Sulfur Pollution : An Environmental Study of Welland, Ontario

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ABSTRACT.—The distribution of sulfur as an environmental pollutant is analysed in the vicinity of Welland, Ontario. A biogeochemical-cycle approach enables areas of excess accumulation to be compared among all linked ecosystem components. Although the patterns of distribution are similar, the amounts of sulfur accumulated in different ecosystems, grassland and woodland, show marked contrasts. The significance of these findings to urban and rural land-use planning is considered.

THE PAST DECADE has produced a tremendous explosion of information about all aspects of pollution. In spite of this there seems to be a major gap in our knowledge or an inability to apply our knowledge of the effects of pollutants within a total environment. This is particularly true in terms of terrestrial environments, yet there is a large volume of material on the effects of individual pollutants upon the separate components of these environments.

Although environment-impact statements are often a prerequisite for planned development of the human environment, the spatial impact of pollution upon the environment is often neglected. With the current rapid rate of urban growth in such places as southern Ontario, the impact of the urban physical environment system upon rural areas will undoubtedly increase.

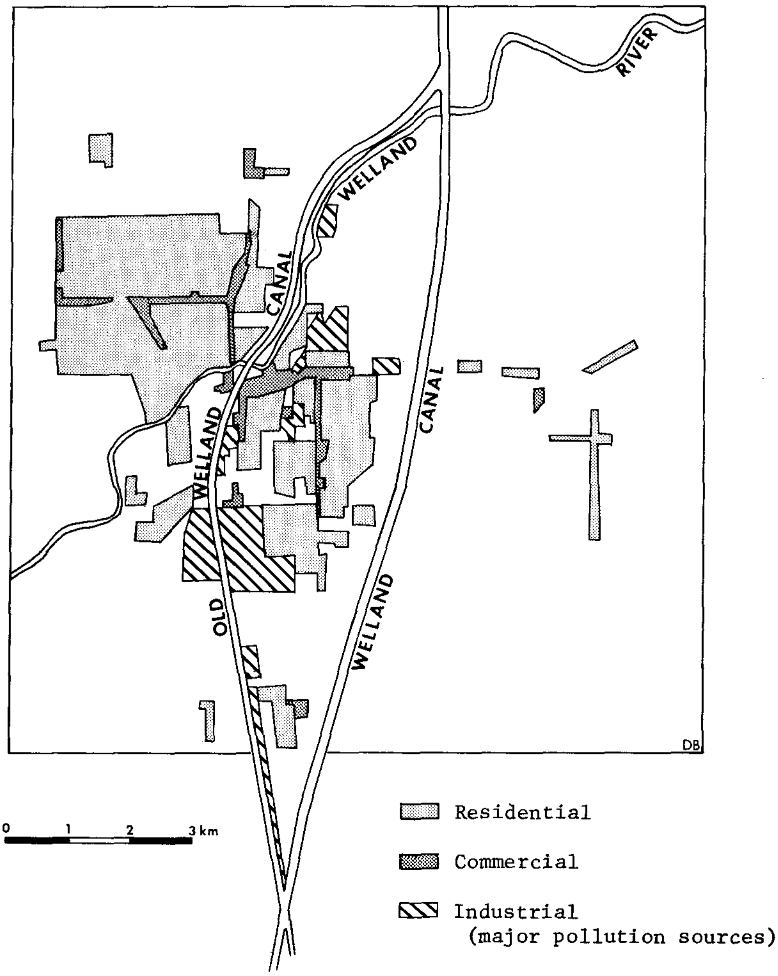
This impact will be most evident in the rural/urban fringe areas of existing urban centres. Yet it is also in these fringe areas that there will be the greatest demands for residential expansion, recreational facilities, and improved standards of environmental quality. This is a report on an attempt to identify the impact of one pollutant, sulfur, upon the total physical environment of Welland, Ontario, and to show how an integrated approach to such a problem can benefit the planning of urban expansion and amenities in the surrounding area.

