ASSESSING ODOUR IMPACTS OF AN ALUMINA REFINERY BY SOURCE MEASUREMENT, DISPERSION MODELLING AND FIELD ODOUR SURVEYING

Coffey, P.S.
Alcoa World Alumina, Australia

Abstract

Concern about the impact of odour emissions from a range of industrial land uses on neighbouring amenity has significantly increased in Australia in recent years. Government response has been to introduce odour standards or guidelines such as in WA. Alumina refineries are characterised by an odour often described as a 'wet cement' smell. The introduction of new processes to enhance production efficiency can create stronger odour emissions. In Western Australia odour from Alcoa's Wagerup alumina refinery has become the subject of growing community concern, resulting in concerted attention by the company and regulatory authorities. Traditional methods of odour impact assessment have relied on source measurement by dynamic olfactometry combined with dispersion modelling. Many debates continue on how real the modelled impacts are and how accurate the predictions can be regarded. Using Wagerup Refinery as a case study of a plant emitting industrial odours within a rural community, this paper discusses the use of field odour surveys as a technique for 'validating' model assumptions and predictions. It also looks at the relative efficacy of three common dispersion models to the challenge of 'reasonably' representing actual odour impacts for a complex industrial source in a rural setting. It is concluded that a combined approach utilising all techniques is necessary to gain a realistic assessment of odour impacts on local communities.

1. Introduction

Odour impact on communities neighbouring industrial facilities remains one of the most difficult and contentious forms of environmental impact on residential amenity, requiring careful management by the facilities concerned as well as regulatory agencies. Wagerup Refinery in south-west Western Australia is an example of a facility that has struggled with the management of its odour impacts upon nearby neighbouring communities.

Bayer process emissions to air comprise numerous organic compounds in generally low concentrations including some that have very low odour thresholds. The odour characteristics of these complex mixtures are very difficult to measure or predict. (Armanios, 1999) Wide ranging programs are in progress at Wagerup to further characterise the nature and magnitude of all detectable chemicals (and mixtures of them) comprising refinery air-borne emissions in order to further understand their nature and behaviour.

In order to reduce nuisance and any perceived health impacts Alcoa is embracing a program aimed at reducing odour emissions to a point where they will become barely detectable under most circumstances. An important management tool in this strategy is the use of odour emissions measurement, dispersion modelling and impact assessment in order to guide and provide a measure of progress in meeting the stated aims of eliminating, or minimising to the maximum extent possible odour impacts upon neighbours.

In this paper the use of the three tools of odour emissions measurement; odour dispersion modelling; and field odour verification is described with reference to some of the management decisions made on the guidance they have provided. These decisions have involved significant resource allocation to the resolution of odour impacts, both in terms of people and their time as well as capital expenditure. It is therefore critically important that Alcoa and regulatory agencies have confidence in the accuracy and reliability of the tools. Starting from a point of low confidence, the parties concerned have gradually increased their confidence to a point where the use of the tools is now regarded as the best available way of providing objective guidance in advance of actions. Time will tell if this confidence is justified, but so far the results are encouraging.

In the structure of the paper to follow, each of the three tools is broadly described and their use in combination shown in relation to the management decisions taken.

2. Odour Emissions Measurement

Emissions sources were measured in two comprehensive odour surveys undertaken in 1999 and following various odour reduction activities again in 2000 (CH2M Hill, 1999, The Odour Unit, 2001). In addition to the comprehensive surveys there has been a continuing program of source odour measurement in response to focussed investigations of numerous individual sources, primarily concentrating on liquor burning, calcination, digestion and slurry storage stacks and vents but also including many other minor sources. Additionally Alcoa has engaged in dialogue with other alumina refiners who have performed odour studies including Queensland Alumina Ltd.

The sampling protocols employed were developed by The Odour Unit Ltd in association with Alcoa. Analysis was undertaken in accordance with the Draft Australian Standard for Dynamic Olfactometry (DR99306) and the draft European Standard for Odour Measurement by Dynamic Olfactometry (CEN/TC 264). The exercise of odour measurement has been an ongoing learning experience for all, involving much effort aimed at improving the repeatability and precision of the odour measurement process. Alcoa and its consultants worked together closely, with all odour emission rate measurements and calculations a joint effort.

