COORDINATED LOCAL AND REGIONAL MONITORING OF AIR POLLUTANT EFFECTS ON ECOSYSTEMS

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ABSTRACT

Mineral processing industries have developed rapidly in a formerly rural area of coastal Queensland, Australia, due to the availability of energy, raw materials resources and deep-water access. The area has acknowledged ecological values and borders the World Heritage-listed Great Barrier Reef. Several industries already operate in an area of complex terrain for which there is limited meteorological information. A coordinated environmental monitoring program is being developed to optimise the planning certainty for existing and proposed industries, the quality of environmental information gathered and the protection of ecological values. A key feature of the program is the recognition of ecosystems that may be at risk from development in general or from particular industrial emissions. Over 100 native vertebrate animal and 500 native plant species might be affected, but pollutant responses are known for fewer than 50 plant species. Coordinated ambient monitoring, dispersion modelling and detailed ecological assessments are being developed to analyse and predict ecological changes with the greatest economy of resources. Species that are functionally critical in their ecosystems, vulnerable to extinction or sensitive to pollutants, will be selected for detailed observation. Environmental management guidelines will be formulated progressively as industrial development proceeds and the amount and quality of information increases. This program may serve as a model for environmental monitoring delling in resource-limited situations where there is incomplete information on ecosystem characteristics and responses to pollutants.

INTRODUCTION

The Central Coast of Queensland, Australia, just south of the Tropic of Capricorn is sparsely populated on a world scale, but is important environmentally for two reasons. First, it borders on the Great Barrier Reef, a World Heritage area of immense conservation significance that stretches 1800 km north to Torres Strait. Second, it provides access to the Central Queensland coal province, with proven reserves of 23 billion tonnes (NRME 2004). Of the two deep-water ports with access through the Great Barrier Reef, Gladstone ships 40 million tonnes of coal per year (GPA 2004). The abundant coal supplies have also enabled the development of coal-fired electricity generation, including capacity of 1680 MW at Gladstone (Table 1).

The combination of resource attributes attracted several minerals processing activities to the region, and the Government of Queensland identified a preferred location for industry, to be managed as the Gladstone State Development Area (GSDA). Most of the 200 km^2 of the GSDA is located between 10 and 20 km from the port (EPA 1999), and infrastructure developments have been undertaken over a period of 30 years. The industrial activities summarised in Table 1 have been initiated over 30 years, and further developments are occurring or are being planned. Atmospheric emissions from these industries are not large on a world scale, but are important locally in an area where the most extensive land uses are beef cattle grazing, tropical fruit-growing and tourism.

The atmospheric environment into which these emissions are released is dry tropical, with a mean annual rainfall of 1020 mm, most of it falling in a wet season from December to May, and a dry season with persistent south-easterly winds from June to November. Although most of the coastline is relatively flat, two small ranges of hills run parallel to the coast through the GSDA, with the highest point (Mt Larcom), about 10 km inland, having an elevation of 700 m. The coastal portion of the GSDA is well ventilated by sea breezes throughout the year, but the area inland of the Mt Larcom Range experiences different wind patterns and more extended periods of calm stable air.

Activity	Product Capacity	Emissions (t/yr)			
	Units	SO_2	NO_x	F^-	VOC
Coal-fired electricity generation	1680 MW	29,000	41,000	300	130
Alumina refining *	3,700,000 tpa	3,200	9,600	78	140
Aluminium smelting	540,000 tpa	11,000	190	460	54
Aluminium smelting – approved	570,000 tpa	n/a	n/a	n/a	n/a
Cement manufacturing	1,433,000 tpa	3	3,600	6.4	28
Lime manufacturing - constructed	300,000 tpa	n/a	n/a	n/a	n/a
Shale oil extraction - established	500,000 bbls	823.4	196	0.75	121.8
Chemical manufacturing: Ammonium nitrate prill Sodium cyanide Chlorine manufacturing Hydrochloric acid	 270,000 tpa 50,000 tpa 9,000 tpa 10,000 tpa	92	530	0	0.34
Total emissions - existing		44,000	55,000	850	470

Table 1. Summary of major industries in Gladstone State Development Area. (Emissions data for established activities taken from National Pollutant Inventory for 2002-2003, www.npi.gov.au). * Additional capacity under construction. n/a not available.