THE AREA

The city of Welland, Ontario, and its immediate hinterland provide an ideal site for a spatial impact study. Welland is a moderate-size urban center (population about 50,000), which is heavily industrialized, having several major steel-producing and metallurgical industries centrally located in an elongated belt paralleling the Old Welland Canal (fig. 1). Furthermore, the city is sufficiently isolated from other major urban/industrial centers such as Hamilton, Ontario (48 km northwest) and Buffalo, New York (24 km east) to remain reasonably free from any influence from such centers. The Welland area also lacks any major topographic barriers — being located on the Haldimand Clay Plain and at a point sufficiently far inland to avoid any significant lake-breeze effects from either Lake Erie (10 km south) or Lake Ontario (22 km north).

It is an area of declining agricultural importance, yet there remain several viable truck farming operations to the northwest. Soils are generally rather poorly drained clays, clay loams, and silty clay loams. Locally they are low-quality soils, but in a broader regional or national context they are classed as

Figure 1.—The city of Welland, Ontario, showing the distribution of major urban land-use types.



soils with only moderate limitations to their future re-use and are therefore of reasonable potential.

Residential expansion is currently thrusting in a northward direction, but further expansion is likely to be to both east and west of the built-up area. Ribbon development is now a common feature along many of the rural roads, and increasing housing demands within the region will no doubt heighten the problem.

Furthermore, to accommodate this expanding urban population, the area (fig. 1) contains five separate locations with high recreational potential, three areas that are unique biological sites, and the banks of the Welland Canals with their recreational potential *(Philips Planning and Engineering 1971a)*.

Planners of human space and environmental quality should be aware of the condition of the physical environment because this will directly affect the amenities outlined above. Since all these amenities are themselves components of the environmental system, it follows that man's impact upon this system (in this case as pollution) should be undertaken from the point of view of a system analysis of the total environmental system. This can be achieved through an ecosystem analysis.

THE APPROACH

An ecosystem approach should provide the most substantial and meaningful studies of environmental pollution *(Moss 1976)*. In this way the biogeochemical cycles, which are a natural functioning part of any ecosystem, can be used as models that naturally perform an integrative function in linking all environmental components. Excess quantities of any biogeochemical element that can be shown to disrupt the normal functioning of any ecosystem can be said to be pollutants. In addition, the biogeochemical cycles provide the necessary information about the precise form of the pollution element to be measured in any one ecosystem component.

By the established pathways taken by such elements, the links from component to component can be identified. At the same time a knowledge of the normal concentration of each element in each component can be used as a measure against which excess concentrations may be noted. It is the effects of such excesses that are considered pollution. Measurement of the distribution of concentrations would therefore identify the spatial impact of a pollutant upon an area.

SULFUR IN THE WELLAND ENVIRONMENT

The approach outlined above will identify the sulfur cycle as a pollution model to be utilized in an environmental context. In almost every ecosystem, sulfur is made available quite naturally either by weathering of bedrock or by absorption of gaseous sulfur from the atmosphere. This system is disrupted in locations where excess amounts of sulfur are injected into the atmospheric component, primarily as SO_2, as a result of fossil fuel combustion and industrial processes. This may be viewed in ecosystem terms as a new pathway introduced into the sulfur cycle, that is, sulfur from the lithosphere reaching the biotic component via the atmosphere in much greater quantities and over a much shorter time span than it possibly could under natural circumstances *(Moss 1976)*.

The sources of excess sulfur in Welland are primarily industrial (fig. 1). In 1968 (the last year for which complete data are available) some 1903 tons were injected into the atmosphere. Of this total, 1,701.5 tons were emitted by industrial sources *(Ont. Dep. Energy and Resour. Manage. 1968)*. This survey of atmospheric sulfur was conducted for March through June, using 20 sites within the built-up area. The results obtained by the lead-peroxide method show a change from winter to summer concentrations with values as high as 1.20 mg SO_3/100 cm^2/day immediately to the east of the main source. More significant is the spatial pattern. In each month the highest values occur to the east, downwind of the major pollution sources. However, a secondary area of moderately high concentrations with values between 0.50 and 0.70 mg SO_3/100 cm^2/day is always present to the west of the Old Canal and extends over the western residential area and into the rural zone. A sharp decrease in values is encountered to the east of the main industrial zone, and a more gradual decline in values to the north and south.

