&EPA
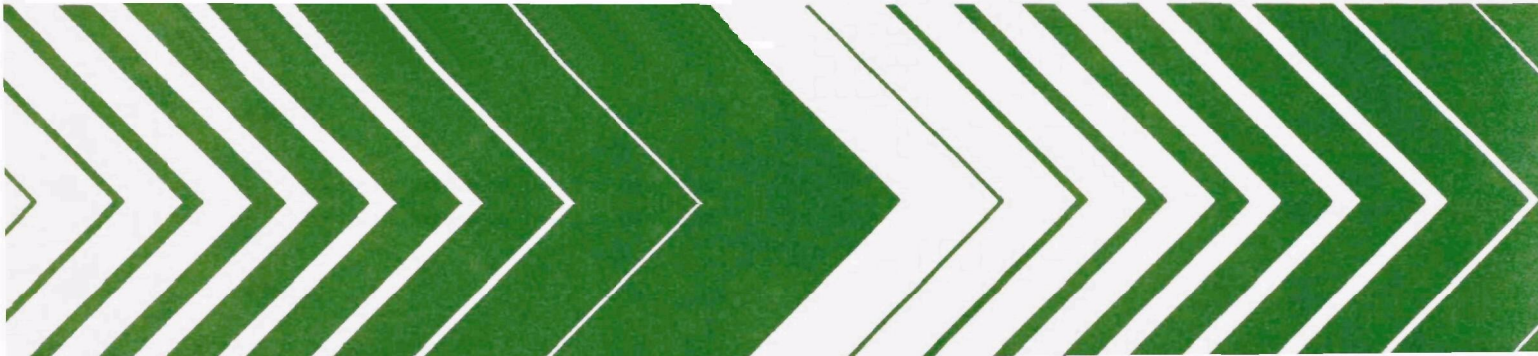
Impact of a Primary Sulfate Emission Source on Air Quality

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research

2. Environmental Protection Technology

3. Ecological Research

4. Environmental Monitoring

5. Socioeconomic Environmental Studies

6. Scientific and Technical Assessment Reports (STAR)

7. Interagency Energy-Environment Research and Development

8. "Special" Reports

9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

IMPACT OF A

PRIMARY SULFATE EMISSION SOURCE

ON AIR QUALITY

by

K.R. BOLDT, C.P. CHANG,
E.J. KAPLIN, J.M. STANSFIELD, B.R. WUEBBER

YORK RESEARCH CORPORATION
STAMFORD, CONNECTICUT 06906

DISCLAIMER

This report has been reviewed by the Environmental Sciences
Research Laboratory, U.S. Environmental Protection Agency, and
approved for publication. Approval does not signify that the
contents necessarily reflect the views and policies of the
U.S. Environmental Protection Agency, nor does mention of trade
names or commercial products constitute endorsement or recom-
mendation for use.

As concern for the human health effects of pollution has grown, so also has the response to that concern. Today, one of the primary goals of environmentally related research is to further quantify the relationship between pollution and human health effects. As a result, Federal, State and Local agencies, as well as the private sector, are directing resources into studies that further clarify the nature of this relationship.

Research into the causes and effects of sulfate emissions is a prime example of this effort. Sulfate has been linked in epidemiological and laboratory studies with adverse effects on human health. Such studies have, in fact, indicated that sulfate may be more hazardous than sulfur dioxide or total suspended particulates. Studies in Europe and the United States have shown sulfates to be major contributors to reductions in visual range caused by atmospheric aerosols. Studies of acid precipitation in Scandinavia have implicated sulfuric acid in a variety of adverse ecological effects.

Several major studies are ongoing in the United States to assess the atmospheric sulfate situation. Among these studies are EPA's Project MISTT and Project MESO, which involve the transformation and transport of sulfates in the atmosphere. Project SURE, managed by the Electric Power Research Institute, focuses effort on the distribution of Sulfates in the Northeast. MAP^{3}S is a study initiated by the Department of Energy to evaluate present and future effects of energy production on pollutant levels. EPA has initiated Project ACES to evaluate presence and formation of sulfate and other aerosols in the atmosphere.

The formation of sulfates, the effect of an oil-fired utility on ambient sulfate levels, and the relationships between sulfates contributed by a point source and background levels in the vicinity of that point source are the subject of this study. The effects of meteorology and source emission variables are also addressed in detail.

The data generated by this study adds significantly to the body of knowledge being accumulated on sulfates, their origin and their impact on the environment.

We at York Research Corporation are particularly pleased to have the opportunity to carry out this program for the United States Environmental Protection Agency.

ABSTRACT

A specific point source of sulfate emissions was chosen in the Northeastern United States to assess the impact of sulfate emissions on air quality. A comprehensive particulate and sulfur emission characterization was performed at the Albany Steam Station, owned and operated by the Niagara Mohawk Power Corporation in Glenmont, New York. The plant has four operating 100 MW boilers, installed in the early 1950's and originally designed to burn coal and oil. During the assessment the plant fired Venezuelan fuel oil containing 1.9% sulfur, 200 ppm vanadium, and a fuel additive to inhibit corrosion.

Emissions of total sulfate varied from 22 ppm to 55 ppm (22 kg/hr. to 82 kg/hr. per boiler, using modified Method 6 tests); sulfuric acid concentration averaged 74% of the total sulfate. Particulate concentration ranged from 60 mg/Nm^3 to 170 mg/Nm^3 (12 kg/hr. to 70 kg/hr. per boiler; 32%-67% of the particulate emissions were soluble sulfates. Mass median particle diameter was 1.8 um to 4.0 um, as determined by in-stack cascade impactors. Vanadium was implicated as the driving force in the magnitude of the primary sulfate emissions.

Historical meteorological and air quality data for the local area was examined. Meteorological and air quality parameters were measured concurrently with emission measurements. The presence of local sulfate sources was detectable by the monitoring network; however, the plume from the plant tended to pass over or between the monitoring stations during most of the sampling period. On the few days when the impact was observed, 5 km downstream from the plant, the sulfate impact was 34% to 60% of the total sulfate concentration. Daily ambient sulfate concentrations were from 3 ug/m^3 to greater than 40 ug/m^3; long term geometric mean concentration for the area was 10.4 ug/m^3.

The measurements discussed in this report were acquired during the period September 18, 1978 to October 15, 1978.

TABLE OF CONTENTS

vi

TABLES

ACKNOWLEDGEMENT

SECTION 1

INTRODUCTION

The suspected adverse effects of atmospheric suspended sulfates has been of increasing concern to the Environmental Protection Agency. As a result of recent ambient atmospheric studies, particularly in the Northeastern United States, the contribution of acid aerosol sulfates to the total ambient loading has raised some serious questions. It has generally been accepted that about one to ten percent of the sulfur in fuel is emitted from the combustion process as SO_4 (sulfate) or acid. However, during the transport process from the point of emission to the point of effect, sulfur dioxide can be transformed into various sulfates. The ability to predict relationships between emissions and ambient air quality--as influenced by physical, chemical and meteorological parameters--is an essential ingredient in the development of cost effective control strategies. This has become increasingly important with the realization that emissions affect not only the air quality in their immediate vicinity, but may extend their influence for hundreds of kilometers.

HEALTH AND WELFARE EFFECTS

Toxicological studies provide evidence that SO_2, in the absence of other pollutants such as ozone or particulates, is a mild respiratory irritant, while certain specific sulfate compounds, especially submicron-sized sulfuric acid aerosol, are more severe respiratory irritants (National Research Counil, 1978). Epidemiological studies conducted in several U.S. cities

1

suggest that high daily or annual sulfate levels are associated
with increased attack frequency in asthmatics, worsened symp-
toms in cardio-pulmonary patients, decreased ventilatory func-
tion in school children and symptoms of acute and chronic
respiratory diseases in children and adults. The association
of these health indicators with sulfates was stronger than that
for SO_2. When viewed together, the results of the toxicologi-
cal and epidemiological studies suggest that specific sulfate
compounds may also be responsible for the observed excesss
mortality associated with high SO_2 concentrations (National
Research Council, 1978).

Economic welfare effects associated with sulfates are ecologi-
cal and agricultural damage, materials damage, and visibility
degradation. Sulfates appear to be a major factor in producing
damaging acid rain in a large portion of the Eastern U.S.

SULFUR EMISSIONS FROM MANMADE SOURCES

Of the total emissions of sulfur from all sources in the United
States (17.7 Tg/yr.), about 89% is attributed to anthropogenic
emissions. Sulfur emissions from natural sources have been
estimated to be less than 2 Tg/yr. These anthropogenic sulfur
emissions are not uniformly distributed as 75% of the anthropo-
genic emissions have been estimated to occur east of the
Mississippi River (National Research Council, 1978). Power
plant emissions, which in 1973 accounted for about 60% of man-
made SO_2 emissions in the U.S., have been a rapidly growing
component of the SO_2 emission complex (National Research
Council, 1978). While total manmade emissions increased by
approximately 46% between 1960 and 1970, power plant emissions
increased nearly 92% (EPA, 1973). During this period energy
production rose considerably along with the consumption of fuel
oil, while the consumption of coal increased only slightly.

2

Sulfur in fossil fuel has long been a concern to utility companies because it contributes to corrosion problems during combustion, forming compounds such as SO_3 (sulfur trioxide, H_2SO_4 (sulfuric acid), and corrosive metallic sulfates. These same by-products of fuel combustion are named in toxicological studies as causing pulmonary dysfunction in human beings and laboratory animals.

Sulfur is liberated from fuel during combustion, forming mostly sulfur dioxide and a very small amount, perhaps 1%, sulfur trioxide within the furnace flame. The furnace gas, containing sulfur dioxide in concentrations less than 100 to greater than several thousand ppm (parts per million), passes through convective gas passages where heat is transferred from the gas to steel tubes that carry steam for superheat and reheat. The tubes generally are coated with ash deposits of low-melting point metals; these deposits can be extremely active catalysts, causing SO_2 to oxidize to SO_3 which then reacts quickly with H_2O to form H_2SO_4. Even the steel tubes themselves, coated with an iron oxide layer, can be strong catalytic surfaces.

Barrett's studies (1966) have shown that reaction rates for catalytic oxidation of SO_2 to SO_3 are very high at temperatures of 1200°F. The temperatures found in a typical convective back passage in a utility boiler is 1200°F to 2000°F, and intimate gas-to-metal contact is very important to efficient operation of these superheat-reheat steam loops.

Vanadium compounds are a big concern because of their catalytic nature and their low-melting point characteristics. Residual fuel oil contains vanadium in variable concentrations, depending on its source. Asphaltic-base crude oils, particularly those from Venezuela, often contain more than 300 ppm vanadium and 2.0% sulfur. The chemical nature of the crude oil ash is such that the vanadium is stable up to 800°F, therefore it is

3

not removed by refinery operations, and invariably ends up in the residual fuel oil.

Vanadium pentoxide is an extremely active catalyst used in the commercial production of sulfuric acid, converting SO_2 to SO_3 prior to gaseous absorption in dilute sulfuric acid. Vanadium pentoxide also has a melting point of 1247°F, and other vanadium compounds such as the sodium vanadates have melting points from 1165°F to 1560°F (Babcock & Wilcox, 1978). When vanadium is present in fuel, these low-melting point compounds are formed and readily stick to superheat-reheat steam tubes. Sodium is also troublesome because it forms complex alkali iron trisulfate compounds with boiler metal.

Coal generally has a lower concentration of vanadium (usually less than 50 ppm) and a higher overall ash content, resulting in less concentrated vanadium deposits in the critical gas passages. The amount of sulfur converted to sulfate is usually 1 to 4% in coal fired boilers and 2 to 10% in oil-fired boilers. The vanadium and sulfur content of the fuel are primarily responsible for the high sulfate emissions from oil combustion.

CONCENTRATION DISTRIBUTION

Based on National Air Surveillance Network data, a large portion of the eastern United States has recorded sulfate concentrations significantly higher than concentrations generally observed in other sections of the country. Urban levels range from 10 to 24 micrograms per cubic meter (ug/m^3) and non-urban levels range from 8 to 14 ug/m^3 (annual average) in a 24-state region east of the Mississippi, roughly bounded by Illinois and Massachusetts to the north and Tennessee and North Carolina to the south. In this 24-state region, the 1972 average of non-urban concentrations exceeded 10 ug/m^3 (annual average) with an urban concentration average of about 13.6 ug/m^3. The high

4

sulfate levels in the 24-state area appear to be spatially cor-related with high SO_2 emission density, high rainfall acidity patterns, and a high density of power plant locations. The remainder of the country does not exhibit similar sulfate con-centrations on a regional scale. The 1972 urban average out-side the 24-state northeastern region was 7.9 ug/m^3; whereas the non-urban annual average was 4.4 ug/m^3. There are some areas, however, such as the Southern California Coastal Basin and Tampa, Florida, in which high sulfate levels are also observed. Thus, while these areas do not exhibit the regional concentration problems characteristic to the northeastern U.S., they do have high local sulfate concentrations.

ATMOSPHERIC CHEMISTRY AND TRANSPORT

Sulfur dioxide is oxidized to sulfuric acid and other sulfur oxide compounds by several mechanisms, most involving reactive agents such as photochemical smog, ammonia, catalytic metals (such as V, Mn, Fe and Ni) and fine particulates. Temperature and humidity also influence the reaction. These agents can complicate the relationship between SO_2 and sulfates; for example, reductions or increases in SO_2 concentrations may not result in proportional reductions or increases in sulfate levels because of the presence of other agents that affect the formation reaction. Inadequate knowledge concerning formation mechanisms currently precludes quantitative assessment of catalytic agent influences.

Studies of large point sources (i.e., power plants) before and after unit start-up indicate measureable increases in sulfate concentrations as far as 40 miles away (OAQPS, 1975). Investi-gations of sulfate formation in plumes of coal-fired plants with particulate control suggest that the oxidation rate of SO_2 is negligible for the first 10 to 20 miles but increases to 3%/hr. or more thereafter (Newman et al., 1974a). Similar

5

studies on oil-fired plants tentatively indicate that the oxidation rate may be more rapid in the first 10 miles (10 to 20%/hr.), with the rate then becoming comparable to that of a coal-fired plant plume (Newman et al. 1974b). This potentially rapid initial oxidation rate in the oil-fired plant plume is most probably the result of certain components in the emitted flyash that catalyze the reaction. Since sulfates formed in plumes are very small particles, the removal rate for sulfates by ground surfaces is much slower than the removal rate for SO_2. Once formed, these sulfate particles may be transported for hundreds of miles, although their downwind concentration is diminished by dispersion.

Although urban SO_2 levels have decreased substantially, no consistent similar trend has been observed for urban sulfates. Long-range transport and complex precursor relationships have been hypothesized as explanations of this phenomenon. While SO_2 emission reductions in cities resulted in less locally formed sulfates, increases in non-urban SO_2 emissions (primarily from power plants) may have caused regional sulfate increases that, on balance, offset the local decreases. This explanation is supported by the apparent increase in manmade sulfates at a limited number of eastern non-urban sites for which data are available. This increase roughly parallels the increase in overall SO_2 emissions during that time. Although, in aggregate, urban sulfate levels showed little change, variable trends were observed for different cities. Variations in both the spatial distribution of sulfur oxides emissions and in atmospheric chemistry could affect the relative magnitude of local versus imported sulfates and account for the variable trends for individual cities.

Despite the uncertainties concerning the relationship between SO_2 emissions and ambient sulfate concentrations, the available evidence suggests that further increases in SO_2 emissions are

likely to produce increases in regional sulfate levels. However, sulfate increases are not likely to be linearly proportional to the total SO_2 emissions increase because of the spatial distribution of the important sources and the complex formation mechanisms.

