Environmental Implications of Coal Development: An Interdisciplinary Research Team Approach

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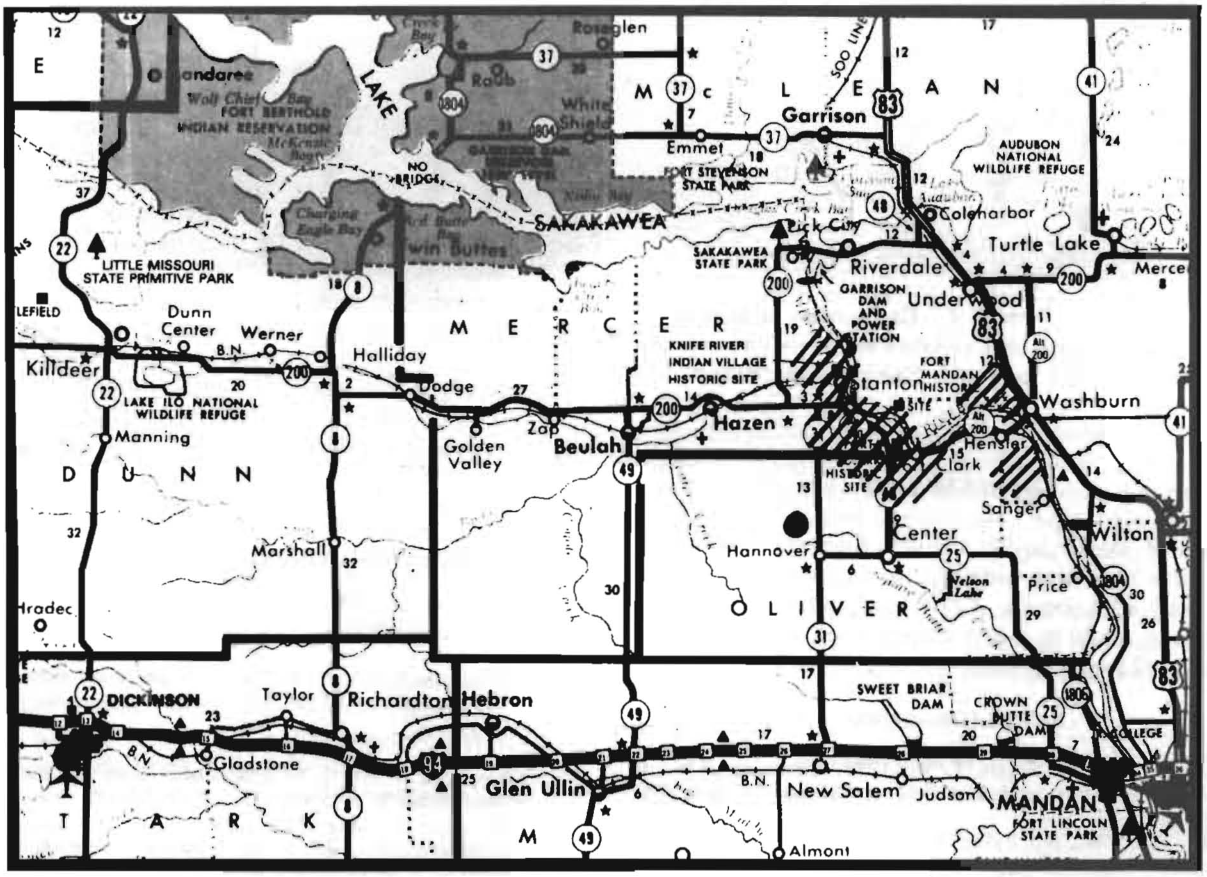

General location of the sites where field data were collected on this project. Climatological data were gathered from two sites (●); one southwest of Dickinson and the other near Hannover. Base line data on grassland and woodland communities were collected from 12 locations (//////////) along the path of the prevailing winds, to the northwest and to the southeast of Stanton, and near Hensler, 10 miles to the east.

