Title

Odour dispersion from a hole in the ground

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Odour, dispersion modelling, physical modelling, wind tunnel, model uncertainty

Abstract

An odour impact assessment was conducted for a new treatment works designed to treat <400m^3/hr urban wastewater. The site was selected following consultation with the planning authority and local interests.

The proposed site is located within a disused quarry with houses nearby. The assessment included a physical survey within the quarry, dispersion modelling (ADMS), smoke tests in the quarry to visualise the flow, computational fluid dynamics modelling (CFD), and wind tunnel measurements using physical scale models.

The predicted odour using ADMS compares well with the physical model, but provides different worst case wind directions. The odour concentrations predicted by CFD were the same order of magnitude as with the physical model, but provided different worst case wind directions and poorer correlation with the physical model when compared to ADMS. The disagreement between the worst case wind directions suggests that for complex terrains, physical models remain the best tool for assessment.

(150 words)

INTRODUCTION

This new WwTW is required to meet the requirements of the Urban Waste Water Directive[1]. The proposed works is located within a disused quarry in a sparsely populated area at the southern edge of the extended catchment. The nearest sensitive receptors to the proposed site are two dwellings, both relatively close to the site boundary. The next closest dwellings to the north are more than 100m distant, on the narrow coastal strip, with steep ground rising behind. To the south, the next closest dwellings are 300m from the site on the steep hillside overlooking the sea.

PROCESS DESCRIPTION

Two design options were considered as part of the Environmental Impact Assessment process[2]: Design Option 1, a single 10m high building with primary treatment only and an odour control stack; and Design Option 2, an 11m high building with adjacent secondary treatment tanks. The final design selected provides

[1] European Union Urban Waste Water Treatment Directive 1991 (91/271/EEC)
[2] RPS Planning Transport & Environment Environmental Statement 2004. At the time of writing the planning application is still being determined. The project sponsors have kindly granted permission for publication provided the location of the site is confidential.

two stages of treatment for sewage arising within the catchment, up to 400m^3/hr flowing into the head of the works. Screened sewage from a number of gravity fed and pumped sewers shall be pumped to the head of works through a 1.6km rising main. The influent is predominantly from domestic and commercial premises with no significant trade effluents within the catchment. The existing collection and transfer infrastructure has been upgraded as part of the enabling works for the scheme to reduce infiltration. The proposed works shall include an inlet works with screens, followed by primary settlement within lamella tanks, and secondary treatment. The inlet and primary settlement processes will be contained within the main process building. The odorous process activity areas will be held under local point extraction with air drawn from the headspace of the enclosed lamellas and other processes to minimise the volume of foul air to be treated. All odorous air from the primary treatment and sludge handling will be passed to an odour control unit (OCU) for treatment before being released to the atmosphere. The proposed OCU consists of a two stage treatment process. Initially the foul air is to be passed through a bio-filter. Bio-filters typically achieve 95% odour removal for this type of application. The treated air from the bio-filter shall then be passed through a carbon filter "polishing" unit to reduce odour emissions further. Properly maintained, the OCU is likely to reduce odour by more than 99% of the inlet concentration. The performance of the equipment is guaranteed by the suppliers to exceed >99.5% removal of odour at the inlet or less than 500 OU_E/m^3 at the outlet. Sludge from the lamellas will be collected and thickened with estimated arisings of approximately 30m^3/day. The liquor from settled and thickened sludge and the secondary treatment plant is returned to the head of the works. The sludge tanks are located outside, but are sealed and vented back to the OCU so that there are no unabated emissions to atmosphere. The thickened sludge will be exported via road tankers. The vapour displaced during the filling of road tankers shall be collected by a flexible connection maintained under negative pressure and passed through the OCU. No active sludge de-watering operations shall be conducted on site. The effluent from the lamella tanks shall be passed to the secondary treatment process, a form of biological aerated filtration which works on the principle of partially treated aerated sewage flowing through a submerged medium. Air is injected within the media bed to ensure the process remains aerobic and to sustain the biological reaction. The secondary treatment process will be covered and the head space extracted and vented to the stack for dispersion. This type of process is typically low in odour, particularly for secondary treatment processes so it is unlikely that this part of the air flow will require odour scrubbing. No bulk liquids or sludge imports are planned[3].