A significant aspect of this effort that proved challenging is the ability to obtain samples with a known pre-dilution rate. Techniques were improved during the course of odour sampling to enable accurate real time dilution measurement by using oxygen concentrations measured at the source and in the diluted samples. This method has proven superior to an earlier technique based on a sampling

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dilution tool (The SampleMaster®). Sample pre-dilution is necessary when sampling high moisture content emission sources due to the tendency for condensation to occur in sample bags and consequent opportunity for erroneous analytical results.

The results of the two major odour surveys for emission source contribution to overall refinery odour emissions are shown in Figure 1.

The overall refinery odour emission rate at the time of the 1999 survey was initially estimated to be 1.8 million odour units per second (MOU/sec). This was later corrected to 2.55 MOU/sec due to an error made in estimating gas flow rates. As a result of the 2000 survey the emission was measured at 1.26 MOU/sec. Shown in Figure 2 is the graphical breakup of source by contribution in the 2000 odour survey. (The Odour Unit, 2001). Taken together, the figures show the significant contribution in 1999 of slurry storage vapour emissions to overall odour, and the dominance in 2000 of calciner emissions as the major refinery contributor. The significant reductions achieved in odour emissions from washers, thickeners and slurry storage vents in 2000 was mainly a result of a program of installing simple flap valves on these vents, thereby controlling the release of vapour associated with these previously always open vents.

Since the 2000 survey, many more odour measurements of the major sources have been completed resulting in a more robust estimate of an average refinery odour emission rate of around 2 MOU/sec. The difficulty in communicating odour survey results including a misplaced reliance on the absolute numbers, a tendency to compare 'snapshot' estimates, as well as the need to independently verify calculations are lessons taken from the odour surveys.

Another form of odour analysis undertaken was intensity testing in line with the seven-point intensity scale used in the German approach (VDI 3882, 1992). Shown in