REMOVAL OF SULFUR COMPOUNDS FROM THE ATMOSPHERE

Mechanisms of Removal

Mechanisms for the removal of sulfur compounds from the atmosphere may be classified as follows:

- Diffusion of sulfur dioxide to soil and vegetation
- Rainout and washout
- Dry removal of sulfate particles

The diffusion of sulfur dioxide to soil and vegetation is relevant to the impact of the power industry on atmospheric sulfates because it constitutes a process whereby part of the conversion of sulfur dioxide to sulfates is circumvented. Unfortunately, from overall environmental considerations, this process has harmful effects on vegetation.

Rainout and washout are differentiated as follows: rainout refers to processes initiated in clouds, and washout refers to processes occurring as precipitation falls through the region below clouds. These processes are probably significant as mechanisms for the removal of both sulfates and sulfur dioxide from the atmosphere. Once formed, sulfate particles may serve as nuclei for the condensation of water as either liquid or ice.

Sulfur dioxide in the presence of water is oxidized to sulfuric acid and other sulfates through several mechanisms. These

7

include photochemical oxidants, ammonia, and catalytic metals. Ambient temperature is also thought to be an important factor (OAQPS, 1975). A simplified example of one of these oxidation mechanisms is the following reaction for ammonia, sulfur dioxide, and water (humidity). The resulting ammonium sulfate would have atmospheric removal characteristics appropriate for particulates.

$$NH_3 + H_2O \longrightarrow NH_4OH$$
$$2SO_2 + 2H_2O + O_2 \longrightarrow 2H_2SO_4$$
$$2NH_4OH + H_2SO_4 \longleftrightarrow (NH_4)_2 SO_4 + 2H_2O$$
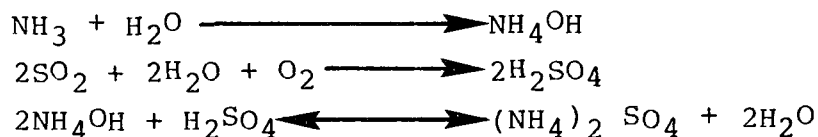
Just as sulfur dioxide can be removed from the atmosphere by diffusion, sulfate aerosols can be removed by diffusion to the surface of the earth. Insofar as the dry deposition of sulfates is concerned, diffusion is regarded as more significant than the alternative process of gravitational sedimentation. Except for the possibility of sulfate particles from sea salt, sulfate particles are generally too small to undergo significant sedimentation under the influence of gravity.

Residence Times

The residence times of sulfur compounds in the atmosphere are not known with a great deal of certainty. Residence times of 14-33 hours have been estimated for sulfur dioxide and 3-5 days for sulfate (National Researach Council, 1978).

Transport Effects

Bearing in mind that the residence times are related to the exponential removal rates, one can easily comprehend the fact that significant fractions of the sulfur dioxide and sulfate persist in the atmosphere until they are transported by wind for long distances. Thus, although deposition on the surface

of the earth may be pronounced in the immediate vicinity of a source of emission, long-range influences are also to be expected.

EFFECT OF BOILER OPERATING PARAMETERS

The absorption of sulfur oxides, metal oxides, and chlorides by deposits in the boiler results in the subsequent conversion of these compounds to sulfates. Therefore, any effect aimed at minimizing these deposits would reduce sulfate emissions. Soot blowing removes some of this material but momentarily increases emission of sulfates and particulates.

There is little evidence to indicate that combustion modification will, in general, be an effective procedure for acid aerosol abatement although low excess air firing, where practical, may be an exception. Existing data indicates that acid aerosol can be reduced by operation with low excess air. The reduction in NO and NO_2 is accompanied by reduced SO_3 formation in the flame and the reduced availability of oxygen pertains through-out the system. This implies extremely good combustion control. It must be kept in mind that in low excess air combustion there is the risk of increased particulate formation which might lead to an increase in catalytic oxidation of SO_2. However, from the standpoint of controlling both NO/NO_2 production and acid aerosol formation, this appears to be a possible approach at the present time.

Another aspect of boiler operation is the use of additives, which in effect change the metal content of the fuel. Generally, materials are used containing either Mg or Zn, both of which readily form sulfates. The particles thus formed may be removed by precipitators thereby reducing the potential for acid aerosol emission. Various forms of the additive have been shown to be effctive, i.e., metals, metal oxides, minerals, or

9

organometallic compounds. There is evidence that suggests the
use of additives can deposit a coating of metallic oxide, such
as magnesium oxide, on the boiler tubes which then deactivates
the catalytic deposits and effects a reduction of sulfate aero-
sol emissions. Generally though, the use of additives is moti-
vated by the reduction of corrosion and acid particulate emis-
sion, through formation of neutral $MgSO_4$ or $ZnSO_4$ or $MgSO_4$.

RELATED RESEARCH PROJECTS

A significant amount of research into the significance of the
effects of acid fallout and their quantitative relationship to
ambient levels of sulfates in the air is currently in progress
by numerous governmental agencies and industrial organiza-
tions. The more important projects to date include:

Project MISTT (Midwest Interstate Sulfur Transformation and
Transport)

The technical approach of Project MISTT, initiated by EPA's
Environmental Sciences Research Laboratory in the summer of
1974, is to study the transformations of SO_2 to sulfate in
polluted air masses undergoing transport. The intent is to
measure pertinent chemical and meteorological parameters with
sufficient accuracy so that they may be used with physical and
mathematical models to derive rate parameters which character-
ize the transformation processes.

MISTT results to date suggest the existence of both homogeneous
and heterogeneous reactions. Homogeneous reactions, which pro-
bably involve the hydroxyl radical, predominate in dry daylight
conditions. The rates vary from 1/2 to 5 percent per hour, de-
pending on sulight intensity, water vapor concentration, ozone
concentration in the background air, background pollution
levels in general, and the extent of mixing of the plume with

10

background air. On the other hand, heterogeneous reactions in-
volving liquid droplets may predominate during high relative
humidity, at night, and in clouds. These rates may be much
higher than the 1/2 to 5 percent for homogeneous reactions.
Good quantitative data on this are not yet available but it is
known that with very high sulfate and very high conversion
rates, liquid droplets do exist.

Project MESO (Mesoscale Sulfur Balance Project)

The mesoscale sulfur balance project, also managed by EPA's
Environmental Sciences Research Laboratory, involves the deter-
mination of the proportion of aerosol in ambient rural air as-
sociated with sulfates formed during long-distance transport.
The relationship among high sulfate measurements, meteorolog-
ical conditions and SO_2 input is also being examined. The pro-
ject is designed to test whether successive SO_2 sources across
the Midwest cause an accumulation of sulfates at a rate sub-
stantially greater than overall removal rates. The hypothesis
being tested is that as air masses move across the country they
pass over successive sources of SO_2, generally large power
plants. Since sulfates are only slowly removed by natural pro-
cesses, a substantial build-up of sulfate can occur from re-
peated emissions of SO_2.

Project SURE (The Sulfate Regional Experiment)

Within the United States, the highest sulfate levels occur in
the Northeast. Concentrations ranging from 5-25 ug/m^3 are
typical. (During "episodes" values up to 80 ug/m^3 have been
recorded). This is in marked contrast to the 3-4 ug/m^3 com-
monly measured in the West. Because of the high Northeast
values, the Electric Power Research Institute (EPRI) decided to
initiate a regional sulfate study focusing the effort on the
populous Northeast. Project SURE is a scaled up version of

EPA's Project MESO. It's two primary purposes are to define ambient sulfate in terms of local SO_2 emissions and to assess the contribution of the electric power industry to regional sulfate levels. The basic elements of sure consist of a ground-based and air-based measurement program, an emission inventory and development of a model to predict regional concentrations as a function of local emissions.

Project MAP^{3}S (Multi-State Atmospheric Power Production Pollution Study)

The goal of MAp^{3}S, the Department of Energy (DOE) sulfate program, is to improve simulation capability for use in evaluating present and future effects due to power production emissions.

Project ACES (Aerosol Composition, Effects, and Sources)

The purpose of EPA's Project ACES is to determine the sources of urban aerosol. Measurements of the composition and size of ambient aerosols have been made in selected cities. The aerosol components are assigned to natural and anthropogenic sources and classified as primary or secondary in nature. These results are compared with emission inventory data. Models, which include aerosol removal mechanisms and secondary aerosol formation mechanisms, are used to relate primary sources of aerosol and precursor gases to ambient aerosol concentrations. Thus, it becomes possible to identify those sources that need to be controlled to provide reduction in total aerosol loading or specific aerosol components.

PERTINENT ISSUES

Under the Clean Air Act of 1970, the Administrator of EPA may establish a National Ambient Air Quality Standard (NAAQS) for "any air pollutant which in his judgment has an adverse effect

12

on public health and welfare", and results from emissions of "numerous or diverse mobile or stationary sources." It is concern for this responsibility that necessitates EPA's intense interest in the sulfate issue. The possibility of an ambient sulfate standard being promulgated by EPA is also a major concern of the electric power industry as the impact would be quite severe.

Promulgation of such a sulfate standard requires a considerable supporting data base. Among the areas where research is warranted (and in most cases already in progress) include:

1. Reliable monitoring methods for total sulfates, sulfuric acid and specific sulfates.
2. Quantitative toxicological data regarding the relative effects of sulfur dioxide and specific sulfates.
3. Investigation into sulfate precursor relationships.
4. Investigation into the mechanisms of acid aerosol formation and destruction.
5. Correlation between sulfate emissions and ambient air concentrations as influenced by physical, chemical and meteorological parameters.

Fortunately, an integrated interagency program of research to address the numerous issues has already been formulated.

The discussion presented above is not intended to be a comprehensive review of this program, but rather identify some of the issues which this study will address in a direct or indirect manner.

SULFATE MEASUREMENT AT A POINT SOURCE

A growing concern over the emission and airborne transport of sulfate materials stimulated this research investigation

13

surrounding a specific point source. The point source for this study was a representative oil-fired utility plant in the Northeastern United States using residual fuel oil with 1.9% sulfur, 200 ppm vanadium and 0.12% ash. The Niagara Mohawk Power Corporation cooperated in the four week field program which consisted of meteorological, ambient air quality, emission and combustion data gathering. The investigation covered the period from September 18, 1978, to October 15, 1978, and centered around the Albany Steam Station in Glenmont, New York.

A comprehensive emission characterization program was performed on all four of the 100 MW rated boilers. Operating data were collected continuously on all boilers, supplying information necessary to assess the emissions on an hourly basis. Daily ground-level total suspended particulate samples were collected at five monitoring sites, ranging 3.0 km to 5.5 km from the emission source. Ground-level particulate samples were also collected at the emission source. Sulfur dioxide concentrations were measured instrumentally at all sampling sites. Two sampling sites included particle sizing capability, using cascade impactors and virtual impactors (dichotomous samplers), and visibility measurement capability using nephelometers. Four sampling sites included NO/NO$_2$ measurement capability.

Meteorological measurements included wind speed and direction on the Hudson Valley floor and at an elevation above the stack height. Atmospheric mixing height measurements were made continuously with an acoustic sounding device; calibration was accomplished with helium-filled balloon sondes. The balloons were tracked with theodolites in order to determine upper level wind speed and direction.

The data were used to identify the contribution of sulfate emissions from a known point source to the ground-level

14

concentration of sulfate in the vicinity of that same point
source. The formation of primary sulfate was investigated as a
function of operational variables and the relationship between
primary sulfate emissions and the ambient ground-level concen-
tration was identified.

Wind speed and direction measurements were available from the
National Weather Service at Albany Airport. Wind speed and
direction, as well as air quality measurements, were available
from the New York State Department of Environmental Conserva-
tion's Rennsalaer monitoring site.

A map of the general area and the Hudson River is shown in
Figure 1, and a map showing the monitoring network is shown in
Figure 2.

SECTION 2
CONCLUSIONS

Total sulfate concentration in the plant effluent ranged from 22 ppm to 55 ppm as measured with a modified EPA Method 6 sampling train. This resulted in emission rates of 22 kg/hr. to 82 kg/hr. from each operating boiler. Sulfur dioxide emission concentration averaged 938 ppm and average emission rate was 856 kg/hr. Sulfuric acid concentration averaged 73.5% of the total sulfate emission as determined using a controlled condensation sampling train. However, a discrepancy exists between the test results using the modified Method 6 train and the controlled condensation train for total sulfate measurement. The total sulfate results from the modified Method 6 tests were approximately twice those from the controlled condensation tests. The results of the modified Method 6 tests were used in the sulfate emission correlations because they are consistent with data obtained from similar emission sources.

Particulate concentrations ranged from 60 mg/Nm^3 to 170 mg/Nm^3 and emission rates ranged from 12 kg/hr. to 70 kg/hr. Between 32% and 67% of the particulate collected at 160°C was in the form of sulfate.

Mass median particle diameter was 1.8 um to 4.0 um during normal operation at high load. Slightly lower diameters were observed at low loads and slightly higher diameters were observed during soot blow.

A proportional relationship was observed between vanadium concentration in the stack gases and the emissions of sulfate. A reduction in sulfate emissions was implicated by the time of on-line boiler operations, using a fuel additive. However, the relationship was not that strong.

16

Local source/sink effects can be seen in the ambient sulfate data from the Albany area. While the specific local sources are not quantified, their presence is detectable.

The ambient sulfate data tend to indicate that the higher concentrations occur as pulses or spikes. These ambient pulses or spikes last on the order of magnitude about one day with lower sulfate values preceeding and following the 24 hour elevated ambient concentrations.

Diurnal variations in both meteorological and air quality parameters were found to exist. These variations suggest that sulfate due to local sources would be minimally observed in the Albany area. The night time surface stable areas would tend to retard the dispersion of elevated sources to the ground. The surface levels of ozone and sulfur dioxide tended to have day time maximums but at different times of day. Thus, photochemical SO_2 to $SO_4^=$ conversions incorporating ozone were probably minimal.

There were limitations in the air sampling network. During the sampling period, the plume from the Albany Steam Station tended to pass over or between monitoring stations resulting in little or no impact at these monitoring stations.

Sulfate transported into the study area was higher during periods of southwesterly flow aloft. Ambient sulfate measurements demonstrated a high variability in sulfate levels. On the three days when the winds were blowing directly towards a monitoring site for at least 12 hours, the average increase of downwind sulfate concentration over upwind concentration was from 3 ug/m^3 to 26 ug/m^3 or from 34% to 60% of the total downwind sulfate concentration.

In the study area during the study period, daily ambient sulfate concentrations ranged from 3 ug/m^3 to greater than 40 ug/m^3. Annual geometric mean sulfate concentrations for downtown Albany range from 8.0 ug/m^3 to 13.0 ug/ m^3 and 7.1 ug/m^3 to 11.0 ug/m^3 for Troy.

SECTION 3
PROGRAM DESCRIPTION

DESCRIPTION OF THE STUDY AREA

General

The macrosphere of this investigation includes the greater
Adirondack Mountain Region, bordered on the East by the Hudson
River, on the South by the Mohawk River, and on the West and
North by Lake Ontario and the St. Lawrence Seaway. The Hudson
River Valley extends to the South, draining into the Atlantic
Ocean at New York City; the Hudson is bordered on the West by
the Catskill Mountain Region and on the East by gently rolling
terrain. The Catskill Mountain Region's Northern border is a
rolling area extending 50 miles to the Mohawk River.

Topography

The greater Albany area lies at the confluence of the Mohawk
and Hudson Rivers. These rivers lie in broad valleys sur-
rounded by the Catskill Mountains to the Southwest, the
Adirondack Mountains to the Northwest and the Green Mountains
to the East. These mountain-valley terrain features tend to
produce North-South surface winds. The topography in the study
area is shown in the terrain cross-sections in Figure 3. These
cross-sections illustrate the small river bottom valley within
the larger Hudson River Valley. The Hudson River bottom land
is confined in a shallow valley about 200 m deep and about 2 km
wide. The terrain on the East side of the river above the bot-
tom land is somewhat higher than that on the West side. The
West side above the river bluff is relatively flat compared to
the more rolling East side.

