APPLICATION OF THE CRITICAL LOADS APPROACH IN SOUTH AFRICA

A.M. VAN TIENHOVEN[1], K.A. OLBRICH[1], R. SKOROSZEWSKI[2], J. TALJAARD[3] and M. ZUNCKEL[3]

[1]*Forestek, CSIR, Private Bag, X11227, 1200, Nelspruit, South Africa.*
[2]*Watertek and* [3]*Ematek, CSIR, PO Box 395, 0001, Pretoria, South Africa.*

Abstract. South Africa is the most industrialised country in southern Africa and stands at some risk from negative pollution impacts. To the authors' knowledge, this paper presents the first attempt to apply the critical loads approach on the African continent; although sensitivity mapping has been performed for Africa and the rest of the world (Kuylerstierna *et al*, this conference). Actual sulphate and base cation deposition loads in Mpumalanga (formerly the Eastern Transvaal province of South Africa) were mapped from 16 monitoring sites. The region is characterised by long, dry periods with little rain, high evaporation (up to 8 mm per day) and low run-off (15% of MAP). Provisional critical load and exceedance maps were produced for the surface waters using the Steady-State Water Chemistry Model and the Diatom model. Maps of soil sensitivity to acid deposition, based on bedrock lithology, soil chemical characteristics and land cover, were produced. A weathering rate of 0.39-0.86 keq/ha/year was calculated for the most sensitive sites and taken as the critical load, based on the assumption that the weathering rate represents the buffering ability of the system. The critical loads were contrasted with measures of actual deposition to examine potential scenario's for critical load exceedances. A key factor in refining the sensitivity maps, and allowing estimation of the critical loads, is the accurate calculation of weathering rates under the warmer and more arid environmental conditions prevalent in South Africa. In a developing country such as South Africa, where research resources are limited, the critical loads approach is a valuable means of assessing the risk of potential impacts of atmospheric deposition.

Key words: South Africa, Eastern Transvaal, Mpumalanga, critical loads, acidification.

1. Introduction

South Africa is recognised as having comparatively high levels of air pollution emissions, particularly in the Eastern Transvaal Highveld. The total SO_2 emission rate for the whole of South Africa is estimated to be 2.9 million tons per annum, of which 1.2 million tons are produced by coal-burning power stations. 75 % of these power stations are located in Mpumalanga (formerly the Eastern Transvaal) (Annegarn *et al*, 1994; Tyson *et al*, 1988, Turner, pers. comm.). If the needs of South Africa as a developing nation are considered, the requirements for economic growth and associated employment, education, housing, and primary health care, greatly overshadow issues relating to air pollution and its impacts. Since the critical loads approach can provide a basis on which cost-effective decisions can be made by regional and national authorities with respect to air quality, its potential use in South Africa was investigated.

This paper presents the results of a pilot study to investigate the application of the critical loads approach in South Africa.

Water, Air and Soil Pollution **85**: 2577–2582, 1995.

2. Materials and methods

The area chosen for the pilot study is the region presently defined as the Eastern Transvaal Province, but now renamed Mpumalanga (Figure 1.). This region encompasses large areas of commercial forest plantations, key natural environments such as the Kruger National Park, and large industrialised areas. Topographically, the area is divided into a plateau in the west (1 400 - 2 000 mamsl) which is relatively dry and cool with frost in the winter months; and a broad gently undulating plain to the east (800 - 150 mamsl) which is generally hot and dry. The two zones are separated by a steep escarpment zone varying between 20 to 40 km wide. The mean annual temperature ranges from 12 °C to 23°C - depending on local topography. Most of the rain falls in the summer months as thundershowers. Rainfall ranges between 500 mm to 2 000 mm per year, but the average rainfall for the region is 880 mm - approximately 70% higher than the mean annual rainfall of 500 mm for South Africa.

In order to estimate actual deposition loads, rain chemistry data was collected from a coordinated monitoring network made up of 16 stations. The actual wet sulphate deposition map was created on a GIS, by finding the product of the mean annual rainfall coverage and the mean volume-weighted sulphate concentration coverage. Pollutant dry deposition was not monitored.

To calculate the critical loads of surface waters, Mpumalanga was divided into grid squares corresponding to the area covered by 1:50 000 Ordinance Survey maps. The most sensitive water body in each grid was selected - based on low base cation concentration and as few sources of anthropogenic pollution, other than atmospheric, as possible. One sample from each grid was analysed for base cations, acidic anions, Cl^{-1} (chlorine), alkalinity and pH.