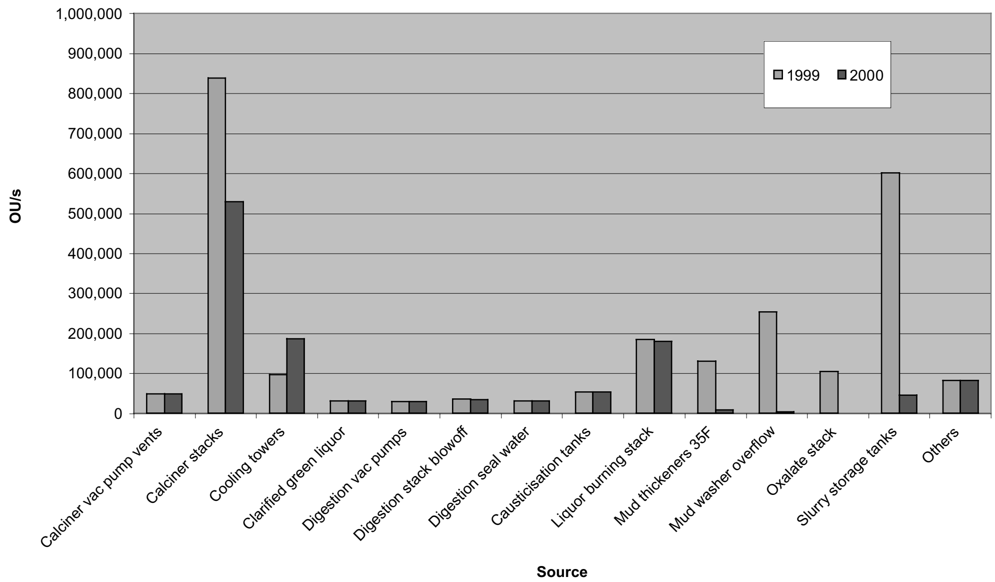

Figure 1 — Source Odour Emissions 1999/2000

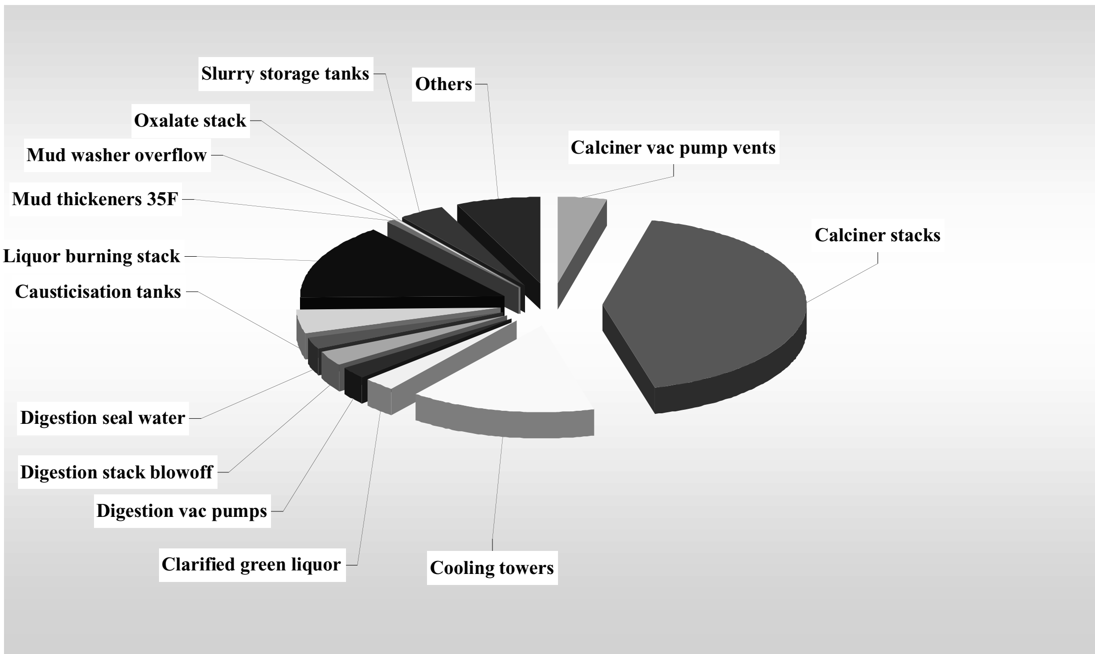

Figure 2 — 2000 Survey — Odour Emissions from major sources

Figure 3 is the form of the intensity/concentration relationship derived from testing of a variety of refinery odour sources. The Environmental Protection Authority in Western Australia (EPA) regards an intensity score of 'distinct' or value 3 as a guide to the threshold for potential odour annoyance, so it is of interest to determine the level corresponding to different refinery sources. For the digestion samples a concentration of 4 OU/m^3 was indicated, while the liquor burning and slurry storage samples both yielded a concentration of 20 OU/m^3. While these levels may be considered an objective assessment of odour nuisance for a greenfields site, where odour impact has not attracted notoriety or sensitised a community, Alcoa's experience is that satisfying the objectives would not of itself guarantee community acceptance at Wagerup. This issue is further explored in the discussion.

3. Odour Dispersion Modelling

Atmospheric dispersion modelling has been undertaken at Wagerup since 1994. In the present case modelling was performed using three dispersion models and results were checked against a computational fluid dynamics model as well as by using field odour surveys and ground level nitrogen oxides measurement. Full description of the modelling is contained in a comprehensive consultant's report by Dr O. Pitts. (Sinclair Knight Merz, 2002) The three models used were Ausplume 5, Calpuff 4.1, and TAPM. Local surface meteorology was collected at Wagerup for model input, and monitoring campaigns were run over winter 2001 to characterise the vertical temperature and wind profiles over a series of days when odour exposure occurred at ground level. The wind fields for Calpuff and TAPM were generated using the meteorological processor in TAPM, and were set to incorporate local surface and upper air meteorology wherever it existed.