ODOUR IMPACT ASSESSMENT

The proposed site was chosen after a protracted site selection process, involving the local planning authority, Environmental Health and the local community. This raised a number of odour related issues including: the credibility of process design assumptions; the odour standards necessary to protect local amenity; and the complexity of the terrain undermining confidence in dispersion estimates, increasing model uncertainty.

The transport and transformation of a pollutant in the atmosphere can normally be predicted with a reasonable degree of confidence using an appropriate atmospheric

[3] OdourNet December 2003. Report for project BRIT03a. This was also confirmed by a site walkover in the summer at a similar site by the author.

dispersion model. The principal factors affecting the dispersion of an atmospheric pollutant are:

- Source characteristics including source strength, height of discharge, density, efflux velocity and temperature of the release;

- Prevailing atmospheric conditions including wind speed and direction, cloud cover, precipitation, ambient temperature and the depth of the mixing layer; and

- The effect of building entrainment, topography and local surface conditions.

In most cases dispersion may be predicted using a suitable mathematical model, where source, atmospheric and topographical conditions are taken into account. Dispersion models have been used in environmental assessment for several decades and have been extensively validated under a range of conditions. Dispersion modelling is relatively straightforward and inexpensive compared to other atmospheric dispersion modelling methods. The dispersion of odour from the process was initially predicted using a widely recognised dispersion model ADMS 3.1[4]. The terrain map used for the models was based on OS Landform Profile data outwith the quarry. A detailed physical survey was conducted within the quarry to provide a high resolution 1m spot height grid, to enable physical and mathematical modelling. The terrain algorithm for ADMS has been validated for slopes < 30^o.The quarry includes near vertical walls with the main wall sloping above 45^o; outwith the conditions for which the ADMS model has been validated. Two field tests were conducted to assess whether the model predictions were reliable. The smoke tests carried out within the quarry confirmed that terrain had a significant effect on flow and that the observed flow was not predicted by the dispersion model. The results from ADMS 3.1 were therefore considered to be unreliable in this situation in the absence of further validation. One other issue was the fact that the version of the model then available crashed whenever terrain effects were modelled together with building effects.

In some cases, e.g. where the terrain is complex, it is necessary to use more complex mathematical models. One such approach is to use a fluid flow modelling approach based on computational fluid dynamics (CFD). CFD models may provide a more realistic description of flow in the quarry. However CFD models don't have the same track record of validation in atmospheric dispersion. The best available method for modelling flow around complex terrain outwith the scope of a conventional dispersion model is to construct a physical model and test air flow under controlled conditions in a wind tunnel. Wind tunnel testing allows flow visualisation over complex terrain and optimisation of stack height and location over a full range of wind speeds and directions. Tracer gases released within the tunnel may be used to provide dispersion estimates around the site. Physical modelling in a wind tunnel is not normally conducted due to the much higher costs when compared to conventional dispersion modelling. Physical modelling in a wind tunnel is a proven technique and can provide robust, credible estimates of dispersion. One potentially significant limitation of the method is that it is difficult to replicate the full range of atmospheric stability conditions within a wind tunnel. CFD modelling, when combined with wind tunnel tests, can be used to provide a range of atmospheric stability conditions to be assessed. The results from the CFD modelling were used to inform

[4] *ADMS-3*, *The Multiple Source Air Dispersion Model,'* CERC, Cambridge, 1999. Details of model validation work can be obtained from CERC's website at http://www.cerc.co.uk/software/publications.htm

conditions for wind tunnel tests. A physical model was constructed at scale 1:200 for the building, stack, quarry terrain and surrounding hillside. Air flow was visualised and tracer gas measurements used to estimate dilution and dispersion from the stack to the nearest two receptors (R1 & R2). Measurements were conducted for a range of wind speeds and directions for two stack heights to obtain site specific dilution factors. This stage was repeated to take account of the design changes resulting from the introduction of secondary treatment at the works. Two wind tunnel sessions were conducted to provide estimates of odour dilution:

- In the case of the *primary treatment only option* measurements were conducted for two stack heights, 3m and 13m above roof ridge level. This assessment did not allow for the possible effect of the secondary treatment tanks on air flow and was updated.

