DOES STOP WORK (AND CAN YOU MAKE IT STICK)?

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ABSTRACT

A Victorian WWTW with a population equivalent of 600,000 was upgraded to meet the requirements of the UWWD and now provides primary and secondary treatment for 16,000m^3/hr. Short-term peak flows are held in storm tanks. The upgrading was the focus of great public concern due to a history of widespread odour complaints mostly provoked by open air sludge handling at the old works. The EIA for the upgrade included a detailed odour assessment. The planning conditions require that odour should not exceed 2.5 ou$_E$/m^3 at the boundary, 98% of the hours in any year. RPS Consultants were appointed to assess odour from the works following its completion in October 2002 using methods proposed by the Planning Authority and their advisors.

Uncovered sources at the new works include preliminary tanks, aeration tanks, clarifiers and a fast flowing open weir channel and highly turbulent spillway outfall. Odour from the inlet works, covered primary tanks and sludge pumping is collected and passed through a two-stage odour control unit. Sludge from the works is now stored in tanks and pumped off-site by buried pipeline for treatment elsewhere.

Emissions from the OCU were measured before and after the scrubber. The OCU reduces 71 - 88% of the odour. Liquor from open tanks was sampled in triplicate throughout the works and Odour Potentials measured using the published WRC method. OP values ranged from 500 - 20,000 with a high correlation between ou$_E$/m^3 and H_2S. Emissions from open tanks have been estimated using the STOP model. The surveys include winter and summer conditions to take account of different treatment flows and biological activity.

Odour at receptors has been predicted using an advanced dispersion model. Time varying emissions have been used to estimate odour from the open tanks taking seasonal variation, surface wind speed and hydraulic conditions into account. The estimation of odour from a works is highly complex and varies according to flow, season, wind conditions, influent load and short-term operational conditions. There are significant uncertainties both in terms of source estimates and dispersion inputs.

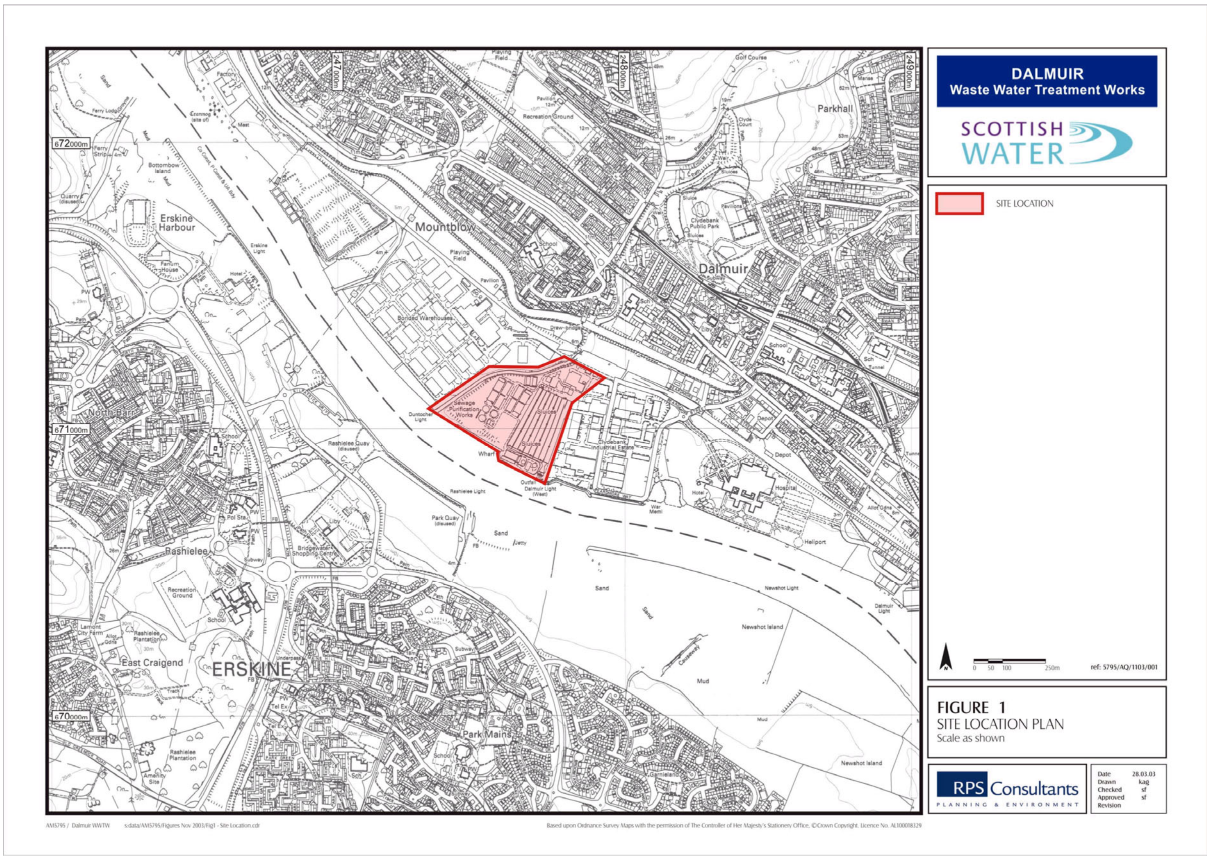
The main contribution at sensitive receptors is from storm tanks. The extent of the predicted impact depends on the assumptions made about frequency of tank use. The OCU makes only a minor contribution off-site. Other sources are of marginal significance. Odour from all sources at the works is predicted to be 2 - 4 ou$_E$/m^3 98%ile at the nearest residential receptors. The STOP emission estimates combined with dispersion modelling appear to be robust apart from the aeration tanks which are quite unreliable. Apart from this discrepancy, the model results are consistent with public complaint.

