Performance evaluation of a dust-dispersion model for haul trucks

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Abstract

A computer model named the "Dynamic Component Program" (DCP) was specifically designed for predicting the dispersion of dust from haul trucks at surface mines. Validation of the DCP was completed by comparing its results with the results of the ISC3 model and with actual dust measurements taken from two operating mine sites. Comparisons of the field measurements, predictions of the ISC3 model and the predictions of the DCP demonstrate that the results from the DCP represent, on average, an 85% improvement over the ISC3 dust dispersion model results.

Introduction

Controlling dust emissions at surface mining operations is an ongoing battle. Methods for controlling dust include applying water or chemicals to the dust source and collecting and filtering the dust from the source. Identifying the dust sources and modeling of the dust dispersion are also important tools in dust control that allow for the identification of potentially hazardous areas.

As part of the permitting process for a mining operation, pollutant modeling can be required if the mine operation emits an amount of any pollutant above certain threshold limits. This modeling is used to determine potential impact areas. Dust is the most prevalent pollutant for surface mining operations, and the most common model used by mining companies for modeling dust is the ISC3 model created by the U.S. Environmental Protection Agency (U.S. EPA). However, this model has been shown to overpredict dust dispersion from actual mining operations by a factor of two to five (Cole and Zapert, 1995; U.S. EPA, Phase III, 1995). A possible cause of this overprediction has been identified as the inability of the ISC3 model to accurately predict dispersion from mobile source emissions (Reed et al., 2002; Reed, 2003).

Recently, the ISC3 model was modified to accommodate dust dispersion from mobile haul trucks at surface mine sites. This model, titled the DCP, has been discussed in detail in previous research publications (Reed et al., 2002; Reed, 2003). Testing of this model with actual field data was completed at two surface mine sites — a stone quarry in Virginia and a coal mine preparation plant in Pennsylvania.

Field studies

Gravimetric and instantaneous dust samplers were used to measure respirable, thoracic and total dust concentrations with the thoracic size range being the primary interest. The respirable portion of dust measured had a median size of 4.0 μm (Lippmann, 1995). The thoracic portion of dust is equivalent to the particulate matter ≤ 10 μm (PM_{10}) size definition determined by the U.S. EPA, which has a median size range of 10.0 μm (Lippmann, 1995). The median size of 50 μm was measured for total dust (MIE Inc., 2000). In addition, the size range of 1.5 to 21.3 μm was sampled using Cascade Impactors.

The sampling equipment used for these studies consisted of MIE personal data RAMs, MSA Escort ELF personal sampling pumps, 10-mm Dorr-Oliver cyclones and BGI GK2.69 cyclones. Samples were collected on 37-mm filters. To measure respirable dust, Escort ELF personal sampling pumps were fitted with 10-mm Dorr-Oliver cyclones. The pumps were set to run at 1.7 L/min (Bartley et al., 1994). The MIE personal data RAMs were used to collect instantaneous dust concentration measurements. They recorded dust concentrations every 2 seconds. The MIE personal data RAMs were fitted with 10-mm Dorr-Oliver cyclones and were operated at 1.7 L/min. Thoracic dust was measured using Escort ELF personal sampling pumps fitted with BGI GK2.69 cyclones. The sampling pumps for the thoracic portion were operated at 1.6 L/min (Maynard, 1999). Total dust concentrations were measured by attaching 37-mm filters directly to the Escort ELF personal sampling pumps, which were set to operate at 1.7 L/min. The Cascade Impactors contained six stages and were connected to Escort ELF personal sampling pumps operating at 2.0 L/min. This flow rate allowed for the measurement of dust concentrations for the cut-off size ranges of 21.3, 14.8, 9.8, 6.0, 3.5 and 1.55 μm (Andersen Instruments Inc., 2002).

The dust samplers were arranged as shown in Fig. 1. The grid layout of the stations was 15 m (50 ft) between each

Table 1 — Coal preparation plant receptor coordinate and haul road layout information.

Receptors	X-coordinate	Y-coordinate
Station A	950.56	1,008.68
Station B	1,000.00	1,000.00
Station C	1,049.24	991.32
Station D	1,098.48	982.64
Station E	1,017.36	1,098.48
Station F	1,066.60	1,089.80
Station G	1,115.84	1,081.12
Haul road starting point	923.28	708.90
Haul road ending point	1,044.83	1,398.26
Slope of haul road line	5.672	
Y-intercept of haul road line	-4,527.94	

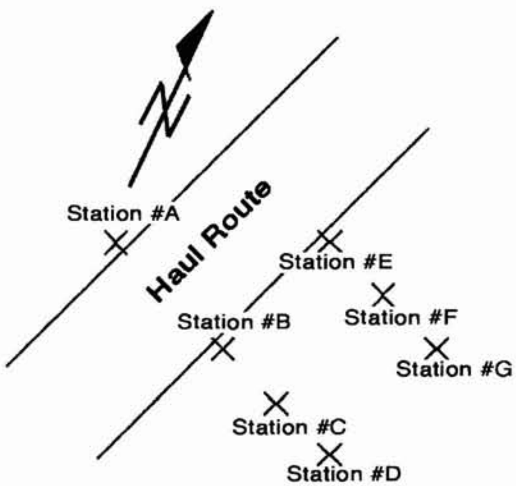

Figure 1 — Dust sampling locations along the haul road.

station in the direction perpendicular to the haul road and 30.5 m (100 ft) between sampling station lines BCD and EFG. Each station contained a respirable dust sampler, an MIE Personal Data RAM respirable dust sampler, a thoracic dust sampler and a total dust sampler. In addition, the Cascade Impactors were located at stations A, B and C. Weather data, consisting of temperature (both dry and wet bulb) and barometric pressures, were recorded hourly. A wind speed and direction station was placed in the center of line CF and recorded wind speeds and directions every 30 seconds.