- The revised design, *the primary and secondary treatment option,* included secondary treatment tanks and a higher treatment building. The dispersion measurements were repeated for a stack release 13m above roof ridge level.

These site specific dilution factors were used to "*back calculate*" the abatement required at the works to protect local amenity. The objective of the assessment is to determine the level of odour abatement required to protect the amenity of sensitive receptors around the proposed works, assuming all odorous activities will be enclosed so that there should be no fugitive emissions e.g. from open tanks and that the only significant source of process odour will be emissions released from the stack[5]. The maximum permitted odour emission rate from the stack was determined by confirming the required standard at the nearest receptor and the likely dispersion between the source and receptor, a method sometimes known as "working back".

ADMS

The ADMS 3.1 dispersion model was tested in the field and rejected as unsuitable for this application. The earlier versions of ADMS 3.1 & 3.2 crashed when building effects and terrain effects were considered at the same time. ADMS has undergone two revisions since the commencement of the assessment process. The current version of the model 3.3 has resolved these technical problems associated with combined re-circulating flows.

CFD Tests

Steady state CFD simulations were conducted for two stack heights prior to detailed wind tunnel tests in order to gain an understanding of the local dispersion characteristics and to help refine the physical model tests[6]. Simulations were carried out for 30^{o} wind sectors for wind speeds of 2m/s and 5m/s. The highest predicted concentration for design option 1 (stack terminating 13m above roof ridge of 20m AOD) was 0.00207% of the emission concentration.

[5] Fugitive emissions are releases to atmosphere which are not discharged from a controlled emission point e.g. a stack or vent. One of the main design elements at this site is the enclosure of the primary and secondary treatment tanks, thus avoiding the main source of fugitive emissions typically associated with WwTW. Examples of fugitive emissions at this site could be through open doors or from spillage of sludge during transfer.
[6] BMT Fluid Mechanics Limited conducted two series of Wind Tunnel Tests in 2004 and 2005.

Wind Tunnel Measurements for Design Option 1

The flow visualisations and measurements in the wind tunnel conducted for design option 1 indicated that, under most conditions, the OCU stack emissions would be drawn into the back of the quarry away from the nearest receptors. The worst case odour would occur when the wind was from 330^{o} at 1m/s. The highest measured concentration for design option 1 (stack terminating 13m above roof ridge of 20m AOD) was 0.00207% of the emission concentration.

Wind Tunnel Measurements for Design Option 2

The significant changes in this design option included increasing the height of the main building by 1m to 21m AOD; relocation of the proposed OCU and stack, the inclusion of the secondary treatment tanks cells and increased stack diameter, flow rate and efflux velocity.

These measurements indicated that the worst case odour is likely to occur where the wind is from 210^{o} at 4m/s. The highest measured concentration for the revised design (stack terminating 13m above roof ridge of 21m AOD and the enclosed secondary treatment tanks) was 0.004% of the emission strength[7&8].

COMPARISON OF MODEL PREDICTIONS

The predicted concentrations in Table 1 below are based an odour emission rate of 28,500 OU_E/s from a stack terminating 13m above roof ridge level with an efflux velocity of 15m/s with worst case wind direction. The wind tunnel measurements are in reasonable agreement with the results predicted by ADMS 3.3 and CFD. The ADMS 3.3 predictions are consistently greater than all three sets of wind tunnel measurements.

Table 1
Worst Case Odour comparing ADMS 3.3, CFD and wind tunnel measurements

Design Assessed	ADMS 3.3 Prediction $OU_{E/m}{}^3$ 98%^{ile} 1 hour	Wind Tunnel Measurement $OU_{E/m}{}^3$ 1 hour	CFD Prediction $OU_{E/m}{}^3$ 1 hour
Design Option 1 (3m stack)	5.6	5.0	2.1
Design Option 1 (13m stack)	3.5	1.4	-
Design Option 2 (13m stack)	3.5	1.1	-

Based on emission rate of 28,500OU_E/s.Stack height = height above roof ridge level.