It is difficult in practice to determine if these operations comply with the planning condition, due mainly to the model sensitivity to storm tank frequency of use. The quantitative approach used here would be appropriate at design stage for assessing the level of abatement required, provided both source and dispersion models are used correctly. This approach is less suitable as the basis of a planning condition on grounds of both cost and enforceability.

INTRODUCTION

The waste water treatment works (WWTW) for the north side of Glasgow are located at Dalmuir, Clydebank (Figure 1). The original Victorian works had a history of provoking odour complaint, mainly from open air sludge handling operations. The works were upgraded to meet the requirements of the Urban Waste Water Directive by a DBO PFI project. The works were designed, built and are now operated by a joint venture company.

FIGURE 1



The Water Authority submitted an Environmental Statement as part of the planning application. [ERM - October 1998. Dalmuir WWTW Upgrading Environmental Statement]. The predicted odour concentrations were obtained using source estimates from WRC STOP equations and an advanced dispersion model. Storm tank odour emissions in the Environmental Statement were modelled with positive mechanical buoyancy which may have overestimated dispersion.

The planning permission granted by West Dunbartonshire Council (WDC) included odour conditions to protect the amenity of the local community. Condition 8 of the Grant of Planning Consent [Ref No. PE98/136] dated 9th March 1999 requires: 'The works shall be designed and operated so that the contribution of the works to odour concentration at the No Complaint Boundary as shown on the approved plan shall not exceed 2.5 ou_E/m^3as a 98th percentile of annual hourly averages. The Consent also requires that an intensive Odour Investigation should be conducted within six months of commissioning. WDC and their advisors, Glasgow Scientific Services, drafted an outline methodology for the post commissioning study. The methods included:

- Measurement of odour emissions from the Odour Control Unit (OCU);
- Measurement of Odour Potential (OP) at key stages in the treatment process;
- Compilation of an emission inventory, taking seasonal factors into account; and
- Prediction of odour concentrations using a dispersion model.

RPS Consultants was appointed in January 2003 to quantify odour emissions from the works, and assess these emissions in terms of the planning condition. The quantification and prediction methods were confirmed in consultation with the Planning Authority.