Dust measurements were collected for approximately six to seven hours per day. During the study, a time study was also conducted of the haul trucks using the haul road. The haul truck time exiting the test section of the road, type of haul truck and speed and direction of travel were recorded.

Analysis of model comparison

After the field studies were completed, a comparison was made between the results obtained and the modeling results. The comparison was completed in the following manner:

- The background information of the field studies was input into the DCP and the ISC3 model. This background information included information on truck size, truck speed, truck emissions, wind direction, wind speed and receptor (sample) locations.
- The DCP and the ISC3 model were run.
- The results of the DCP and the ISC3 model were compared with the results of the field studies. A comparison was also made between the two models.
- An analysis of the results was completed.

The data used in the comparison were the gravimetric time-weighted-average dust concentrations for the thoracic fraction for each day of each study. The DCP accepted data from the field study to calculate time-weighted-average concentrations of dust dispersion from the haul trucks. The DCP has the ability to calculate these results for any length of time. This is important because time-weighted-average dust concentrations are only comparable to concentrations with similar lengths of time (Rock, 1995). The ISC3 model also accepted the same data used in the DCP, calculating the dust dispersion results of the haul trucks. The 6-hour time period for the time-weighted-average dust concentration was chosen because it was equal to the duration of the field study (6 hours).

Table 2 — Coal preparation plant field study information (2002).

	Aug. 2	Aug. 5	Aug. 6
Average speed of haul truck, m/s as calculated from field study	6.92	6.62	7.79
Number of haul trucks passing sampling stations during field study	57	47	64
Haul truck weight, st	50	50	50
PM_{10} background dust concentration level (as measured from field study instantaneous data), mg/m^3	0.1470	0.3747	0.0328
Number of wind speed and direction data points recorded	719	713	815
Sampling time of field study, minutes	330	325	384
Haul road moisture content, %	0.65	0.68	0.54
Haul road silt content, %	21.18	26.20	18.34
Haul road material specific gravity	2.44	2.49	2.52

Model input data

The data used as input from each field study are shown in Tables 1, 2, 3 and 4. The data include information concerning the receptor coordinates and the layout of the haul road, as shown in Tables 1 and 3 for the coal preparation plant and stone quarry, respectively. These data were input to the DCP. The coordinates for the locations of the receptors were based on a local coordinate system. The background dust concentration level, haul road material specifications such as silt content and moisture content and haul truck speed and weight are shown in Tables 2 and 4 for the coal preparation plant and the stone quarry, respectively. These data were used to calculate the haul truck dust emissions using the U.S. EPA's emissions factor for unpaved roads (U.S. EPA, AP-42, 1998). The wind speed and direction data used in the modeling process were the same as those measured during the field study. Each field study day's weather data were input into the DCP for the corresponding modeling comparison (i.e., the August 5th weather data was used for the August 5th model comparison). The weather data were input via an ASCII file. These same data were input into the ISC3 model so that all conditions were identical in order to achieve comparable results. Once the information was entered, the calculations were completed and the results were used in the model comparison.

Table 3 — Stone quarry receptor coordinate and haul road layout information.

Receptors	X-coordinate	Y-coordinate
Station A	953.02	1,017.10
Station B	1,000.00	1,000.00
Station C	1,046.98	982.90
Station D	1,093.97	965.80
Station E	1,034.20	1,093.97
Station F	1,081.18	1,076.87
Station G	1,128.17	1,059.77
Haul road starting point	873.90	726.34
Haul road ending point	1,113.32	1,384.13
Slope of haul road line	2.747	
Y-intercept of haul road line	-1,674.26	

Comparison of stone quarry field study results to modeling results

The comparison of the stone quarry study data is presented in Figs. 2 through 7. Figures 2, 3 and 4 show the comparisons for stations A, B, C and D and Figs. 5, 6 and 7 show the comparisons for stations E, F and G. Table 5 shows the percent differences of the DCP model and the ISC3 model from the field study results. As shown, the DCP model performs better than the ISC3 model. The DCP model has average percent differences of 248% on July 16th, 154% on July 17th and 366% on July 18th, compared to 4,721%, 2,615% and 4,365%, respectively, for the ISC3 model. In all cases for this field study, both models overpredicted the actual results. These results show that the ISC3 model results are 26 to 47 times the actual results, whereas the DCP model results are generally within two to four times the actual results.

Table 4 — Stone quarry field study information (2002).