Comparison of the performance of the models showed that no single model was best at representing all conditions and sources at the refinery. For the elevated stack releases, TAPM appeared good at representing ground level concentrations in the area where maximum impacts were predicted, though it had a tendency to over predict the maximum values occurring elsewhere. Ausplume was able to reproduce the impact of elevated sources reasonably, but substantially over predicted the effect of low level odour sources during near-calm stable conditions. This effect was also noted with Calpuff, and is thought to be due to F class dispersion curves over specifying the amount of vertical turbulence under such conditions. It was concluded that Calpuff (using dispersion generated from micrometeorology) was the best model for representing the contribution of all refinery sources taken together, due to its superiority at correctly representing the low level sources and its credible handling of elevated sources. TAPM and Ausplume were deemed appropriate for investigating the impacts from taller stacks alone.

Shown below are two figures that indicate the contribution that the dispersion models have made to Alcoa's analysis and understanding of odour impacts at Wagerup. Figure 4 shows the cumulative impact of all refinery sources on areas surrounding the refinery, as plots of odour contours at the 99.5% three-minute level. This odour statistic is chosen as it forms the basis of the EPA's odour guidance objective mentioned above. The plot is for the refinery condition at the time of the 2000 odour survey.

Inspection of the figure shows that the predicted odour concentration at ground level in the northern part of Yarloop township (near Boundary Road) is approximately 2.3 odour units (OU). This contrasts with an odour annoyance threshold value of between 4 and 20 OU resulting from use of the EPA Odour Guidance approach, and highlights the difficulty of reconciling theoretical and empirical approaches to gauging community odour acceptance.

In Figure 5, TAPM is used to indicate the effect of increasing the height of calciner stacks 1 to 3 and bringing the stacks together into a multi-flued arrangement. The effect of this intended alteration to stack configuration, in

