THE IMPACT OF ROAD STRUCTURES AND BUILDINGS ON URBAN AIR QUALITY

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1. Street canyons
2. Highways with and without noise barriers
3. Depressed/elevated highways
4. Vegetative barriers
5. Urban meteorology
Depressed Road Effects

USEPA Wind Tunnel, Heist et al. (2009)
Depressed Road Effects

Near surface concentration (Heist et al., 2009)
Depressed Road Effects Modeling (van Ulden, 1978)

\[
C(x, z) = \frac{A}{q} \frac{\exp \left( - \left( \frac{Bz}{\bar{z}} \right)^s \right)}{U^2} \exp \left( \frac{\beta}{2} \right)
\]

\[
\bar{z} = \left( a \frac{\beta u^*}{U_r} z^p x + bh_0^{p+1} \right)^{\frac{1}{p+1}}
\]

\( h_0 = \text{Initial mixing height} \)

\( \beta = \text{Turbulence enhancement factor} \)
Depressed Road Effects Modeling

Model estimates for flat and 6 m depressed highway compared with measurements

<table>
<thead>
<tr>
<th>Case</th>
<th>$h_0(m)$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLAT</td>
<td>1.2</td>
<td>1.00</td>
</tr>
<tr>
<td>D690</td>
<td>4.8</td>
<td>1.12</td>
</tr>
<tr>
<td>D630</td>
<td>3.6</td>
<td>1.37</td>
</tr>
<tr>
<td>D990</td>
<td>5.9</td>
<td>1.31</td>
</tr>
</tbody>
</table>
Vegetative Barriers

Downwind concentrations can increase or decrease depending on the relative magnitudes of “blocking” and “stabilizing” effects.
Vegetative Barriers (Heist et al., 2016)

Wind

\[
\frac{x}{H} = 4
\]

\[
\frac{x}{H} = 5
\]
Sacramento Field Study

Two sites: 5 m barrier extending over 500 m on the east side of CA-99 highway, and a barrier of the same height with a row of 15-18 m high pine trees planted next to it extending over 200 m along the highway.
Sacramento Field Study-Results

The graphs illustrate the concentration levels over time under different conditions:

- **Top-left graph:**
  - X-axis: Time
  - Y-axis: Concentration #/cm³
  - Legend: Wall, Wall+Vegetation, Background
  - Observations: Concentration peaks at certain times, with Wall+Vegetation showing higher variability.

- **Top-right graph:**
  - X-axis: Time
  - Y-axis: Concentration #/cm³
  - Legend: Wall, Wall+Vegetation, Background
  - Observations: Lower concentration levels compared to the top graph, with Wall+Vegetation showing a consistent trend.

The graphs indicate the impact of walls and vegetation on concentration levels during the study period.
Sacramento Field Study - Results

Graph 1: \( C_{WV}/C_W \) vs. Upwind wind speed (m/s)

Graph 2: \( \sigma_{WV}/\sigma_W \) vs. Upwind \( \sigma_W \) (m/s)
Sacramento Field Study-Modeling

Adapted solid barrier model
1. Decreased entrainment into wake
2. Decreased dispersion above wall-\textit{stabilization}
3. Increased effective height of barrier-\textit{blocking}
Urban Micrometeorology (Luhar et al., 2006)

Internal boundary layer model

\[
\frac{dh}{dx} = \frac{\sigma_w}{U} \varphi \left( \frac{h-d}{L_u}, z_{ou} \right)
\]

\(L_u = \infty\) when \(L_r > 0\)
\(L_u = L_r\) when \(L_r < 0\)

\[U_u(h) = U_r(h)\]

\[
u_{*u} = \frac{kU_u(h)}{\ln \left( \frac{h-d}{z_{ou}} \right) + \varphi_m \left( \frac{h-d}{L}, z_{ou} \right)}
\]
A Campbell scientific CSAT3 sonic anemometer measured the three components of the wind speed vector and the sonic temperature at 10 Hz on the roof of city hall. Another sonic anemometer was placed at Riverside airport, about 7.8 km southwest from city hall, at 2.7 m above ground level. The micrometeorological measurements were made continuously between July 30 and September 9, 2015.
Urban Micrometeorology-Results

Model estimates of rooftop friction velocity compared with observations. Left panel: Accounts for stability. Right panel: Assumes neutral conditions at both locations.
\[
\frac{u_{*\text{urban}}}{u_{*\text{rural}}} = \left( \frac{z_{0\text{urban}}}{z_{0\text{rural}}} \right)^\alpha
\]

\( \alpha = 0.14 \)

\( \sigma_w = 1.3 u_* \)

Can be derived from the IBL model. Fisher et al. (2006) recommend \( \alpha = 0.07 \)
Conclusions

1. Dispersion effects associated with depressed highway can be modeled through simple modifications of flat terrain model.

2. Need more work on the effects of vegetative barriers - increased downwind concentrations need better explanation.

3. Need better models to estimate urban micrometeorology - stability effects can be neglected?