PROCESS DESCRIPTION

The works receives the flow from three gravity fed sewers draining north Glasgow, with a population equivalent of approximately 600,000. The works provide primary and secondary treatment for up to 16,000m^3/hour of raw sewage. The works has 4 large open storm tanks. Short-term peak flows in excess of the full treatment capacity are passed to storm tanks and held until the inlet flow to the works reduces to below 16,000m^3/hr, when the sewage held in the storm tanks is fed back into the works. Inlet flow passes through coarse screens and a de-gritting channel within a negatively ventilated building. The flow passes through fine screens and grease removal, known as preliminary treatment. The preliminary tanks are mainly covered, allowing only minor fugitive odour emissions from an open channel located within a deep well. The flow then passes to enclosed and ventilated primary settlement tanks. Odorous air from the inlet works, primary tanks and sludge pumping is collected and passed through a two-stage scrubber. The flow from the primary tanks is passed to 4 uncovered aeration tanks in parallel where fine bubble air is diffused though the liquor. Sludge from the works is collected in three storage tanks and pumped off site by buried pipeline for treatment elsewhere. The final effluent passes through a fast flowing open channel and measurement weir and then drops over a highly turbulent spillway into the river Clyde.

RECEPTORS

Clydebank industrial estate is located along the eastern boundary. The land to the west is occupied by whisky bonding warehouses. The nearest residential dwellings are located north of Beardmore Street, ~400m north east of the works.

ODOUR COMPLAINTS

At the time of writing, there have been nine recorded odour complaints since the works became fully operational in November 2002. These complaints coincided with the cleaning out of storm water tanks after prolonged use, and the failure of the lamellas in some of the primary tanks in early October 2003.

ODOUR SURVEY METHODS

OP was measured at key stages of the works including the storm tanks, preliminary tanks, aeration tanks, clarifiers and the outfall using methods agreed by WDC. The survey included winter and summer conditions to take account of different load and biological conditions at the works. At least three samples were obtained at each process stage under investigation. All samples were obtained from the surface layers either by drawing by bucket or pumping. The pH and temperature were recorded at the time of sampling. Approximately 20 litres of liquid was obtained for each sample and placed into clean airtight containers.

The standard approach developed by WRC assumes that liquor samples are stripped off on site and subsequently analysed by olfactometry. Due to the difficulties in getting a sampling rig on site at short notice to sample the storm tanks, the method used in this assessment has been to dispatch sampled liquors by refrigerated transport for stripping and subsequent olfactometry at the laboratory. The liquor samples were refrigerated to arrest any subsequent bacteriological growth between the time of sampling and analysis.

Samples were dispatched by refrigerated courier overnight to the Silsoe Research Institute for subsequent odour analysis in accordance with the published WRC method. [WRC March 1998 PT 2052/10592]. This method estimates the potential odour within the sample by blowing air through the liquid and collecting the odours within a Nalophan NA sample bag. The level of H_2S in off gas in the samples thus obtained was also measured using a calibrated Jerome analyser.

Samples for OP measurements were obtained as described and submitted for dynamic olfactometry analysis in accordance with the European CEN standard for measurement of odour concentration (BSEN13725). The results from the Odour Potential survey are presented in Table 1.

ODOUR SURVEY RESULTS

The OP values for the preliminary tanks are about five times higher in the summer than those measured in the winter (excluding the winter samples with high floating solids). The high floating solids in the winter preliminary tanks were due to fat accumulations with corresponding high emissions of H_2S.

The average odour potential of the liquor into the clarifier tanks is approximately double the winter values. This may be partly explained by the reduced inflow to the works, and increased seasonal biological activity. One of the primary tanks was temporarily out of service during the survey and loading into the clarifiers is therefore higher than would otherwise be the case under typical operational conditions. Fresh storm water samples were obtained in the winter survey and provided the greatest range of OP results. This may be due to non-homogenous inlet flows (first flush) or due to residual accumulations within the tanks.