Wind tunnel tests are conducted in conditions that represent neutral atmospheric stability and cannot create the full range of unstable and stable atmospheres. The three wind tunnel tests provide limited validation of the ADMS 3.3 predictions. This suggests that while the physical model cannot recreate the unstable and stable atmospheric conditions in the wind tunnel, these limitations appear to be insignificant overall. The CFD predictions are of a similar magnitude to the dispersion estimates provided by both other models.

The comparison between the worst case wind directions is less convincing. The results for design option 1 wind tunnel measurements indicated that the worst-case wind direction for the nearest house was 330^{o}, whereas the dispersion model ADMS

[7] The original wind tunnel measurements were for a flow rate of 0.41m^3/s. This was increased to 1.05m^3/s mainly due to the proposed extract ventilation of the headspace in the cells enclosure.
[8] BMT Fluid Mechanics Limited 2005.

3.2 predicted the highest odour concentrations when the worst case wind direction would be 270°. ADMS failed to predict the re-circulating flow observed in the quarry during the smoke tests.

The results from the revised design wind tunnel measurements indicated that the worst-case wind direction for the nearest house is 210°, whereas the dispersion model ADMS 3.3 predicted the highest odour concentrations when the worst case wind direction would be 240°. While the CFD worst case predictions agree reasonably well with the other models considered, the worst case wind directions predicted by CFD are completely different.

Table 2 Worst Case Wind Direction comparing ADMS 3.3 CFD and wind tunnel measurements

Design Assessed	ADMS 3.3 hills	Wind Tunnel	CFD
Design Option 1 3m stack	210	270	180
Design Option 1 13m stack	240	330	-
Design Option 2 13m stack	240	210	-

Based on worst case wind direction (degrees) at any receptor.

ASSESSMENT CRITERIA

There is no evidence that community annoyance caused by exposure to offensive odour is non-stochastic i.e. that amenity is no longer adversely affected or that complaints stop below a certain level of odour exposure. It is therefore reasonable in the absence of detailed studies of community annoyance proving the contrary, to conclude that a lower odour exposure will reduce the likely impact on amenity.

Table 3 WwTW Odour Assessment Criteria (at sensitive receptors)

Predicted Odour concentration OU_E/m^3 1 hour 98%ile	Adverse Significance	Justification
>10	Major	Unpublished research by UK Water Industry Research[9] proposed an industry wide standard of 10 OU_E/m^3 1 hour 98%ile as the basis for determining statutory nuisance and 5 OU_E/m^3 1 hour 98%ile as the basis for the design of new works. Subsequent published reports[9] suggest no consensus on what odour levels are likely to be acceptable, but most commentators probably agree that odour exposure > 10 OU_E/m^3 1 hour 98%ile would be a major adverse impact.
5 – 10	Moderate/Major	See above
1.5 – 5	Moderate	The PPC document H4, in draft, proposed a benchmark of 1.5 OU_E/m^3 1 hour 98%ile for WwTW.
<1.5	Minor	According to H4, people exposed to this predicted odour would not have reasonable a cause for annoyance. This standard is based on avoiding annoyance and protecting amenity rather than just preventing statutory nuisance.
<0.5	Marginal /Insignificant	Available research indicates that odour complaints or annoyance are unlikely at this level of exposure. [10]

There are reasonable grounds for believing that odour nuisance is unlikely to occur where the predicted 98%ile of 1 hour averages is less than 5 OU_E/m^3. This standard

[9] UK Water Industry Research Ltd. 1 Queen Anne's Gate London SW1H 9BT. 04/WW/13/6 - Odour Standards for the Wastewater Industry ISBN: 1-84057-341-4

[10] Ap Van Harreveld; N Jones & M Stoaling July 2002. Assessment of Community response to odorous emissions. Environment Agency P4-095/TR This research report concluded suggests that the stating point for annoyance potential is associated with exposure to 1.5 OU_E/m^3 1 hour 98%ile.

