# Quarry Dust Deposition Model (QDDM V1.0)
## A quarry operator's guide

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**AIR** pollution has been an important area of research for the last two decades because of its adverse effect on health, visibility, animals, forests and materials. The presence of dust in the air causes several serious health effects such as aggravated asthma, increasing respiratory symptoms such as coughing and difficulty or painful breathing, chronic bronchitis, decreased lung function, premature death, *etc* (US EPA., 2004).

Generally, larger dust particles are responsible for nuisance effects. Nuisance complaints from mineral work activities such as quarrying are normally in conflict of the soiling effect, i.e. deposition of nuisance dust onto surfaces such as windows, furniture and the residents' cars (Johnson et al., 1995). Dust emission, dispersion patterns and deposition impacts are difficult to predict due to the wide range of activities that give rise to dust within minerals workings and the uncertain influence of local meteorology and topography. Computer modelling techniques can provide crude predictions of likely dust dispersion and deposition patterns in and around a quarry site. This article reports on the development and evaluation of a new modelling system by MRC, called QDDM, for studying dust deposition rate at local quarries.

### QUARRY DUST DEPOSITION MODEL (QDDM)

QDDM was developed to estimate dust deposition based solely on the principle component analysis (PCA) results, followed by stepwise multiple regression analysis (MRA) of reliability analysis (RA) findings from data sampled at selected quarry sites. The empirical formula obtained indicated that seven parameters included in the model, i.e. wind speed, receptor distance from source, percentage and number of windblown to receptor, blasting frequency, total drill hole, number of vehicles and quarry road distance, are responsible for the dust deposition pattern in and around a quarry site (Izhar and Eric., 2008).

### QDDM ALGORITHM

The QDDM was created using Microsoft Visual Basic 6.0. Once the program is started, information is requested via interactive menus. The first input is the quarry information and production followed by meteorological, source and receptor coordinates which is requested through a series of window displays. Figure 1a shows a simplified flow chart for the QDDM algorithm, and Figure 1b shows the startup window and a series of window display interfaces.

The procedure for calculating dust deposition concentration by QDDM starts by reading the monthly production data entered into the program. These data are used together with the monthly meteorological data. Each meteorological data point will be used at the X and Y coordinates of the source and the modelling exercise is calculated for each receptor location. The coordinates of the source and receptor locations (X, Y and Z) are used to calculate the distance with respect to the terrain complexity options chosen by the user.

The QDDM end result will be a list of receptor dust deposition concentrations sequenced by receptor locations, emission report for each source and source-receptor distance.