Table 1. Odour Potential Measurements Dalmuir WWTW 2003

Source	**Winter OP,** ou_E/m^3	**Summer OP,** ou_E/m^3
Preliminary	13248 802 610	3080 2757 4348
Clarifier Inlet Channels	5152 8638 9254 -	20289 15214 15208 15204
Clarifier Outlet Weirs		8150 6121 5464 10247
Storm Tanks	3146 2366 1992 1500 580 570	
Outfall	398 774 642	9395 5441 4343

The average OP at the outfall is approximately 10 times the measured winter value. This may partly be explained by the reduced flow through the works and increased seasonal biological activity. The difference between summer and winter OP values at the outfall may also be due to the reduced treatment in the primary tanks.

No storm tank samples were obtained for the summer, as storm events did not coincide with the availability of the odour laboratory.

Odour from the OCU was measured before and after the scrubber. Additionally, measurement of H_2S in the duct was conducted during bag sampling. Flow measurements and temperatures were recorded. The flow rate at the odour control unit (OCU) is relatively high, ~18m^3/s. Overall the odour emission rate from the OCU during the summer was approximately double the winter survey.

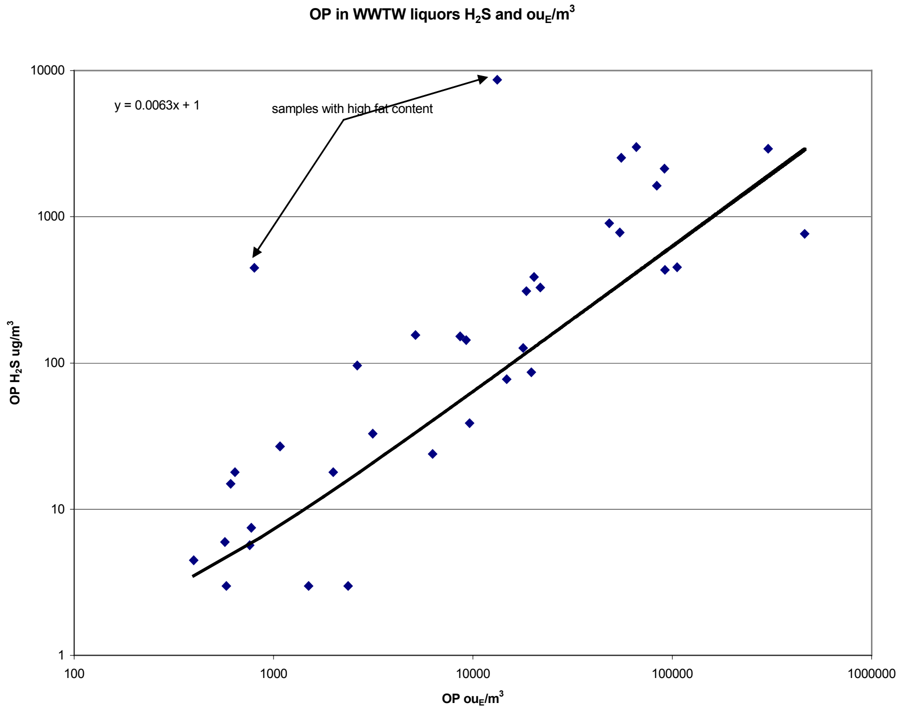
Table 2 OCU before and after scrubber ou_E/m^3

	Inlet	**Outlet**	**%age removal**
Winter	2,663	760	71%
Summer	11,623	1,355	88%

RELATIONSHIP BETWEEN H_2S AND ODOUR CONCENTRATION

The relationships between ou_E/m^3 and H_2S for winter and summer samples are presented in Figure 2. The results from the preliminary tanks (winter samples 1 & 2) included a high concentration of floating solids, which appeared to be grease. In the case of the fatty samples H_2S may account for 37- 44% of the total measured odour. The grease accumulations in the preliminary tanks were not evident during subsequent summer surveys. Measured H_2S in the samples account for less than 5% of the total odour in all cases, excluding the fatty samples in the preliminary tanks. The results from these data suggest that H_2S may not be used as a proxy at low levels of odour.