19

FIGURE 1

THE HUDSON RIVER VALLEY

VERMONT

ALBANY
COUNTY
AIRPORT

SCHENECTADY

TROY

COHOES

ALBANY

TACONIC RANGE

ALBANY
STEAM
STATION

RENSSELAER

CASTLETON

MASS.

HUDSON

CATSKILL MOUNTAINS

HUDSON RIVER

HARTFORD

POUGHKEEPSIE

CONNECTICUT

PA.

NEW
HAVEN

RAMAPO MOUNTAINS

LONG ISLAND SOUND

10 5   10
Miles

NEW
YORK

LONG ISLAND

10 5   10
Kilometers

NORTH

Aprox. 1000
foot contours

Aprox. 2000 ft. contours

20
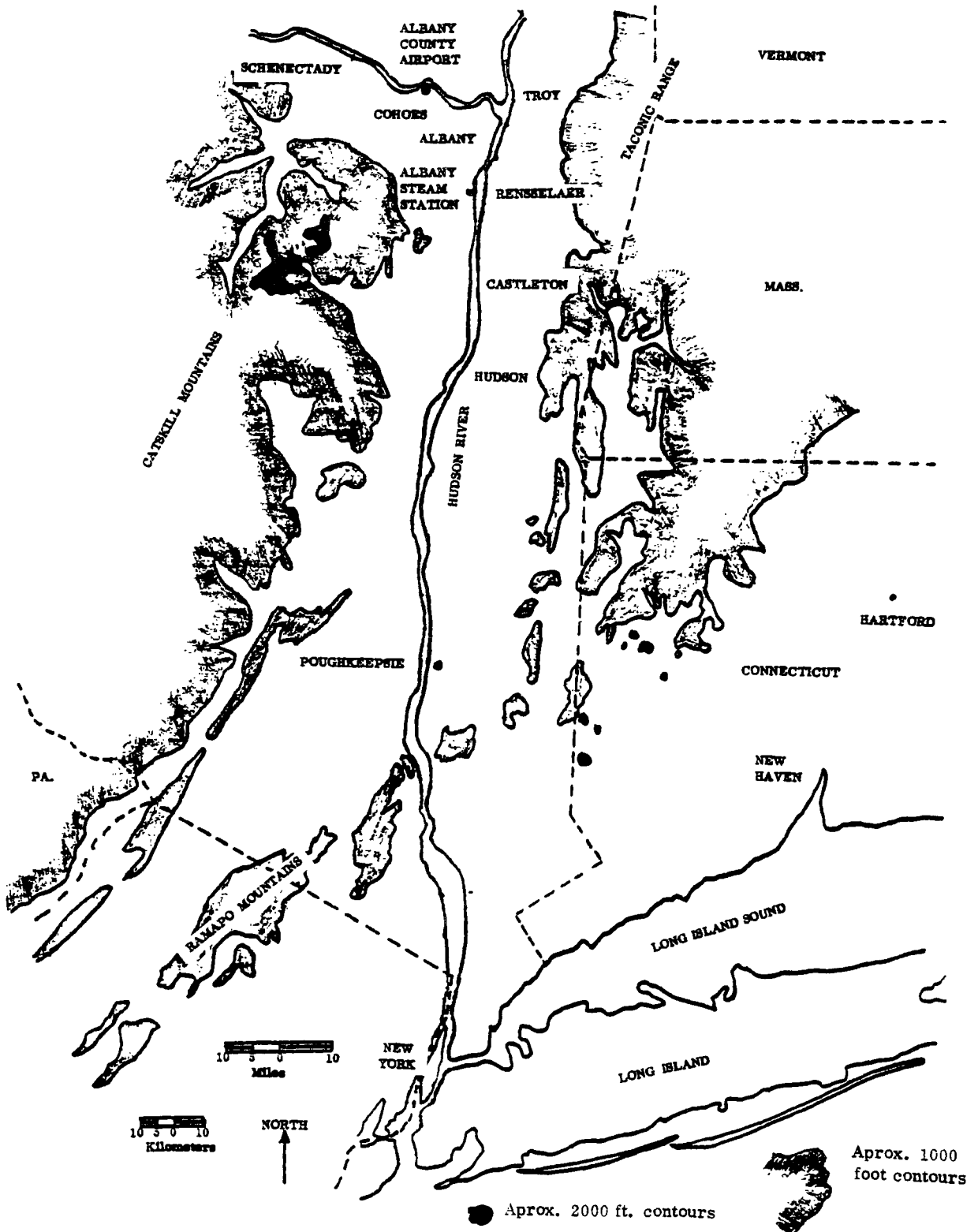
The Albany-Troy-Schenectady Metropolitan area is the reception point for airborne materials carried by South winds from the Newburgh-Kingston-Poughkeepsie industrial areas of the Mid-Hudson Valley. The New York City-Philadelphia-Baltimore area sources are still further South. Westerly winds transport airborne materials from Buffalo-Rochester-Syracuse and from industrial areas along the shores of Lake Erie and Lake Ontario. Northwest winds may transport materials from the St. Lawrence Valley area, a major paper manufacturing industrial center.

The three cities of Albany, Schenectady, and Troy and their environs form one of the major metropolitan areas of the country. This area, located near the juncture of the Mohawk and Hudson rivers, is one of the nation's oldest industrial and commercial centers. From early colonial days, ocean-going ships ascended the Hudson River to Albany, which served as a transhipment point to and from the interior. The opening of the Erie Canal between Buffalo and Albany in 1825 provided further incentive for growth.

The land between Albany and Troy is completely built up and the area between Albany and Schenectady is nearly so. Manufacturing employs about one-third of the total labor force. One of the main industries is the manufacture of electrical equipment, mostly in Schenectady. Other manufacturing in the area includes textile mills, locomotives, paper products, chemicals, meat products and foundries. Albany, the State Capital contains a sizeable number of professional and clerical workers (Bogue and Beale, 1961). Between Albany and Poughkeepsie, to the South, are several cement plants.

In addition to the present Port of Albany, other transportation facilities include Interstate Highways 87 and 90. The Penn Central maintains railroad tracks on both sides of the Hudson River. There is a sizeable railroad marshalling yard to the

21

FIGURE 2
LAYOUT OF STUDY AREA

SECTIONAL VIEW OF SAMPLING NETWORK

Site 01 Cross-Section

Emission Source Cross-Section

Site 05 Cross-Section
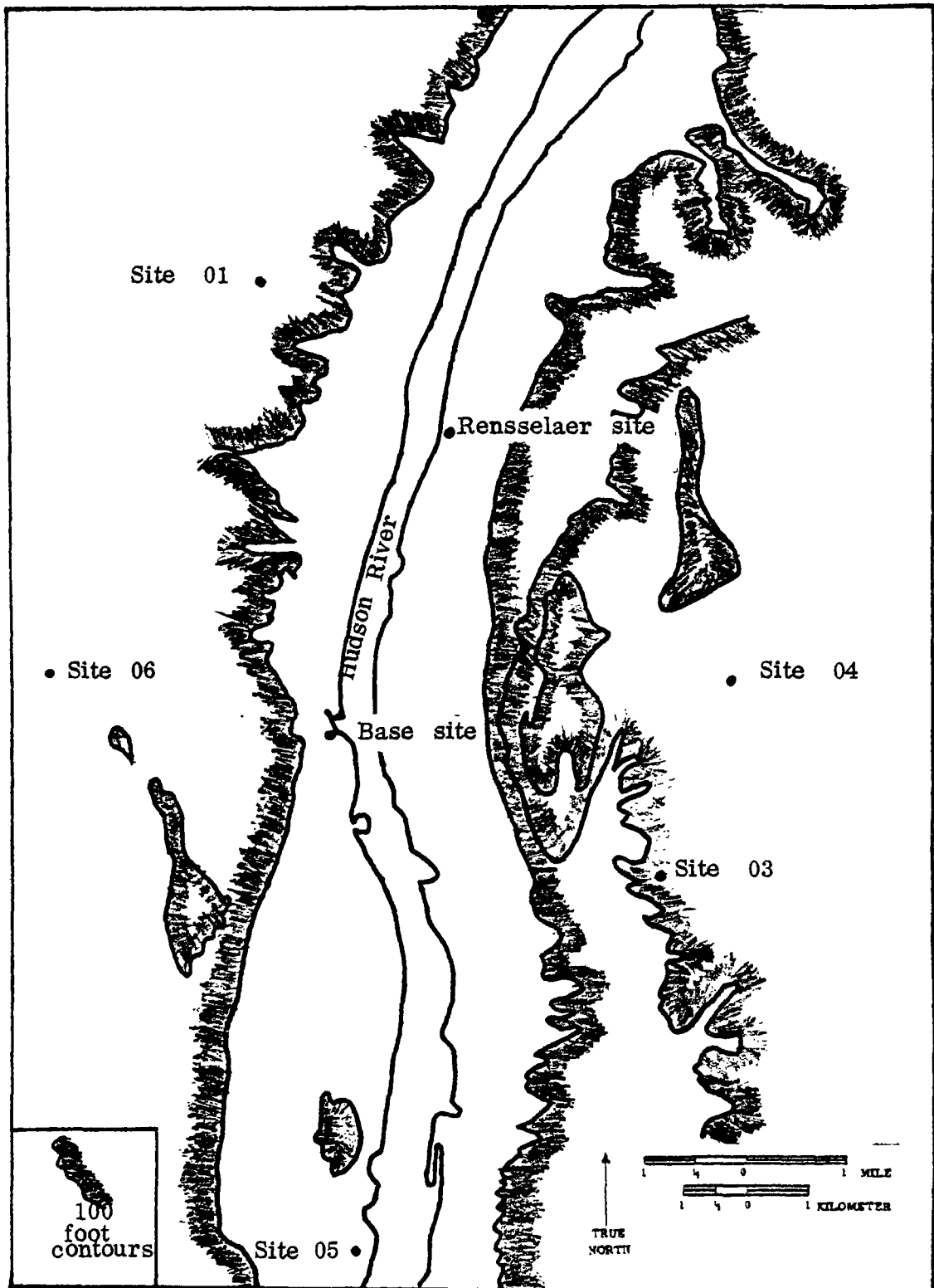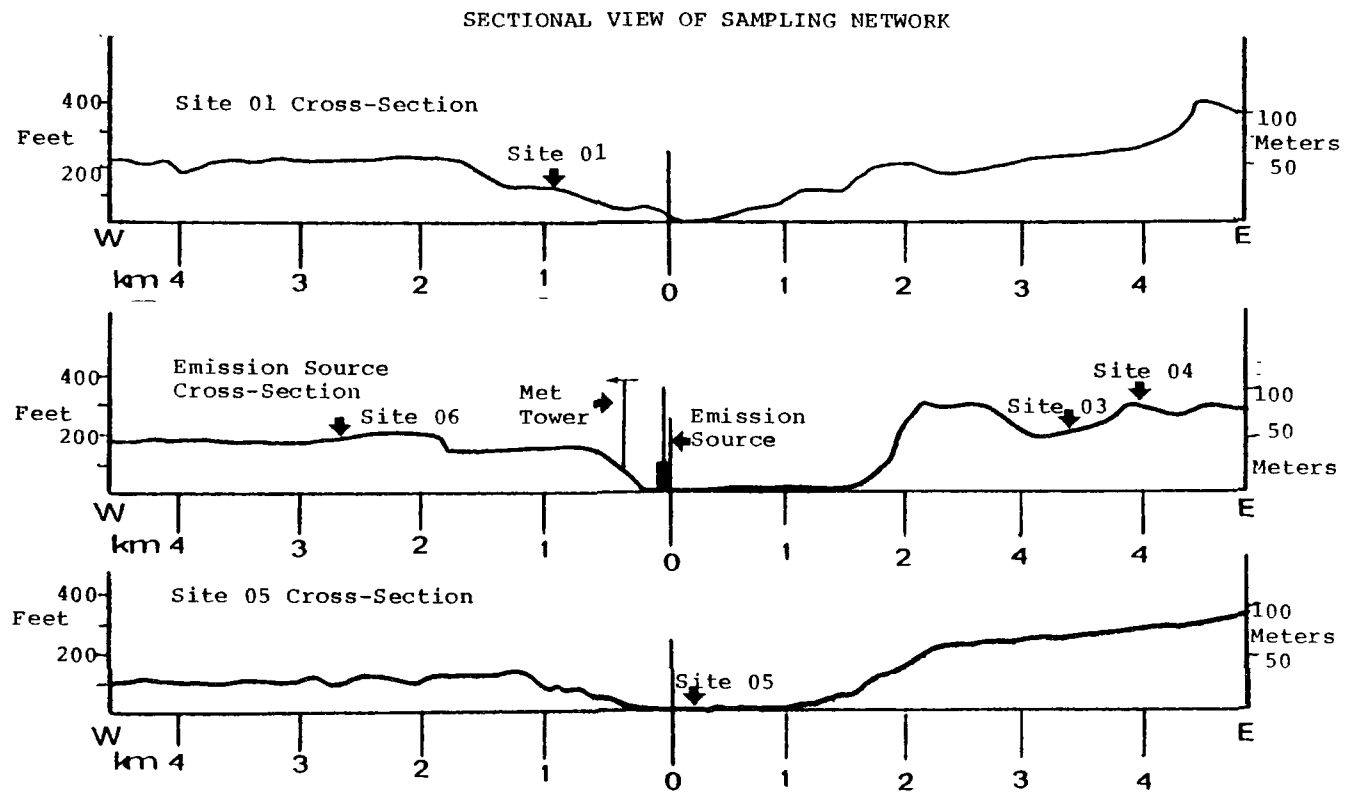
FIGURE 3

23

South of Albany as well as another marshalling yard in the Port
of Albany area. The Albany airport is served by scheduled air
carriers, and airport services include an FAA Air Traffic
Control Tower, Flight Service Station, and an office of the
National Weather Service.

DESCRIPTION OF THE EMISSION SOURCE

General

The emission source under study is an oil-fired utility power
plant consisting of four boilers with a total net steam gener-
ating capacity of 400 MW, and 140 MW capacity using gas tur-
bines. The plant is part of the Niagara Mohawk Power Corpora-
tion's generating system, which serves the Northern section of
New York State, including the Syracuse and Albany areas and the
Adirondack Region, and a portion of the Western tip of the
State, including Buffalo. One component of the generating
system is an oil-fired plant with 1136 MW of net generating
capacity at Oswego in the Mohawk Valley. Also included in the
system are two coal-fired plants in the Buffalo area with a
combined total of 1040 MW of net generating capacity. Numerous
hydro-electric plants also supply power to the customers in the
Adirondack Mountain Region (Electrical World, 1978).

Albany Steam Station

Each of the four boilers at the Albany plant is a Combustion
Engineering unit with tangential combustion, rated at 675,000
lbs. steam per hour and 100 MW net power output. During the
28-day time period under study, three boilers were operating
normally on 17 days, four boilers were operating normally on 10
days, and two boilers were operating on one day.

The boilers are housed in a large brick building, approximately 50 meters high; each boiler exhaust is vented to an individual stack, the base of which is supported by the power plant structure. The top of each stack is approximately 100 meters above ground and has an inside diameter of 3.86 meters.

During the period of study the plant was firing residual fuel oil of Venezuelan origin with an average sulfur content of 1.9%; vanadium and ash concentration was 200 ppm and 0.12% respectively. Since the object was to study the point source-related contribution sulfates have on ambient levels, this plant was chosen because its fuel is likely to have a significant effect on primary sulfate emissions. Fuel was transported via ocean-going tank ships up the Hudson River to the plant site. Two fuel handling circuits transported oil from the three storage tanks to the four boilers as it was combusted. Each fuel circuit was capable of drawing oil from any combination of the three storage tanks.

A fuel additive, consisting of magnesium and magnesium oxide in a petroleum liquid, was added to the oil just prior to combustion to inhibit corrosion caused by sulfuric acid. The additive was stored in a bulk tank outside the plant structure. The liquid was periodically transferred from the main tank to holding tanks from which it was drawn and injected into the oil lines at a nominal ratio of 2500:1 (oil: additive by volumetric measure).