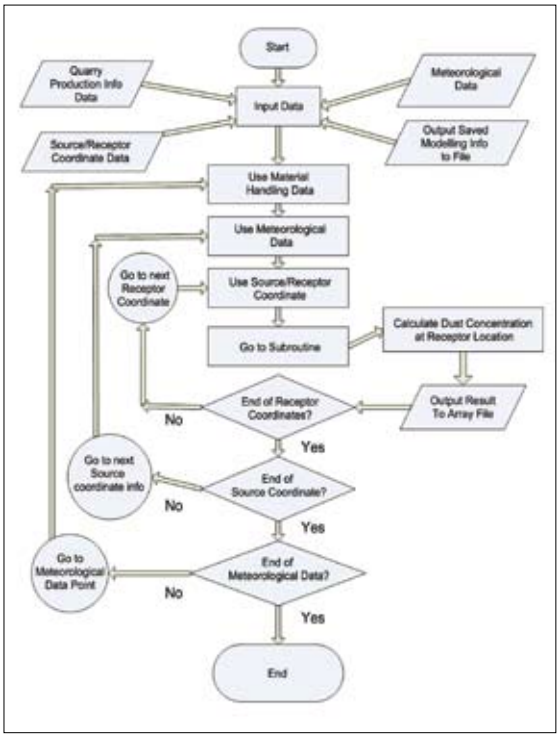


*Figure 1a: Flow chart of simplified algorithm for QDDM.exe*

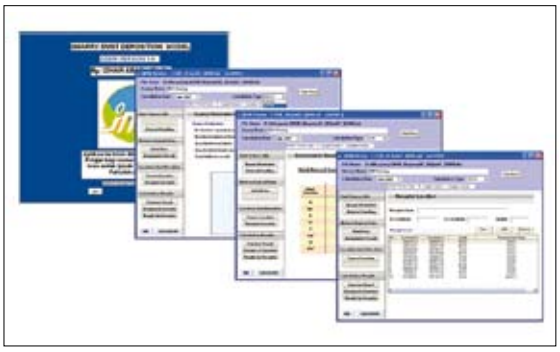

*Figure 1b: The QDDM interfaces*

### CASE STUDY: VALIDATION OF THE QDDM

#### Background of study area

This work focuses on the validation of the system's performance with two models; DUSTCON (Semi-empirical model) and ISC3 (Source Gaussian model). These models have been evaluated using measured dust deposition

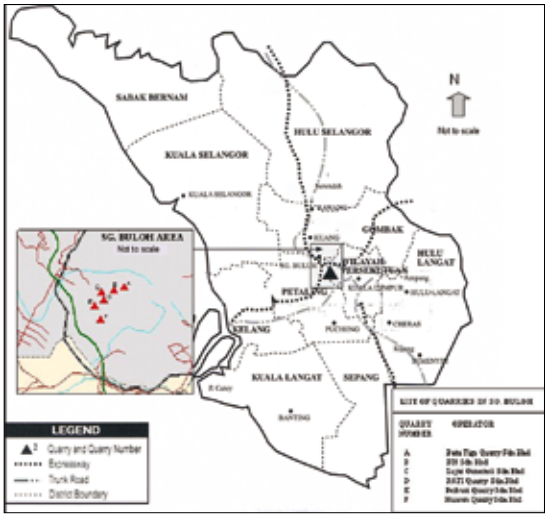


*Figure 2: Quarry location in Bukit Lagong*

*Figure 3: Picture of Frisbee Gauge*

data for October 2007 until April 2008 from six monitoring stations at six different quarries at Bukit Lagong, Selangor. Quarries in Bukit Lagong were chosen as a validation test bed because of their high volume of quarry production (Figure 2). The quarries are also located relatively close to residential areas.

### Sampling stations and analytical procedures

Frisbee Gauge is a static sampler used in this study to measure the dust deposition rate (Figure 3). One (1) Frisbee Gauge was set up for each quarry at their quarry face (± 2m above the ground). Sample collection from the equipment was carried out one month after installation and analysed in the laboratory based on the Australian Standard 2724.1,1984. The rate of dust deposition was calculated in $g/m^2/month$.

### Statistical treatment of the data

Concurrent with the dust deposition measurements by Frisbee, all data relevant to the model input were collected from the quarry management. All modelling results from QDDM, DUSTCON and ISC3 were validated with dust deposition data obtained from October 2007 to April 2008. A total of 42 data sets have been collected for this validation exercise. The statistical package SPSS 13.0 for windows (SPSS, Inc., Chicago, IL, US, 2004) was used for all statistical calculations. The accuracy of the model was estimated by comparing the observed measurements using Frisbee Gauge and predicted dust deposition.

For this analysis, the average values of six monitoring points were compared. The method of least square and curve fitting techniques were used to establish the relationship between all sets of values, i.e. observed measurement and predicted value. Attempts were made to determine whether there was any linear relationship between all sets of data by finding their respective correlation coefficient ($R^2$), and ranking coefficient by Spearman's Rho (ρ), which is between -1 and 1. Value 0 means there is no relationship between the two fields. Value -1 or 1 means a strong relationship. A higher value of '$R^2$' indicates a better linear relationship between the variables and a higher value of 'ρ' indicates the good ability of the model to estimate the spreading or dispersal pattern.

## RESULT AND DISCUSSION

### Comparison of monthly dust deposition rates

The modelled and measured monthly average dust deposition rates are presented in Table 1. Actual dust deposition rates ranged from 7.70$g/m^2/month$ to 25.75$g/m^2/month$. Actual dust levels are significantly high at all sampling points compared to local guidelines (<4.0 $g/m^2/month$), reflecting the much higher quarry activities, or higher urban background concentrations. QDDM and DUSTCON estimated lower values from 1.47$g/m^2/month$ to 3.22$g/m^2/month$ and 0.19$g/m^2/month$ to 0.78$g/m^2/month$ respectively. On the other hand, ISC3 estimated a higher value of 8.85 to 33.09$g/m^2/month$. All these models are based on markedly different theoretical approach and thus the same output results should not be expected. Actual dust concentration can also vary from the predicted value. No matter how complex and complicated a model is, they cannot reflect perfectly the real situation on a dust environment.

