the odour impacts from various process units at WTP.

The importance of considering AUSPLUME modelling results in conjunction with complaints data and community survey results was illustrated at WTP. Although AUSPLUME modelling indicates that the odour concentration at some sensitive receptors is approximately 100ou, there have not been any odour complaints attributable to WTP over the last 18 to 24 months. Therefore, if only AUSPLUME modelling was considered in odour assessment, the odour impact of the plant would be considered very large and regular odour complaints would be expected. However, community surveys indicate that although residents are aware of WTP as a source of odour, 85% of respondents said that where they lived, the air was always or usually clean. Whether respondents believed odours were attributed to WTP appeared to depend on whether there were other odour causing activities in their immediate vicinity.

AUSPLUME can over predict odour impact due to causality effects for large modelling domains, and as such, a desktop assessment was undertaken to determine whether CALPUFF or TAPM would better represent odours from WTP. It was recommended that CALPUFF modelling be undertaken for WTP, as it is not impacted by causality effects and takes into consideration spatial variation in meteorology across the modelling domain.

The odour risk management investigation at WTP illustrated the importance of using a variety of H_2S and odour emissions data, and assessment methods, to verify results and determine the true odour impact of WTP on the surrounding community. Due to the scale of the plant, small changes in emission rates will result in large changes in predicted odour impact, and the extent of odour mitigation works required at the plant.

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