The operating boilers produced an average of 67 percent maximum generation capacity from 2200 hours through 0500 hours during the study period, with an average of 80 percent maximum generation capacity from 0900 hours to 1600 hours. Transition to a peak 'approaching 90 percent maximum generation capacity occurred in the intermediary time periods.

25

The boiler plant operates on a rotating schedule with each
boiler out of service for four to six weeks to perform pre-
ventive maintenance at least once anually. During the outage
the various boiler-turbine-generator components are disas-
sembled, cleaned, inspected, repaired or replaced, and reas-
sembled. At the initiation of the study period, Boiler Unit 3
was out of service to perform a four-week maintenance program;
Boiler Unit 4 had been in service for two weeks since its
annual overhaul; Boiler Unit 1 had been in service six weeks
since an outage for replacement of a transformer: and Boiler
Unit 2 had been in service ten weeks since annual overhaul.
Boiler Unit 3 was returned to service after the 18th day of the
study period.

DESCRIPTION OF THE TEST PROGRAM

Emission Measurement Boiler Operations

In order to quantify the rate of sulfate and other specific
materials emitted from the point source stacks, samples were
extracted from the stack effluent concurrent with the meteoro-
logical and ground-level concentration measurements. Through-
out the investigation, combustion and operational variables,
which can have a significant effect on the quantity of ejected
materials, were continuously documented by recording instru-
ments. Using statistical methods, the simultaneous operational
variables and emission test results were correlated in order to
assess the quantity of materials emitted on a continuous real-
time basis.

Samples of particulate matter were obtained by filtration of
the boiler exhaust gas according to EPA Particulate Test Method
5 (40 CFR 60 App. A). The glass fiber medium was kept at 160°C
to prevent condensation of sulfuric acid. The samples of flue-
gas were extracted isokinetically through an electrically

heated glass-lined probe with a stainless steel nozzle pointing into the gas stream. Discrete annuli were established at the centers of concentric equal areas within the stack cross-section.

Each annulus was sampled at the center of each of four quadrants. The particulate sample consisted of a sum of material extracted from twelve representative points. The material was analyzed for total weight and composition, including sulfate and other water soluble ions, and specific metallic content, i.e., nickel, calcium, sodium, potassium, vanadium, iron, magnesium, and manganese.

The particulate sampling method was used to quantify the specific materials in terms of mass per unit volume of gas ejected from the stack. Simultaneous measurements of the physical gas characteristics (velocity pressure and temperature) and quantitative analysis of the major gas constituents (water vapor, oxygen, nitrogen, carbon dioxide) resulted in an assessment of the volumetric rate of total flue gas emission. Specific concentrations of ejected materials were then computed in terms of mass per unit time.

The discharge of particulate sulfate materials was quantified using the method described above. However, a large portion of the sulfate materials leaving the stack can be in the form of sulfuric acid, which may be gaseous at the filtration temperature. An additional test method was used whereby the flue gas was extracted through a heated glass-lined probe; particulate matter was removed from the sample stream with a quartz wool plug prior to flowing into the probe. Collection of the gaseous sulfate materials was accomplished by bubbling the sample gas through an aqueous solution of isopropyl alcohol. Gaseous sulfate, a hygroscopic material, was absorbed in the aqueous solution, while sulfur dioxide passed through

27

solution, while sulfur dioxide passed through unchanged. A second bubbling solution of hydrogen peroxide and water was used to oxidize and absorb the sulfur dioxide. Both solutions were immersed in an ice bath to enhance condensation and collection.

The sampling and analysis was performed in accordance with EPA Sulfur Dioxide Test Method 6 (40 CFR 60 App. A). The plug filter, probe washings, isopropyl alcohol, bubbler exit plug filter, and hydrogen peroxide solution were analyzed separately for sulfate using barium-thorin titration with cation removal pretreatment of the plug filter and probe washings. Results were obtained in units of mass per unit volume and volume per unit volume of total flue gas emission. Since these tests were performed concurrently with the gas volumetric assessment, the results could be converted to mass emission per unit time.

A sulfate characterization system was used by EPA personnel during the field sampling to assess the quantity of primary sulfate that was emitted as sulfuric acid. The system consisted of a high-temperature heated quartz probe, followed by a high-temperature quartz filtration device. The filtration device was enclosed with a custom made heating mantle, and had a coarse quartz frit for support of the filtering pad. Following filtration, the gaseous sulfuric acid was converted to the aerosol form in the temperaturecontrolled Goksoyr-Ross condensation coil (Cheney and Homolya, 1979).

The acid aerosol was collected in a Greenburg-Smith bubbler containing an 80% solution of isopropyl alcohol and water. Following this the sulfur dioxide was collected in an impinger containing 3% peroxide and water. The recovered samples were analyzed using the barium-thorin procedure described in EPA Sulfur Dioxide Test Method 6 (40 CFR 60 App. A).

The particle size distribution of ejected materials also be-
comes an important factor in the analysis due to air transport
considerations. Cascade impactors were used to obtain samples
of particulate matter within specific size ranges concurrent
with the samples of total particulate. The impactors each con-
tained eight fractionating jet plates in series, with collec-
tion substrates below them. The substrates were composed of
glass fiber material and served as impingement surfaces for the
particles exiting through the jet directly above. Each jet
plate has a design cut point with a 50% probability that a par-
ticle with that aerodynamic diameter will impinge on the sub-
strate below it. Smaller particles follow the gas streamlines
through the successive jets until the jet with the appropriate
size is reached. Particles below about .5 um are collected on
the backup glass fiber filter. The filter and substrates were
analyzed for net particulate material and presented as the per-
centage of particulate per stage.

Samples of particulate size range, total particulate, sulfate
and sulfur dioxide were procured from each boiler concurrently
with the documentation of operational variables. No attempt
was made to modify the combustion controls from the normal
operational procedures. The load generation was purposefully
lowered on several days in order to obtain samples under this
type of normal operation, however no alterations were insti-
tuted. The normal soot blowing schedule was not changed, how-
ever each occurrence was documented and several samples were
obtained during soot blow conditions. Samples of fuel oil and
chemical oil additive were obtained on a daily basis. Fuel
sulfur content was determined daily with more detailed analyses
including metals content analyses performed weekly.

The volumetric concentration of gaseous sulfur dioxide, oxygen,
carbon dioxide, and gas temperature was measured continuously

on two stacks using instrumental analyzers. These data provided a general representative profile of ejected materials on a daily basis.

Ambient Air Quality Assessment

The distribution of sulfate materials in the ambient ground-level atmosphere was determined concurrently with meteorological air transport factors in order to ascertain the source of such materials. A network of monitoring stations was necessary to assess the impact of source-emitted materials on ground-level concentrations. The emission source had been the subject of previous and ongoing studies and was surrounded by several satellite monitoring stations. Seven stations (see Figure 2) were equipped with continuous sulfur dioxide analysis capability: two stations to the North and one to the South in the Hudson Valley; one station to the West above the West bank of the river; two stations to the East above the East bank of the river; and one station was located immediately to the North of the plant.

Six of the monitoring sites were supplied with the capability of measuring total suspended particulate concentration on a 24-hour basis. Throughout the time interval during which this experiment was performed, a sample of total suspended particulate matter was obtained each day at each of these sites. These samples were analyzed for sulfate composition, other water-soluble constituents, and acid-soluble metallic constituents.

The mass fraction of airborne particulate matter within certain size ranges was determined with the use of cascade impactors. The impactors separate the particles according to individual aerodynamic diameter by impaction upon a glass fiber material. The impactors were located at the base site immediately North

30

of the emission source, and at site 5 to the South of the emission source.

Two dichotomous samplers were used to discriminate between particles with aerodynamic diameters above and below a specific diameter. The dichotomous sampler accelerates the particulate matter through a nozzle; particles with an aerodynamic diameter smaller than 3.5 um follow the gas streamlines and are removed by a Teflon micropore filter while the larger (greater than 3.5 um) particles impact upon a separate filter medium. The dichotomous samplers were also located at the base site and site 5.

One obvious factor concerning air quality is visibility. Nephelometers were used to quantify the amount of light-scattering particulate (other than condensed water vapor) present in the atmosphere during the test program. These instruments were located at the base site and site 5.

Nitrogen oxide analyzing instruments operated at sites 1, 3, and the base site. Ozone analysis capability was included at the base site. Most of the ambient measurement capability mentioned above was also available at the NYSDEC station in Rensselaer. Total suspended particulate historical data was available from NYSDEC at downtown Albany, Schenectady, and Troy on a one day in six basis.

Sulfate Artifact Experiment

Ground-level concentrations of sulfate as measured with high-volume sampling apparatus can consist of primary sulfates emitted from point sources plus secondary sulfate formed by the conversion of sulfur dioxide during airborne transport. A possibility also exists for the formation of sulfate artifact to occur during or after the sampling period by chemical reactions with sulfur dioxide, metallic oxides, and moisture. A program

was conducted to isolate the effects of sulfate artifact formation and to evaluate the contributory factors involved in measurement error caused by this conversion. The results of this series of tests are presented separately.

Filter media, handling procedures, and gas dosage with sulfur dioxide were evaluated. Three types of filter media were investigated: 01-Gelman Type A/E glass fiber; 02-Gelman Type A glass fiber; 03-Gelman Microquartz. A collection device was designed and fabricated, consisting of a modified high-volume sampler motor with four identical stainless steel inlet tubes; each tube contained mating surfaces fitted between the two halves of a 90 mm diameter filter holder, enabling a maximum of four identical simultaneous samples of total suspended particulate. The openings of the four inlet tubes extended five feet above the roof of the monitoring trailer.

An overhanging cap was designed so as to comply with specifications for collection of suspended particulate less than 100 um. The exhaust of the high-volume motor was ducted outside the trailer with flexible tubing.

As part of the operational procedure, at least two different types of filters were simultaneously exposed during the sampling interval. After exposure, certain filters were placed in glassine envelopes and sealed in air tight polyethylene envelopes. The remaining filters were placed in glassine envelopes and manila envelopes (standard procedure for all high-volume sampling). The protected filters had minimum contact with the atmosphere prior to removal for analysis, whereas the unprotected filters were subject to such atmospheric conditions as could penetrate the standard envelopes. These filters were evaluated to determine if there were any significant contributions attributed to the handling and storage procedures.

In addition, provisions were made on several test days to introduce sulfur dioxide gas into the sampling tube. The sulfur dioxide injection tests were performed on three separate days using type 01 filters. All filters on these days were sealed in air tight polyethylene envelopes until analysis.

Meteorological Assessment

In order to assess the impact of source emissions on the ground-level concentration of sulfate materials, an understanding of the local meteorology is essential. To a certain extent the transport of airborne materials is dependent upon the topography of the area under study, however the measurement of physical characteristics of the atmosphere is the prime method of understanding this airborne transport mechanism.

The emission source comprising the subject of this investigation is part of an area that has, on a continuous basis, extensive meteorological documentation. The National Weather Service has a station at the Albany County Airport located in the center of the triangle formed by Albany, Schenectady, and Troy. The New York State Department of Environmental Conservation operates an air quality and meteorological monitoring station at Rensselaer, across the river and in a north-northeasterly direction from the emission source. The Niagara Mohawk Power Corporation maintains a meteorological tower on the slope of the West bank of the Hudson River Valley bottom land just above the emission source.

In addition to the existing meteorological network, two monitoring stations were added on the floor of the Hudson River bottom land; one approximately three hundred meters North of the plant and another approximately five and one-half kilometers South.

Significant knowledge of the air transport factors was available from the instrumented tower located on the slope above the emission source. Wind factors on the floor of the river valley may have been affected by the steep slopes on either side, causing a wind-channel effect within the valley quite different from the wind pattern above the slopes. The upper level instruments on the tower are one hundred meters above grade; the grade on the slope is 33 meters above the grade of the valley floor, resulting in measurements at a point that is 33 meters above the stack exit. Wind and temperature are measured at this point (top of the tower) and at a lower point (90 meters below the top of the tower). In addition to wind speed and direction, air temperature and the temperature difference between the two instrument levels are obtained.

An acoustic sounder was used to determine the height at which upward rise of pollutants terminates. An acoustic signal directed upward rebounded from the atmospheric layer at which the temperature change occurred. The length of time necessary for the signal to return was proportional to the mixing height.

The acoustic instrument operated continuously and was augumented by the use of balloon-borne temperature sensors. While a radio receiver-recorder plotted the signals from the sensor, the balloon was tracked manually by two theodolites, precision optical instruments capable of measuring both the elevation angle and azimuth angle of the balloon at 15 second intervals. A computer was used to translate angles into wind speed and direction with height using the method of Norman Thyler (1962).

Meteorological and Ambient Air Quality Site Descriptions

Base--

The base site was located 600 feet North of the Albany Steam
Station. It consisted of one of the York Research trailers
equipped with ambient air intakes. These intakes included a
glass manifold for sampling of gaseous SO_2, NO, NO_2, NO_x and
O_3; a stainless steel sampling device for the multi-head high
volume sampler; and an air intake for use by the nephelometer.
The trailer was kept at a constant temperature ($25° \pm 5°C$).
Outside the trailer the solar radiometer was mounted at a
height of 5 feet; a 10 meter tower was erected with wind direc-
tion and speed at 10 meters and temperature and dew point at
the 8 meter height. Other instrumentation included a rain
gauge, an acoustic sounder with transceiver located within a
lead enclosure, and 2 high volume samplers located 8 feet above
the ground. On the roof of the trailer at a height of approxi-
mately 12 feet were the dichotomous sampler and the cascade
impactor with flow control. Balloon launchings were also
carried out at this location. Satellite stations surrounding
the plant were equipped as follows:

Site 1--

Located at a Niagara Mohawk Substation on Delaware Avenue in
downtown Albany, it consisted of a Meloy SO_2 monitor, a Teco
NO, NO_2, NO_x monitor and two 24-hour high volume samplers.

Site 3--

Located on Hays Road in a rural environment this site included
a Meloy SO_2 unit and a Teco NO, NO_2, NO_x unit along with two
24-hour high volume samplers. (Site 2 designation was not used

as it represents an inactive monitoring site owned by Niagara Mohawk).

Site 4--

Located in the Greenbush Power Substation it contained a Thermo Electron SO_2 monitor and two 24-hour high volume samplers.

Site 5--

This site was located in Bethlehem Park approximately 100 feet from the shore line of the Hudson River. There were two shelters located here, one contained the Meloy SO_2 and the dichotomous sampler, while the other contained the recorders for wind speed and direction located on a 30 foot tower as well as temperature sensor, a nephelometer, and a multi-head high volume particulate sampler. Also located here were two 24-hour high volume samplers, a cascade impactor and flow control unit, and a rain gauge.

Site 6--

Site 6 was located in the Bethlehem substation and contained a Meloy SO_2 unit as well as two 24-hour high volume samplers.

Meteorological Tower--

The tower was located approximately 1,000 feet Northwest of the plant. Wind speed and direction were taken from two levels: upper level 462 feet above mean sea level, lower level 150 feet above mean sea level. Delta-T was also measured here with a height difference of 312 feet.

Rensselaer (Port of Albany)--

The NYSDEC monitoring station in Rensselaer was located on the Northern side of the ship turning basin for the Port of Albany. To the South of this station on both sides of the river are the docking facilities and tank farms of the port. To the North of this monitoring station extends an industrial district.

SECTION 4
EMISSION MEASUREMENTS

PARTICULATE MEASUREMENTS

Samples of particulate matter were extracted on glass fiber filters using EPA Particulate Test Method 5. The filters were kept at 160°C or greater to prevent condensation of sulfuric acid during sampling. Gas and particulate samples were extracted isokinetically from twelve sampling points through a heated glass-lined probe. The particulate material was analyzed for total weight, water soluble ions, sulfate, nitrate, ammonia, chloride, and specific metals, nickel, calcium, sodium, potassium, vanadium, iron, magnesium, and manganese. Measurements were made that permitted calculation of the volumetric rate of gas flow.