FIGURE 2



Emission Inventory

Emission rates from open tank processes were obtained using the method developed by the Water Research Council ((WRc, 1998, 'Odour Emission Rates from Sewage Treatment Works,' Report UC 3110). The summary calculations for the summer and winter process emissions are presented in Table 3.

Table 3 Dalmuir WWTW - Summary of Process Emissions

Source	No. of sources	STOP Eq.	Summer	Winter	Units	modelled as
OCU	1	-	25745	13680	ou_E/s	point
preliminary treatment open channel & free fall	1	11 & 04a	116	24	ou_E /m/s	26m long line source
clarifier inlet channels	-	11	1677	782	ou_E /s	-
clarifier turbulent - feed channels		06, 07 & 08	809	377	ou_E /s	-
clarifier weirs	-	_03	6593	709	ou_E /s	-
clarifier tank (other surface emissions)	4	-	12.4	2.5	ou_E /m^2/s	area source 735m2
clarifier tank surfaces (wind stripping)*	4	_01	5.8	0.5	ou_E /m^2/s	area source 735m2
storm tanks*	2	_01	7.2	7.2	ou_E /m^2/s	area source 7360m2
measurement weir	1	03, 04a & 11	891	148	ou_E /m/s	33m long line source
outfall	1	03, 04a & 11	13362	2221	-	point

* Emission rates are time varying as well as seasonally adjusted

For most fugitive emission sources there is no ambiguity about the appropriate STOP model algorithm to be used. In the case of the preliminary tanks, emissions have been estimated using two STOP model equations: approximately 5% of the full flow treatment drops 2.8m from siphons into a fast flowing open channel. This source is located in a deep open well, so while the STOP model emission estimates may be reasonably applied to this source, dispersion of the emissions from the enclosed well are likely to be less than if modelled assuming an open source.

In the case of the clarifier tanks there are four different sources that may contribute to odour. These are: the fast flowing inlet channels; the feed channels to the clarifiers; the flow of the clarifier outlet weirs; and wind stripping from the quiescent settlement zone above the lamellas. In the case of the feed channels to the clarifiers, three separate equations have been used to represent odour emission along the length of the channel. The odour from the clarifier overflow weirs has been used in preference to the equation for flow in open channels. The emission from the storm tanks is based on the STOP equation for quiescent open tanks. In the case of the spillway, emissions could be characterised by drop of variable height, depending on the state of the tide, or flow over a weir. None of these algorithms are entirely appropriate for the outfall spillway and odour from the measurement weir and the outfall spillway are based on flow in open channels. Emission values for each source were estimated using a range of STOP equations and the most appropriate selected in consultation with WDC. The emissions from the aeration tanks were discounted, as the STOP model equation does not appear to bear any relation in practice to conditions on site. Emissions from open tanks were calculated using site specific measurements measured at U_{10} and at 1m above tank surface height using ultrasonic wind vanes.

The dispersion of emissions was modelled using ADMS-3.1. [ADMS-3, The Multiple Source Air Dispersion Model,' CERC, Cambridge, 1999]. This is a later version of the model used for the EIA.

POTENTIAL DIFFICULTIES IN ASSESSMENT

Potential difficulties and limitations in this assessment include:

- sampling and modelling process variability;
- errors in sampling and analysis used to measure Odour Potential;
- errors in the STOP model used to estimate odour emissions;
- errors inherent in the dispersion model used; and
- errors introduced by the model user due to inappropriate or unrepresentative input values such as meteorological data, terrain, building effects or surface roughness values.

Sampling and analysis errors have been reduced by obtaining samples in triplicate, refrigerating samples and using a laboratory with UKAS accreditation for odour analysis. Conservative process assumptions have been used to obtain odour emission rates in the STOP model. A sensitivity analysis was conducted to determine the potential errors arising from user specified input values in the dispersion model.