Both the diatom model (Battarbee, 1993) and the steady state water chemistry model (Henriksen *et al.*, 1986) were utilised in the assessment of the critical loads for surface waters. Two versions of the steady state water chemistry model were tested. The first method (Battarbee, 1994) considers the levels of sulphate in the surface waters, whereas the second method (Sverdrup *et al*, 1990) does not include this sulphate in the calculation.

The estimates for soil critical loads were derived by producing a sensitivity map of the region according to the guidelines of the Stockholm Environment Institute (Chadwick *et al.* 1991), using factors such as land cover, geology (or lithology) and soil features such as pH, cation exchange capacity and base saturation. Critical loads were then assigned to the final sensitivity classes.

Although climate is an important determinant of sensitivity to acidification, we elected to ignore rainfall, as its effects are implicit in both the land cover coverages and the soil coverages.

Soil critical loads were assigned to the sensitivity classes by assuming that if the mineral weathering rate provides sufficient cations to balance incoming acid deposition, then the ecosystem will not acidify. All other inputs and outputs of acidity and alkalinity were ignored.

Most of the soils of Mpumalanga contain inert or very slow weathering minerals, so much of the region is sensitive to acidification (Task Force on Mapping, 1993, Sverdrup, 1990).

Weathering rates were derived by scaling European weathering rates to local weathering conditions. Data from the Lake Gårdsjön catchment served as the standard against which local environmental parameters were adjusted (Sverdrup *et al*, 1990). The Sabie River catchment was chosen to represent conditions in Mpumalanga since there is readily accessible environmental data for the catchment (Schutz, 1990). The catchment also falls within a high rainfall, forestry area with sensitive soils and geology. In terms of acidification potential the Sabie River catchment can be described as a sensitive ecosystem.

The weathering rate for the Sabie River catchment was calculated to range from 0.7 to 1.54 keq/ha/yr. This estimate was improved by considering the exposed mineral surface (Sverdrup *et al*, 1990) and adjusting for significant differences in soil moisture saturation, texture, acidity and temperature between Gårdsjön and Sabie to give a final rate of 0.39-0.86 keq/ha/yr.

3. Results and Discussion

The generalised approaches used and the results obtained are summarised in Table I.

Table I. Synthesis of approaches and calculations adopted in applying the critical loads approach in South Africa

Approach		Results	
		Classes	Critical load
Actual deposition of sulphate	Product of mean annual rainfall and mean volume-weighted sulphate concentration	Actual deposition ranged from 0.1-0.7 keq SO_4^{2-}/ha/yr	
Soil sensitivity	Derived from : Land cover (forestry, woodland, grassland, cultivated lands) Soil features (CEC, pH, base saturation) Lithology (eg granite, quartz, shale, etc)	1: sensitive 2 3 4 5: resistant	Estimated weathering rate of a sensitive site (class 1) to be the critical load for class 1 sites ie. 0.39-0.86 keq/ha/yr is the critical load for sensitive sites
Surface water critical loads	Critical load = (pre-acidification flux of base cations) - (base cation concentration in rainfall) - (alkalinity leaching)		<0.2 keq H^+/ha/yr - Sensitive 0.2-0.5 0.5-1.0 1.0-2.0 >2.0 keq H^+/ha/yr - Resistant

Actual wet deposition loads of sulphate range from 0.1 to 0.7 keq sulphate/ha/yr with the greatest deposition occurring in the western and southern portions of the province - areas where most of South Africa's power-generating plants are found. Actual deposition is lowest in the eastern parts, where large natural areas, such as the Kruger National Park, are situated.

A recent South African study estimated dry deposition of sulphate (so_4^{2-}) over a forested area to be 0.109 keq/ha/yr compared with 0.025 keq/ha/yr over grassland (Piketh *et al*, 1994). Closer to an industrialised area dry deposition estimates ranged between 1.02 - 1.69 keq/ha/yr.

The diatom and steady state models for determining critical load exceedances for surface waters presented quite different pictures. The diatom model showed that critical loads for surface waters of only a small part of Mpumalanga were exceeded, and these were restricted to the south-eastern part of the region. Few surface waters were found to be acidified - pH values were mostly greater than 6.0. In contrast, the steady state method showed that significantly more of the region's surface waters were exceeding their critical loads. The calculation which included sulphate concentration in the surface waters resulted in many negative values - suggesting much variability, which could be attributable to analytical errors, or because sulphate concentrations in the surface waters are not in balance with the atmospheric inputs.