In May, 1974 a team of researchers from North Dakota State University launched a project aimed at investigating "The Implications of Coal Development on the Atmospheric Environment and Plant Ecosystems of Selected Sites in Western North Dakota." It was an interdisciplinary effort of four basic study areas, namely: Soils, Climatology, Engineering, and Botany. Support was provided by the U. S. Forest Service, U. S. D. A., under a Surface Environment and Mining (SEAM) cooperative agreement with the North Dakota Agricultural Experiment Station. The investigations which lasted 4½ years, were designed to accomplish three primary objectives. First was to analyze the frequency, intensity, and duration of low-level radiation inversions in western North Dakota. The second was to determine the probable dispersion of wastes to the atmosphere from various theoretical operational

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levels and types of coal development in the specified area. Lastly was evaluation of the effects of probable changes in air quality on the plant ecosystems in the area.

The following sections are summaries of the findings of the three research work groups constituting the team. Although interrelated and complementary to one another, the findings of each group also stand as significant contributions to their own disciplines and may likely serve as base line data by which to interpret long range impacts of coal development in western North Dakota. Therefore, they are presented individually according to the objectives of each work group making up the team.

I. CLIMATOLOGY OF INVERSIONS IN WESTERN NORTH DAKOTA

Two towers, one located in west-central (Hannover) and one in southwestern (Dickinson) North Dakota, were instrumented to determine the climatology of low-level temperature inversions. Platinum bulb thermisters were placed at 1, 2, 5, 14, 35, and 91 meter heights at Hannover and at 2, 8, 20, 55, 104, and 157 meter heights at Dickinson. Temperatures were recorded continuously from June, 1974 to June, 1977 on multipoint strip chart recorders, but equipment failure was a severe and continuing problem. The equipment was operational 58% and 66% of the potential time at Hannover and Dickinson, respectively.

One year's data from another tower located near Dunn Center, North Dakota, were also obtained for incorporation into this study. In addition, pertinent results from the North Dakota Regional Environmental Assessment Program study, the Northern Great Plains Resources Program study, and a National Weather Service upper air study were obtained.

Temperatures for all levels were averaged over 0.5 hour periods. An inversion condition was said to exist when a lapse rate $\geq 1^{o}C/100$ meters was recorded. The resulting inversion conditions were analyzed with respect to frequency, duration, and intensity. The results indicate that definite diurnal and seasonal trends exist.

The per cent frequency of occurrence of inversions in any half-hour period was about 30 to 35% in the spring, summer, and fall and increased to about 50% in winter. Daytime inversion conditions are rare during the summer, but occur with about a 20% frequency during the winter. Changes in the commencement and ending times correspond with the seasonal changes in sunset and sunrise times. Inversion conditions occur most frequently during summer darkness hours. On an annual basis inversion conditions exist about 35% of the time in any half hour period. When the frequency of occurrence is analyzed on a daily basis, the data show there is about a 90% chance of an inversion occurring on any given day. This chance is greater in summer than in winter.

Most inversions were of short duration, only 22% and 18% were longer than 10 hours at Hannover and Dickinson, respectively. The average length on an annual basis was 5.9 hours at Hannover and 5.0 hours at Dickinson. The duration of inversions exhibits strong seasonal trends. Average durations in winter were 8 to 10 hours, which is about 2-3 times longer than in summer.

The maximum intensities of all inversions ranged from 1 to $7^{o}C/100m$, while average intensities were $2\text{-}3^{o}C/100m$ at Hannover and only $1\text{-}2^{o}C/100m$ at Dickinson. The lower intensities at Dickinson probably reflect the greater height of the tower and not an aerial difference. The only seasonal variation was a slight tendency for winter inversions to be more intense than summer ones. A nearly linear relationship was found between average intensity and average duration ($R^2 = 0.59$) indicating either that longer inversions are also more intense or that more intense inversions are able to persist longer.

An inversion index consisting of the product of average monthly frequency, duration, and intensity provides a relative indication of air pollution potential. The winter time values were triple the summer ones, which indicates a much higher pollution potential in the winter. However, the October index was almost as high as the winter values. Apparently, the relatively dry air and calm winds in October can combine to cause a relatively high pollution potential.

Fumigation results when a plume is trapped in a turbulent zone below an inversion. This results in high concentrations of pollutants near the surface. Such a condition typically occurs during inversion breakup shortly after sunrise and is of short duration; 86% lasted one hour or less. The longest event was 4.5 hours duration. Fumigation conditions were far more common in winter, where they occurred 6-7% of the time.

