Chapter 2
Modelling Air Pollution in Sixteenth Century Lüneburg

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As part of the workshop the students were presented with an exercise concerned with estimating the concentration and deposition of air pollutants around the salt works of Lüneburg during the sixteenth century.

We began with a short exercise that allowed students to reflect on issues that concerned late medieval Lüneburg from the perspective of influential civic groups (mostly merchant's guilds). Students were divided into groups representing urban guilds of: (1) saltmakers, (2) doctors and surgeons, (3) carters and haulers, (4) butchers, (5) bakers, (6) mayor and other elites. They discussed and ranked issues of concern to their guild considering issues such as: wood, food, trade, water, smoke, war and health or plagues.

During an excursion to the German Salt Museum at Lüneburg with an original boiling house from medieval times the students convinced themselves of the severe working conditions in the small rooms containing the boiling pans made out of lead. Figure 2.1 gives an impression of these working conditions, clearly indoor pollution was an important topic those days not because of incomplete combustion of the fire wood but also because lead from the pans entered air in considerable amounts.

Later in a computer laboratory they were provided with copies of SCILAB (similar to MATLAB) and two programs and their linked functions to model pollution. This allowed atmospheric dispersion of the pollution from the salt works to be modelled. Two approaches were adopted:

1. The average deposition flux of large particles was determined by considering the fall rate of the particles along with their dispersal by wind – (deposition model).
2. The concentrations in the air was estimated from a simple Gaussian plume models – (plume model).

The results gave a picture of air pollution in Lüneburg when it was a great salt producing town.

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Fig. 2.1 Worker at a lead pan in a salt boiling house. Photographic reconstruction of the medieval working conditions (Photo provided by Lüneburg Marketing)

2.1 Emissions

The models required that we estimate emission from the salt works Qp from the fuel use. This was available from historical data for the annual firewood use and overall salt production (Witthöft 1989; Lamschus 1993). Emission factors were required for relevant pollutants to determine emissions. These were taken as:

- Soot from wood 12 g/kg
- Particulate matter from wood 15 g/kg
- NOx from wood 0.2 g/kg
- PAH from wood 41,000 ng/kg
- Benzo(a)pyrene 1,200 ng/kg
- PCB from wood 550 ng/kg
- PCDD/PCDF from salt production 130 ng/kg – this has been enhanced tenfold over typical values for wood to allow for the large chloride concentration in the salt works

2.2 Deposition Model

In the case of long term deposition of particulate material we calculated the particle deposition around the sources using the early Bosanquet et al. (1950) model for the dispersion and deposition of large particles about a point source. This allows the flux of particles to the ground to be determined from as:

$$F_{bosanquet} * F_{wind} * Q_p * a * p * p/He^2$$

Input, along with some initial guesses of values, includes:

- x = distance from source
- Q_p = source strength in g/s
- r = 25; particle radius in μm
- ρ = 1; particle specific gravity
- He = 10; emission height in m
- p = 0.05; dispersion factor
- u = 4.6; average wind velocity in m/s
- f_i = the wind probability along eight compass points. N, NE, E, etc.
- v_f = fall velocity this includes Stokes settling plus the Cunningham correction with radius, mean free path (La, 0.065) in μm, i.e.,
- $\mathrm{vf} = 1.210^{-4} * \rho * \mathrm{r} * \mathrm{r} * (1 + \mathrm{La/r} * 1.26 + .4 * \exp(-1.1 * \mathrm{r/La}))$

There are also two functions to be executed in SCILAB,

1. The Bosanquet function treats the fall of the particles to the ground and utilises the gamma function (Γ) available in SCILAB:

$$F_{\mathrm{bosanquet}} = (v_f/p*u)*(\mathrm{He}/p*x)(2+v_f/p*u)*\exp(-\mathrm{He}/p*x)/\Gamma(1+v_f/p*x)$$

2. F_{wind} which determined wind direction in 45° sectors at each point on the grid from an averages from a year's modelled meteorological data.

The calculations, although not especially difficult, can be rather tedious, particularly if we need to determine the concentration and deposition at a range of locations and do this for many salt-pans (49 were used in the modelling exercise). SCILAB allowed these to be done rapidly for multiple pans and for many deposition points and then plotted out as contoured deposition fields, using one of the numerous plotting functions available in SCILAB.