Test Schedule

Tests were performed at various points along an operational line from 50% to 100% maximum load, with the majority of tests performed at the upper end. No combustion optimization was performed and the boilers operated routinely depending on system demand. Only during specific periods when a boiler was off the automatic load control for lowload tests did any instituted controls occur. A breakdown of the fuel use ranges and the tests performed in those ranges is shown on Table 1.

38

TABLE 1

PARTICULATE TESTS IN SPECIFIC FUEL USE RANGES

	Unit 1	Unit 2	Unit 3	Unit 4
100 gal./hr.	58-62	60-62	59-63	59-65
(No. of tests)	(7)	(8)	(7)	(14)
100 gal./hr.	54	43-56	42	-
(No. of tests)	(3)	(3)	(1)	-
100 gal./hr.	34	31-32	-	32
(No. of tests)	(3)	(6)	-	(2)

Test Results

Results of individual particulate tests are presented with simultaneous combustion parameters on Table 2. Results of filterable particulate varied from about 60 mg/Nm^3 at low load conditions to about 170 mg/Nm^3 at maximum load conditions. One extreme occurred during soot blow when the particulate concentration was in excess of 300 mg/Nm^3 (Unit 2, 9-26,0950). This may also have been contributed by blockage of ash in the cyclone hoppers. Total (filterable plus condensible) particulate concentration ranged 70-225 mg/Nm^3. Filterable particulate emission rate ranged 12-70 kg/hr. and total particulate emission rate ranged 17-85 kg/hr.

A model of particulate emission was developed using oil consumption, boiler oxygen concentration, and fuel additive ratio as the independent variables. The model can be found in Section 4.

Particulate Composition

The particulate samples were analyzed for water soluble $SO_4^=$, Cl^-, $N-NH_4^-$, $N-NO^-_3$ and for metals Na, K, Mg, Ca, Ni, Mn, Fe,

TABLE 2

COMBUSTION PARAMETERS AND PARTICULATE TEST RESULTS

Date	Time*	Oil Flow gal/hr	Fuel S-%	Boiler O$_2$-%	Stack O$_2$-%	Stack Temp-°C	Front-½ mg/Am^3	Total mg/Am^3	Front-½ mg/Nm^3	Total mg/Nm^3	Front-½ kg/hr	Total kg/hr
Unit 1												
9-18	1430	5900	1.95	3.1	5.8	161	89.79	120.98	146.26	197.07	53.66	72.30
9-19**	1040	6100	1.98	3.1	5.6	166	99.27	122.59	160.06	197.68	61.95	76.50
9-19	1240	6100	1.98	3.1	5.9	161	89.78	139.52	146.55	227.74	53.59	83.28
9-19	1515	6100	1.98	2.6	5.4	160	95.93	137.13	156.75	224.08	57.87	82.72
9-20	1005	6000	1.78	3.0	5.6	160	96.82	126.57	159.24	208.18	56.45	73.80
9-20**	1210	6100	1.78	2.5	5.7	160	115.44	137.94	189.09	225.95	66.86	79.90
9-20	1430	6200	1.78	2.5	5.8	159	106.58	119.04	174.45	194.85	64.36	71.89
9-29	1110	5400	2.00	3.8	7.1	163	66.93	72.00	107.81	115.97	40.61	43.68
9-29	1305	5400	2.00	3.8	7.2	159	65.32	91.95	106.72	150.22	37.33	52.54
9-29	1500	5400	2.00	3.8	7.2	161	72.27	90.80	115.10	144.62	43.41	54.54
9-30	1045	3400	2.05	3.6	7.7	154	60.40	86.63	96.74	139.08	21.61	31.07
10-01	1015	3400	1.80	3.2	7.6	152	49.47	81.50	79.13	130.36	17.89	29.48
10-01	1200	3400	1.80	3.2	7.7	150	52.50	69.81	84.88	112.87	19.03	25.30
Unit 2												
9-21	1300	6150	1.70	2.2	5.5	188	102.55	123.12	181.38	217.77	67.09	80.55
9-21	1449	6100	1.70	2.0	5.6	188	83.90	94.22	150.08	168.54	56.77	63.75
9-22**	0955	6100	1.75	2.3	5.4	179	104.19	115.16	178.84	197.67	69.26	76.56
9-22	1400	6050	1.75	2.2	5.3	177	73.53	83.35	124.05	140.62	48.93	55.46
9-23	0951	3100	1.90	4.6	8.1	148	58.12	66.38	89.99	102.79	23.18	26.47
9-23	1155	3100	1.90	4.6	8.3	148	55.23	60.14	85.83	93.46	21.14	23.02
9-23**	1416	3100	1.90	4.5	8.2	153	68.45	80.35	107.41	126.08	26.00	30.52
9-24	0945	3200	1.50	3.6	7.6	150	52.78	90.77	84.02	144.29	21.30	36.64
9-24	1130	3100	1.50	3.5	7.8	149	54.54	74.56	86.60	118.40	21.29	29.11
9-24**	1340	3100	1.50	4.0	7.4	157	66.94	73.35	107.51	117.80	25.83	28.31
9-25	0950	6150	1.97	2.2	6.3	177	69.86	80.52	119.47	137.70	45.90	52.91
9-26**	0950	6000	1.95	2.0	6.1	170	183.84	191.61	302.14	314.91	114.20	119.03
9-26	1155	6200	1.95	2.0	6.0	177	81.49	96.91	136.42	162.22	54.66	65.00
9-26	1340	6100	1.95	1.9	5.9	185	69.28	88.92	118.84	152.52	45.18	57.98
9-27	0940	5600	2.05	2.2	6.3	165	76.10	82.14	125.51	135.48	45.29	48.88

* EDT
** Soot Blow Test

40

TABLE 2

COMBUSTION PARAMETERS AND PARTICULATE TEST RESULTS (CONTD.)

Date	Time*	Oil Flow gal/hr	Fuel S-%	Boiler O_2-%	Stack O_2-%	Stack Temp-$^\circ$C	Front-$\frac{1}{2}$ mg/Am^3	Total mg/Am^3	Front-$\frac{1}{2}$ mg/Nm^3	Total mg/Nm^3	Front-$\frac{1}{2}$ kg/hr	Total kg/hr
Unit 2 (Contd.)												
9-27	1145	5600	2.05	2.3	6.4	166	73.42	101.45	121.70	168.17	45.12	62.35
9-28	0950	4300	2.25	3.8	7.4	158	60.41	83.63	97.17	134.52	30.98	42.89
Unit 3												
10-11	1002	6300	2.10	2.3	6.3	145	94.73	102.82	148.59	161.28	58.26	63.24
10-11	1150	6300	2.10	2.1	6.0	148	79.07	105.71	125.82	168.23	47.58	63.61
10-11	1335	6300	2.10	2.2	6.1	149	92.87	115.53	149.49	185.97	54.75	68.10
10-12	1010	5900	2.28	2.6	6.4	146	107.99	127.22	170.39	200.75	64.38	75.85
10-13**	0930	6200	2.20	2.1	6.2	146	93.81	112.47	149.18	178.85	52.97	63.51
10-13	1125	6200	2.20	2.1	6.2	143	77.23	87.56	120.85	137.01	48.08	54.51
10-13	1315	6300	2.20	1.9	6.0	146	101.75	108.28	161.55	171.93	59.56	63.38
10-15	1005	4200	2.14	3.5	7.8	119	39.23	56.96	57.44	83.39	12.11	17.59
Unit 4												
10-03	1010	6300	2.10	2.7	6.8	157	70.38	98.01	114.04	158.82	47.67	66.39
10-03	1209	6400	2.10	2.7	6.4	160	64.96	84.60	106.21	138.33	43.45	56.59
10-03	1410	6300	2.10	2.5	6.7	156	53.76	64.51	87.37	104.85	32.78	39.34
10-04	1325	6000	2.20	2.0	6.6	153	74.16	97.70	118.80	156.52	41.58	54.79
10-05	0940	6150	1.50	1.9	6.2	157	75.57	96.01	123.45	156.82	43.94	55.82
10-05	1125	5900	1.50	1.8	7.2	150	60.65	85.89	94.81	134.27	28.95	41.00
10-05**	1330	6300	1.50	2.1	6.4	155	87.22	126.31	141.27	204.58	51.67	74.82
10-06	0950	6100	1.40	1.9	6.6	157	79.37	88.96	129.63	145.29	45.70	51.22
10-06	1145	6000	1.40	1.6	6.3	158	79.63	89.98	130.77	147.77	48.32	54.61
10-06	1340	6100	1.40	1.7	6.6	160	72.48	77.99	120.52	129.68	43.42	46.72
10-07	1025	6200	1.40	2.1	5.9	166	68.65	89.17	115.00	149.38	43.81	56.91
10-07	1240	6050	1.40	2.4	6.3	161	65.67	72.25	108.25	119.11	40.31	44.35
10-08	1105	3200	1.70	5.5	9.6	131	43.83	51.27	65.96	77.16	17.52	20.49
10-08	1304	3200	1.70	5.0	9.7	133	39.87	42.51	60.21	64.19	15.75	16.79
10-09	1055	5950	1.96	3.5	6.4	157	66.47	102.64	107.10	165.37	39.85	61.53
10-09	1440	6500	1.96	3.2	6.4	160	95.74	103.81	154.44	167.51	60.58	65.71

* EDT
** Soot Blow Test

and V. These results are shown in Table 3. An unusual set of tests occurred on Unit 2, where very high levels of Na, K, Ca, and Cl$^-$ were observed. These elements are common in sea water, indicating that some stratified water was present in the fuel tanks during these tests. The abrupt decrease of the anomolous elements on 9-27 indicates a fuel supply switch to a different tank. Consistently high values of vanadium are present due to the high vanadium content in the fuel oil (see Table 14). Sodium and magnesium are also high, although not quite as consistent as vanadium. The consistency with which vanadium is present in the particulate emissions, combined with the fact that vanadium is not a common element in airborne particulate, makes it an excellent tracer when measured in the ambient air. Magnesium and sodium do not share this distinction, being common elements of windblown dust.

Particulate Sulfate

The particulate sulfate results have been tabulated with simultaneous combustion parameters on Table 4. The emission of particulate sulfate ranged from less than 10 kg/hr. at 50% load to somewhat less than 30 kg/hr. at full load with soot blowing. Particulate sulfate fraction of filterable particulate ranged from 32% to 67% and an inverse relationship with fuel consumption was apparent.

A model of sulfate fraction of particulate was developed using fuel consumption, boiler oxygen concentration, fuel oil additive ratio, and days of operation since the last boiler wash. The model can be found in Section 4.

TOTAL SULFATE AND SULFUR DIOXIDE MEASUREMENT

The particulate sulfate materials discharge was quantified by analysis of EPA Method 5 samples. However, a large portion of

TABLE 3

COMPOSITIONAL ANALYSIS OF PARTICULATE EMISSIONS

Date	Time**	Na %	K %	Mg %	Ca %	Ni %	Mn %	Fe %	V %	Cl %	SO4 %	N as NH4 %	N as NO3 %
Unit 1													
9-18	1430	2.95	.02	1.91	.146	1.84	.03	.83	3.65	.21	45.1	1.98	.05
9-19*	1040	2.45	.04	4.70	0.0	1.47	.01	.69	4.92	.23	33.7	1.62	.05
9-19	1240	2.40	.02	3.11	0.0	1.14	.05	.33	4.24	.36	27.7	.71	.02
9-19	1515	1.85	0.0	2.34	0.0	.92	.02	.29	3.68	.19	42.2	1.38	.02
9-20	1005	1.77	0.0	2.09	0.0	.93	.02	.30	3.17	.24	47.8	.80	.03
9-20*	1210	2.38	.02	4.93	.033	.99	.02	.60	4.10	.18	48.2	.45	.05
9-20	1430	1.70	.01	2.27	0.0	1.02	.01	1.25	3.15	.20	43.6	.38	.04
9-29	1110	2.16	.02	1.05	0.0	.927	.02	.24	3.46	.03	60.6	.55	.02
9-29	1305	2.96	.04	1.25	0.0	1.27	.02	.12	4.32	.03	56.1	.68	.02
9-29	1500	2.29	.02	1.06	0.0	.91	.01	.09	3.65	.03	50.6	.73	.01
9-30	1045	2.68	.04	1.70	0.0	.99	.02	.47	4.36	.68	46.9	.48	.04
10-01	1015	3.94	.03	2.29	0.0	1.13	.03	.36	4.66	.46	53.9	.57	.02
10-01	1200	4.14	.04	2.42	0.0	1.27	.03	.18	5.15	.49	62.6	1.13	0.0
Unit 2													
9-21	1300	3.27	.18	2.88	1.33	1.13	.04	.49	4.93	2.39	36.3	.72	.04
9-21	1449	3.14	.17	2.86	1.43	1.00	.03	.29	4.42	2.03	40.6	.74	.03
9-22*	0955	3.39	.14	4.87	.76	1.59	.04	.29	7.10	2.12	44.0	.67	.06
9-22	1400	3.58	.16	3.18	1.47	1.24	.02	.38	5.33	3.03	56.1	.77	.07
9-23	0951	4.63	.20	2.98	1.75	1.13	.02	.39	5.26	2.98	53.2	2.35	.04
9-23	1155	6.27	.33	3.64	3.38	1.29	.02	.59	5.60	5.19	51.5	1.80	.06
9-23*	1416	5.28	.26	3.71	2.38	1.39	.02	.40	5.95	3.45	53.0	.90	.07
9-24	0945	6.86	.31	2.83	3.28	1.11	.02	.28	5.32	4.22	52.2	1.09	.05
9-24	1130	7.44	.42	4.08	4.78	1.08	.02	.18	4.94	6.00	56.3	.68	.04
9-24*	1340	7.60	.33	4.78	2.85	1.61	.02	.24	7.83	4.13	50.1	.41	.07
9-25	0950	4.75	.33	3.45	1.93	1.31	.02	.42	5.85	3.97	53.2	.63	.13
9-26*	0950	3.17	.12	4.60	.19	1.47	.03	.29	8.24	1.00	46.1	.21	.04
9-26	1155	4.46	.22	2.27	1.04	1.33	.01	.34	6.06	2.53	51.4	.57	.04
9-26	1340	4.38	.25	2.64	1.98	1.05	.01	.18	4.57	2.72	54.5	.56	.02
9-27	0940	7.59	.73	2.76	2.15	1.11	.01	.30	5.36	3.31	48.8	.52	.04
9-27	1145	5.22	.29	1.92	0.0	1.16	.01	.17	5.01	.45	43.5	.43	.06
9-28	0950	3.86	.12	1.54	0.0	1.25	.02	.25	4.42	.41	46.6	1.27	.04