Surface water critical loads (Figure 1.) less than or equal to 0.5 keqH^+/ha/yr were largely restricted to the upland areas of the province, or areas where the soil type was sandy with low levels of base cations. The highest critical loads and hence the lowest sensitivities (> 2.0 keqH^+/ha/yr) were found primarily in the south-western parts of the province.

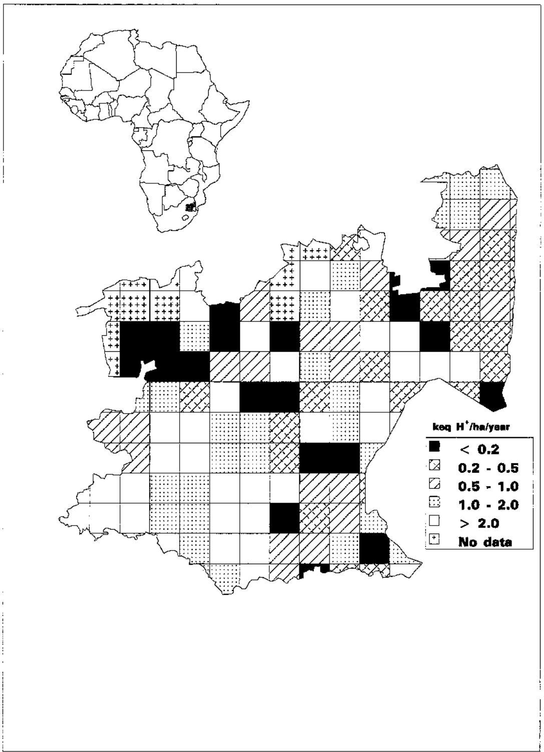

Fig. 1 Provisional critical loads for the surface waters of Mpumalanga province, South Africa, calculated with the steady state water chemistry model.

The critical load exceedances were calculated by subtracting critical loads from the measured deposition levels of sulphate. The areas where these exceedances occurred corresponded significantly with sites where the critical loads were less than or equal to 0.5 keqH^+/ha/yr, being largely confined to upland areas which have a steep topography. The surface waters where the critical loads were exceeded were often not acid i.e. had a pH level of greater than 7.0. Even though exceeded areas may show no evidence of damage at present, the time lag of responses needs to be considered - damage effects may only become apparent after some time.

Sulphate retention in the studied catchments varied between 5 and 95% (mean of 81%). It is not known how long this sulphate remains in the soil, what the lag time is before the sulphate appears in the surface waters, or whether the sulphate concentrations in the surface waters are in a steady state with the atmospheric inputs.

The region is also characterised by a high evaporation rate. Consequently, there is a low runoff percentage ranging between 3% and 74% (mean 15%) which is far less than the runoff rates experienced in Europe and North America where runoff often exceeds 50%.

The soil sensitivity map showed the most sensitive soils to largely correspond with the escarpment area, where there is a combination of high rainfall and acid soils. The south western parts of the province are more resistant to acid deposition- this area is predominantly farmland.

The weathering rate for the Sabie River catchment was roughly calculated to range from 0.39 to 0.86 keq/ha/yr. This value was then considered to be the amount of buffering capacity available to neutralise the atmospheric inputs of acidity and so it represents an estimate of the potential critical load for the **most sensitive** site classification.

Actual deposition over Mpumalanga was shown to range from 0.1 to 0.7 keq/ha/yr but was in the range 0.4 to 0.5 on the most sensitive sites. Thus the weathering rates given for the Sabie catchment, i.e. 0.39 to 0.86 keq/ha/yr should be adequate to balance acid inputs to these sensitive sites on an annual basis.

We conclude there is no immediate cause for concern over potential negative impacts of acid deposition on soils in Mpumalanga. However the ranges calculated are broad and exceedance can occur if the larger deposition rates are set against the slowest weathering rates.

In addition, the available estimates of dry deposition in Mpumalanga vary between approximately 1.5 and 1.9 times that of wet deposition (Skoroszewski, 1995; and Olbrich and Du Toit, 1993). If all wet sulphate deposition load classes are scaled up by 1.9 times, then there would be critical load exceedances even at the upper limit of the weathering rate. It is therefore important that estimates of dry deposition for the whole region be considered as this has a substantial impact on the estimated exceedances.