has been accepted at public inquiries in the UK and is confirmed, to an extent, by industry experience in the UK. Despite the fact that the $5OU_E/m^3$ 1 hour 98%ile site boundary standard has been accepted at planning inquiries, it is probably inevitable, in the absence of specific planning Guidance, that planning authorities may seek to impose H4 style standards to protect amenity. The standards proposed in H4[11], strictly speaking, do not apply to this process, nor are the draft H4 standards based on new research into odour and annoyance.

The approach adopted in this study was not to propose the adoption of a particular odour design standard. The likely impact on local amenity has been assessed by comparing the predicted odour to both 5 OU_E/m^3 and 1.5 OU_E/m^3 1 hour 98%ile. The justification for the assessment criteria are set out in Table 3 above.

APPROACH TO ODOUR CONTROL

So far these predictions are based on the notional emission rates that would be required to achieve compliance with typical industry design standards. The approach adopted by the project's design team was to achieve odour emission rates as low as reasonably practicable, rather than simply to aim for compliance with indicative benchmarks or other criteria. Accordingly the process operator proposes to aim for a level of abatement ~99%[12] with a stack terminating 13m above the roof ridge, even although the odour impact at the nearest receptors could be achieved with a much higher emission rate. This approach was selected to: provide maximum model headroom[13]; take account of potential model uncertainties; and the need to provide additional confidence in the assessment, in view of the proximity of the nearest receptors.

Table 4 – Expected outlet odour emission rates from process

Source	Flow m^3/s	Emission Concentration OU_E/m^3	Emission rate OU_E/s
OCU flue – via common stack	0.55	500	275
Secondary Tanks - via common stack	0.50	1500[14]	750
Total emission from stack	1.05		1025

The indicative anticipated odour emission estimates are summarised in Table 4. As can be seen from the predicted odour concentrations in Table 5, for three emission scenarios, the dispersion achieved by the proposed stack, would be likely to achieve less than 5 OU_E/m^3 98%ile with no odour control.

Table 5 Predicted Odour 1 hour 98%ile OU_E/m^3 from stack terminating 13m above roof ridge

Emission Scenario Assumed Emission Rate	*Receptor 1*	*Receptor 2*
31,250 OU_E/s	5.0	3.3
9,375 OU_E/s	1.5	1.0
1,025 OU_E/s	<0.1	<0.1

Note : These predicted odour concentrations are based on the wind tunnel measurements.

[11] Environment Agency October 2002. Draft Horizontal Guidance for Odour. EA Technical Guidance Note H4 (para 1.2).
[12] The suppliers guarantee is underwritten by Bord na Mona.
[13] Model headroom is the difference between the predicted impact and the environmental quality standard.
[14] This is considered to be a conservative estimate, of odour concentration. Odour from aerated secondary treatment processes tend not to have typical sewage odours and have what is sometimes described as an "earthy" odour. The odour from the secondary treatment plant should therefore have less potential for annoyance when compared to the foul odours from the primary treatment.

UNCERTAINTIES IN THE ASSESSMENT

Potential uncertainties in the odour impact assessment include:

- Lack of information about the level of odour likely to be acceptable to communities.
- Uncertainties in the likely odour emission rate at the inlet to the works.
- Uncertainties inherent in the model used such as the model scale or approximations in the physical model or errors in the sampling and analysis used to derive dispersion estimates.
- Limitations in the wind tunnel physical model due to the difficulties in creating stable and unstable atmospheric conditions within boundary layer wind tunnels.

The assessment criteria proposed are based on industry standards, gained over years of experience in odour complaints.

The approach used in this study allows back calculation, so the estimates are less sensitive to the uncertainty in the inlet odour conditions. The emission rate is guaranteed commercially and underwritten by a reputable supplier.

The assessment included a detailed model sensitivity analysis[15]. The results from the dispersion models indicate that the impact from the proposed works are likely to be well below the level where annoyance is likely to occur, so that model uncertainties are unlikely to be significant.