2.3 Plume Model

The concentration of pollutants downwind from the salt works is determined using a simple plume model (e.g., Pasquill and Smith 1983). As the emission height is very low with little plume rise so a ground level source approximation was adopted (although this simplification was not possible under the deposition model).

$$c = Q_p/(\pi\sigma_y\sigma_z U) * \exp(-\,y^2/(2*\sigma_y))$$

c is the concentration and the whole expression has to be multiplied by a conversion factor to go from g m^{-3} to more comprehensible units such as from μg m^{-3} or ng m^{-3}.

y is the distance off the plume axis in metres, z is the height above the plume axis in metres, σ_y and σ_z are measures of dispersion in the cross-wind and vertical directions (perhaps thought of as standard deviation widths). These are functions of the distance from the source and the atmospheric stability, usually expressed as the Pasquill class. In the model these are calculated by a function called pasquill.

The meteorological input to the model for came from hourly meteorological data for the region Lüneburg (interpolated to the centre of a grid at: 10.4 °E, 53.25 °N) which was calculated using the MM5 model driven by ERA 40 reanalysis for the year 2000. It contained wind direction (degrees at 10 m), wind speed (m/s at 10 m), temperature at 2 m in K and incoming short wave radiation in W m^{-2}.

2.4 Results

The results suggested that the largest deposits of particulate materials occurred to the north east towards St Lambeth's Church, now dismantled. In Fig. 2.2 this is shown as an overlay on an inverted version of the pictorial map from Fig. 1.2. It was possible residual carbon and other recalcitrant deposits might be evident from soil cores. We also discussed the possibility of deposition of polychlorinated compounds in the fields to the beyond the nearby city wall. Plans were also developed for how this work might be used in a small brochure on pollution impacts for visitors to the Deutsches Salzmuseum.

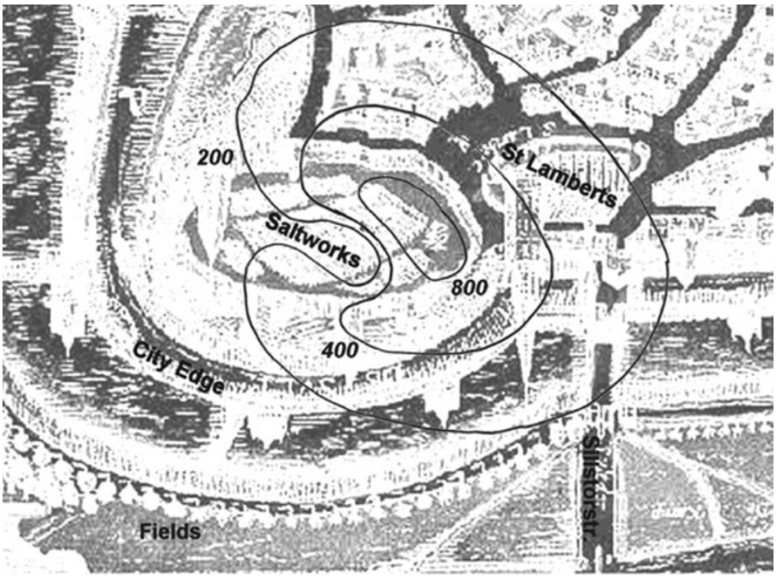

Fig. 2.2 The annual deposit of soot estimated from the model (g m^{-2}) as estimated from the deposition model plotted on an inverted and negative image of the pictorial map from Fig. 1.2

Although the models were not sophisticated it gave the students a flavour of what might be done with historical data. Students with experience of dispersion modelling had many, quite justifiable objections to the simplicity, those who had not done modelling or even programming before were excited with their achievements.

References

Bosanquet, C.H., W.F. Cary, and E.M. Halton, 1950: Dust deposition from chimney stacks, Proc. Inst. Mech. Eng. 162, 355–365.

Lamschus, C., 1993: Die Holzversorgung der Lüneburger Saline in Mittelalter und früher Neuzeit. In: Urbanski, S., C. Lamschus, G. Ellermeyer (eds.), Recht und Alltag im Hanseraum. De Slute, 4, 321–333.

Pasquill, F. and F.B. Smith, 1983: Atmospheric Diffusion, 3rd ed., Wiley, New York.

Witthöft, H., 1989: Das Maß der Arbeit an Sole und Salz. In C. Lamschus (ed.), Salz – Arbeit und Technik, De Sulte, Luneburg, 3, 69–82.

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