MODEL PARAMETERS

The efflux velocity and volume of release for all fugitive emissions from open tanks are assumed to be zero. The sources were considered as continuous, steady state releases. The emission heights were modelled at tank surface height above local ground level. The surface roughness conditions at the site were assessed for a range of values (0.3 - 1.5m) across the domain. 6 years of hourly sequential meteorological data from Glasgow Abbotsinch were used to predict dispersion. The effects of buildings on dispersion has been ignored, except in the case of the OCU building. Results from the model were obtained for 25m resolution and fixed receptors. Terrain effects were ignored. Once released to the atmosphere, odour emissions will tend to decay by means of photolytic reactions and oxidation. Since the rate of odour decay is unknown, the effects of decay have been ignored. Other removal mechanisms were considered to be insignificant and have been ignored. It is assumed that odours from different process stages are additive.

PREDICTED ODOUR CONCENTRATIONS

The odour concentrations for both scenarios were predicted at 11 receptor locations around the WWTW. The predicted contribution from all the sources considered are presented in Table 4. The storm tanks are the main source of odour at receptors and other sources are of marginal significance. The predicted odour contours are also plotted in Figure 3.

FIGURE 3

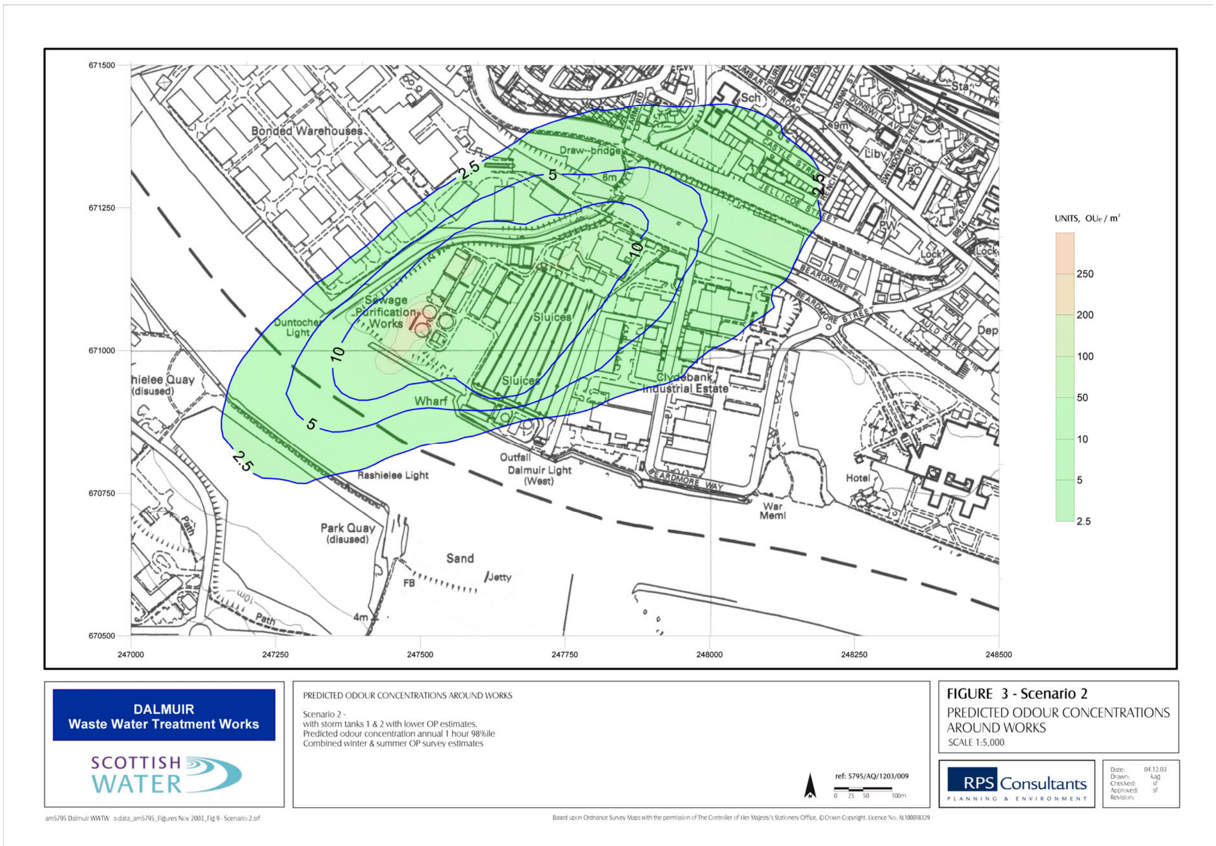


Table 4 Dalmuir WWTW Predicted Odour Concentration – Source Contribution – 98%ile ou$_E$ /m3