	July 16	July 17	July 18
Average speed of haul truck, m/s as calculated from field study	6.84	7.39	6.84
Number of haul trucks passing sampling stations during field study	305	262	230
Haul truck weight, st	20	20	20
PM_{10} background dust concentration level (as measured from field study instantaneous data), mg/m^3	0.1628	0.1715	0.3774
Number of wind speed and direction data points recorded	897	845	838
Sampling time of field study, minutes	443	417	414
Haul road moisture content, %	0.26	0.17	0.06
Haul road silt content, %	26.96	20.26	19.50
Haul road material specific gravity	2.85	2.85	2.87

Comparison of coal preparation plant field study results to modeling results

The comparison of the coal preparation plant study data is presented in Figs. 8 through 13. Figures 8, 9 and 10 show the comparisons for stations A, B, C and D and Figs. 11, 12 and 13 show the comparisons for stations E, F and G. Table 6 shows the percent differences of the DCP model and the ISC3 model from the field study results. Again, the DCP model results match the field measurements more closely than the ISC3 model. The DCP model has average percent differences of -1.6% on August 2nd, 249% on August 5th and -72% on August 6th, compared to 507%, 678% and 18%, respectively, for the ISC3 model. The negative percent difference represents underprediction. These results show that the ISC3 model results are generally five to seven times the actual results, whereas the DCP model results, except for August 5th, are generally within two times the actual results. August 6, 2002, was an exception, where the ISC3 model predictions were rela-

Table 5 — Percent difference over (+)/under(–) from field study results of a stone quarry.

		Station							
Date	Model	A	B	C	D	E	F	G	Average % difference
7/16/02	DCP	74	242	249	339	337	243	253	248
	ISC3	1,527	4,664	5,060	5,974	5,996	4,990	4,839	4,721
7/17/02	DCP	51	86	207	161	82	202	290	154
	ISC3	1,288	1,940	3,325	2,529	1,906	3,326	3,992	2,615
7/18/02	DCP	234	334	432	634	178	357	389	366
	ISC3	1,743	4,773	5,466	6,349	3,040	4,785	4,402	4,365

Table 6 — Percent difference over (+)/under(–) from field study results of coal mine preparation plant.

		Station							
Date	Model	A	B	C	D	E	F	G	Average % difference
8/02/02	DCP	-73	-27	19	45	-15	1.5	38	-1.6
	ISC3	-64	466	692	649	568	592	646	507
8/05/02	DCP	42	139	403	458	62	294	348	249
	ISC3	1,004	748	853	498	486	696	460	678
8/06/02	DCP	-75	-84	-70	-70	-88	-61	-58	-72
	ISC3	405	-42	-44	-68	-56	-23	-48	18

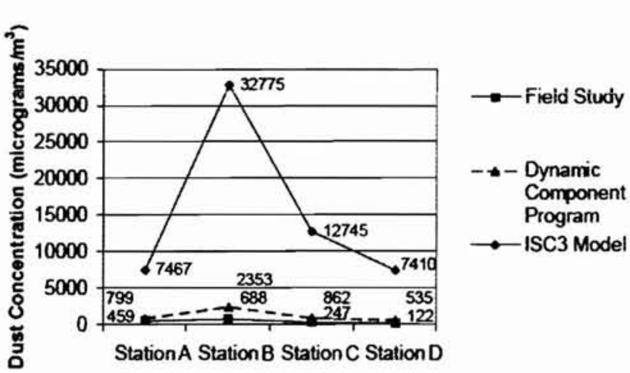

Figure 2 — Comparison of modeling and field study results for stations A, B, C and D at the stone quarry location for July 16, 2002.

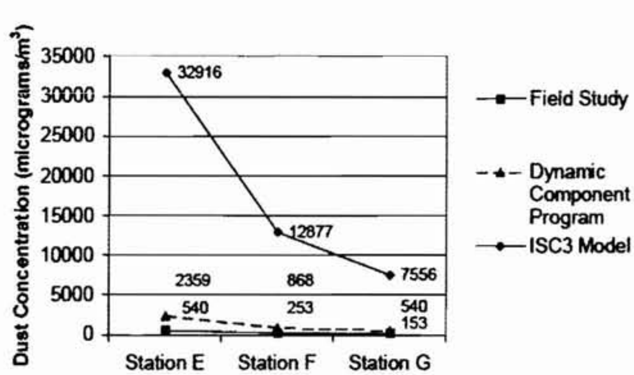

Figure 5 — Comparison of modeling and field study results for stations E, F and G at the stone quarry location for July 16, 2002.

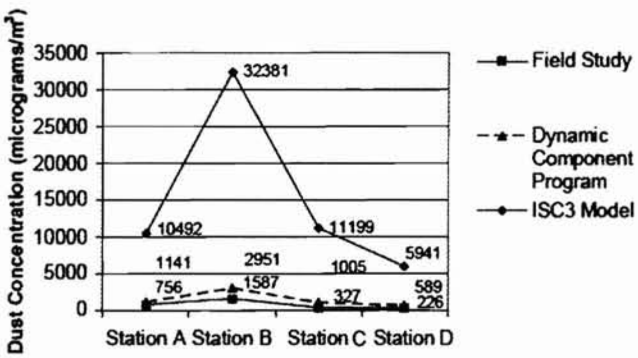

Figure 3 — Comparison of modeling and field study results for stations A, B, C and D at the stone quarry location for July, 17, 2002.