II. ENGINEERING ASPECTS OF AIR AND THERMAL POLLUTION

The Engineering Group worked on the problems of air pollution and thermal pollution associated with the major activities of coal development. This work resulted in a survey of pollution control technology, emission rate of pollutants and possible impacts on the environment. In addition, it included mathematical models and the methodology used for prediction and estimation. The approach adopted for subsequent studies was characterized by considering the general relationship between the possible impacts and the plant design parameters. The method of case study was used either to illustrate the methodology recommended or to stimulate the possible impacts of the plant waste effluents.

Three specific studies were conducted as listed:

1. The impact on air quality of coal consuming products.
2. An air pollution study for fossil-fuel power plant.
3. A thermal pollution study for fossil-fuel power plant.

In the first study estimations were made of the by-products from fossil-fuel power plants and coal gasification plants. The by-products included SO_2, NO_x, bottom ash, fly ash, waste heat, and others. The results were presented in a series of equations and charts.

The mathematical model selected for air pollution calculations was the UNAMP (Users Network of Applied Modeling of Air Pollution). It consists of six computer programs which were originally developed by the Environmental Protection Agency at Research Triangle Park, North Carolina. For this project the Engineering Group prepared a user's guide for these programs.

To simulate the possible impacts of air pollutants on the environment, the study investigated two hypothetical facilities. These facilities, a coal-fired electric-generating plant and a coal-gasification plant, if built in western North Dakota would consume North Dakota lignite coal. Applicable meteorological conditions were described for western North Dakota as well as the Federal and State air pollution regulations. Several methods of controlling the concentration of air pollutants were considered and their effects on concentration levels was investigated. The effects of different atmospheric conditions were also included.

The hypothetical power plant had a generating capacity of 600 MW and coal gasification plant 250 MMSCFD (million cubic feet of standard dry gas per day). Information on the gasification plant simulation was presented in the final SEAM report.

Based upon the simulations of the hypothetical plants it was indicated that air pollution control equipment will be necessary to avoid exceeding State and Federal Air Pollution Regulations. Generally, the facilities will not exceed the stated regulations, but under certain atmospheric conditions temporary rises in air pollution concentration levels can be expected. When these conditions exist, primarily low mixing heights, the plant operation will either have to be curtailed or air pollution control equipment will have to be used.

A comparison of the estimated SO_2 concentrations from a coal-fired electrical generating plant and coal gasification plant can be made assuming no SO_2 scrubbers are used. Although a 600 MW electrical generating plant may emit 50% more SO_2 to the atmosphere than a 250 MMSCFD coal gasification plant, the coal gasification plant will generally create higher ground-level concentration of SO_2 because of its shorter stack.

The study of these two hypothetical facilities does indicate that they will have a considerable impact on the air quality in western North Dakota, but with the use of air pollution control equipment the impact can be minimized and reduced to acceptable levels. An area that was not studied is the effect of placing several electrical generating and coal gasification units throughout western North Dakota. The building of a large number of these units in the western part of the state may have an unacceptable cumulative effect on the air quality and the problem will have to be studied further in the future.

To supplement this, a second study was conducted in air pollution of a fossil-fuel power plant. In this case a brief survey of air pollution control technology was presented. Technologies such as fluidized-bed combustion and various SO_2 removal processes were found more effective than the use of tall stacks. The study also reviewed some plume rise equations and found the significant impacts on the prediction of ground-level concentrations. In addition Document 4 included the mathematical models used for air pollution calculations and a general scheme for stack height selection. A case study was used to illustrate a use of this general scheme and to show the general relationship between the environmental impacts and engineering design parameters.

The engineering group also completed a study on the thermal pollution associated with an operation of fossil-fuel power plant. Attention was focused to the possible impacts on the atmospheric environment rather than on the natural water body.

The approach used for this was characterized by relating the environmental impacts to the control technologies or to the plant engineering design parameters. Three control technologies considered in this study are:

1. evaporative cooling towers;
2. cooling pond;
3. dry-type cooling towers.

Waste heat generation was expressed in terms of plant heat rate or plant efficiency. In general, the magnitude of the thermal discharge is staggering. For a 1000 MW fossil-fuel power plant the waste heat rejection to the environment will be approximately equal to 5120×10^6 Btu/hr. It is obvious that concern of the thermal discharge from power plants is justified.

The study also included the possible impacts of thermal discharge on the environment. The impacts were generally in the form of cooling water evaporation, drift, formation of cooling tower fog and cooling tower plumes. Calculations were made for a hypothetical power plant showing all possible impacts. The results were approximate, and obtained with the mathematical models available in literatures or with engineering equations.