*   Soot Blow Test

**   EDT

TABLE 3

COMPOSITIONAL ANALYSIS OF PARTICULATE EMISSIONS

Date	Time**	Na %	K %	Mg %	Ca %	Ni %	Mn %	Fe %	V %	Cl %	SO$_4$ %	N as NH$_4$	N as NO$_3$
Unit 3													
10-11	1002	2.24	.02	4.01	0.0	1.37	.02	.35	5.60	.24	36.0	.27	.09
10-11	1150	2.43	.02	3.94	0.0	1.41	.03	.30	5.82	.29	37.8	.21	.05
10-11	1335	2.06	.02	2.41	0.0	1.32	.02	.27	5.00	.39	34.0	.21	.10
10-12	1010	2.17	.02	4.00	0.0	1.20	.02	.29	4.99	.36	29.0	.22	.07
10-13*	0930	2.45	.04	5.07	0.0	1.31	.03	.43	6.07	.45	34.4	.25	.08
10-13	1125	2.26	.02	4.43	.03	1.36	.03	.32	5.23	.27	26.6	.32	.08
10-13	1315	2.33	.02	4.53	.02	1.30	.03	.34	5.17	.32	32.3	.27	.13
10-15	1005	4.32	.03	2.88	.03	1.56	.05	.35	6.62	.76	60.6	.90	.05
Unit 4													
10-03	1010	4.87	.06	3.61	0.0	1.82	.02	.44	7.33	.07	48.8	.55	.09
10-03	1209	4.34	.15	4.03	0.0	1.73	.02	.31	6.77	.09	53.2	.32	.08
10-03	1410	4.34	.06	2.56	0.0	1.64	.02	.23	5.44	.11	61.7	.62	.03
10-04	1325	3.89	.04	3.68	0.0	1.56	.02	.36	6.38	.36	46.7	.55	.04
10-05	0940	3.07	.11	3.16	.07	1.37	.02	.17	5.33	.27	50.7	.52	.04
10-05	1125	3.16	.03	2.21	0.0	1.33	.02	.22	4.88	.07	50.2	.81	.05
10-05*	1330	3.09	.07	4.20	0.0	1.61	.02	.24	5.97	.04	40.3	.39	.05
10-06	0950	3.04	.02	3.55	0.0	1.55	.02	.20	6.17	.04	47.0	.44	.08
10-06	1145	2.84	.03	3.97	0.0	1.68	.01	.29	6.40	.10	41.4	.33	.08
10-06	1340	3.60	.03	3.57	0.0	1.59	.02	.22	6.01	.09	43.5	.44	.07
10-07	1025	3.78	.03	3.22	0.0	1.52	.02	1.12	5.16	.28	51.2	.81	.06
10-07	1240	3.44	.04	3.46	0.0	1.40	.02	.19	6.77	.51	52.7	.21	.04
10-08	1105	4.10	.04	3.28	.03	1.12	.03	.18	5.26	.72	66.7	1.03	.16
10-08	1304	4.56	.05	2.18	.05	1.20	.04	.27	5.39	.85	67.6	.81	.07
10-09	1055	3.83	.04	2.47	0.0	1.54	.03	.27	6.77	.47	43.3	.99	.05
10-09	1440	2.68	.04	5.37	0.0	1.95	.02	.34	7.96	.37	45.3	.41	.11

*   Soot Blow Test

**   EDT

44

TABLE 4

COMBUSTION PARAMETERS AND PARTICLE SIZE TEST RESULTS

Date	Time**	Oil Flow gal/hr	Fuel S-%	Boiler O_2-%	Stack O_2-%	Stack T.-°C	Stage 0-%	Stage 1-%	Stage 2-%	Stage 3-%	Stage 4-%	Stage 5-%	Stage 6-%	Stage 7-%	Back Up Filter %
Unit 1															
9-18*1636		5900	1.95	3.1	5.8	161	38.43	10.06	8.14	7.22	7.37	8.55	5.35	3.31	11.58
9-19*1202		5900	1.98	3.1	5.6	161	26.67	13.45	6.00	7.74	2.48	8.21	5.69	9.67	20.10
9-19 1523		6100	1.98	2.6	5.4	160	9.06	7.37	10.28	8.98	8.67	5.83	5.59	6.23	37.98
9-20 1150		6100	1.78	2.7	6.2	160	9.56	9.60	11.38	9.50	10.26	8.95	6.60	4.57	29.59
9-20 1350		6150	1.78	2.5	5.7	159	4.16	4.56	5.91	5.57	8.06	10.93	7.01	8.10	45.71
9-20 1615		6100	1.78	2.4	5.8	159	11.40	14.34	10.97	9.23	8.74	6.16	4.43	2.35	32.37
9-29 1310		3500	1.97	3.6	7.2	159	3.78	8.05	11.22	11.25	6.22	16.70	10.17	7.33	25.29
9-30 1128		3400	2.05	3.7	7.7	152	2.43	2.63	2.20	5.20	8.64	7.04	4.30	8.60	58.95
10-01 1053		3400	1.80	3.2	7.6	150	8.12	7.11	8.51	7.39	8.26	9.15	6.24	7.16	38.06
Unit 2															
9-21*1246		6150	1.70	2.2	5.5	188	10.95	10.30	9.98	11.17	9.29	9.40	6.74	5.46	26.71
9-21 1521		6100	1.70	2.0	5.6	188	10.34	12.52	12.34	10.47	10.68	7.84	5.12	4.59	26.10
9-22*1000		6050	1.75	2.3	5.4	179	13.06	13.58	14.28	11.13	12.18	8.10	6.24	4.95	16.47
9-22 1450		6150	1.75	2.2	5.3	177	9.05	10.71	13.08	9.83	8.80	7.14	6.26	4.43	30.71
9-22 1554		6000	1.75	2.3	5.3	177	10.70	9.67	11.19	8.60	11.13	7.27	4.87	3.89	32.70
9-23*1412		3100	1.90	4.5	8.2	153	8.28	10.80	14.25	9.66	11.00	7.99	5.42	3.50	29.09
9-24 1035		3150	1.50	3.6	7.6	150	6.12	6.08	7.31	5.02	6.43	8.19	8.28	8.94	43.64
9-24*1313		3100	1.50	3.8	7.4	157	7.22	4.11	9.65	9.40	8.80	11.91	3.75	7.26	37.90
9-25 1030		6100	1.97	2.2	6.3	177	10.23	10.23	13.47	10.01	10.31	9.15	7.10	5.27	24.23
9-26*1030		6100	1.95	2.0	6.1	177	13.16	8.70	7.99	9.36	12.70	14.65	10.63	6.32	16.48
9-26*1145		6150	2.00	2.0	6.0	177	14.48	14.95	13.11	11.50	11.70	8.69	4.92	4.09	16.56
9-26 1245		6100	2.03	2.0	6.0	180	10.00	10.38	9.91	10.11	10.03	9.95	7.56	6.56	25.49
9-27 1028		5600	2.05	2.2	6.4	166	8.39	9.79	11.04	8.15	7.18	7.18	5.85	3.98	38.44
9-27 1140		5600	2.05	2.3	6.4	166	7.97	13.19	12.26	10.60	9.43	7.93	4.37	3.97	30.27
9-28 1008		4300	2.25	3.8	7.4	158	9.66	11.32	11.84	9.47	9.05	8.60	5.32	3.96	30.78

* Soot Blow Test
** EDT

45

TABLE 4

COMBUSTION PARAMETERS AND PARTICLE SIZE TEST RESULTS (CONTD.)

Date	Time**	Oil Flow gal/hr	Fuel S-%	Boiler O_2-%	Stack O_2-%	Stack T.-°C	Stage 0-%	Stage 1-%	Stage 2-%	Stage 3-%	Stage 4-%	Stage 5-%	Stage 6-%	Stage 7-%	Back Up Filter
Unit 3															
10-11	1055	6300	2.10	2.1	6.3	145	25.62	10.59	6.23	6.10	6.51	6.04	3.53	5.02	30.35
10-11	1208	6300	2.10	2.1	6.0	148	22.01	9.96	7.71	8.87	6.33	6.90	3.81	2.93	31.49
10-11	1320	6300	2.10	2.3	6.1	149	22.68	11.49	7.56	6.82	9.38	7.49	3.71	3.72	27.15
10-12	1021	6100	2.28	2.6	6.2	146	31.85	10.72	8.45	6.78	7.90	6.18	2.86	3.26	21.99
Unit 4															
10-03	*1302	6400	2.10	2.5	6.7	156	11.39	10.74	11.12	8.53	10.90	9.15	6.43	5.71	26.03
10-04	*1440	6200	2.20	2.0	6.6	152	11.66	9.03	10.36	7.21	9.25	8.10	5.05	3.86	35.48
10-05	1045	5600	1.50	2.7	6.4	154	16.19	13.81	12.16	4.00	3.85	3.94	3.43	2.14	40.48
10-06	0955	6100	1.40	1.9	6.6	157	19.23	11.77	7.56	7.31	5.52	7.08	2.75	3.10	35.70
10-06	1110	6050	1.40	1.6	6.3	157	16.93	10.75	11.71	9.39	11.01	6.29	4.25	2.71	26.96
10-06	*1230	6050	1.40	1.7	6.6	160	20.73	11.94	9.64	7.08	7.40	7.50	4.35	2.87	28.49
10-07	1115	6200	1.40	2.3	5.9	166	10.71	8.29	2.64	8.46	9.72	9.88	7.98	7.58	34.74
10-07	1235	6100	1.40	2.4	6.3	160	13.90	11.11	10.92	5.60	9.61	7.24	5.25	2.88	33.49
10-08	1105	3200	1.70	5.0	9.6	135	6.15	5.21	5.96	4.11	8.68	10.27	8.16	7.48	43.98
10-08	1335	3200	1.70	5.0	9.7	135	4.48	5.36	5.97	5.16	8.49	9.40	5.94	10.39	44.81
10-09	1100	5950	1.96	3.5	6.4	157	13.31	8.91	8.38	6.72	8.05	10.13	7.29	6.47	30.74
10-09	1440	6600	1.96	3.2	6.4	157	13.70	9.86	9.60	9.45	10.30	10.07	6.70	5.26	25.06

* Soot Blow Test
** EDT

the sulfate materials leaving the stack can be in the form of gaseous sulfuric acid. Total gaseous plus particulate sulfate emissions were determined using a modification of EPA Sulfur Dioxide Test Method 6 (40 CFR 60 App. A). The flue gas was extracted through a heated glass-lined probe normal to the flue gas flow; particulate matter was removed from the sample stream with a quartz wool plug prior to flowing into the probe. Gaseous sulfate was collected by bubbling the sample gas through an 80% solution of isopropyl alcohol and distilled water in a midget bubbler. The aqueous solution absorbed the gaseous sulfate, while sulfur dioxide passed through unchanged. A 3% solution of hydrogen peroxide and distilled water in a series of two midget impingers oxidized and absorbed the sulfur dioxide. Both solutions were immersed in an ice bath to enhance condensation and collection. The probe filter, probe washings, bubbler exit plug filter, and hydrogen peroxide absorbing solution were analyzed separately for total sulfate using the published barium-thorin titration with pretreatment of the plug filter and probe washings for cation removal. The analysis procedure is described in EPA Sulfur Dioxide Test Method 6 (40 CFR 60 App. A).

Sulfur Oxides Test Results

Sulfur oxides concentration are shown on Table 5; combustion parameters and sulfur oxides test results are shown on Table 6. Total sulfate concentration ranged from 22 to 55 ppm and the emission rate ranged from 22 to 82 kg/hr. Mean values were 37 ppm and 51 kg/hr. Sulfur dioxide concentration ranged from 700 to 1100 ppm with boiler oxygen concentrations slightly less than 2% to greater than 5% and fuel sulfur content from 1.4% to 2.2%. Emission rate of sulfur dioxide ranged from 500 kg/hr. to 1200 kg/hr; mean emission concentration was 938 ppm and mean emission rate was 856 kg/hr.

TABLE 5

SO$_x$ TEST RESULTS

Date	Time *	SO$_2$ ppm/v	SO$_2$ mg/Nm^3	T-SO$_4$** ppm/v	T-SO$_4$** mg/Nm^3	SO$_4$/SO$_x$ v/v	SO$_4$/SO$_x$ w/w
Unit 1							
9-19	1040	918.0	2435.2	26.696	106.1	2.83	4.18
9-20	1005	894.7	2372.1	42.790	182.7	4.56	6.69
9-20	1210	948.4	2512.9	44.267	175.7	4.46	6.54
9-20	1430	944.6	2505.6	44.198	175.6	4.47	6.56
9-29	1110	1088.4	2869.9	55.309	219.9	4.84	7.03
9-29	1305	1032.1	2732.9	44.023	131.7	4.09	6.01
9-29	1500	1068.8	2840.6	49.615	188.3	4.44	6.51
9-30	1045	927.0	2459.8	32.121	127.7	3.35	4.94
10-01	1015	902.0	2389.6	33.754	133.9	3.61	5.31
10-01	1200	889.3	2360.7	32.787	130.4	3.56	5.24
Unit 2							
9-21	1040	933.6	2476.7	29.736	113.2	3.09	4.56
9-21	1249	950.0	2517.6	29.425	116.9	3.00	4.44
9-21	1441	931.4	2472.7	31.928	127.1	3.31	4.89
9-22	0941	948.9	2522.6	43.256	171.9	4.36	6.40
9-22	1422	943.9	2509.2	29.354	117.9	3.02	4.46
9-22	1539	951.8	2527.9	25.767	102.5	2.64	3.90
9-23	1220	944.9	2502.2	35.979	144.3	3.67	5.40
9-23	1400	834.3	2214.1	28.248	117.7	3.24	4.83
9-24	0930	887.1	2355.8	24.648	101.4	2.70	4.00
9-24	1050	909.8	2397.2	29.003	114.5	3.09	4.56
9-24	1215	911.7	2418.0	23.825	94.6	2.55	3.77
9-25	0949	979.3	2597.2	36.329	144.3	3.58	5.27
9-26	0940	954.7	2529.8	37.794	150.0	3.81	5.61
9-26	1119	932.5	2480.3	41.874	166.8	4.30	6.31
9-26	1256	944.5	2509.6	40.969	163.0	4.16	6.11
9-27	0929	926.1	2459.7	38.348	152.5	3.98	5.85
9-27	1108	983.9	2611.8	35.849	142.5	3.52	5.18
Unit 3							
10-11	1154	1068.2	2834.1	36.141	143.6	3.27	4.83
10-12	0946	1099.8	2915.1	43.440	172.4	3.80	5.83
10-13	1049	1155.7	3068.6	42.863	170.4	3.58	5.26
10-13	1223	1125.4	2987.1	42.787	170.1	3.66	5.40
10-15	0950	953.3	2533.2	62.535	245.9	6.16	8.96

* EDT
** Total Water Soluble Sulfate

48

TABLE 5

SO_x TEST RESULTS (CONTD.)

