Ecological Research Series

The Bioenvironmental Impact of Air Pollution From Fossil-Fuel Power Plants

National Environmental Research Center
Office of Research and Development
U.S. Environmental Protection Agency
Corvallis, Oregon 97330

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This report has been assigned to the ECOLOGICAL RESEARCH series. This series describes research on the effects of pollution on humans, plant and animal species, and materials. Problems are assessed for their long- and short-term influences. Investigations include formation, transport, and pathway studies to determine the fate of pollutants and their effects. This work provides the technical basis for setting standards to minimize undesirable changes in living organisms in the aquatic, terrestrial and atmospheric environments.

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THE BIOENVIRONMENTAL IMPACT OF AIR POLLUTION FROM FOSSIL-FUEL POWER PLANTS

by

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ABSTRACT

The body of information presented in this paper is directed to environmental scientists and engineers and to those land managers who will be involved in assessing the effects of energy conversion activities on the environment. A prototype investigation of the bioenvironmental effects of air pollution challenge from coal-conversion facilities is summarized. Objectives, rationale, and the overall design of this research are presented. Recommendations regarding the selection of suitable criteria of environmental damage are also made. The authors hope that this paper will serve to stimulate thought and discussion that will lead to a predictive capability in the area of bioenvironmental impact assessment.

CONTENTS

INTRODUCTION

The Nation is presently faced with a series of problems concerning the production, distribution and consumption of fossil fuel energy sources. Because of great abundance at relatively low cost, the administration's commitment to energy self sufficiency by 1980, and other factors, it is clear that the United States is moving toward an economy based on coal as the primary fossil fuel resource.[1] Indeed, by early 1974, there were approximately 970 fossil fueled power plants in operation nationwide, with a total generating capacity of some 302,000 megawatts.[2] Apportionment of this generating capacity by fossil fuel source is approximately: 55 percent coal-fired, 17 percent oil-fired, and 28 percent gas-fired.

The decisions that will ultimately resolve the environmental and economic issues we face must be made with full knowledge of the constraints imposed by the need to minimize environmental impacts associated with energy production and utilization. The present paper summarizes the National Ecological Research Laboratory's (NERL) approach to the solution of one portion of this problem set. NERL, in cooperation with other Federal agencies, the State of Montana, and several universities, has initiated a research program designed to assess the impact of coal-fired power plants on a grassland ecosystem and to develop a valid and effective environmental impact assessment protocol.

Preliminary to the development of this program, a thorough review of the relevant biological and air pollution literature has led us to the conclusion that most investigations of the effects of air pollution from coal conversion facilities are largely site specific and have, furthermore, only retrospective value. Clearly, a predictive capability is required if we are to make rational decisions regarding the siting of such facilities.

This capability may be realized if research programs are designed to integrate process studies of the soil, animal, and vegetation components of the ecosystem. Before beginning these programs, reviews of existing research are necessary. A review of laboratory process studies and field ecosystem programs allows us to begin to piece together such an integrated research approach. For example, the Department of Agriculture publication on the effects of air pollutants on domestic animals[3] lists results of laboratory investigations. Numerous publications by the academic community and EPA have characterized the effects of pollution on vegetation.[4-10] There is a paucity of laboratory data available for air pollutants affecting soil microfauna and flora. It is the synthesis of these process studies that ultimately leads toward achieving the total systems approach.[11]

Few air pollution field studies have attempted to combine soil, vegetation and animal research into an integrated program. The Southwest Energy Study,[12] the La Cygne, Kansas, Coal-fired Power Plant Study,[13] the Tennessee Valley Authority Cumberland[14] and Widows Creek[15] Coal-fired Power Plant Studies represent research efforts that have attempted to combine the various components of the ecosystem (air, water, soil, vegetation, and animal) into an integrated biological program.