Receptor name	Preliminary & clarifiers	outfall	Storm tanks	OCU	all
Jellicoe Street	0.6	1.1	1.9	0.8	4
Beardmore Place	0.4	0.8	1.8	0.5	4
Beardmore Street	0.2	0.6	1.1	0.3	2
Beardmore Hotel	0.1	0.3	0.3	0.1	1
Industrial Estate W	0.4	2.2	9.4	0.6	13
Industrial Estate N	0.3	1.5	4.0	0.6	6
Industrial Estate S	0.1	0.4	0.4	0.1	1
Industrial Estate E	0.3	0.9	2.1	0.5	4
Rashielee Light	0.2	1.3	1.2	0.4	3
Farm Road	0.6	1.4	0.6	0.7	3
School	0.6	1.1	1.2	0.8	4

The storm tank values may have been affected by accumulations from previous storm events. The results in Table 4 are based on a single year of meteorological data and do not include any uncertainty estimates. A sensitivity analysis was conducted for model inputs, to consider the uncertainty arising from source quantification (e.g. for the storm tanks), the relative significance of each source at receptors, meteorological data and surface roughness.

Six years of hourly sequential data was used in the sensitivity analysis. The sensitivity analysis has only been conducted for the storm tanks, not all sources. This analysis assumes that other sources would be similarly affected and this correction has been applied to all sources. The results indicate that the meteorological data used is of marginal significance overall at most receptors and does not significantly affect predicted levels in terms of the planning condition requirements.

The effects of surface roughness values have been considered for 0.3m (agricultural areas) to 1.5m (large urban areas). This indicates that the use of different surface roughness values has a major effect on the predicted odour concentrations. It is likely that surface roughness values at the south end of the site at the river are lower than assumed in the model, in which case the predictions may be too optimistic on the south bank of the river. The roughness values to the north of the river are considered to be appropriate and the predicted concentrations have not been modified.

The time varying emissions from sources have been modelled separately and added together for each receptor location. Ideally these sources should be modelled in the same model run to ensure that the 98%ile calculations are valid. In practice it is not feasible to run more than 6 time varying files at the same time. This approximation is unlikely to significantly affect the predictions for area surface sources such as the storm tanks because the poorest dispersion conditions are likely to be similar for these types of sources.

The predicted odour impacts are based on both summer and winter measurements of Odour Potential and the contribution from the OCU. No summer values for the storm tanks were obtained due to the difficulties in co-ordinating laboratory availability with the infrequent storm events during the summer. The best case predictions in Table 5 include the lowest predictions taking meteorological and surface roughness into account. The average model predictions are based on the average odour concentration over six years and assume the most realistic surface roughness values. The predictions do not include for all process variability and use the same STOP algorithms for all scenarios. The predictions assume normal process conditions and ignore isolated odour events associated with poor operational control or failure of abatement at the works.

Table 5 Dalmuir WWTW Odour Concentration best/worst case predictions– 98%ile ou_E /m^3

Receptor name	average prediction	worst case	best case
	ou_E/m^3	ou_E/m^3	ou_E/m^3
Jellicoe Street	6	21	2
Beardmore Place	3	10	1
Beardmore Street	2	6	1
Hotel	2	8	0
Industrial Estate W	15	42	5
Industrial Estate N	9	30	2
Industrial Estate S	3	8	1
Industrial Estate E	4	16	2
Rashielee Light	4	16	1
Farm Road	6	28	2
School	5	15	2

The equations used to calculate odour emission rates from fugitive sources are based on empirical data, only some of which has been published. There are no estimates of potential error for the emission equations. The STOP model equation for the aeration tanks predicts extremely high odour emission rates that bear no relation to conditions on site. Odour from this source has therefore been discounted. It is difficult to predict the effective odour emission from the preliminary tanks as the source is located within a deep well. In the case of the odour from the outfall there are several possible STOP equations that could be used to estimate odour emission. The reliance on two "snap-shots" of process operating conditions introduces further uncertainty into the predictions.