Date	Time *	SO_2 ppm/v	SO_2 mg/Nm³	$T\text{-}SO_4$** ppm/v	$T\text{-}SO_4$** mg/Nm³	SO_4/SO_x v/v	SO_4/SO_x w/w
Unit 4							
10-03	1150	979.6	2600.4	35.576	141.4	3.50	5.17
10-05	0950	855.4	2272.0	44.794	178.2	4.98	7.28
10-05	1122	841.7	2226.9	30.265	119.9	3.47	5.12
10-05	1253	837.4	2221.6	35.558	141.3	4.07	5.99
10-06	0950	884.6	2348.2	33.762	134.2	3.68	5.41
10-06	1127	975.3	2590.9	43.498	173.1	4.27	6.27
10-06	1257	891.9	2367.8	35.579	141.5	3.84	5.65
10-07	0957	962.2	2554.7	41.003	163.0	4.09	6.01
10-07	1131	939.3	2490.3	41.624	165.3	4.24	6.23
10-07	1313	913.3	2429.2	35.098	139.8	3.70	5.45
10-08	1029	701.8	1860.4	30.407	120.7	4.15	6.10
10-08	1202	742.4	1971.3	22.331	88.8	2.92	4.32
10-09	1026	823.3	2186.5	36.467	145.0	4.24	6.23
10-09	1421	934.2	2485.8	47.938	191.1	4.88	7.15

* EDT
** Total Water Soluble Sulfate

TABLE 6

COMBUSTION PARAMETERS AND SO$_x$ TEST RESULTS

Date	Time*	Oil Flow gal/hr	Fuel S -%	Boiler O$_2$- %	Stack O$_2$-%	Stack Temp-°C	SO$_2$ ppm v	SO$_2$ kg/hr	SO$_4$** ppm v	SO$_4$** kg/hr
Unit 1										
9-19	1040	6000	1.98	3.0	5.6	166	918.0	942.4	26.696	41.1
9-20	1005	5800	1.78	3.0	5.6	160	894.7	840.9	42.790	64.8
9-20	1210	6100	1.78	2.8	5.7	160	948.4	888.5	44.267	62.1
9-20	1430	6200	1.78	2.5	5.8	159	944.6	924.4	44.198	64.8
9-29	1110	5400	2.00	3.8	7.1	163	1088.4	1081.0	55.309	82.8
9-29	1305	5400	2.00	3.8	7.2	159	1032.1	955.8	44.023	46.1
9-29	1500	5400	2.00	3.8	7.2	161	1068.8	1071.2	49.615	71.0
9-30	1045	3400	2.05	3.6	7.7	154	927.0	549.5	32.121	28.5
10-01	1015	3400	1.80	3.3	7.6	152	902.0	540.4	33.754	30.3
10-01	1200	3400 ·	1.80	3.2	7.7	150	889.3	529.2	32.787	29.2
Unit 2										
9-21	1040	6200	1.70	2.4	5.5	188	933.6	916.1	29.736	43.7
9-21	1249	6150	1.70	2.2	5.6	188	950.0	952.3	29.425	44.2
9-21	1441	6100	1.70	2.0	5.6	188	931.4	935.3	31.928	48.1
9-22	0941	6100	1.75	2.2	5.4	179	948.9	954.1	43.256	65.0
9-22	1422	6150	1.75	2.2	5.3	177	943.9	989.6	29.354	46.5
9-22	1539	5800	1.75	2.3	5.3	177	951.8	997.0	25.767	40.4
9-23	1220	3000	1.90	4.6	8.3	148	944.9	616.4	35.979	35.7
9-23	1400	3100	1.90	4.5	8.2	153	834.3	536.0	28.248	28.5
9-24	0930	3300	1.50	3.6	7.6	150	887.1	597.3	24.648	25.7
9-24	1050	3200	1.50	3.6	7.8	149	909.8	589.4	29.003	28.1
9-24	1215	3100	1.50	3.5	7.4	157	911.7	581.0	23.825	22.7
9-25	0949	6100	1.97	2.1	6.3	177	979.3	997.9	36.329	55.5
9-26	0940	6000	1.95	2.0	6.1	170	954.7	956.3	37.794	56.7
9-26	1119	6200	1.95	2.0	6.0	177	932.5	993.8	41.874	66.8
9-26	1256	6100	1.95	1.9	5.9	185	944.5	954.0	40.969	62.0
9-27	0929	5600	2.05	2.2	6.3	165	926.1	887.4	38.348	55.0
9-27	1108	5600	2.05	2.2	6.4	166	983.9	968.3	35.849	52.8
Unit 3										
10-11	1154	6300	2.10	2.1	6.0	148	1068.2	1071.6	36.141	54.3
10-12	0946	6200	2.28	2.1	6.4	146	1099.8	1101.4	43.440	65.2
10-13	1049	6200	2.20	2.1	6.2	143	1155.7	1220.7	42.863	67.8
10-13	1223	6100	2.20	2.0	6.0	146	1125.4	1101.2	42.787	62.7

* EDT
** Total Water Soluble Sulfate

TABLE 6

COMBUSTION PARAMETERS AND SO$_x$ TEST RESULTS (CONTD.)

Date	Time*	Oil Flow gal/hr	Fuel S- %	Boiler O$_2$-%	Stack O$_2$-%	Stack Temp-^oC	SO$_2$ ppm v	SO$_2$ kg/hr	SO$_4$** ppm v	SO$_4$** kg/hr
Unit 4										
10-03	1150	6400	2.10	2.7	6.4	160	979.6	1063.8	35.576	57.9
10-05	0950	6000	1.50	2.1	6.2	157	855.4	808.7	44.794	63.4
10-05	1122	5000	1.50	3.0	7.2	150	841.7	680.0	30.265	36.6
10-05	1253	6300	1.50	2.0	6.4	155	837.4	812.6	35.558	51.7
10-06	0950	6100	1.40	2.0	6.6	157	884.6	827.9	33.762	47.3
10-06	1127	6100	1.40	1.9	6.3	158	975.3	957.4	43.498	64.0
10-06	1257	6100	1.40	1.8	6.6	160	891.9	853.1	35.579	51.0
10-07	0957	6200	1.40	2.0	5.9	166	962.2	973.2	41.003	62.1
10-07	1131	6200	1.40	2.3	6.3	161	939.3	927.4	41.624	61.6
10-07	1313	6000	1.58	2.4	6.3	161	913.3	904.7	35.098	52.1
10-08	1029	3200	1.70	5.5	9.6	131	701.8	494.0	30.407	32.1
10-08	1202	3200	1.70	5.3	9.7	133	742.4	515.6	22.331	23.2
10-09	1026	5900	1.96	3.2	6.4	157	823.3	814.2	36.467	54.0
10-09	1421	6400	1.77	3.1	6.4	160	934.2	975.1	47.938	75.0

* EDT
** Total Water Soluble Sulfate

51

Sulfur dioxide and total sulfate emission models were developed and can be found in Section 4.

SULFUR OXIDES CHARACTERIZATION

A sulfate characterization was performed by EPA personnel during the field sampling, using a controlled condensation sampling system. The system consisted of a high-temperature quartz probe, followed by a quartz filter. The filter was enclosed within a custom made heating mantle, kept at 260°C or greater, and had a coarse quartz frit for support of the filtering pad. Following filtration, the gaseous sulfuric acid was converted to the aerosol form in a temperature-controlled Goksoyr-Ross condensation coil, maintained at 60°C. Sampling rate was maintained at 10 l/min. or greater (Cheney and Homolya, 1979). The acid aerosol was collected in a Greenburg-Smith impinger containing an 80% solution of isopropyl alcohol and water.

Following this the sulfur dioxide was collected in an impinger containing 3% hydrogen peroxide and water. The recovered samples were analyzed using the barium-thorin procedure described in EPA Sulfur Dioxide Test Method 6.

Characterization Results

The results of the sulfate characterization using controlled condensation are shown on Table 7. The percent of H_2SO_4 ranged from 63.1% to 85.3% with a mean value of 73.5% of the total sulfate. Total sulfate measurements obtained using the controlled condensation technique averaged 19.5 ppm, which was significantly below the 37 ppm average of the measurements made with modified Method 6. The tests were performed under similar conditions and at the same point in the flue gas flow stream, therefore it is possible that there is an inherent interference in comparing the test methods. The isopropanol used in the

52

TABLE 7

SULFATE CHARACTERIZATION TEST RESULTS
(CONTROLLED CONDENSATION SYSTEM)

Date	Time[*]	Oil Flow gal/hr	Fuel S-%	Boiler O_2 - %	SO_2 ppm	SO_4 ppm	H_2SO_4 % of SO_4
Unit 1							
9/19	1139	6100	1.98	3.1	865	20.0	73.6
9/19	1258	6000	1.98	3.1	872	23.5	74.8
9/19	1350	6100	1.98	2.6	934	21.0	63.1
9/20	0908	5900	1.78	3.0	859	23.9	73.3
9/20	1033	6000	1.78	3.0	770	16.8	76.3
9/20	1132	6100	1.78	2.7	876	19.9	85.3
Unit 2							
9/21	1005	6200	1.70	2.4	897	26.9	71.7
9/21	1107	6150	1.70	2.4	928	25.5	78.4
9/21	1205	6150	1.70	2.2	896	23.6	77.3
9/21	1312	6150	1.70	2.2	916	25.2	76.7
9/21	1407	6100	1.70	2.0	813	19.0	75.1
9/22	0915	6100	1.75	2.1	927	19.7	77.2
9/22	1011	6050	1.75	2.3	910	17.5	70.4
9/22	1103	6000	1.75	2.3	912	20.4	70.0
9/22	1202	5650	1.75	2.3	904	17.0	70.8
Unit 4							
10/5	1010	6000	1.50	2.1	896	16.3	69.1
10/5	1135	5000	1.50	3.0	807	12.7	67.9
10/5	1239	5000	1.50	3.0	868	18.5	77.5
10/5	1322	6300	1.50	2.1	901	18.5	67.4
10/6	0817	5900	1.40	2.4	867	15.1	71.5
10/6	0911	6000	1.40	2.1	861	20.6	77.1
10/6	0952	6100	1.40	1.9	911	16.6	77.8
10/6	1055	6100	1.40	2.2	885	16.8	65.1
10/6	1154	6000	1.40	1.6	913	14.1	76.2

[*] EDT

modified Method 6 tests was checked for oxidants and found to be free of oxidants. Quartz wool was used to filter the sample gas so that an SO_2--glass wool reaction is not possible. A possible explanation of the discrepancy lies in the sampling rate; the controlled condensation system uses a large diameter probe and a 10 l/min. rate while the modified Method 6 test uses a small diameter probe and a 0.4 l/min. sampling rate. Nozzles were not used and the samples were not extracted iso-kinetically, therefore sampling velocity may have affected the influence of particles and particulate sulfate, thereby modifying the total sulfate measurements.

PARTICLE SIZE DISTRIBUTION

In-situ cascade impactors were used to obtain segregated samples of particulate matter within specific size ranges. The impactors each contained eight fractionating jet plates in series, with collection substrates below them. The substrates were composed of glass fiber material and served as impingement surfaces for the particles exiting through the jet directly above. Each jet plate had a design such that a particle with unit density and a diameter equivalent to the design cut point (D_{50}) impinged on the substrate below it with a 50% probability.

Smaller particles are able to follow the gas streamlines through the successive jets until the jet with the appropriate size is reached. Particles below about .5 um are collected on the backup glass fiber filter. The filter and substrates are analyzed for net particulate material and presented as the percentage of particulate per stage. The filters and substrates were transmitted to EPA for further analysis.

Particle Size Test Results

The results of the individual particle size determinations are shown in Table 8. The tests were also grouped by unit, (high or low) load, and (normal or soot blow) operating conditions. Each grouping is represented on a graph of cumulative particle size less than the D_{50} cut point on the ordinate and D_{50} particle size on the abscissa. The maximum, minimum, and mean (average of all tests in that grouping) are plotted in Figures 4 through 13. The mass median diameter (or size where 50% of the weight is greater and 50% is smaller) are summarized on Table 9. Median particle size is inversely proportional to load and is greater during soot blow than during normal operation.

COMBUSTION RECORDS

The chart recordings of several important combustion parameters were reduced to hourly summaries for use in characterizing the operating schedule of the boilers. These parameters are steam flow, oil flow, fuel sulfur content, boiler gas-oxygen content, air heater temperatures, and oil/additive ratio. The average daily values for each of the boilers are presented in Tables 10 through 13. A summary of the weekly fuel oil analysis is presented on Table 14 and the summary of weekly additive analysis is shown on Table 15.

EMISSION PREDICTION MODELS

Methodology

Quantitative and qualitative experiments were performed daily on the source-emitted materials in concert with the valuation of ground-level concentrations and meteorological factors. Samples of gaseous and particulate materials were extracted

TABLE 8

COMBUSTION PARAMETERS AND PARTICLE SIZE TEST RESULTS

Date	Time**	Oil Flow gal/hr	Fuel S-%	Boiler O_2-%	Stack O_2-%	Stack T.-°C	Stage 0-%	Stage 1-%	Stage 2-%	Stage 3-%	Stage 4-%	Stage 5-%	Stage 6-%	Stage 7-%	Back Up Filter %
Unit 1															
9-18*1636		5900	1.95	3.1	5.8	161	38.43	10.06	8.14	7.22	7.37	8.55	5.35	3.31	11.58
9-19*1202		5900	1.98	3.1	5.6	161	26.67	13.45	6.00	7.74	2.48	8.21	5.69	9.67	20.10
9-19 1523		6100	1.98	2.6	5.4	160	9.06	7.37	10.28	8.98	8.67	5.83	5.59	6.23	37.98
9-20 1150		6100	1.78	2.7	6.2	160	9.56	9.60	11.38	9.50	10.26	8.95	6.60	4.57	29.59
9-20 1350		6150	1.78	2.5	5.7	159	4.16	4.56	5.91	5.57	8.06	10.93	7.01	8.10	45.71
9-20 1615		6100	1.78	2.4	5.8	159	11.40	14.34	10.97	9.23	8.74	6.16	4.43	2.35	32.37
9-29 1310		3500	1.97	3.6	7.2	159	3.78	8.05	11.22	11.25	6.22	16.70	10.17	7.33	25.29
9-30 1128		3400	2.05	3.7	7.7	152	2.43	2.63	2.20	5.20	8.64	7.04	4.30	8.60	58.95
10-01 1053		3400	1.80	3.2	7.6	150	8.12	7.11	8.51	7.39	8.26	9.15	6.24	7.16	38.06
Unit 2															
9-21*1246		6150	1.70	2.2	5.5	188	10.95	10.30	9.98	11.17	9.29	9.40	6.74	5.46	26.71
9-21 1521		6100	1.70	2.0	5.6	188	10.34	12.52	12.34	10.47	10.68	7.84	5.12	4.59	26.10
9-22*1000		6050	1.75	2.3	5.4	179	13.06	13.58	14.28	11.13	12.18	8.10	6.24	4.95	16.47
9-22 1450		6150	1.75	2.2	5.3	177	9.05	10.71	13.08	9.83	8.80	7.14	6.26	4.43	30.71
9-22 1554		6000	1.75	2.3	5.3	177	10.70	9.67	11.19	8.60	11.13	7.27	4.87	3.89	32.70
9-23*1412		3100	1.90	4.5	8.2	153	8.28	10.80	14.25	9.66	11.00	7.99	5.42	3.50	29.09
9-24 1035		3150	1.50	3.6	7.6	150	6.12	6.08	7.31	5.02	6.43	8.19	8.28	8.94	43.64
9-24*1313		3100	1.50	3.8	7.4	157	7.22	4.11	9.65	9.40	8.80	11.91	3.75	7.26	37.90
9-25 1030		6100	1.97	2.2	6.3	177	10.23	10.23	13.47	10.01	10.31	9.15	7.10	5.27	24.23
9-26*1030		6100	1.95	2.0	6.1	177	13.16	8.70	7.99	9.36	12.70	14.65	10.63	6.32	16.48
9-26*1145		6150	2.00	2.0	6.0	177	14.48	14.95	13.11	11.50	11.70	8.69	4.92	4.09	16.56
9-26 1245		6100	2.03	2.0	6.0	180	10.00	10.38	9.91	10.11	10.03	9.95	7.56	6.56	25.49
9-27 1028		5600	2.05	2.2	6.4	166	8.39	9.79	11.04	8.15	7.18	7.18	5.85	3.98	38.44
9-27 1140		5600	2.05	2.3	6.4	166	7.97	13.19	12.26	10.60	9.43	7.93	4.37	3.97	30.27
9-28 1008		4300	2.25	3.8	7.4	158	9.66	11.32	11.84	9.47	9.05	8.60	5.32	3.96	30.78

* Soot Blow Test
** EDT

TABLE 8

COMBUSTION PARAMETERS AND PARTICLE SIZE TEST RESULTS (CONTD.)