Southwest Energy Study

The Southwest Energy task force was established in May 1971, to undertake a study of electrical energy generation and transmission in the Southwestern United States. The objectives and scope of the project were to evaluate (1) the importance of the existing natural resources, aesthetic factors, cultural patterns and economic needs of the area; (2) the quantitative long-term need for power in the southwest, (3) the effects of incremental power development on quality of air, land, water, wildlife and human needs; (4) the environmental tolerances of the area for power development; and (5) the alternatives available for achieving optimum development with tolerable impact.

Working groups were selected to investigate (1) power development and economic effects, (2) water supply, (3) water and air pollution, (4) water resources monitoring, (5) atmospheric studies, (6) land use, (7) cultural, economic and social factors, (8) biota, (9) recreation and aesthetics, (10) coal resources, (11) coal production methods and techniques, and (12) alternative uses of Colorado River Basin coals. The biota work group evaluated the effect of coal-fired power plant activities upon vegetation within the southwest energy area and upon a number of animal species that inhabit the area. Emphasis was placed on biotic effects. The analysis of stack emissions on animals was based primarily on a review of extant scientific literature. Analysis of the effects of stack emissions on plants was based primarily on American sources of literature and on current research within EPA.[4-10]

The biotic committee recommended (1) a short-term review of literature on the biotic effects of air pollution (2) a mass balance study of trace elements, including heavy metals at the Four Corners Power Plant; (3) a short-term study of vegetation in areas likely to be damaged by stack emissions; (4) short-term aquatic studies to determine basic indicator organisms and food chains; (5) Monitoring of vegetation in the vicinity of power plants to determine the effects of sulphates, fluorides, and trace elements; (6) aquatic monitoring and fishery research studies of streams, natural lakes, and reservoirs; (7) terrestrial and wildlife monitoring of animals and their habitat; (8) the study of physical and chemical characteristics of precipitation downwind from power plants; (9) determination of radiation levels in the ambient air, aquatic and terrestrial organisms, water, bottom sediments, and soil; and (10) establishment of a specialized work force of government employees to assess environmental problems associated with future southwest power plants.

Based on the assessment of the various working groups, several agency and university groups initiated research problems to assess the impact of coal-fired power plants on the southwest environment. The Department of Biological sciences, Northern Arizona University,[16] initiated several studies to assess the effects of power plant activities on biota. These studies are located near the proposed Kaiparowits and Navajo generating stations. In addition, the Center for Environmental Studies at Brigham Young University[17] is conducting an aquatic and environmental impact study at the Huntington Canyon project, Utah. The research will determine the effects of Huntington Canyon power plant and Electric Lake on the aquatic environment of Huntington Canyon and its drainage system.

Tennessee Valley Authority Studies

The Tennessee Valley Authority has mounted a biological program to assess the effects of coal producing activities in several locations. A 2600 megawatt power plant located on the bank of the Cumberland River, will emit approximately 1600 tons/day SO_2 into the atmosphere when operating at normal full load. The Tennessee Valley Authority has identified the Cumberland Steam Plant as an SO_2 source that could impact vegetation and animals in the vicinity of the power plant and have selected it for extended study. Vegetation surveys, timber stand growth and conditioning surveys, soil surveys, total atmospheric SO_2 loading surveys, and a lichen survey are being performed in the vicinity of the power source. The objectives of the program are to sample the major pathways of sulfur decomposition and movement in the environment (precipitation, sedimentation, and absorption by vegetation) and to assess the effects of pollution on the growths of timber stands. The sulfur content of soil, litter, and vegetation is being monitored. Prior to the plant going on line, the Tennessee Valley Authority had collected three years of preoperational (background) data on local flora and fauna for before and after comparison purposes.

The Tennessee Valley Authority is also conducting forestry surveillance activities in the vicinity of the Widows Creek Steam Plant. Their objective is to determine the extent to which operation of the steam plant has affected the appearance, growth, and survival of local timber stands. In addition, they are testing the feasibility of applying remote sensing techniques to the detection of SO_2 injury.