Low estimation of emission factors could be the major reason for QDDM and DUSTCON to under-rate the dust deposition in this study. Secondly, although the emission factor input for all models are based on a similar calculation, there are significant differences in the treatment of meteorological inputs. For ISC3, a detailed meteorological preprocessor is needed to produce atmospheric stability parameters, whereas in QDDM and DUSTCON, only the average wind speed and simple conversion of wind stability is required. In the case of ISC3, high value estimations are expected since many mineral working companies in the US and UK have repeatedly demonstrated that this model over-predicts the actual amount of dust by 2-5 times (Reed and Westman., 2005).

*Table 1: Descriptive statistic value for Frisbee and all modelling from results*

**FRISBEE GAUGE DUST DEPOSITION RATE RESULTS**

| LOCATION | AVERAGE | VARIANCE | STD DEV |
|---|---|---|---|
| FR 1 | 13.92 | 57.99 | 7.62 |
| FR 2 | 18.19 | 76.35 | 8.74 |
| FR 3 | 9.75 | 19.85 | 4.45 |
| FR 4 | 13.76 | 30.52 | 5.52 |
| FR 5 | 25.75 | 132.17 | 11.50 |
| FR 6 | 7.50 | 78.68 | 8.87 |

**QDDM MODELLING DUST DEPOSITION RATE RESULTS**

| LOCATION | AVERAGE | VARIANCE | STD DEV |
|---|---|---|---|
| FR 1 | 2.26 | 1.11 | 1.05 |
| FR 2 | 2.25 | 0.35 | 0.59 |
| FR 3 | 1.67 | 0.15 | 0.39 |
| FR 4 | 1.95 | 0.60 | 0.77 |
| FR 5 | 3.22 | 0.26 | 0.51 |
| FR 6 | 1.47 | 0.33 | 0.57 |

**DUSTCON MODELLING DUST DEPOSITION RATE RESULTS**

| LOCATION | AVERAGE | VARIANCE | STD DEV |
|---|---|---|---|
| FR 1 | 0.53 | 0.10 | 0.32 |
| FR 2 | 0.78 | 0.21 | 0.46 |
| FR 3 | 0.76 | 0.27 | 0.52 |
| FR 4 | 0.43 | 0.23 | 0.48 |
| FR 5 | 0.72 | 0.27 | 0.52 |
| FR 6 | 0.19 | 0.02 | 0.14 |

**ISC3 MODELLING DUST DEPOSITION RATE RESULTS**

| LOCATION | AVERAGE | VARIANCE | STD DEV |
|---|---|---|---|
| FR 1 | 23.63 | 174.62 | 13.21 |
| FR 2 | 23.07 | 190.59 | 13.81 |
| FR 3 | 33.09 | 154.24 | 12.42 |
| FR 4 | 25.50 | 1551.88 | 39.39 |
| FR 5 | 8.85 | 6.84 | 2.62 |
| FR 6 | 14.44 | 22.58 | 4.75 |

## Correlation results

The correlation results are plotted in Figure 4. R square (correlation coefficient) values for QDDM, DUSTCON and ISC3 are plotted as 0.95, 0.33 and 0.27 respectively. It can be interpreted that a higher value of $R^2 = 0.95$, indicates good linear relationship between the variables and a higher predictive capability for QDDM. The ranking correlation (Spearman's rho) between QDDM and Frisbee (Table 2) was also encouraging. This indicates that for long-term averages, a fully empirical model such as QDDM was sufficient for estimating the dust deposition rate and pattern.