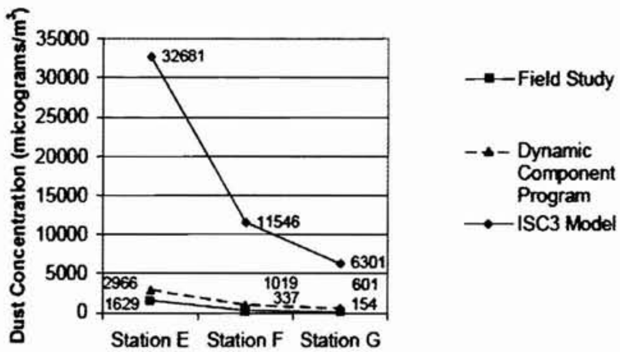

Figure 6 — Comparison of modeling and field study results for stations E, F and G at the stone quarry location for July 17, 2002.

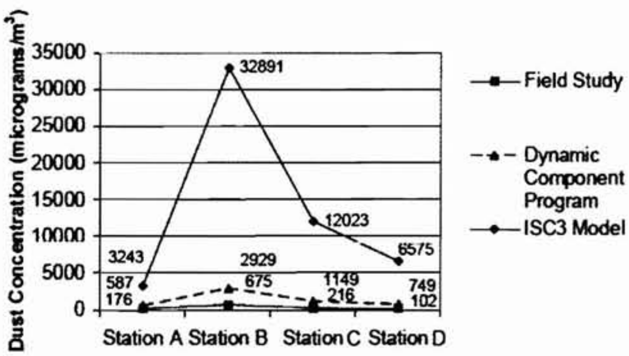

Figure 4 — Comparison of modeling and field study results for stations A, B, C and D at the stone quarry location for July 18, 2002.

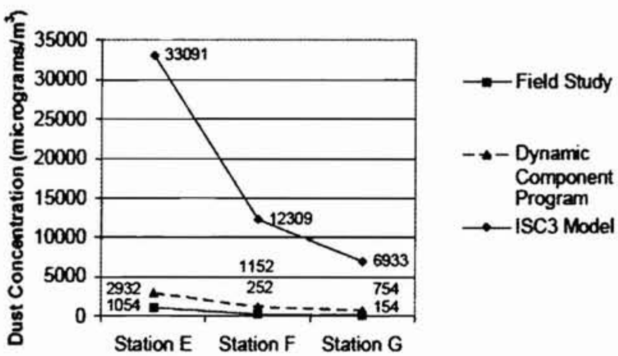

Figure 7 — Comparison of modeling and field study results for stations E, F and G at the stone quarry location for July 18, 2002.

tively close to the actual field study results, with an 18% difference.

Discussion of results

As expected, in the comparison of the modeling vs. field study results, both models overpredicted the thoracic dust concentrations for each day, with the DCP performing better than the ISC3 model. There is an exception (the results for August 6th), where the DCP, on average, underpredicted the actual results. The underprediction of the DCP to actual results on August 2nd is not considered because the 1.6% underprediction is within ±5% error.

The only unusual finding in this study was the stone quarry study modeling results. In comparison to the coal preparation plant study, the magnitude of the overprediction by ISC3 model for the stone quarry is much larger (26 to 47 times the actual results) than the overprediction by the DCP (two to four times the actual results). This magnitude of over-prediction is also much greater than the overprediction of two to five times the actual results documented in past research (Cole and Zapert, 1995; U.S. EPA, Phase III, 1995).

The main cause for the large magnitude of overprediction is the large number of truck passes in the stone quarry field study compared to the number of truck passes in the coal

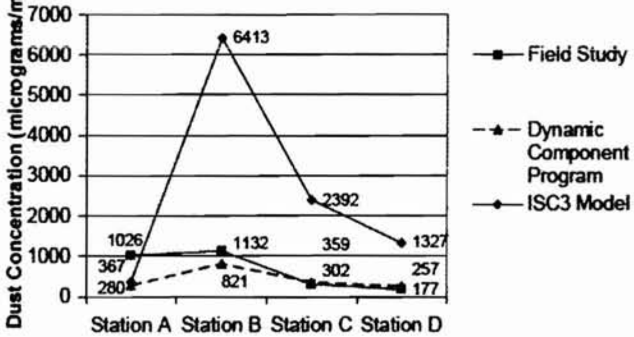

Figure 8 — Comparison of modeling and field study results for stations A, B, C and D at the coal preparation plant location for August 2, 2002.