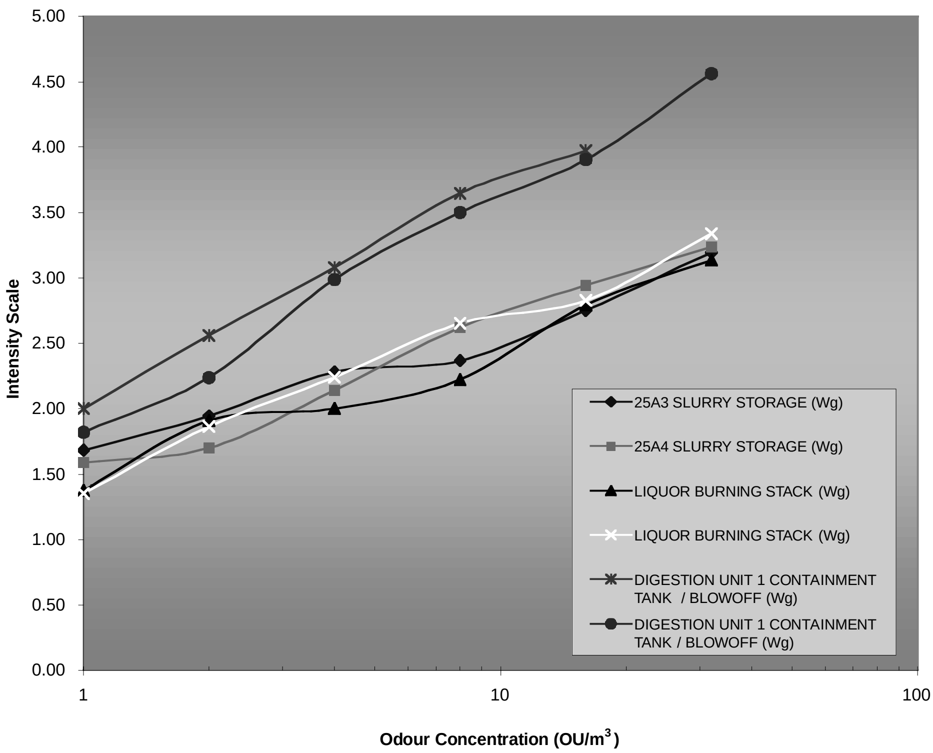

Figure 3 — ALCOA wagerup intensity all sources

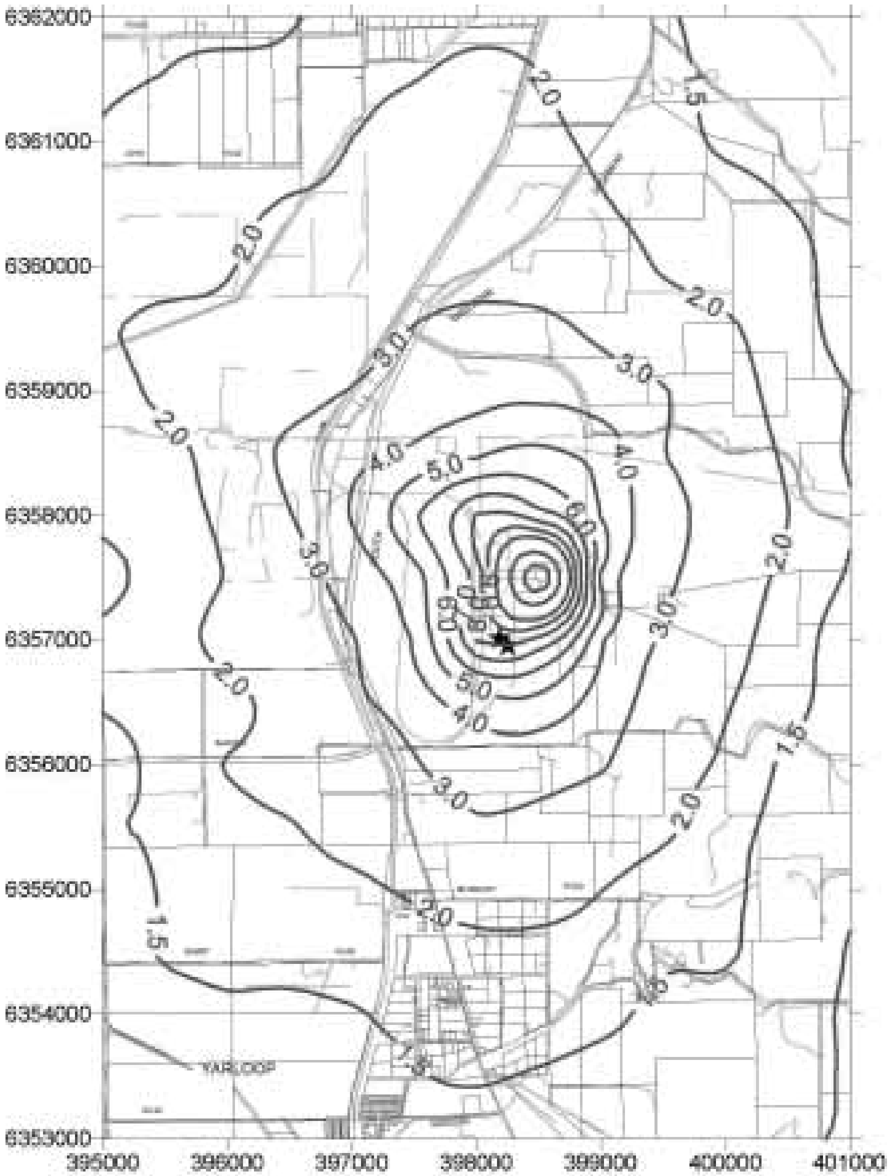

Figure 4 — Predicted 3-minute 99.5 percentile ground level concentration from Wagerup Refinery using the 2000 odour survey

terms of reducing peak impacts of odour, is clearly seen in the results of the model runs performed. TAPM has been used similarly for evaluating the effects of various management options including the impacts of other taller stacks, multi-flued existing stacks, and changes to stack exit conditions (velocity, temperature, etc).

Analysis of the overall effects of reductions in source emissions by reduction programs as well as changes in emissions as may be anticipated with changes to production rates have similarly been undertaken using Calpuff. In this way the strengths of the two models have been utilised appropriately to the purpose of modelling.