The Tennessee Valley Authority has developed a substantial amount of experience in operational atmospheric monitoring. Precipitation is sampled biweekly and analyzed for volume, pH, and content of sulfate, nitrate, ammonia, calcium, magnesium and strong acid. Samplers collect information on volume of precipitation, pH, and sulfate content. Sulfate aerosol collectors sample weekly and analyze for suspended particulates and sulfates.

La Cygne Power Plant Study

The La Cygne, Kansas Coal-fired Power Plant Study is sponsored by the Environmental Protection Agency and is being conducted by Wichita State University. The terrestrial environment, including vegetation, animals, and soils is being investigated. The objective of the program is to evaluate the influence of stack emissions from a new coal-fired electric generating plant on the surrounding ruralagricultural and old field communities. Sampling for trace elements around the power source has been in progress since 1972. The investigators are attempting to (1) monitor pollutant dispersal; (2) determine pollutant concentrations in plants; (3) and to monitor trace elements in animals and soils. The program has not stressed community or ecosystem dynamics.

Other Investigations

In addition to the activities mentioned above, there are several research programs that deal with the interpretation of basic processes that occur in a variety of ecosystems. The International Biological Program (IBP) sponsored by the National Science Foundation for the past several years, has investigated a number of basic biological processes such as carbon fixation, photosynthate primary and secondary translocation, turnover of organic matter, recycling of nutrients and trace elements and the development of ecosystem models. Results from the deciduous forest, grassland, desert, and coniferous forest biome projects in addition to other major programs[18-21] may supply basic information that will support applied research directed to the assessment of the effects of pollutants on whole ecosystems.

An Approach to the Study of Impact Assessment

The following discussion presents an overview of NERL's recently-initiated coal-fired power plant project. The broad objective of this program is to measure and predict change in a grassland ecosystem as a function of meaningful environmental parameters including air pollutants. We are concerned not only with the stability of ecosystem organization in relation to ambient conditions, but also with the predictability and reproducability of changes that do occur. Insight into the mechanisms of dynamic-structural responses to air pollution challenge is also sought. It is particularly important to identify the subsystem functions that contribute to ecosystem regulation and the mechanisms whereby such regulation is effected.

Based on this comprehensive investigation, we hope to generate a defensible, sensitive, and relatively simple program that may be used in other grassland situations to monitor, evaluate, and predict bioenvironmental effects of air pollution from fossil fuel conversion processes. We envision an evolving program that will allow managers to gradually refine cost-benefit determinations in making decisions concerning site-selection and air pollution control of coal-conversion facilities.

Rationale

In addition to the "simple" direct effects of air pollutants that have been reported from experimental studies of natural systems, we may expect to observe complex changes in ecosystem dynamics as a function of pollution challenge. We know that insults to the environment from rather diverse sources (toxic substances, pesticides, radiation, disease, adverse climate) produce a similar array of effects at the community level in spite of very different effects on individual organisms studied under experimental conditions. The response mechanisms may be complex, but they often result in a "reversal" of succession or a simplification of ecosystem structure, a reduction in the ratio of photosynthesis to respiration, and a reduction in species diversity at more than one trophic level; this may include the elimination of certain species (e.g., in grassland, usually rare, but characteristic species). Effects may be temporary and reversible (i.e., the system adapts) or chronic and cumulative. In any case, if a coal-fired power plant has a measureable impact on the environment, there is every reason to believe that it will be registered as a loss of community structure. Both plant and animal diversity and energy transfer between and within trophic levels are measures of community structure. Furthermore, these functions may be regarded as important ecosystem resources. It is our view that the immediate population-level effects of an environmental stressor may result from differential impairment of competitive ability. At the relatively low pollution levels anticipated in our investigation, we may expect to find prediposing and subclinical effects that will be impossible to detect in the absence of appropriate population dynamic, biochemical, and physiologic information.