Based upon the simulation of hypothetical plant operations, it was concluded that thermal discharge from fossil-fuel power plants will definitely have an impact on the atmospheric system. But with a careful selection of pollution control methods and optimal engineering design, the impact can be minimized and reduced to acceptable levels.

III A. BASE LINE DATA FOR GRASSLAND COMMUNITIES NEAR STANTON

During the growing seasons of 1974, 1975, and 1976 seven woodland and five prairie sites were analyzed to determine species composition and structure and standing crop. Eight study sites were arranged in a northwest to southeast pattern (direction of the prevailing winds) around the Stanton, North Dakota, vicinity where the Basin Electric Cooperative and the United Power Association coal-fired power plants are located. A prairie site and three woodland sites were located near Hensler, North Dakota, 10 miles to the east of the power plants out of the prevailing winds.

The prairie sites were analyzed using the points analysis method. Square foot quadrats were used to determine the forb component of the vegetation. The per cent basal cover of graminoid species, the average number of plants per square foot, frequency and relative density of the forb species was determined for each prairie site. The standing crop at the end of each year was determined.

All of the prairie sites studied could be called Mixed Grass Prairie communities with the dominant graminoid species being *Bouteloua gracilis*, *Stipa comata*, *Agropyron smithii*, and *Carex filifolia*. The most common forbs were *Artemisia frigida*, *Aster ericoides*, *Chenopodium leptophyllum*, *Hedeoma hispida*, *Lappula redowski*, *Lactuca oblongifolius*, *Lepidium densiflorum*, *Linum rigidum*, *Orthocarpus luteus*, *Psoralea argophylla*, and *Taraxacum officinale*. The standing crop ranged from 1245 to 2323 lbs. per acre on the prairie sites.

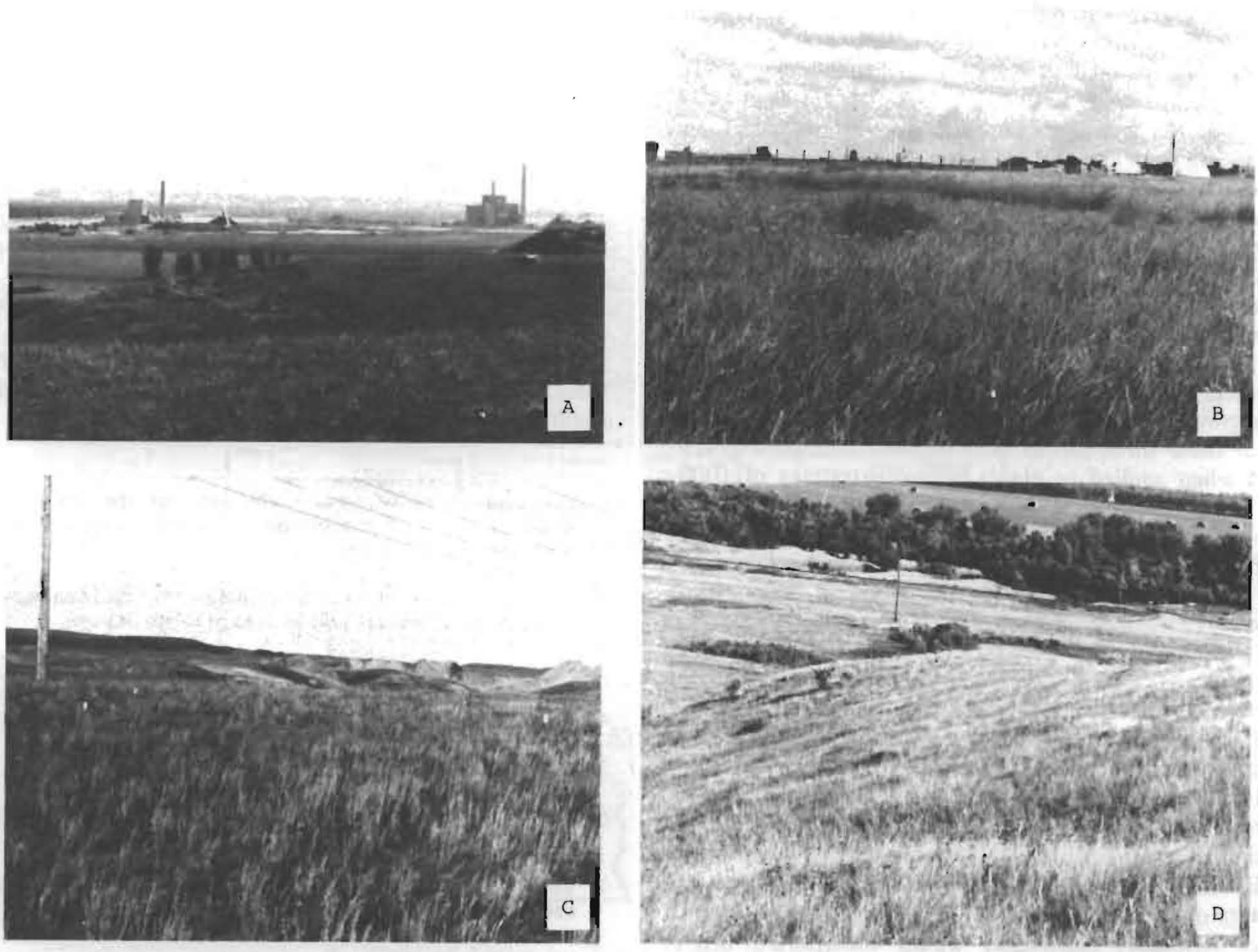
The woodland sites were analyzed using a belt transect method to determine density, relative density, frequency, relative frequency, dominance and relative dominance and importance value for each species. Within each transect the diameter at breast height (d.b.h.) was measured for trees with a d.b.h. equal to to greater than 2 inches. Five transects were used in each woodland study area except for one of the areas where ten transects were run. Understory vegetation was sampled using square meter quadrats.