CONCLUSIONS

Generally the OP summer samples are at least double those obtained in winter months. In some cases the summer samples are much higher. This may be due a combination of factors including lower flows during the summer surveys, reduced primary treatment at the works as well as increased biological activity in warmer weather.

The odour potentials in the storm tank have the greatest range, probably due to circulation within the tanks, first flush flow or accumulations from previous storm events.

There is a good relationship between measured OP values and the equivalent H_2S concentration. H_2S only accounts < 5% of total odour from the works so this relationship may not be used to convert H_2S measurements into equivalent odour units at or beyond the site boundary. Based on the site specific relationship between odour and H_2S discussed above, H_2S would be likely to be undetectable where modelled odour concentrations are < 350 ou_E/m3. This means that relying on H_2S as a proxy for odour at the site boundary could significantly underestimate odour emissions from the works and that H_2S may not be used to validate the model predictions at or beyond the boundary fence.

The STOP equations appear to provide rational estimates of odour emission that generally correspond to the conditions experienced on site except in the case of the equation for aeration tanks which is highly suspect. A degree of judgement is required when selecting the appropriate algorithm for some process operations. It is essential to confirm theoretical estimates by checking conditions on site.

The robustness of the STOP emission estimates and dispersion modelling depends on the user inputs. The results from the post commissioning surveys are (a lot) higher than the OP values assumed in the Environmental Statement. The dispersion modelling from tanks assumed a positive efflux velocity and resultant dispersion may also have been overestimated in the design. Overall the use of STOP at Dalmuir to inform the design process has been successful, except in the case of the storm tanks. This is probably due to weaknesses in the design assumption rather than shortcomings in the STOP emission equations.

The OCU, preliminary tanks, biological aeration tanks, clarifiers, measurement weir and outfall are of marginal significance in terms of odour. The storm tanks are the main source of odour at receptors. The contribution from this source is likely to be highly variable, due to the apparent heterogeneous nature of the liquor, the variable residence time in the tanks and the variation in flow velocities during storage. It is difficult in practice to predict the odour from this source in terms of the 98%ile due to the unpredictability of storm tank use and these other factors. The primary focus of odour management at the works is now to reduce odour from short-term events such as de-sludging the storm tanks as quickly as possible to reduce the duration of odour events.

Odour from the works, as assessed, may comply with the planning condition, depending on the STOP equations and other model assumptions adopted. The uncertainties within the source estimates and dispersion modelling, combined with the variability in operational conditions within the works make it difficult to demonstrate conclusively whether the planning condition of $2.5ou_E/m^3$ is being complied with 98% of the hours in any year.

Based on subjective assessment of the conditions on site over the summer, normal operating conditions at the works are unlikely to provoke off-site complaints. Complaints appear to be associated with odour from short term, irregular events such as emptying the storm tanks after prolonged use or one-off failures such as the lamella plates in the primary tanks. Odour from these events has not been quantified due to lack of source estimates.

Predicted odour for typical process conditions are well above 5 ou_E/m^3 at the slte boundary and do not provoke complaint. The experience at Dalmuir suggests that the STOP model is conservative and tends to over predict emission rates. It could be misleading to draw firm conclusions from apparent community acceptance (of typical process conditions). Receptors around the works were previously exposed to odour concentrations several orders of magnitude above current levels and may be more tolerant than would otherwise be the case in a green field site.

The method considered here is suitable for assessing the environmental impact from a new process subject to its proper use. It is probably less appropriate to use this technique to implement the design objective directly as a planning condition. The uncertainties in the emission and dispersion modelling estimates for fugitive releases are too large to justify a quantitative approach to regulation.

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