Effects need not be mediated by alterations in food chains or energy flow. Food chains and mass and energy flow patterns, of course, will be affected, although possibly secondarily, whenever population adjustments occur. For example, an environmental stressant may alter the physiology or behavior of the individuals that comprise a population. These alterations are ultimately reflected in altered survival, reproduction and/or emigration rates. Such effects may be subtle and difficult to relate to the specific stressor. In the real world, numerous stressors are operating in complex ways and with various lag times; these tend to confound the results of any field evaluation of a single stressor. The end result of the response of a community to a continuing environmental stress is a readjustment of the component populations (plant and animal) at a new state of dynamic equilibrium. It is not possible to predict with any confidence, either the adjustments and mechanisms most importantly involved or the nature of the final population levels or the balance that will be reached. By studying a rather broad range of interacting variables and, in particular, by an intensive study of certain populations, some may be isolated as sensitive and reliable measures of air pollution. The approach envisioned requires (1) the use of reasonably comprehensive models of component populations of the ecosystem; (2) the use of appropriately structured field and laboratory experiments; and (3) evaluation of physiologic and biochemical functions that may serve as specific indicators (or even predictors) of air pollution stress.

Period of Investigation

The span of field site activity will be three years with the months of April through October being devoted to major on-site activities. A minimum of three years is needed for the field phase of the investigation because it is necessary to measure the normal cycling and variation through time and space of the ecosystem and also to look for large, random effects that might otherwise be viewed as possible functions of pollution.

Furthermore, reproductive rates and annual cycles of plants and animals can be expected to be affected by the pollution stresses. Even provisional assessment of such effects in annually breeding populations requires information spanning 2-3 generations. A fourth year will be required to complete data evaluation, to write terminal data summaries and reports, and to establish formal guidelines for the assessment of air pollution impact from coal-fired power plants.

OUTLINE

The research plan is outlined below; some of the major components are discussed subsequently:

1. Field Investigation

   A. Temporal and spatial quantitative inventory of components of the study area, with particular focus on annual cycle phenomena of key species.

   B. Meteorological measurements to support the modeling and experimental air pollution research efforts.

   C. Development of remote sensing as a tool for detecting effects of air pollutant challenge on the ecosystem.

   D. Measurement of loss of inventory attributed to strip mining, power lines, human activity, water use, and other potentially confounding influences (e.g., pesticides, disease, population cycling).

II. Air Pollution Experiments

   A. Experimentally controlled air pollution of spatial segments of an ecosystem.

   B. Detailed measurement of biological structure and function, including energy flow, nutrient cycling and species condition, composition, and diversity during and following air pollution stress.

III. Laboratory Experiments

A. Measurement and evaluation of physiologic, biochemical, and behavioral mechanisms of response to air pollution challenge.

B. Precise measurement of parameters that support dynamic models.

C. Experiments designed to test whether changes observed in experimental study plots can be attributed to air pollutant stress.

D. Secondary stressor experiments (e.g. disease, temperature stress, water stress, non-specific stress).

E. Experiments designed to test field-generated hypotheses.

IV. Modeling

A. Use of an ecosystem level model to describe and predict effects of air pollutant challenge.

B. Use of models to help design experiments.

C. Use of models to help disentangle pollutant effects from natural variation and system dynamics.

D. Meteorological and dispersion modeling to describe the mode of entry of pollutant into the ecosystem and its time and space distribution and concentration.

Criteria for Damage to the Environment

There is no firm evidence regarding the sensitivity and reliability of criteria that might be employed to assess damage to a grassland ecosystem at relatively low chronic levels of pollution from coal-fired power plants. Nevertheless, a suitable criterion must have several of the following characteristics: (1) relatively low cost of measurement; (2) standard methods for measurement and assessment; (3) specificity; (4) potential for use in prediction; (5) stable and relatively noise-free response; (6) a potential for yielding results in a time frame of a year or less; (7) a potential for retrospective evaluation; (8) be suitable for validation in subsequent years or at other sites; and (9) reasonable sensitivity to air pollutants.