Vegetation formations in the area are relatively complex, varying with geology and landform from closed forests (rainforest) to open eucalypt forest and woodland with grassy ground cover. Vegetation associations in Queensland have been classified into Regional Ecosystems (Sattler and Williams 1999) and more than 50 have been recognised in the GSDA. One of these, a semi-evergreen vine thicket, is considered to be endangered because it is not represented in dedicated conservation areas. Most of the more open vegetation types have been modified for agriculture and grazing. Rainforests on volcanic soils of low slope were mostly cleared for horticulture, but some areas at higher elevations remain in a relatively undisturbed condition. More than 100 native vertebrate animal species and 500 plant species have been recorded from the area, with 12 plant species being of conservation concern.

The combination of landscape, meteorology, biological diversity and industrial potential provide a challenge to the location and management of industrial activities so that the GSDA may provide an ecologically sustainable focus for mineral processing in Australia and the south-west Pacific area. It is clear from Table 1 that several industries emit common atmospheric pollutants, and the proximity of some sources (e.g. the electric power station, chemical works, new alumina refinery, new aluminium smelter and shale oil facility are located within an 8 km radius) may mean that the effects of each industry are difficult to separate. However, the impact of these emissions on the environment will depend less on the particular source than on the total concentration or load. It therefore becomes important to minimise the adverse effects of multiple sources and to develop a means whereby the impact of individual sources may be determined.

REGULATORY FRAMEWORK

Environmental guidelines have been established in terms of maximum acceptable ambient concentrations of pollutants for a variety of averaging times, with decreasing concentrations at extended exposure durations (Table 2). Compliance with environmental guidelines can be determined by atmospheric analysis, and in the Gladstone area, four monitoring stations have been established by the Queensland Environmental Protection Agency (EPA) to record ambient concentrations of sulfur dioxide, and one station records sulfur dioxide, oxides of nitrogen and ozone using differential optical absorption spectrometry. Therefore, at these locations it is possible to determine directly whether acceptable conditions have been achieved, but it is not immediately possible to interpolate between or extrapolate from these stations to other more distant localities.

One method for interpolating information is through dispersion modelling based on actual meteorological and pollutant emission records. This approach is clearly necessary in the GSDA, where multiple sources of pollutants are introduced into a somewhat complex terrain. Maintenance of this information on a common geographical information system is regarded as essential to effective analysis, reporting and decision-making.

Contaminant and units	Averaging time							
	1 h	4 h	8 h	24 h	7 d	30 d	90 d	1 y
Sulfur dioxide ($\mu g/m^3$)	570*	-	-	100	-	-	-	60
Nitrogen dioxide ($\mu g/m^3$)	320* 210	95	-	-	-	-		30
Carbon monoxide (mg/m^3)	-	-	10	-	-	-	-	-
Ozone ($\mu g/m^3$)	210	170*	-	65	-	-	60$^{\#}$	-
Fluoride								
General land use ($\mu g/m^3$)	-	-	-	2.9	-	0.84	0.5	-
Special land use ($\mu g/m^3$)	-	-	-	1.5	-	0.4	0.25	-
Conservation use	-	-	-	-	-	-	0.1	-

Table 2. Ambient guideline values for atmospheric contaminants relevant to biological integrity in Queensland (Schedule 1, Part 2, Environmental Protection (Air) Policy), (Queensland 1997). * Values for human health; $^{\#}$ Value for 100 days.

Biological monitoring permits interpolation of effects between ambient monitoring sites, and it can also provide semi-quantitative information over large areas that can be compared with dispersion modelling results. This procedure is important because it enables a conclusion to be reached at a large number of locations on the occurrence of environmental harm, which can be described as alteration by an environmental contaminant of the composition, function or appearance of an ecosystem or of its components. The form of biological monitoring that is most effective will vary with the ecosystem, the identity and concentration of the contaminant, so the system of reporting must be consistent between contaminants.

The environmental guidelines for sulfur dioxide, carbon monoxide and oxides of nitrogen (Queensland 1997) were based on their human health effects, with little consideration being given to effects on other animals or plants. Guidelines for fluoride were developed to protect vegetation, which is many times more sensitive than humans (Weinstein and Davison 2004) Human responses to short-term exposures (one hour or 10 minutes) have dominated considerations, but vegetation is exposed continuously to the ambient conditions, and longer term exposures may be of equal or greater importance than short term exposures (cf. Table 2). Therefore, it is possible that environmental harm may be discerned in terms of changes in ecosystem health (presence, abundance, functioning or appearance of species) while there are no detectable effects on humans.