The DUSTCON model shows a weak agreement with the actual data but is moderately correlated with the ranking correlation value ($\rho = 0.54$). The dust deposition ranking at five out of six receptor points are not fully detected by this model. All receptor points are situated inside the quarry and quite close to the dust sources. This could be the reason why DUSTCON fail to detect a high concentration in a real situation in this study because small particles, which DUSTCON was developed for, were found to travel a longer distance. ISC3 claims to be the best available model for estimating the dispersion of dust from surface mining operations including quarries (Reed and Westman., 2005). However, in this study, it shows a very low negative correlation with the monitored data ($R^2 = -0.27$ and $\rho = -0.43$). Basically, it was designed to deal with the very detailed condition of either point or non-point sources. Setting up the correct input to the model can be quite time consuming and cumbersome.

Its original intended use was for facilities that emit pollutants via smoke stacks. In the absence of specific information for each site, default values recommended by USEPA were used. This might be the reason why the performance of this model was so low.

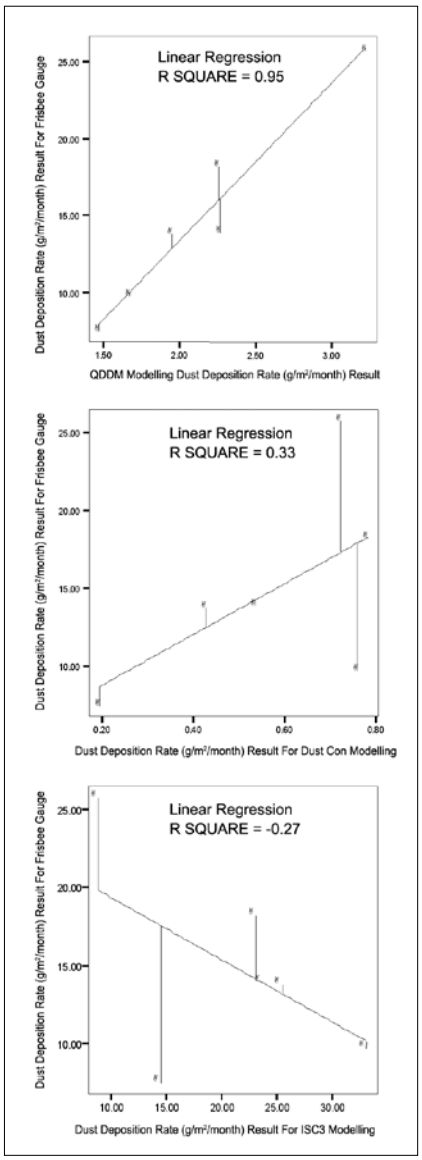


*Figure 4: Correlation plots between measured and modelled results with all models*

## CONCLUSION

A new fully empirical model called QDDM which was developed solely based on the PCA results claims to be the simpler and faster model to estimate dust deposition from quarry activities.

The validation study of QDDM in this study has produced promising results. QDDM results showed an improvement over DUSTCON and ISC3 results in comparison with actual field data. A higher value of correlation coefficient (0.95) and ranking coefficient $\rho$ (0.94) indicates a good linear relationship between the variables and a higher predictive capability for QDDM. There are still some areas for improvement. The underestimation of dust by QDDM could be caused either by uncertainties in the quarry or other background activities. It is suggested that such sources, for example, re-suspension of dust from the road should be better quantified. In order to increase the forecasting ability of dust, it is necessary to incorporate an additional number of factors such as surface temperature, humidity, surface atmospheric pressure and dew point temperature. Dust concentration levels are also influenced by these variables, but those variables were not considered in QDDM. As a model, QDDM cannot reflect perfectly the real situation on a dust environment, but this study shows that it can be used as a feasibility tool before embarking on a higher investment.

*Table 2: Spearman correlation obtained from modelling results*

| Spearman's Rho | FRISBEE GAUGE | QDDM | DUSTCON | ISC3 |
|---|---|---|---|---|
| FRISBEE | 1.000 | 0.943* | 0.543 | -0.429 |
| QDDM | 0.943* | 1.000 | 0.371 | -3.710 |
| DUSTCON | 0.543 | 0.371 | 1.000 | 0.143 |
| ISC3 | -0.429 | -0.371 | 0.143 | 1.000 |

**Correlation is significant at the 0.01 level (2-tailed)

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