From September 1973 to January 1974, I extended the survey area, using 15 stations primarily to the east of Welland and extending several miles into the rural area. The use of Huey plates provided data similar to that of the 1968 survey and showed the highest values obtained to be 1.22 mg SO_3/100 cm^2/day in January 1974 for the site equivalent to that mentioned above for the 1968 survey. Again the highest values of SO_3 were immediately east of the main source, and values decreased at varying rates from this peak. One major deviation from this pattern, however, is encountered at distances approximately 4.8 to 6.4 km east of the source, where a zone of secondary concentration is encountered.

If the results of the two surveys are now combined to produce a pattern indicative of long-term conditions, then the distribution of atmospheric sulfur in the Welland area appears to be one of three fairly well defined and distinct areas of concentration (fig. 2). The most evident is the zone of high values encountered immediately east (downwind) of the major source. Here values greater than 1.00 mg SO_3/100 cm²/day are encountered. This area is separated from the other two zones, which are due east and west, by troughs of fairly low mean values. Both secondary concentrations indicate values in the range > 0.50 to < 0.75 mg/100 cm²/day. The area of secondary concentration to the east appears to be less prominent in fig. 2. than it actually is in each month because of its north-south migration over 4.8 or 6.4 kms. at different months.

Anthropogenically - produced atmospheric sulfur has several possible fates. Some will undoubtedly drift outside the immediate area, but the natural pathway for this atmospheric sulfur is to enter the biotic component of the environment either as gaseous SO_2 absorbed by soils and vegetation or as $SO_4^{=}$ deposition, mainly in precipitation to the soil surface and subsequently to plant roots *(Moss 1976, 1975a)*.

Soil samples from the A1 mineral soil horizon were collected from sites within 8.5 km of the main sources of atmospheric sulfur and were analyzed for $SO_4^{=}$ content by the barium sulfate turbidimetric technique. A total of 26 sites were used, the majority to the east of the city. When results are presented in graph form and plotted against distance from the source, some significant patterns emerge (fig. 3). The data show values to decrease with increasing distance from the source to a point about 4.0 km and then subsequently rise to a second and lower peak at about 6.4 km and then decrease. When woodland soils are distinguished from grassland soils this trend is particularly marked in woodland soils, the grasslands showing greater variation near to the source.

Figure 2.—Schematic representation of the seasonal average concentration of atmospheric sulfur over Welland and adjacent rural areas. Isolines drawn at 0.10 intervals, show SO_3/100 cm²/day.