Even in a comprehensive investigation, extensive studies of a large array of species or processes is not possible. Considerable research is required to identify the specific parameters that will give an adequate, sensitive measure of air pollution to a grassland ecosystem or components thereof. Broad categories of important functions that should be investigated include: (1) changes in productivity or biomass of ecosystem compartments; (2) changes in life cycle and population dynamic functions of "key" taxa. (3) Changes in community structure or diversity; (4) changes in nutrient cycling; (5) sublethal biochemical or physiological changes in individuals or compartments; (6) behavioral changes in mobile organisms; and (7) changes in reproductive patterns.

If we are to assess and interpret the effects of air quality on natural ecosystems, it is essential that we understand also the wide range of abiotic factors (e.g., weather, geography, insolation, hydrology) that influence the dynamics of the living components of the ecosystem. Optimum production, the maintenance of stability and diversity and other desirable properties of ecosystems all depend upon a variety of abiotic factors.

In addition to air quality monitoring (see below), the following abiotic factors should be measured continuously or at frequent intervals:

a. Time
b. Precipitation
c. Relative humidity
d. Air temperature (at varying heights above ground)
e. Soil temperature (at several depths)
f. Wind speed
g. Total radiation
h. Net radiation
i. Soil water (2 depths)
j. Soil heat flux

Air Quality Measurements

The NERL mobile air quality laboratory in Montana will measure SO_2, $NO/NO_2/NO_x$, ozone, total and detailed hydrocarbons, CO, methane, and meteorological variables continuously. A second mobile laboratory will be located near Colstrip to characterize the aerosols in the vicinity of the power plant. The two lab trailers together will allow the characterization of the gases and aerosols in the vicinity of the power plant. This will provide the basis for comparative evaluations during the operating years. The present schedule allows for the gas monitoring trailer to be located in Colstrip, Montana, from April through October each year. The aerosol trailer will be located in Montana for periods up to two months during the growing season each year.

Data assimilation and recording will be effected by a Monitoring Laboratories Data Acquisition System. The data are assimilated and printed via teletype into one information package. The system retains the information and provides teletype printouts of 1 hour, 4 hour, 8 hour, or 24 hour averages.

The air quality data registered by the two EPA mobile laboratories will be supplemented by similar data on gases from two mobile air quality laboratories operated by the State of Montana. Refrigerated air samples collected daily from approximately ten study sites, will also be analyzed for major pollutants. The structure of this air quality monitoring network was determined largely on the basis of diffusion modeling, topography, land use, and by biological, fiscal, and land ownership constraints. While this system is far from ideal, we feel that it is adequate to establish annual and diurnal patterns and variance in pollution levels, pollution gradients, and their relationship to biological parameters.

Remote Sensing

Whereas we are primarily concerned with effects of air pollution, secondary and potentially confounding impacts from diverse sources invariably occur in association with coal mining, conversion, and combustion for delivery as electrical energy. Unless we are able to identify these sources and magnitudes of their effects, we may be unable to fully identify and isolate the effects of air pollution *per se*. Furthermore, control strategies can be set only if we have the capacity to investigate effects over large areas and at considerable distances from active mines and their associated power plants.

Remote sensing can thus be employed as one possible tool to inventory some of the major ecosystem resources and to provide information on the larger scale ecosystem changes that occur during and prior to the period of study.

Conclusions

The present investigation represents an attempt to characterize the impact of air pollutants on a total ecosystem. More importantly, it is the first to attempt to generate methods to predict bioenvironmental effects of air pollution before damage is sustained. In the past, most air pollution field research has dealt almost exclusively with direct acute effects on vegetation. It is expected that complex changes in ecosystem dynamics as a function of relatively long term, chronic pollution challenge will be observed. By studying a rather broad range of interacting variables, we hope to isolate some as sensitive and reliable measures of air pollution impact.

The approach envisioned requires (1) the use of reasonably comprehensive models of component populations of the ecosystem; (2) the use of appropriately structured field or laboratory experiments; and (3) evaluation of physiologic and biochemical functions that may serve as specific indicators of air pollution stress. The study will establish one part of the cost/benefit matrix that will provide for the normalization of environmental impact information.

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16. Abstracts

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