4. Field Odour Verification

Unlike single chemical species modelling, odour dispersion has no direct monitoring instrumentation available by which to collect field results for model verification. The models used here were compared by running for nitrogen oxides emissions and collecting field data at two continuous NO_x monitor stations external to the refinery. This verification produced reasonable correlation between predicted and measured levels of NO_x. Nevertheless it was considered desirable to have a credibility check performed on odour dispersion predictions by conducting some form of field odour measurement. Dynamic olfactometry was considered too unreliable and inaccurate at the high dilutions expected in the field (concentrations of a few, perhaps up to ten odour units), as it is a method that is based on dilution of source emissions samples to the detection threshold. When the number of dilutions of a sample to threshold is few the method has high inaccuracy.

The German standard approach to conducting field odour surveys is based on panels of odour assessors taking odour 'observations' in the field over ten minute periods made up of successive ten second samples. For each sampling the assessor notes the odour intensity he/she sensed using a seven point rating scale established in the standard (VDI 3882, 1992). An odour would be ascribed a value of 0 if not present, 1 if it was barely detectable, 3 if distinct, and up to 6 if extremely strong. The method requires the assessors to be trained in odour recognition and to have undergone calibration against the standard reference material (n-butanol) in a dynamic olfactometry laboratory. They are then required to meet the criteria for acceptance in a dynamic olfactometry panel as well as to be able to correctly rank and ascribe intensity values for pre-prepared

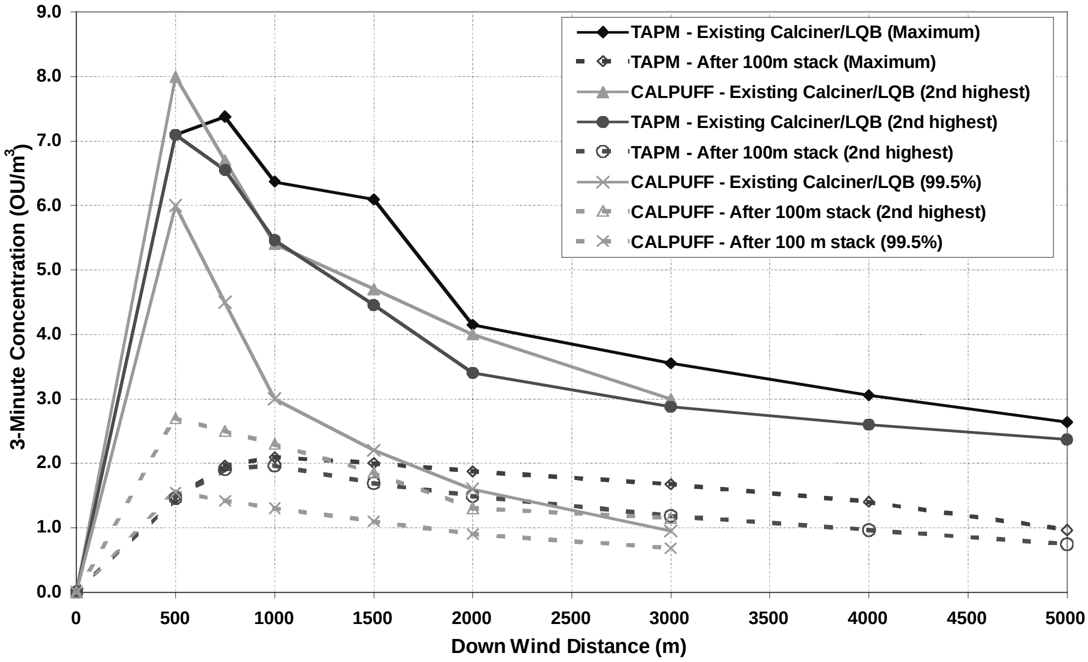

Figure 5 — Predicted 3 minute odour concentrations (OU/m^3)

dilutions of n-butanol in the field immediately prior to undertaking of a field assessment.