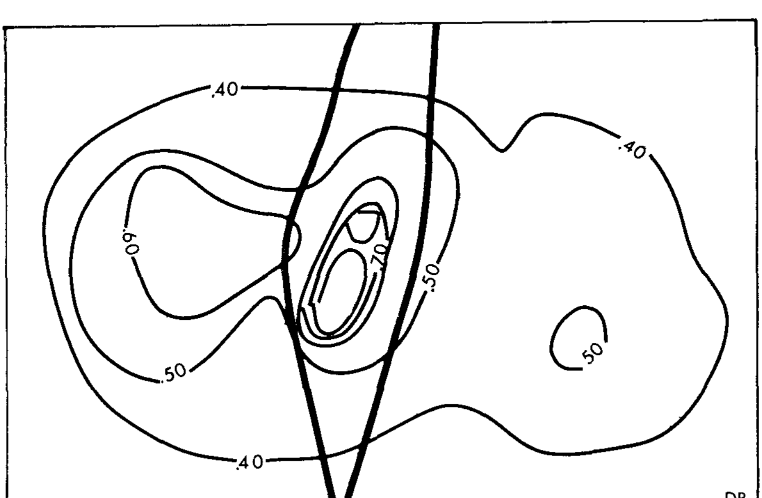
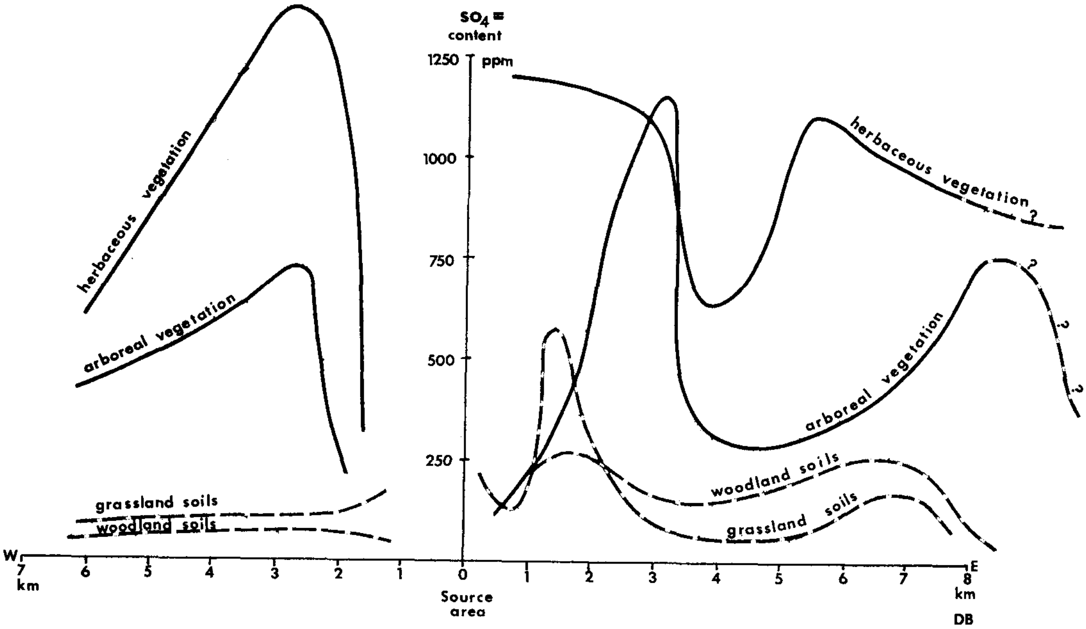


Figure 3.—The generalized distribution of sulfate in soils and vegetation samples with respect to distance from the main source area.



Data to the west are too sparse for any significant identification of trends because of fewer possible sampling points. The mean value for all soil $SO_4^=$ values is 134 ppm, which can be subdivided into one of 160 ppm (range 18 to 726 ppm: n=13) for grassland soils and 134 ppm (range 50 to 284 ppm: n=3) for woodland soils.

Vegetation was analyzed for $SO_4^=$ in related surveys, one of herbaceous vegetation growing in abandoned fields and one of leaf samples from woodland sites. The results of these analyses are included in figure 3. Complete data for both soils and vegetation and the cartographic presentation of results have been published *(Moss 1975a)*. Sites were the same as those used for soil sampling.

Herbaceous vegetation samples consisted of clippings of $1m^2$ quadrats, five for each location. Every effort was made to ensure uniformity of herbaceous species and age of abandonment.

The results for herbaceous vegetation show that, except for two points about 4.0 km from the source, the amounts decrease very slightly over 8.0 km in an easterly direction. Values obtained are consistently between 1,000 and 1,280 ppm $SO_4^=$ except at 4.0 km, where values fall to 588 and 802 ppm. To the west, the three locations sampled indicate a rise from 267 to 1,400 ppm over 0.6 km and a drop to 527 ppm at 6.1 km.

In sampling woodland vegetation, more consistency was possible in the materials sampled. In each case oak leaves were collected. Quantities measured ranged from 190 to 1,250 ppm and, as in the case of herbaceous vegetation, the pattern to the east showed two areas of relatively high values, one centered around 3.2 km and the other around 8.0 km from the source. To the west arboreal samples show a similar pattern to herbaceous vegetation.