Vegetation monitoring is a valuable component of the assessment of environmental health when responses to stress are visible in plant species before they become apparent in other organisms. For monitoring to be effective, its purpose, the existing condition and the effects of additional sources of pollutants on ecosystem health must be described, as well as the variation in ecosystem health that may be associated with normal environmental variation. In the GSDA, it is suggested that the purpose would be to record vegetation structure and composition as a basis for the analysis of long-term changes resulting from industrial operations and other natural environmental pressures such as drought, and allowing for the inevitable occurrence of fire. Cornelissen et al. (2003) provide a useful model for this work.

ENVIRONMENTAL MONITORING INITIATIVE FOR THE GSDA

The first priority for ecosystem monitoring in a complex industrial environment should be identification of the essential components of a monitoring program that would yield robust information, avoid replication of monitoring effort and minimise uncertainty in the interpretation of results. In the GSDA, the program would need to be implemented by a consortium of industries and the regulator, in this case the EPA.

Objectives of the terrestrial monitoring program for the GSDA are to:

1) Establish a geographical information system for the recording, analysis and presentation of information relating to the terrestrial environment, to be maintained by the EPA.
2) Develop and maintain a comprehensive meteorological monitoring network for the GSDA.
3) Establish sites in areas of secure land tenure for ambient monitoring of atmospheric pollutants in relation to:
    a) Locations likely to be exposed to the highest ambient concentrations of pollutants of concern.
    b) Areas of human habitation.
    c) Areas of agricultural or horticultural value.
    d) Areas of ecological importance.
4) Collate atmospheric emissions data from specified industrial sites in the GSDA:

   a) Regularly compare emissions data, dispersion model predictions and ambient measurements.
   b) Use these data for refinement of the Gladstone Airshed Model.
5) Record the condition of terrestrial ecosystems throughout the GSDA:
   a) Identify critical (e.g. endangered) Regional Ecosystems for the purpose of monitoring their condition.
   b) Identify representative (i.e. widespread) Regional Ecosystems and sites within them for monitoring purposes.
   c) Identify and locate threatened plant and animal species.
   d) Identify and progressively incorporate pollutant-sensitive species into monitoring program.
   e) Develop a consistent methodology for monitoring ecosystem health, including:
      i) Ecosystem sampling intensity within critical and representative Regional Ecosystems.
      ii) Distribution of ecosystem sampling sites with respect to proximity to emission sources or to areas of predicted maximum ground level concentrations of pollutants.
      iii) Sampling intensity for threatened plant and animal species.
      iv) Monitoring procedures for plant and animal species, (e.g. seasonal assessment of animal numbers, activity or physiological condition; annual assessment of plant community structure, species abundance, species condition assessment, and visible injury of known pollutant-sensitive or ecologically important species).
6) Develop procedures for distinguishing between the impacts of co-occurring contaminants:
   a) Statistical procedures to describe responses to individual and combined contaminants.
   b) Descriptions of plant condition, visible injury or function for individual contaminants or their combinations.
7) Develop procedures for auditing all aspects of environmental monitoring.
8) Incorporate emissions effects results in the revision of environmental management plans for industrial operators.
9) Develop procedures for establishing monitoring progressively if the program has to be instituted in stages.
10) Provide monitoring and modelling information to prospective industrial developers to ensure optimal environmental outcomes for new activities.
11) Negotiate the apportionment of monitoring activities and costs between the industries operating within the airshed and the EPA. Possible approaches include:
   a) Contributions proportional to total emissions (e.g. based on reports to the National Pollutant Inventory)
   b) Predicted ground level concentrations of pollutants at particular locations
   c) Scaling of charges for pollutants based on the relative health and environmental impacts of the pollutants (e.g. as established by the National Pollutant Inventory).
12) Secure public participation in the development and approval of the program.

CONCLUSIONS

Key monitoring activities include the establishment of meteorological stations to sample the major components of the regional airshed, and ambient monitoring at locations likely to experience the highest ground level concentrations of pollutants. High quality meteorological data are necessary for reliable dispersion modelling, and this should precede proposals for industrial development. Biological monitoring can be initiated according to more flexible criteria, and its intensity can be adjusted according to short-term needs. The detailed monitoring work requires careful coordination and continuous maintenance of databases so that participants and members access the information. Existing ecosystem monitoring procedures can incorporate air pollutant effects in ecosystem health assessments.

Apportionment of responsibilities for monitoring activities is crucial where emissions from several industries may impact on a particular site. Continuing negotiation may be needed for several aspects of the monitoring program (e.g. scale of monitoring and contributions by various parties). Finally, public support for the whole program is necessary if the objectives of ecologically sustainable industrial development are to be achieved.

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