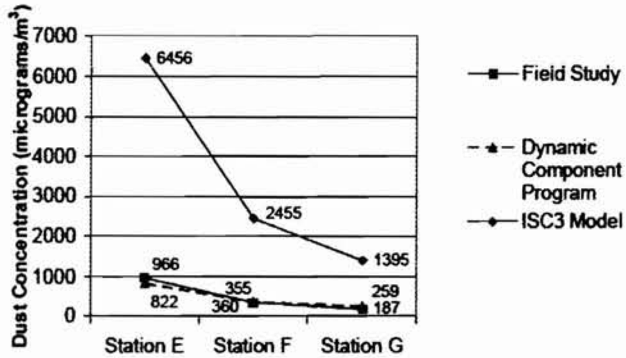

Figure 11 — Comparison of modeling and field study results for stations E, F and G at the coal preparation plant location for August 2, 2002.

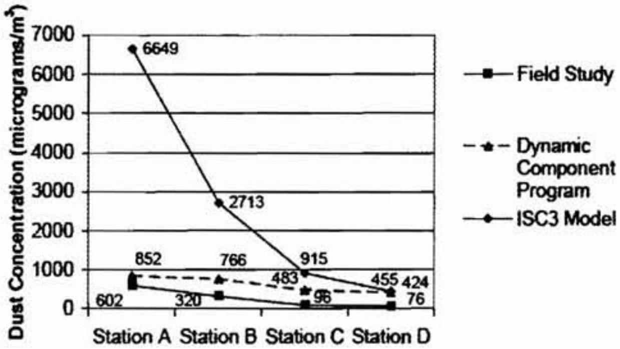

Figure 9 — Comparison of modeling and field study results for stations A, B, C and D at the coal preparation plant location for August 5, 2002.

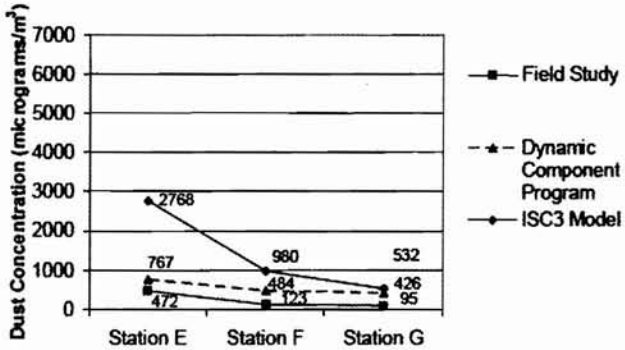

Figure 12 — Comparison of modeling and field study results for stations E, F and G at the coal preparation plant location August 5, 2002.

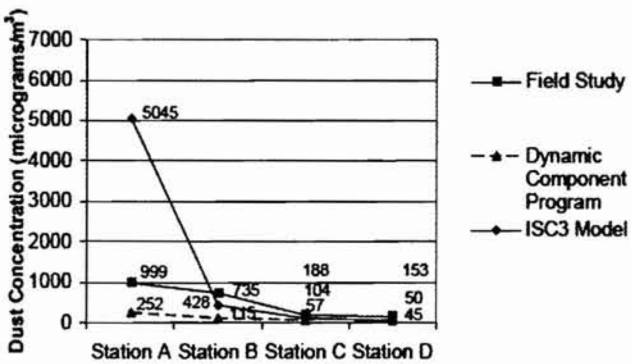

Figure 10 — Comparison of modeling and field study results for stations A, B, C and D at the coal preparation plant location for August 6, 2002.

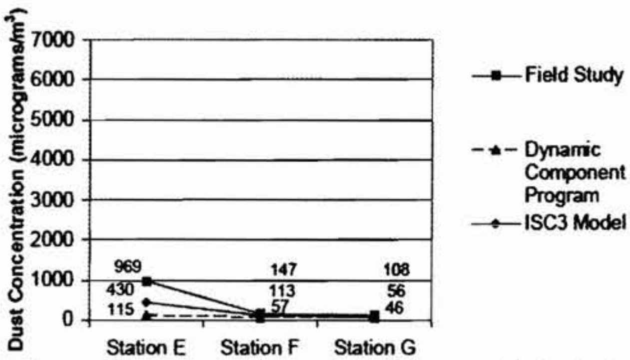

Figure 13 — Comparison of modeling and field study results for stations E, F and G at the coal preparation plant location for August 6, 2002.

preparation plant study. The stone quarry study had three to five times more trucks passing the field study area than the coal preparation plant study. This difference in the amount of trucks seemed to have no effect on the actual results and the DCP. However, it affected the results of the ISC3 model because it (the model) incorrectly employs the haul truck emissions. The ISC3 has been shown in past research to incorrectly utilize the emissions of mobile sources (Reed et al., 2002; Reed, 2003). The ISC3 model uses the emissions from all the trucks and applies them to the entire haul road as a constant emission during the entire time frame being studied. In contrast, the DCP has the capability to apply the emissions only at the time the haul trucks are actually in operation on the haul road. Thus, the DCP's method of using the haul truck emissions is more representative of a haul truck traveling a haul road. This ability to correctly apply the haul truck emissions results in the DCP having more accurate dust dispersion predictions for mobile sources than the ISC3 model.

