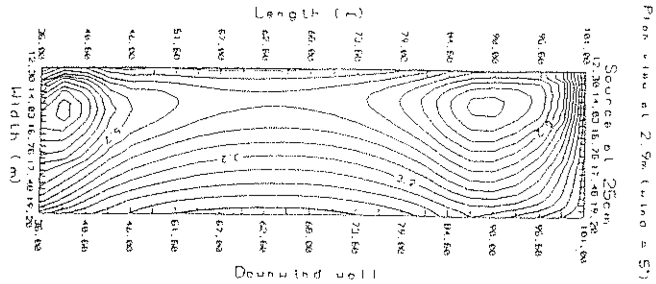

Figure 2: Plan view for θ = 5° at a height of 2.9 m.

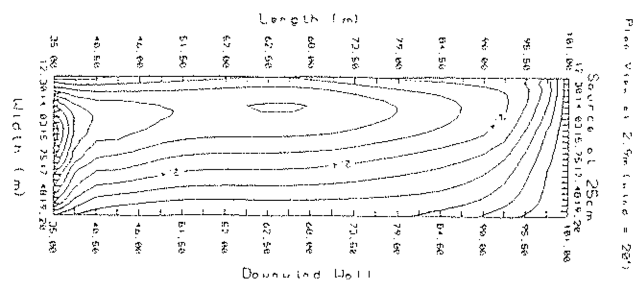

Figure 3: Plan view for θ = 20° at a height of 2.9 m.

For all wind directions tested the maximum concentrations at a height of 0.75 m are found at 2-3 m from the leeward wall. The reason for this consistency is that the vortex, which is induced in the cross-canyon flow, is maintained despite the down-canyon flow introduced as the angle-of-approach increases. Figure 4 shows the effect of the vortex on the concentration field for perpendicular flow.

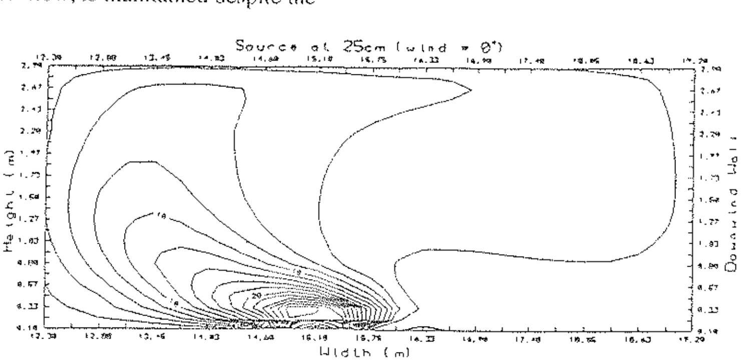

Figure 4: Cross-section at mid-canyon for perpendicular flow.

It has already been noted that peak concentrations occur near the canyon ends. Figure 5 shows the concentrations in the vertical section at 0.3 m from the leeward wall for perpendicular flow. As the angle-of-approach increases the maximum concentration 0.3 m from the leeward wall decreases (Table 1).

Table 1

Angle	0°	5°	10°	15°	20°
Max. Concentration (ppm)	7.7	7.6	4.7	4.3	4.0

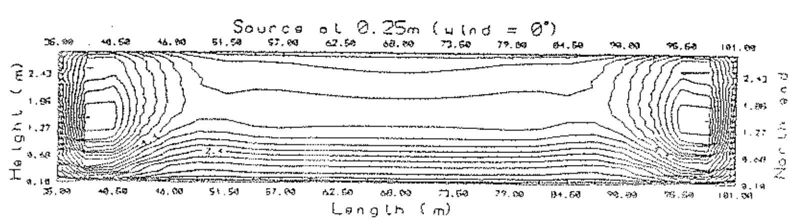

Figure 5: Along-canyon cross-section 0.3 m from the leeward wall, for perpendicular flow.

2.2 Sensitivity to Source Strength, Length and Placement

Tests confirmed that predicted concentrations were directly proportional to source strength, verifying the accuracy of the source simulation. It was found that reducing the length of the source so that it did not extend the full length of the canyon, condenses the area over which significant concentrations are found but does not change the distribution pattern. The actual height of the line source was not a critical factor either. Placing the source (a small volume source) at heights of 0.1 m, 0.25 m and 0.5 m had little impact on concentrations above 0.75 m.

As a further test, the source was placed close to the windward wall (at 1.5 m) rather than at centre-canyon. Flow in that region is stronger and putting the source there, resulted in reduced concentrations but the overall pattern through the canyon did not change appreciably.