The woodlands studied included two areas of cottonwood forest on the floodplain, four areas of cottonwood-green ash-boxelder forest on the slopes of the Missouri River Valley and two areas of hardwood draws. *Populus deltoides* dominates the floodplain and most Missouri River Valley forests. *Fraxinus pennsylvanica* and *Acer negundo* are subdominant trees in the Missouri River Valley forests. Cottonwood seedlings are absent in the forests, indicating that these forests are undergoing a succession favoring green ash and boxelder. The shrub species *Prunus virginiana* and *Amelanchier alnifolia* are common in the understory of these forests. Other commonly encountered species are *Symphoricarpos occidentalis, Toxicodendron radicans, Parthenocissus vitacea* and *Rosa woodsii*. The common herbaceous understory species were *Smilacina stellata, Biomus purgans, Lysimachia ciliata* and *Thalictrum venulosum*. The hardwood draw forests were dominated by green ash. Other woody species common to these areas were *Ulmus americana, Prunus virginiana, Shepherdia argentea, Rhus trilobata, Symphoricarpos occidentalis, Rosa woodsii, Amelanchier alnifolia*, and *Crataegus chrysocarpa*.

III B. PHYSIOLOGICAL RESPONSES

Growth and germination of wheat, barley, switchgrass, western wheatgrass, blue grama, and green needlegrass treated with Zn, Cd, Pb, and Mo were investigated. Cadmium was the most toxic heavy metal throughout the studies, effectively reducing growth and germination of all species as treatment concentrations of this metal were increased.

In solution culture, concentrations of $CdCl_2$ as little as 1 ppm reduced shoot growth, root growth, and dry matter production of all species. Switchgrass was the most sensitive species in that $CdCl_2$ significantly reduced growth



Examples of the sites studied include (A) Prairie Site 2 near the United Power Association and Basin Electric Cooperative power plants; (B) the Fort Clark Historic Site, location for Prairie Site 3 and Woodland Site 3; (C) Prairie Site 2 showing the proximity of lignite strip mining; and (D) Prairie Site 4 located above the Missouri Valley near Fort Clark.

at concentrations of 1 ppm in solution culture studies and 10 ppm in the vermiculite studies. Abnormal root development, including stunted growth and darkened tissues, occurred in plants grown in solution culture treated with Zn, Cd, Pb, or Mo.

Wheat, barley, and western wheatgrass, to which Zn or Cd solutions were applied foliarly, did not show any symptoms of metal toxicity. Furthermore, no significant differences in growth of these plants was observed between the different treatment concentrations.