In all six separate field monitoring sessions were held at Wagerup on days when the meteorology indicated a high chance of 'odour events' occurring in neighbouring communities. The assessments indicated observed ten-minute odour concentrations (derived from the intensity scores by use of the laboratory generated intensity/concentration regressions) of between 2 and 11 OU. Precise correspondence between model predictions and field results was not obtained for specific times, but when considered as an ensemble of measured and predicted results over the duration of a session, the correspondence was reasonably good.

Odour assessors employed in the field monitoring were drawn from the general community and had not previously been associated with Alcoa or had any significant exposure to alumina refining. In this way the olfactory response of the panellists could be considered a reasonable indicator of the 'average person's' sensation of refinery odours. An example of the odour distribution noted on one of the field survey days is shown in Figure 6.

5. Discussion and Conclusion

The process of evaluating the outputs from each component of the investigations undertaken has been instructive. Initially the data on odour emissions magnitude provided valuable information for ranking sources by mass emissions and logically by their potential impact. This enabled early focus upon immediately available and lower cost measures to reduce overall refinery emissions. Programs aimed at minimising vapour emissions from slurry storage and digestion, reducing the organic content of hydrate input to calciners, shutting down the oxalate destruction kiln and searching for additional odour reduction opportunities were a result.

The assembly of odour intensity data also proved very valuable — as for the first time Alcoa was able to attribute a relative ranking to odour sources on the basis of their perceived odour intensity, and to consider this in assessing the relative impacts of the various sources within and external to the plant. An outcome of this was that liquor burning, which had hitherto been regarded by employees and neighbours as the primary culprit in causing odour impacts, was determined to be less significant than some other sources such as calcination and digestion. Use of the WA EPA odour guidance criterion (equivalent to a distinct intensity level) enabled derivation of a tentative odour nuisance level to apply as a goal for emissions reductions programs. (Refer section 2.0)

Comprehensive dispersion modelling evaluation was able to identify and address the strengths and shortcomings of the three models used — and enabled refinement of model settings and data requirements to produce good agreement with field observations and expressed odour concerns. The collection of field data on upper air profiles further strengthened the power of dispersion models and demonstrated the ability to correctly simulate actual dispersion patterns observed. This aspect will be further explored this winter with tracer release studies to further improve model validation.

Field odour surveys offered greater endorsement of the predictions of models and enabled confidence in their use for predicting odour impacts associated with changes to stack configuration of the calciners. A project to increase the height of calciner stacks 1–3 and to bring the stacks together into a multi-flue arrangement is a result. This is due for completion in June 2002.

The field studies have also highlighted an apparent disconnect between theoretical definitions of odour nuisance levels based upon dynamic olfactometry characterisation and the evidence of odour concerns and complaints as registered at Wagerup. This discrepancy may perhaps be related to some prior sensitisation of individuals to refinery odours and a consequent heightened sensory reaction to even very low (& otherwise non-concerning) levels of odour. The issue of the differing olfactory sensitivity of people impacted by odour is highlighted by Alcoa's experience at Kwinana where odour complaints are less frequent even though ambient concentrations may be higher.

The latter suggests that neighbourhood factors such as the relationship between the facility and its surrounding community, the community's expectations of local amenity and the predominant land use of the surroundings may all be equally important in defining local odour tolerance