2.3 Sensitivity to Canyon Geometry

A previous study (Johnson et al., 1995) has investigated the sensitivity of concentrations to canyon geometry. It established that, near the leeward wall and close to the ground concentrations decreased as the canyon width increased. These results are confirmed by an independent numerical modelling study (Lee et al., 1994) and by a wind tunnel study (Hoydysh et al., 1994). They also found that, increasing the length of the canyon increased the concentrations, and then postulated that the decreased vortex speed at mid-canyon gives rise to this increase.

2.4 Summary

SCAM produced results which suggest that the numerical procedures used are stable with respect to changes in input parameters. Further, the assumptions made in the formulation of the model have not rendered it especially sensitive to input changes and the variations in predictions observed are physically plausible and in accord with other numerical and wind-tunnel studies.

In particular, predictions are not sensitive to changes in wind direction except at canyon-ends. Thus there is value in comparing model predictions with field measurements even though they will be taken in unsteady flow conditions. Of course it will be desirable to choose those periods of least variability.

On the basis of these preliminary modelling studies it was determined that in the field program most measurements would be taken mid-canyon (lengthwise) both near the leeward wall and at centre-canyon (widthwise).

3 FIELD PROGRAM 1 (FP1)

3.1 Skimming Flow Regime

The analysis of the wind data (see Part I) suggested that a skimming flow regime was present with a characteristic vortex flow counter to the prevailing wind direction and essentially decoupled from the ambient flow. This conclusion is counter to the prevailing wisdom which is typically expressed in terms of the relative geometry of the canyon. In this context it is assumed that skimming flow does not occur for aspect ratios less than 0.65. The aspect ratio for FP1 is 0.42.

What flow does SCAM predict for FP1? If vortex circulation is present, then as the approach flow deviates from the perpendicular a spiral (cork-screw) pattern should develop due to the presence of increasing down-canyon flow. To investigate these issues , the wind-flow model was run with approach directions of 0°, 5°, 10° and 20° from the perpendicular. Vertical cross-sections at mid-canyon (Figure 6) show clearly that the model predicts a vortex circulation in each case, indicating qualitative agreement with the observed data. Plan views (Figure 7) show along-canyon flow increasing as the approach angle increases indicating an increasing spiral pattern, again in agreement with observations.

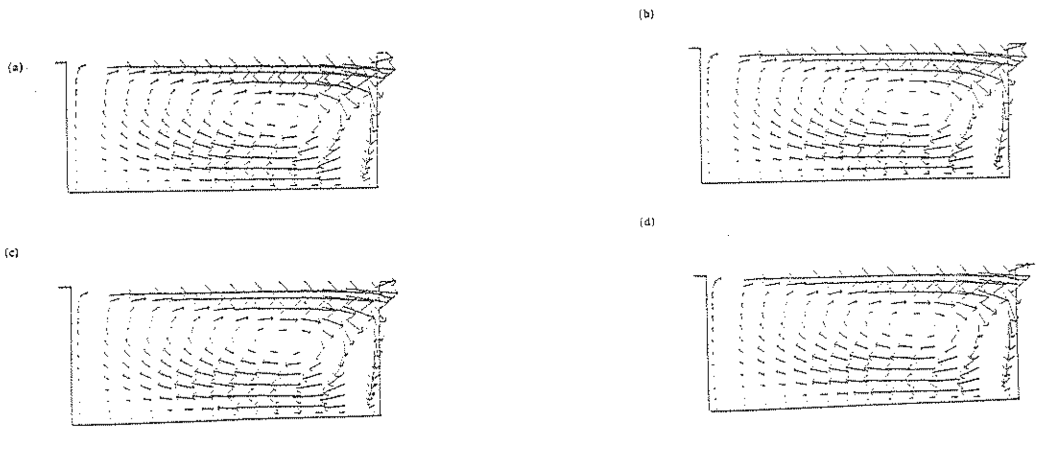

Figure 6: Cross-sections of modelled velocity vectors at centre-canyon; (a) 0°, (b) 5°,(c) 10° and (d) 20°.