MITIGATION

The mitigation measures for the design include a new collection and transfer (C&T) system in the catchment with septicity dosing; all treatment operation enclosed will be contained with point extraction to maintained negative pressure; all treatment processes shall be contained within a sealed building with air-lock double doors; back venting of sludge holding tanks and charging of road tankers; and an operational odour management plan to include both the works and the C&T.

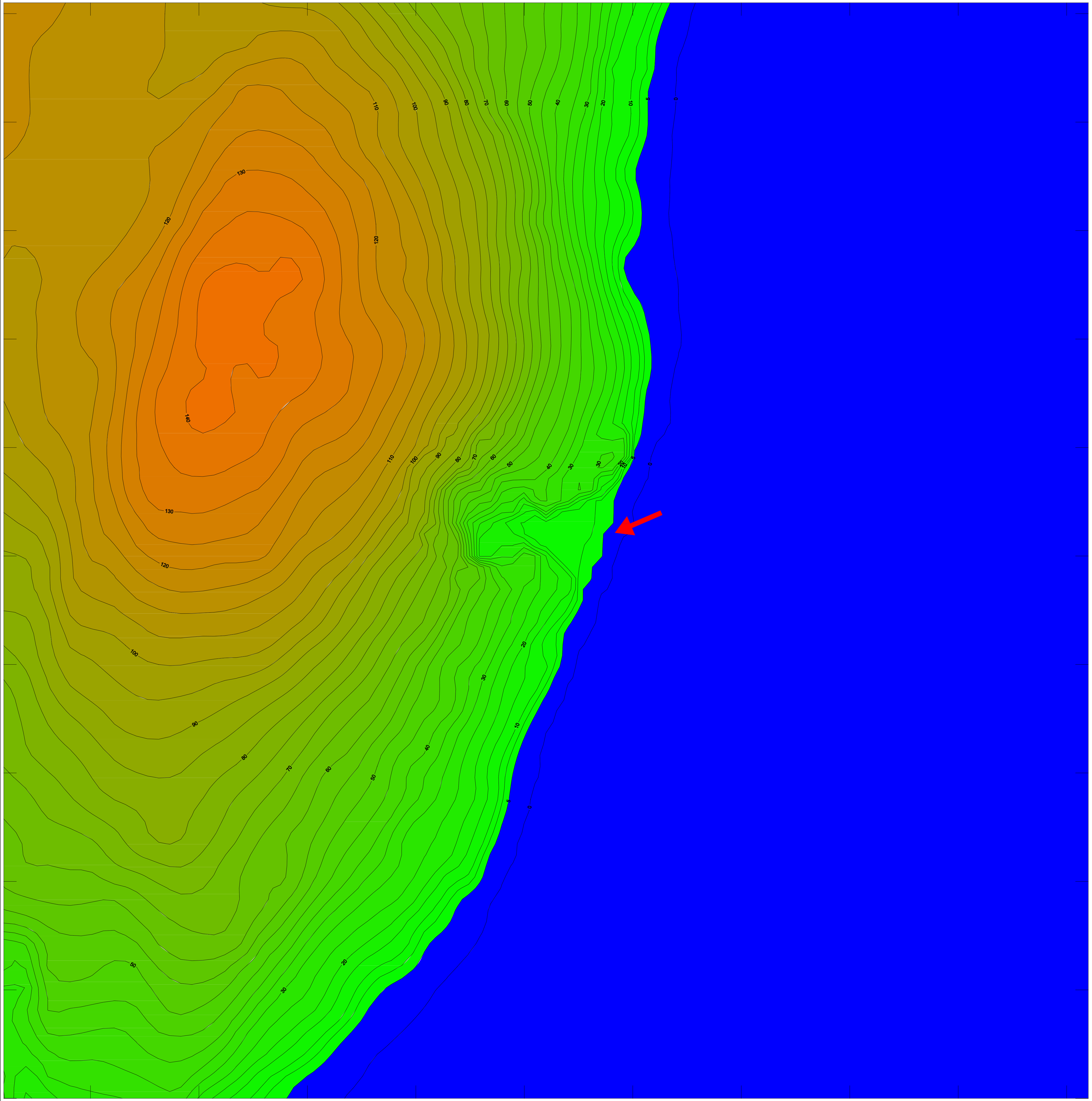
CONCLUSIONS

The results from all three models provide reasonably good agreement. Wind tunnel tests for dispersion do not fully simulate convective turbulence or stable atmospheres. In practice this limitation appears to be insignificant.