4. Conclusions

Estimates of critical loads and their potential exceedances have been calculated for both the surface waters and the soils of Mpumalanga. Consideration of sensitivity of both surface waters and soils indicates that there is a large degree of parity between the areas where both environmental receptors are identified as sensitive to acidification.

At present the indications are that there is little threat of acidification through **wet** deposition. However, dry deposition may prove to be a more significant contributor to acidic deposition in the area. Future research efforts should focus on accurately quantifying this component.

The critical loads approach, incorporated into a wider system to define air pollution policies, should be adopted at a national level. It is the authors' firm belief that this system can provide the most cost effective solution to the country's needs in terms of air quality and air pollution impacts.

Acknowledgements

This work was funded through the CSIR's STEP (Scientific and TEchnological Positioning) scheme. Bob Scholes' assistance in quantifying soil weathering rates is gratefully acknowledged.

References

Annegarn, H.J., Kneen, M.A., Piketh, S.J., Crouch, A., Maenhaut, W. and T.A. Cahill.: 1994. "Remote aerosols over southern Africa and global warming." Proceedings of the 1994 Clean Air Conference, Cape Town, South Africa.

Battarbee, R.W.: 1993. Critical loads and acid deposition for UK freshwaters (summary). A report to the Department of the Environment for the Critical Loads Advisory Group for Freshwaters.

Battarbee, R.W.: 1994. " Critical Loads of Acidity for Freshwaters." In: Critical Loads of Acidity in the United Kingdom. Critical Loads Advisory Group. Report to the Department of the Environment, U.K. pp 19-27.

Chadwick, M.J., Kuylenstierna, J.C.I. and Gough, C.A.: 1991. "The Stockholm Environment Institute map of relative sensitivity to acidic depositions in Europe". In: Mapping Critical Loads for Europe Eds Hettelingh, J., Downing, R.J. and de Smet, P.A.M. Coordination Center for Effects Technical Report No. 1. RIVM Report No. 259101001, National Institute of Public Health and Environmental Protection, the Netherlands. pp 49-57.

Henriksen, A., Dickson, W. and Brakke, D.F.: 1986. "Estimates of critical loads to surface waters." In Critical loads for sulphur and nitrogen. Ed Nilsson, J. Nordic Council of Ministers, Copenhagen. pp 87-120.

Kuylenstierna, J.C.I., Cambridge, H., Cinderby, S. and M.J. Chadwick.. 1995. "Assessing the sensitivity of ecosystems to acidic deposition in developing countries." Proceedings of the 5th International Conference on Acidic Deposition, 26-30 June, Göteborg, Sweden.

Olbrich, K.A. and B. Du Toit.: 1993. "Assessing the risks posed by air pollution to forestry in the Eastern Transvaal, South Africa". Confidential report to Eskom, Division of Forest Science and Technology Report FOR-C 214, CSIR, Pretoria.

Piketh, S.J. and H.J. Annegarn.: 1994. "Dry deposition of sulphate aerosols and acid rain potential in the Eastern Transvaal and lowveld regions. Proceedings of the 25th Clean Air Conference, 24-25 November, Cape Town..

Schutz, C.J.: 1990. "Site relationships in Pinus patula in the Eastern Transvaal escarpment area". PhD thesis, University of Natal, South Africa.

Skoroszewski, R.W.: 1995. "Sensitivity of surface waters in the Eastern Transvaal province." CSIR report WM 769.

Sverdrup, H.U.: 1990. The kinetics of base cation release due to chemical weathering. Lund University Press, Sweden. 246pp.

Sverdrup, H., de Vries, W. and A. Henriksen. 1990. Mapping critical loads - a guidance to the criteria, calculations, data collection and mapping of critical loads. Environmental Report 1990:14 prepared for the Workshop and Task Force on mapping critical loads and levels. 124pp.

Task Force on Mapping.: 1993. Draft Manual on Methodologies and Criteria for mapping Critical Levels/Loads and Geographic area where they are exceeded. Convention on Long-Range Transboundary Air Pollution, UN-ECE. Geneva. 109pp.

Tyson, P.D., Kruger, F.J. and C.W. Louw.: 1988. Atmospheric pollution and its implications in the Eastern Transvaal Highveld. South African National Scientific Programmes Report 150, CSIR, Pretoria. 114pp.