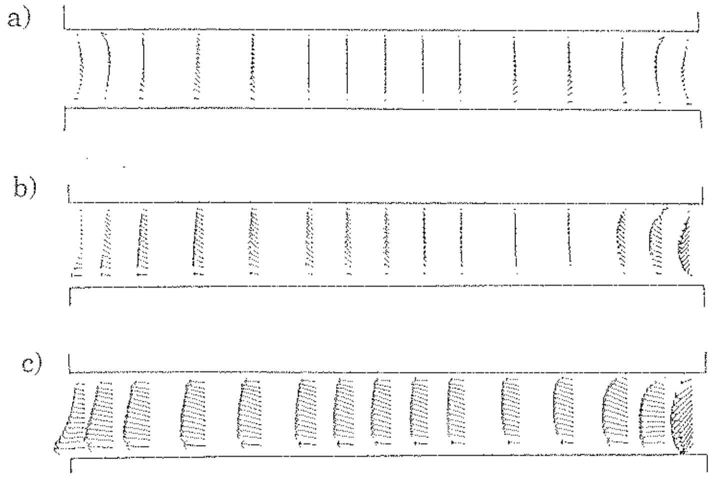

Figure 7: Plan views of modelled velocity vectors at (a) 0°,(b) 10° and (c) 20°

3.2 Scalar Concentrations

In our preliminary studies we have not matched the field program scalar source terms. This will be done later. The simulations reported here are based on a uniform line source running the length of the canyon at the same height as that used in the field program. Thus at this stage we can only compare concentrations in a relative sense.

At the leeward wall the measured field showed high concentrations in the slow moving air near the base of the wall, with lower concentrations at higher levels due to the increased air movement there (Figure 8). Decreases in concentrations were also observed in simulations which used the wind direction averaged over the 30 minutes during which the measurements were taken (Figure 9). In the field program the ratio between the concentrations was 0.78 on the run of 21 September and 0.49 on that of 19 October. For the simulations the ratios were about 0.75 and 0.40 respectively.

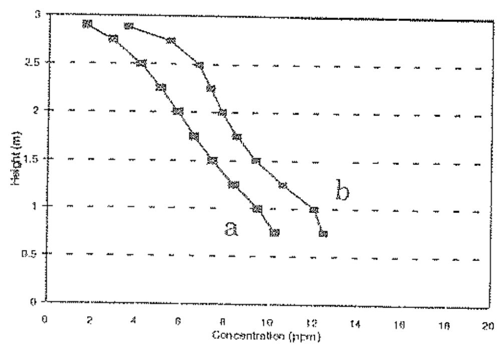

Figure 9: Modelled concentrations at leeward wall on (a) 21 September and (b) 19 October.

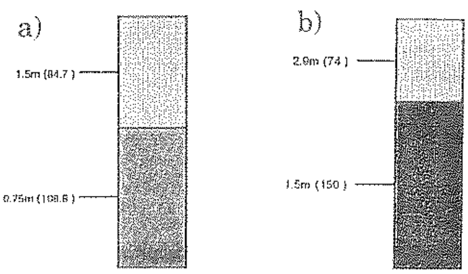

Figure 8: Measured concentrations at leeward wall on (a) 21 September and (b) 19 October.

The fluctuations in the concentration field arising from changes in wind direction were studied further for the run on 19 October, a day with relatively steady perpendicular flow. The mean measured wind direction was calculated (265°) and measured concentrations corresponding to a one-minute average wind direction more than one standard deviation (20°) from the mean were discarded. Coefficients of variation were calculated for four sensors on the reduced data set. SCAM simulations were then run with an upwind profile at each extreme direction (245° and 285°) and the model variation (Ω) calculated. A comparison of these coefficients (Table 2) shows that SCAM predicts (taking the average of the 285° and 245° values) about the same variation as that measured at the lower sensors but less variation than was measured at the higher sensors. Some of the variation in the measurements would be due to wind speed changes rather than directional changes so, in a sense, the model variation is of the correct order of magnitude.

Table 2

	Measured	Model (285°)	Model (245°)
Site	Coefficient of variation (V)	Model variation (Ω)	Model variation (Ω)
ML 1.5	18%	9%	31%
ML 2.9	24%	8%	10%
MC 1.5	19%	9%	21%
MC 2.9	22%	9%	9%

Correlations between different sites within the canyon were also considered. On 21 September concentrations were measured at two sites (ML0.75 and ML1.5) over a period of 30 minutes when the average wind direction was about 215°. The concentrations at the two sites were well correlated ($r^2 = 0.9$) and the linear regression between the concentrations was

$$[ML1.5] = 0.7*[ML0.75].$$

Performing linear regression on the modelled concentrations produced the same relationship.

The literature suggests that highest concentrations at mid-canyon occur when flow is normal to the canyon, and that concentrations increase towards the leeward wall (Wedding et al., 1977 Dabberdt et al., 1991). To investigate these issues SCAM simulations for 19 October were studied. Given a mean measured approach angle of 265°, simulations for angles of 245°, 265° and 285° were used. Figures 10 and 11 show that predicted and measured concentrations are greater near the leeward wall than at centre-canyon, and concentrations decrease with height.