Other causes of the large overprediction, which would affect both models, may be related to the assumptions of the Gaussian equation, i.e., there is no deposition of PM_{10} and downwind dispersion is negligible (Beychok, 1994). This is clearly not the case in field circumstances, as layers of dust

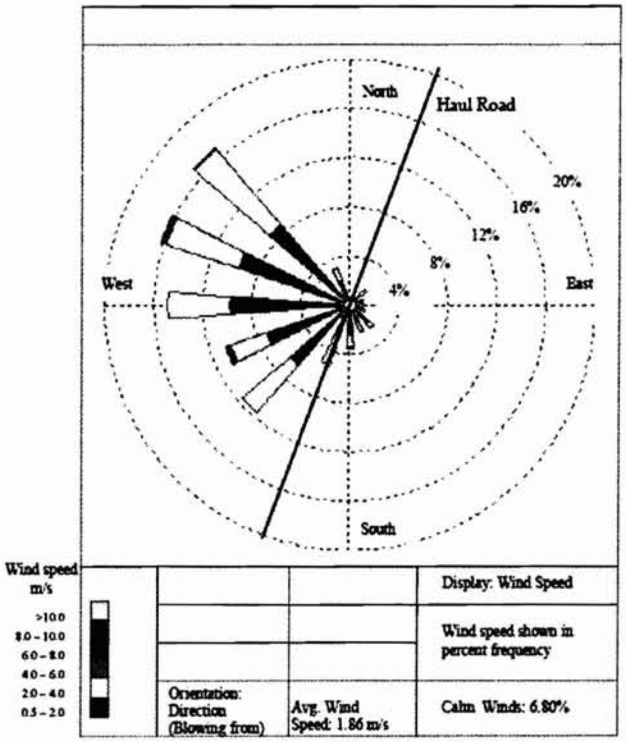

Figure 14 — Wind rose plot for the Stone Quarry on July 16, 2002.

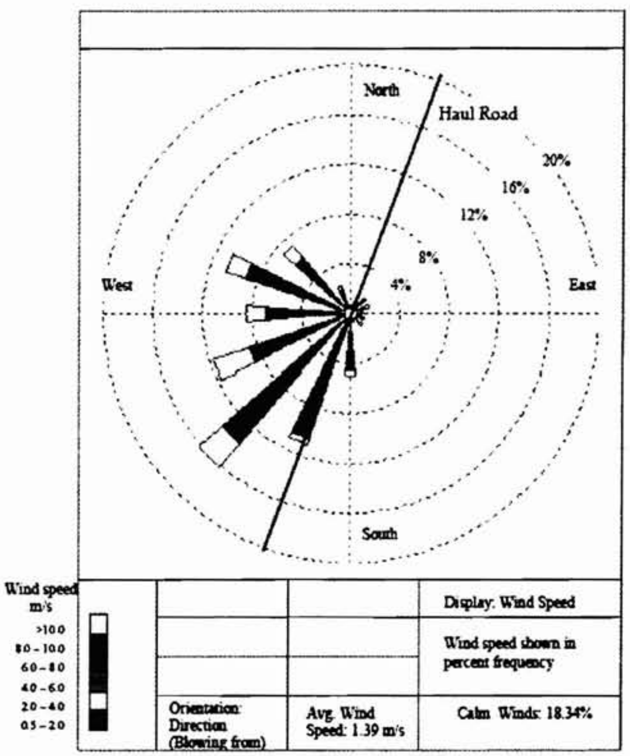

Figure 15 — Wind rose plot for the stone quarry on July 17, 2002.

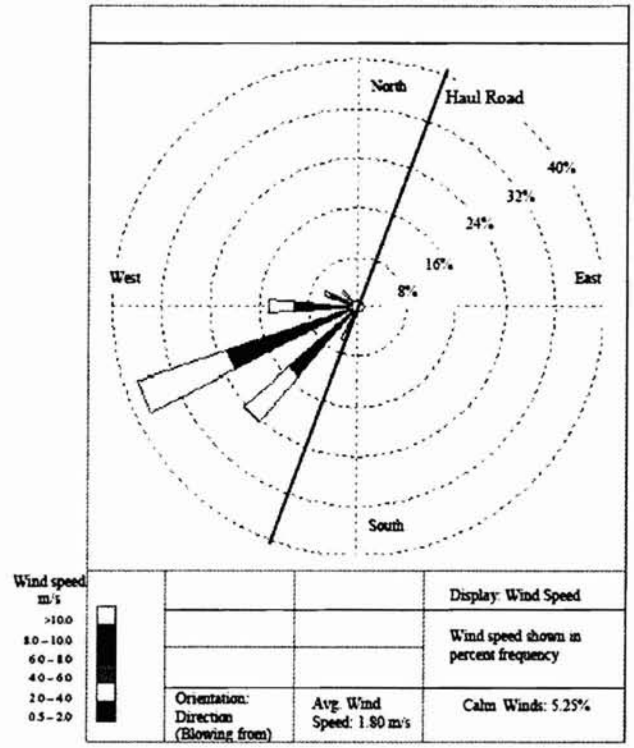

Figure 16 — Wind rose plot for the stone quarry on July 18, 2002.

could be seen on the dust measurement equipment being used in the study and dispersion clearly occurred with the dust plume thinning out as it traveled away from the haul truck. Therefore, if the modeling assumes neither deposition of PM_{10} nor downwind dispersion, then the modeled concentrations may be higher than the actual concentrations, especially the downwind concentrations.