The ground level concentrations at the nearest receptors provided by the wind tunnel tracer gas measurements and ADMS 3.3 predictions are similar and this good agreement has been repeated for three separate physical models. This provides limited validation for terrain algorithm in ADMS 3.3, for slopes $>30^{o}$, at least in terms of overall dilution estimates. ADMS 3.3 does not appear to reliably predict the re-circulating flows within the quarry observed during the preliminary smoke tests conducted within the quarry.

[15] Royal Meteorological Society May 1995. Policy Statement Atmospheric Dispersion Modelling Guidelines on the justification of choice and use of models and the communication and reporting of results.

The disagreement between the worst case wind directions obtained by the three different techniques: the wind tunnel tests, CFD and AMDS 3.3, suggests that for complex terrains, physical models remain the best tool for assessment.



Landform Profile and Site Survey

Site Location

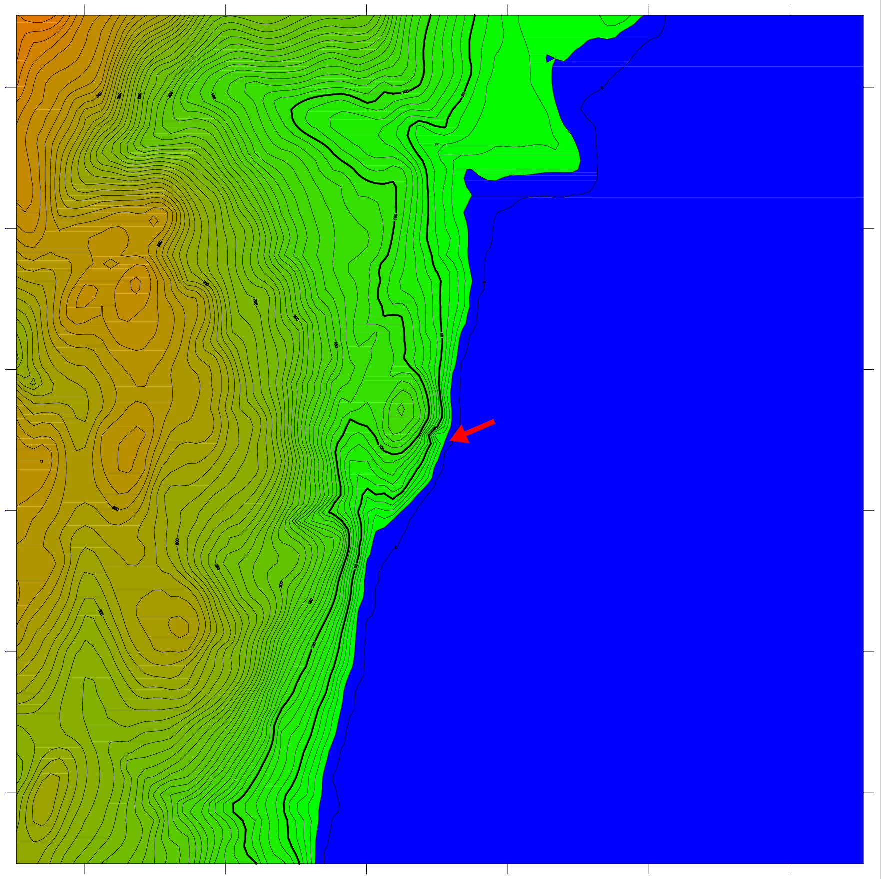


Figure 1

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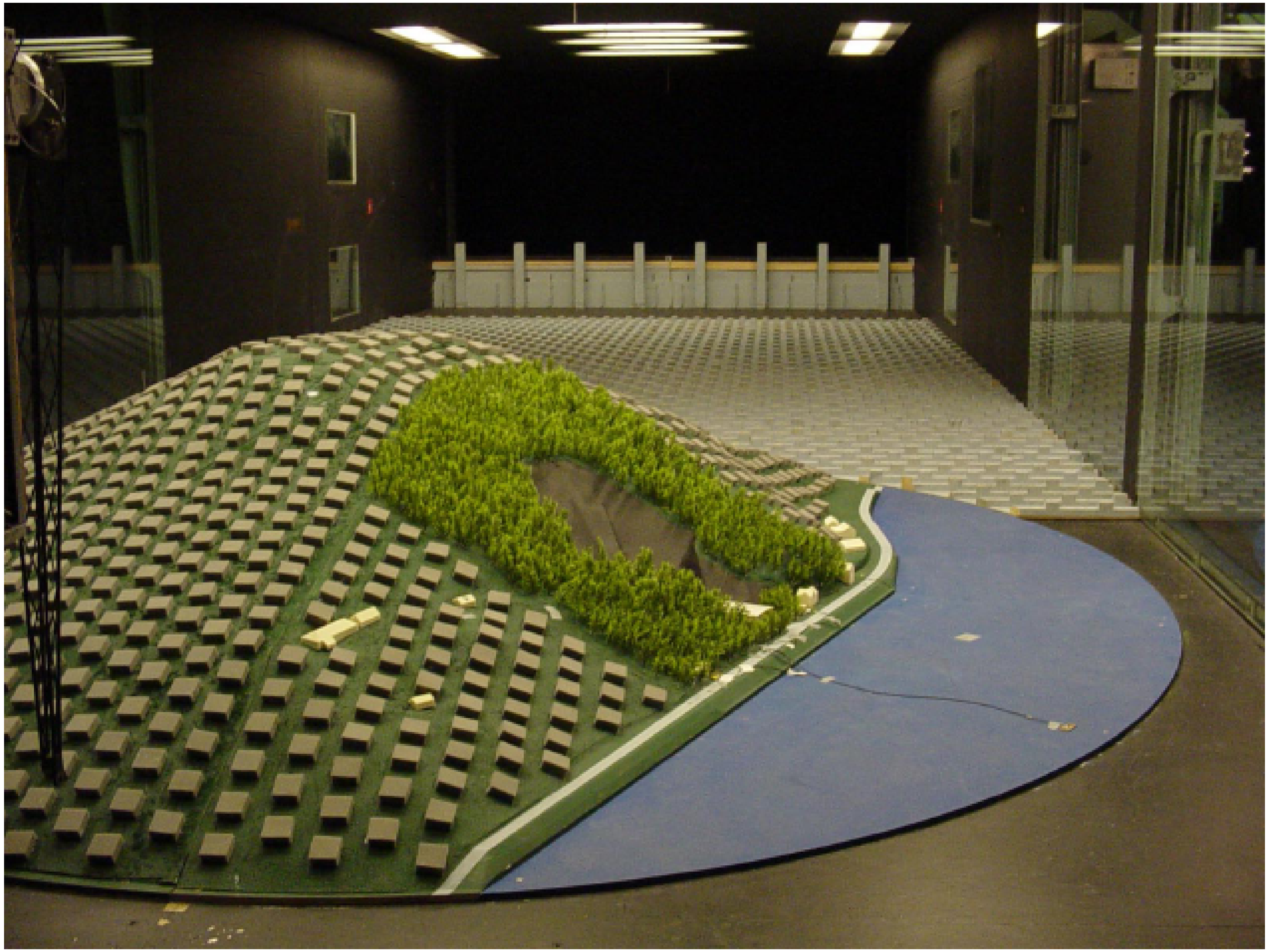
The Airshed

Overall view of the 1:200 scale model located in the wind tunnel



Scale Model in Wind Tunnel

Close up view of the quarry

Wind Tunnel Testing by BMT Fluid Mechanics

Figure 2

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