In vermiculite studies where solutions of the heavy metals were applied topically, the following order of toxicity was observed: Cd $>$ Mo $>$ Zn $>$ Pb. The four native grasses: blue grama, switchgrass, green needlegrass, and western wheatgrass were especially sensitive to $CdCl_2$ treatments. Plants treated with 1000 ppm Cd died within 5 to 7 weeks of the first treatment. This report does not attempt to detract from the importance of Pb as a pollutant. In this study, some of the available Pb was probably precipitated and unavailable to plants. Thus, the other three heavy metals were more toxic to plant growth.

In vivo nitrate reductase activity (NRA) (activity of the plant enzyme that reduces nitrate nitrogen to ammonia) in wheat and barley was reduced by treating the plants with Cd or Mo solutions or by adding Cd or Mo to the incubation medium. Wheat was more resistant than barley where NRA in plants treated with concentrations of 100 to 1000 ppm Cd or Mo was significantly ($P < 0.01$) reduced. In experiments in which Cd was applied to the incubation medium, similar reductions in activity were observed with Cd as $CdSO_4$ and Cd as $CdCl_2$. Also, a general decline in leaf protein contents occurred in wheat and barley treated with increasing concentrations of Cd and Mo. Leaf resistance of these plants increased as treatment concentrations were increased, indicating a decline in transpiration rate.

Topical applications of Zn, Cd, or Pb to wheat and barley grown in soil had little effect on shoot growth, but each of these three metals reduced the production of dry matter when applied to plants in concentrations of 1000 ppm. Preincorporation of Zn or Cd salts into soil prior to planting resulted in stunted, chlorotic seedlings. Molybdenum solutions applied topically also reduced shoot growth and dry matter production in both wheat and barley.

It is apparent that a variety of factors influence the availability of heavy metals applied to soil. In these experiments, soil with a pH of 7.6 decreased the availability of Cd, Zn, and Pb to plants while increasing the availability of Mo. Because increased toxicity to plants resulted from metal salts preincorporated into the soil, the metals are apparently loosely bound to the soil complex and are available for plant uptake. However, the metals must be distributed throughout the potted soil mixture to facilitate optimum contact with root surfaces. In contaminated farmland, cultivation would incorporate heavy metals into the soil profile, while metal concentrations might remain high near the soil surface in undisturbed areas possibly affecting germination. High surface concentrations of heavy metals would be expected to accumulate in the Northern Great Plains where the ground is frozen for a large part of the winter.

The plant responses cited here have been reported on the basis of application rates for each of the metal treatments. This need not necessarily indicate the actual concentrations attained within the tissues because of precipitous factors in the environment and biological barriers to the absorption and transport of a heavy metal to the root or leafy tissue. Atomic absorption spectrophotometry of wet digested samples of root and leaf tissue collected from plants subjected to various experimental treatments indicate physiologically active concentrations to be considerably less than application rates for Zn. Base line data for Zn levels of field samples taken from the vegetation analysis sites is provided.

Contamination of soil with heavy metals is cumulative and not easily reduced by leaching. In North Dakota, the State Health Department (Miller et al. 1977) has reported that a direct relationship exists between higher soil concentrations of trace elements and coal-fired power plants. Although heavy metal toxicity in vegetation has not yet been reported, it has been estimated that North Dakota's electrical generating capacity will increase from the January 1974 level of 862 megawatts to 14,910 megawatts by the year 2000, an increase of $\simeq$ 17 times (Northern Great Plains Resource Program, 1974). In areas of present and future coal development, resulting increases of heavy metals in emissions may not reach toxic levels for plants but may accumulate and become hazardous to animal life and/or pose a potential health hazard to human populations.

Details and complete data supporting these summary statements are included in the progress and final reports of the research team to SEAM. The final report was in the form of several documents accompanying an executive summary statement. These documents included:

1. **The implications of coal development on the atmospheric environment and plant ecosystems of selected sites in western North Dakota: Final summary statement.**
2. **The implications of coal development on the atmospheric environment of selected sites in western North Dakota.**
3. **The impact on air quality of coal consuming facilities.**
4. **An air pollution study for fossil-fuel power plants.**
5. **A thermal pollution study for fossil-fuel power plants.**
6. **Baseline data for selected grassland and woodland communities near Stanton, North Dakota.**
7. **The effects of cadmium, zinc, lead, and molybdenum on germination and growth of selected grasses.**