Another explanation for the model overprediction is the fact that the emissions factor equation, used in calculating the amount of PM_{10} emissions that a haul truck generates, overpredicts the amount of PM_{10} generated by the haul truck. Past research by the National Stone, Sand and Gravel Association has pursued this aspect of the overprediction problem and proposed an equation that lowers the amount of emissions created by haul trucks. This equation can be used in place of the emissions factor equation recommended by the U.S. EPA (Richards and Brozell, 2001). Reducing the amount of input emissions into the model will obviously lower the amount of the dust concentrations predicted by modeling.

An issue concerning the emissions-factor equation is that this current study measured dust dispersion from two significantly different types of haul trucks. The stone quarry study measured dust dispersion from over-the-road haul trucks, while the coal mine study measured dust dispersion from off-road haul trucks. However, the emissions factor equation is supposed to correct for this disparity through the use of the weight factor (weight of the haul truck) in the equation (U.S. EPA, AP-42, 1998; Richards and Brozell, 2001).

The shapes of the curves shown in Figs. 2 through 13 have similar trends. They progress from high concentrations to low concentrations as the location becomes further away from the haul road. Station A dust concentrations can be either higher or lower than Station B, depending on wind direction. When Station A is upwind of Station B, then it has a lower dust concentration than Station B. When Station A is downwind of Station B, then it has a higher dust concentration than Station B. Wind speed may also have an effect, but it was not examined because wind speed was not as variable as wind

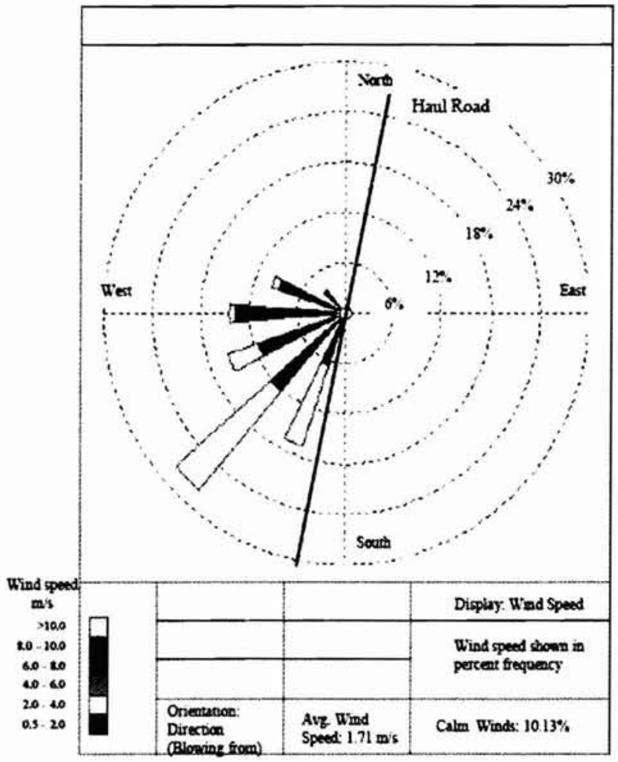

Figure 17 — Wind rose plot for the coal preparation plant on August 2, 2002.

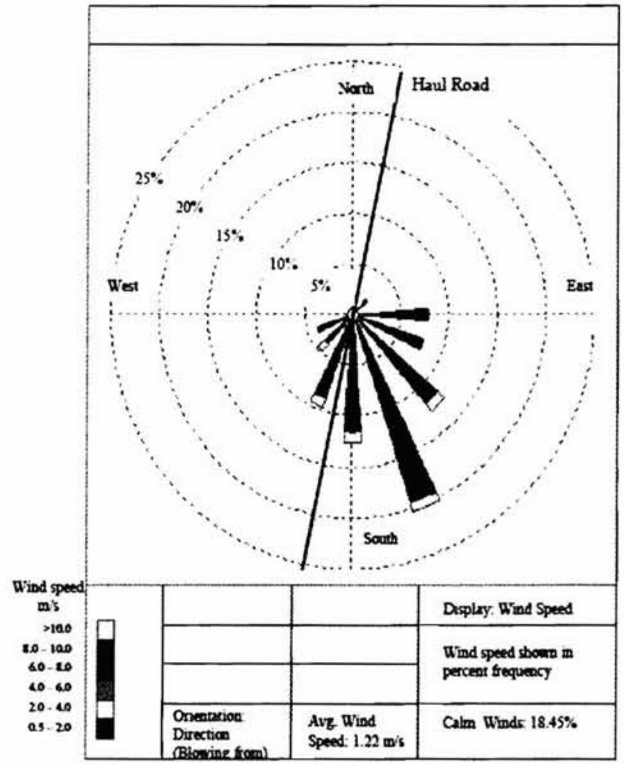

Figure 18 — Wind rose plot for the coal preparation plant on August 5, 2002.

direction in these studies. However, the actual results of the field study showed that Station A seemed to have values that were similar in magnitude to values from Station B. This was thought to be caused by the dust plume from the haul truck having sufficient kinetic energy to slightly counteract the effects of the wind speed and wind direction. Figures 14 through 19 show the wind rose plots that display the different wind directions that occurred during each day of the field studies. It should be noted that the phenomenon of the similar dust concentration values for Stations A and B was predicted by the DCP.