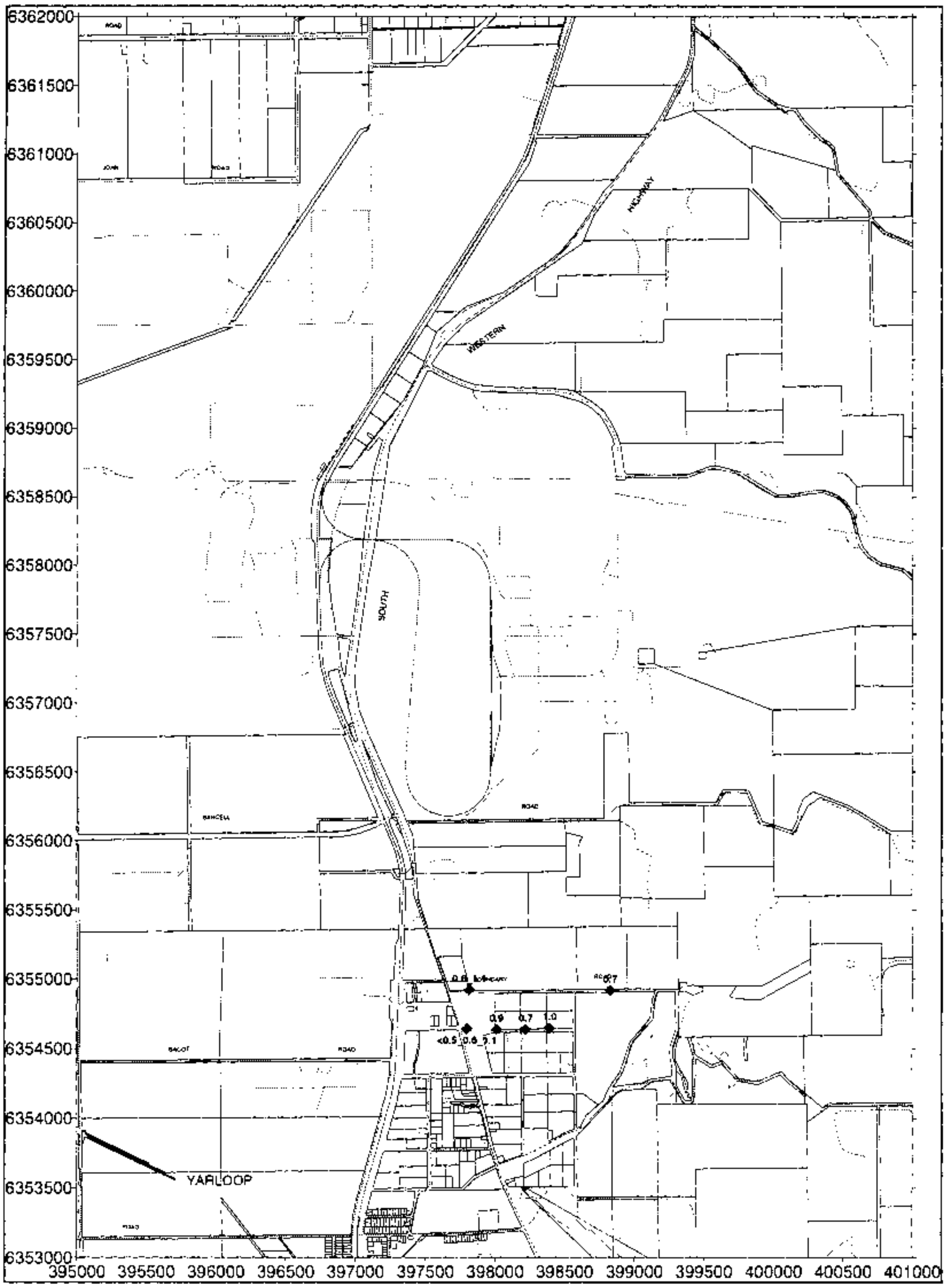

Figure 6 — Estimated odour concentrations for 13/8/2001 0845-0945

levels as much as the actual odour levels experienced. Kwinana is a significant industrial area with numerous other industry sources of odours and a community generally well acclimatised to the proximity of industry. Wagerup by contrast is in a predominantly rural community with some traditional rural industries like dairies and a timber mill but only more recent experience with an expanding chemical industry. Neighbouring residents are a mixture of third or fourth generation rural landowners and more recent residents, including refinery and bauxite mine workers attracted to the area by its natural and rural setting.

Alcoa is continuing with the use of the tools described in this paper to assist in ongoing management of refinery air emissions and odours. The experience has been that although not perfect, these methods offer a valuable practical means of quantifying and describing the impacts of odour and relating these to their primary causes. Only by doing so can future improvements be made and performance be measured.

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