Comparison between the arboreal and herbaceous data sets indicates that the mean concentration in herbaceous vegetation for all sites is 975 ppm (1047 ppm to the east, 731 ppm to the west). Mean values for arboreal samples is 546 ppm for all sites (576 to the east and 472 to the west). In seven cases herbaceous and arboreal samples were collected less than 0.4 km apart, yet in five of these cases the arboreal samples showed values to be about one-half or less of the herbaceous $SO_4^{=}$ values.

DISCUSSION

Though it is not possible to obtain statistically valid correlations in the spatial distributions of sulfur between either the atmosphere, the vegetation, or the soil, there is a remarkable correspondence in the nature of the distributions encountered. Both ecological and pedological reasons can be advanced for this lack of statistical relationship *(Moss 1975a).* This result, however, differs from the similar work of Johansson *(1959)* and McGovern and Balsillie *(1972)*, who were able to show a straightforward linear relationship between distance from source and atmospheric sulfur and vegetation-accumulated sulfur. Lihnell *(1969)* found a somewhat irregular pattern in his results from using similar variables. What these contrasting results do show, however, is that in many cases individual locations have to be treated independently. Although there are established functional links between all environmental components, the patterns that emerge are determined primarily by the source and the atmospheric dynamics of the site. Successive stages in the movement of the pollutant from component to component will reflect this atmospheric spatial pattern.

In the Welland case the occurrence of three distinct areas of atmospheric sulfur concentration should have direct implications for any development in areas adjacent to the present built-up area. In terms of air-quality standards, continuous monitoring for sulfur oxides at the most heavily polluted site showed that in 1973 on no occasions did concentrations exceed Ontario criteria for desirable air quality *(Ont. Minist. Environ. 1973).* But whereas sulfur in the atmosphere is relatively short-lived and there is a constant throughput when this passes to the next component, there will be build-up. Here, in the soils and vegetation, sulfur will accumulate over a long period of time; a growing season for vegetation and longer for soils. In both of these, local variables will determine accumulations. For Welland, where the atmospheric sulfur is not severe, values of soil sulfur reach 726 ppm. This is considerably higher than any value obtained in the heavily industrial Sheffield region in England *(Moss 1975a).* For Trail, British Columbia, a mean of 185 ppm *(Katz et al 1939)* is not appreciably different from that of 134.12 ppm for Welland. For vegetation the Welland values appear to be extremely high when compared with, for example, data from industrial South Wales, where oak leaves yielded a high of 113 ppm at 2.4 km from a source.

The significant point from the above comparisons is, that to determine areas of environmental pollution requires an initial extensive survey to determine the extent of the atmospheric sulfur pattern, even in an area of relatively uniform surface topography. The quantities of the pollutant encountered in the next environmental component should reflect the atmospheric pattern although in different localities what may be acceptable limits in one component may be quite unacceptable in another.

Furthermore, there are obvious differences between the amounts of sulfur absorbed and accumulated by soils and vegetation between grassland and woodland ecosystems. The fact that grassland ecosystems appear to accumulate more sulfur could have significant repercussions on air hygiene in the area. The planting and maintenance of sulfur-tolerant grass species could be useful in land-use planning.

CONCLUSIONS

By identifying the spatial limits of potential pollution from the first stage of environment transfer — the atmosphere — the spatial limits of potential environmental pollution are set. In this way the erroneous and restricted limits of the area affected by air pollution recognised by local planning studies as being limited to two centers between the Old and New Welland Canals would be overcome *(Philips Planning and Engineering, 1971)*. Any other environmental components can only be vertically linked by the natural pathways. Differences in the reaction of these biotic components to accumulation can yield significant clues to the maintenance of viable ecosystems. Although concentrations and accumulations do not indicate pollution in the true sense, they do identify where pollution will occur. Thus the occurrence of higher values of sulfate being encountered in precipitation at 8 km from the source than at 4 km from the source, and the significance this has for precipitation pH, can be explained *(Moss 1975b)*. Only by such a method can a more meaningful environmental approach to environmental planning be initiated.

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