The wind directions in the stone quarry study were favorable for dust sampling, with the wind directions predominantly blowing across the haul road and the dust sampling stations being on the downwind side of the road. This was not the case in the coal preparation plant field study. During this study, the majority of the wind directions were nearly parallel to the haul road and sometimes Station B through G were upwind of the haul road instead of downwind as desired.

Parallel wind directions are expected to cause the dust concentrations for the actual field study results to be higher than if the wind were perpendicular to the haul road. When the wind is in a direction perpendicular to the haul road, the dust sampling stations would collect PM_{10} from only a small segment of the haul road directly adjacent to the measuring stations as the haul truck went by. This segment's size increases as the wind direction goes from perpendicular to parallel to the haul road. When the wind direction is parallel to the haul road, the dust sampling equipment would collect PM_{10} from the haul truck dust plume, which travels the entire length of the haul road, parallel and upwind of the equipment. This action causes the airborne dust to compound upon itself, thus causing higher recorded dust concentrations. This effect can be seen in Figs. 10 and 13, where the DCP and the ISC3 model generally underpredict the actual results on August 6th. The parallel wind effect is also thought to be the reason why the ISC3 model results were closer to the actual results for this day. This effect is closer to what the ISC3 model simulates; the

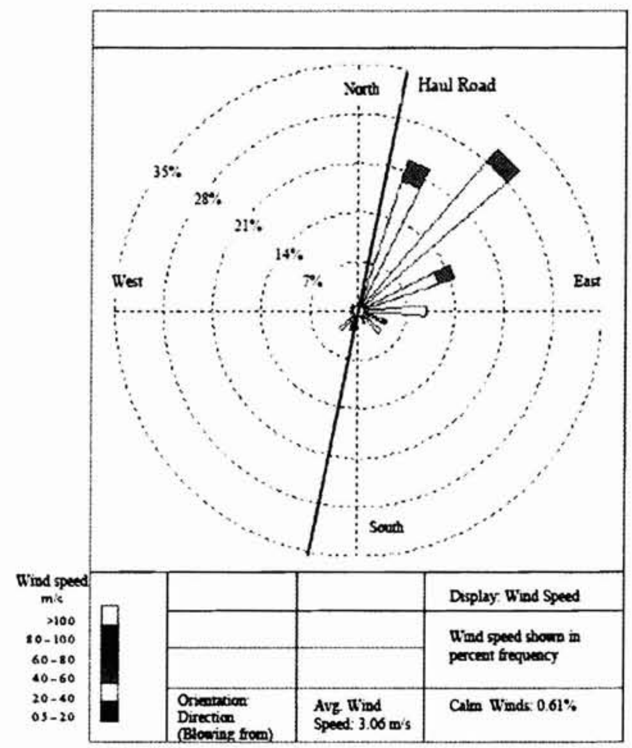

Figure 19 —Wind rose plot for the coal preparation plant on August 6, 2002.

emissions from the entire haul road instead of just a small area of influence at the sampling point. Due to the higher variability of the wind direction, this effect cannot be seen in the graphs of the actual results for August 2nd and August 5th in Figs. 8, 9, 11 and 12.

Conclusion

Modeling dust dispersion is an inexpensive method to identify potential hazardous areas for mine workers. However, for the modeling to be effective, it has to be accurate. The ISC3 model is sufficient for modeling dust dispersion from stationary sources. However, the DCP is on average 85% better at modeling dust dispersion from mobile sources than the ISC3 model.

By comparing the modeling and field study results, it was concluded that the following causes contributed to the overprediction of dust dispersion of the ISC3 model over the actual results. The main reason is due to the inability of the ISC3 model to handle mobile emissions sources. Applying the source (haul truck) emissions over the entire haul road is not representative of the actual emissions from a haul truck. Applying the emissions as a moving point source along the haul road, as accomplished by the DCP, is a better representation of the actual emissions from a haul truck and ensures more accurate results. In addition, as the number of trucks passing the study area increased, the amount of over-prediction by the ISC3 model also increased. This did not occur in the results for the DCP. This effect is related to the previously mentioned method of application of the source (haul truck) emissions in the ISC3 model. The other cause of the overprediction, which would affect both models, is the overprediction of the amount of emissions from the source when using the emissions factor equations from the U.S. EPA. It is obvious that if the amount of emissions input into the model is less, then the resulting modeled dispersion will be less, resulting in a lower magnitude of overprediction by the models.

The results from the modeling comparison demonstrate that the DCP model is clearly an improvement over the ISC3 model. The DCP model generally better predicts PM_{10} dispersion from haul trucks by a factor of two to three. If the frequency of haul trucks is high (over 200 trucks per day), then the DCP's performance becomes significantly better, by an order of magnitude, due to the inability of the ISC3 program to handle emissions from mobile sources. This has been demonstrated for two different mine sites that each have different characteristics, one being a stone quarry and the other being a coal-mining site.

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