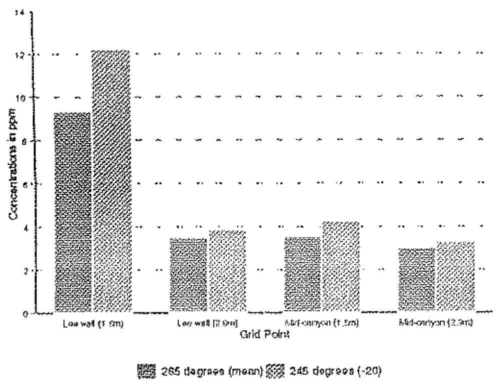

Figure 10: Modelled concentrations at leeward wall and centre-canyon for $\theta = 265°$ and 245°.

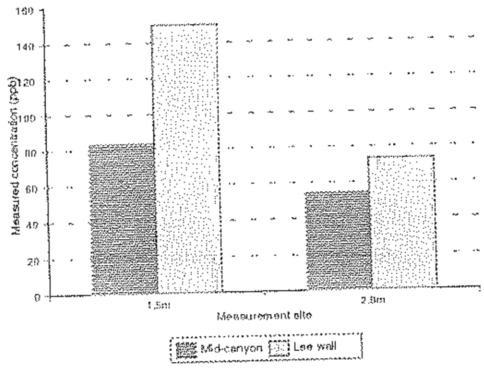

Figure 11: Measured concentrations at leeward wall and centre-canyon for mean $\theta = 265°$.

4 FIELD PROGRAM 2 (FP2)

4.1 Flow Regime

The canyon used in FP2 had an aspect ratio of unity and it was expected that the within-canyon flow would be characterised by a cross-canyon vortex as a component of a skimming flow regime. On an analysis of the measurements from the few sensors within the canyon it was difficult to establish the presence of such a flow. The reason for this was the increased importance of lateral flows. Once established, it appears that the lateral component within the canyon is maintained until overcome by an opposing flow from the opposite direction (see Part I).

The field data suggested that significant lateral flow would be induced once the approach flow was other than perpendicular to the canyon. Simulations with SCAM were performed to test the sensitivity of the predicted flow to variations in approach-angle for a canyon of the dimensions of that used in FP2.

Figure 12 shows plan views of modelled velocity vectors for the given canyon for approach angles of 0°, 5° and 45°. The small shift in flow direction to 5° is sufficient to induce distinct lateral flow. Increasing the angle to 45° dramatically enhances the lateral flow, so much so that any cross-canyon flow is obscured. These predicted flows are entirely in accord with the characteristics of the flows actually observed, even though those flows were quite unexpected and their features suggest that some of the current rather simplistic descriptions of canyon flows may prove to be inadequate.

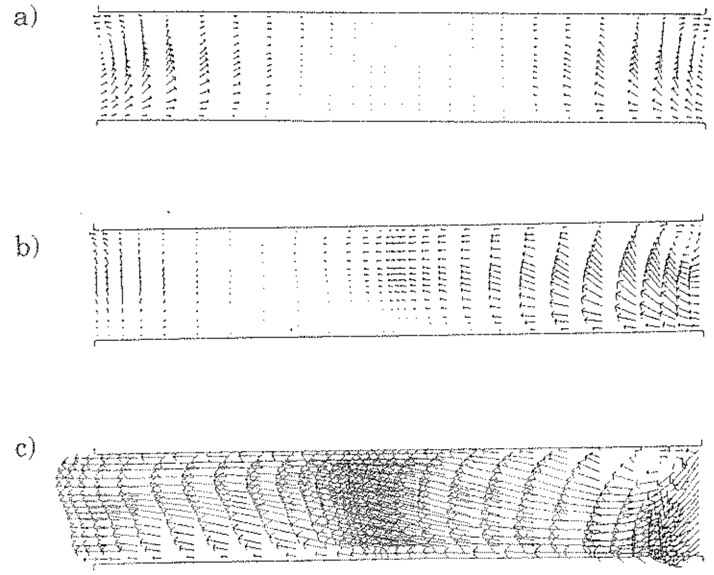

Figure 12: Plan views of modelled velocity vectors at (a) 0°, (b) 5° and (c) 45°.

4.2 Scalar Concentrations

At this point no simulations of the concentration fields of FP2 have been simulated. Due to the results which surfaced from the analysis of the unusual flow fields all of the simulations for FP2 were related to those fields and no work has yet been done investigating scalar dispersion.

5 CONCLUSIONS

(a) SCAM is able to predict the detailed structure of within canyon flows based on a knowledge of the upwind profile and the canyon geometry.

(b) SCAM shows promise of being able to predict the dispersion of scalars within canyons, especially to identify the locations of maximum concentrations. Further evaluation of this aspect of the model should be pursued using the data gathered in the field programs.

(c) SCAM simulations indicate that the assumption that canyon aspect ratio is the sole determinant of flow regime requires further study, in particular through a series of model runs using selected canyon geometries.

6 ACKNOWLEDGMENTS

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