Date	Time**	Oil Flow gal/hr	Fuel S-%	Boiler O_2-%	Stack O_2-%	Stack T.-°C	Stage 0-%	Stage 1-%	Stage 2-%	Stage 3-%	Stage 4-%	Stage 5-%	Stage 6-%	Stage 7-%	Back Up Filter
Unit 3															
10-11	1055	6300	2.10	2.1	6.3	145	25.62	10.59	6.23	6.10	6.51	6.04	3.53	5.02	30.35
10-11	1208	6300	2.10	2.1	6.0	148	22.01	9.96	7.71	8.87	6.33	6.90	3.81	2.93	31.49
10-11	1320	6300	2.10	2.3	6.1	149	22.68	11.49	7.56	6.82	9.38	7.49	3.71	3.72	27.15
10-12	1021	6100	2.28	2.6	6.2	146	31.85	10.72	8.45	6.78	7.90	6.18	2.86	3.26	21.99
Unit 4															
10-03*	1302	6400	2.10	2.5	6.7	156	11.39	10.74	11.12	8.53	10.90	9.15	6.43	5.71	26.03
10-04*	1440	6200	2.20	2.0	6.6	152	11.66	9.03	10.36	7.21	9.25	8.10	5.05	3.86	35.48
10-05	1045	5600	1.50	2.7	6.4	154	16.19	13.81	12.16	4.00	3.85	3.94	3.43	2.14	40.48
10-06	0955	6100	1.40	1.9	6.6	157	19.23	11.77	7.56	7.31	5.52	7.08	2.75	3.10	35.70
10-06	1110	6050	1.40	1.6	6.3	157	16.93	10.75	11.71	9.39	11.01	6.29	4.25	2.71	26.96
10-06*	1230	6050	1.40	1.7	6.6	160	20.73	11.94	9.64	7.08	7.40	7.50	4.35	2.87	28.49
10-07	1115	6200	1.40	2.3	5.9	166	10.71	8.29	2.64	8.46	9.72	9.88	7.98	7.58	34.74
10-07	1235	6100	1.40	2.4	6.3	160	13.90	11.11	10.92	5.60	9.61	7.24	5.25	2.88	33.49
10-08	1105	3200	1.70	5.0	9.6	135	6.15	5.21	5.96	4.11	8.68	10.27	8.16	7.48	43.98
10-08	1335	3200	1.70	5.0	9.7	135	4.48	5.36	5.97	5.16	8.49	9.40	5.94	10.39	44.81
10-09	1100	5950	1.96	3.5	6.4	157	13.31	8.91	8.38	6.72	8.05	10.13	7.29	6.47	30.74
10-09	1440	6600	1.96	3.2	6.4	157	13.70	9.86	9.60	9.45	10.30	10.07	6.70	5.26	25.06

* Soot Blow Test
** EDT

FIGURE 4   PARTICLE SIZE DISTRIBUTION

Unit 1
High Load-Normal Operation
4 Tests

58

FIGURE 5   PARTICLE SIZE DISTRIBUTION

Unit 1
High Load-Soot Blow
2 Tests

FIGURE 6 PARTICLE SIZE DISTRIBUTION

Unit 2
High Load-Normal Operation
7 Tests

FIGURE 7 PARTICLE SIZE DISTRIBUTION

Cumulative % Less Than D_p

Maximum

Minimum

Mean

Unit 2
High Load-Soot Blow
4 Tests

Aerodynamic Particle Diameter- D_p μm

61

FIGURE 8 PARTICLE SIZE DISTRIBUTION

Cumulative % Less Than D_p

Aerodynamic Particle Diameter- D_p μm

Mean

Maximum

Minimum

Unit 3
High Load-Normal Operation
4 Tests

62

FIGURE 9   PARTICLE SIZE DISTRIBUTION

Unit 4
High Load-Normal Operation
8 Tests

63

FIGURE 10 PARTICLE SIZE DISTRIBUTION

Unit 4
High Load-Soot Blow
3 Tests

64

FIGURE 11 PARTICLE SIZE DISTRIBUTION

Maximum

Minimum

Mean

Unit 1
Low Load-Normal Operation
3 Tests

Cumulative % Less Than D_p

Aerodynamic Particle Diameter- D_p μm

65

FIGURE 12   PARTICLE SIZE DISTRIBUTION

Unit 2
Low Load-Normal Operation
2 Tests

Cumulative % Less Than D_p

Aerodynamic Particle Diameter- D_p μm

99

FIGURE 13 PARTICLE SIZE DISTRIBUTION

Unit 2
Low Load-Soot Blow
2 Tests
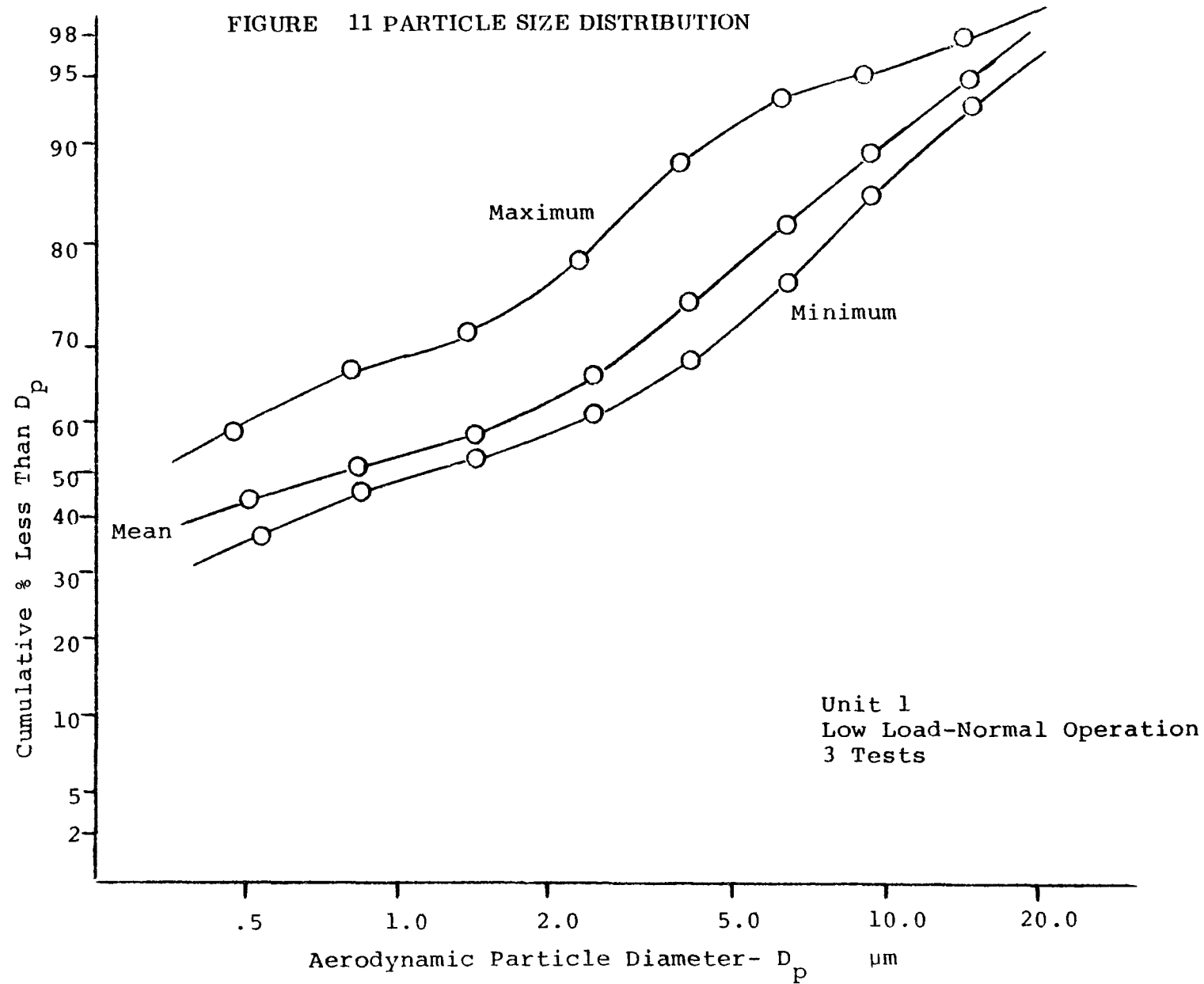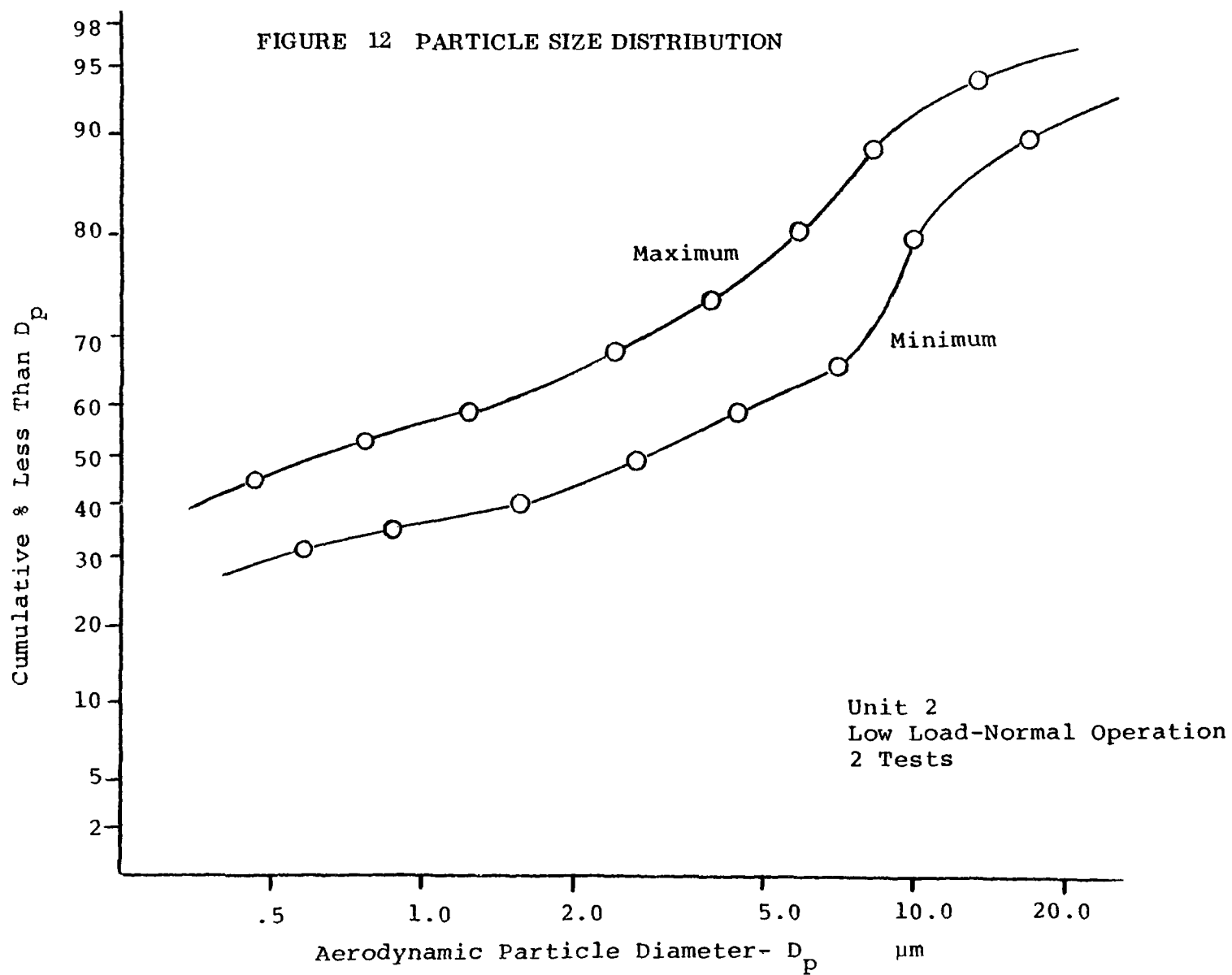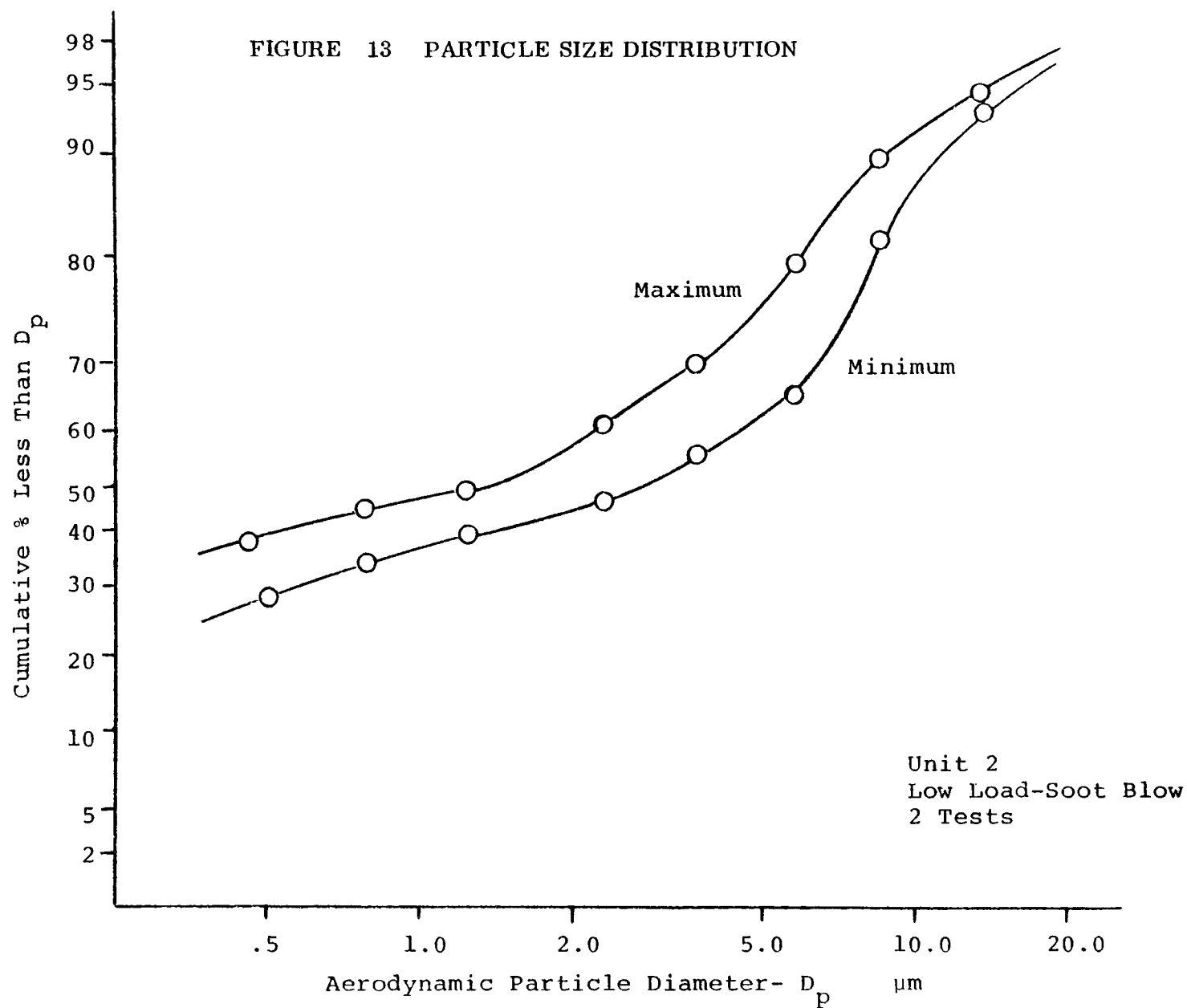
TABLE 9

SUMMARY OF MASS MEDIAN PARTICLE DIAMETER

	Operating Conditions	Number of tests	Mass Median Particle Diameter μm
Unit 1	High Load Normal	4	1.8
	High Load Soot Blow	2	5.5
	Low Load Normal	3	0.8
Unit 2	High Load Normal	7	3.0
	High Load Soot Blow	4	3.5
	Low Load Normal	2	1.4
	Low Load Soot Blow	2	1.9
Unit 3	High Load Normal	4	4.0
Unit 4	High Load Normal	8	2.2
	High Load Soot Blow	3	3.0

TABLE 10

AVERAGE DAILY COMBUSTION PARAMETERS

UNIT 1

Date	Steam Flow 1000 lb/hr	Oil Flow gal/hr	Fuel Sulfur %	Boiler O_2-%	AH Temp.-In °F	AH Temp.-Out °F	Additive Ratio gal oil/gal add.	Days* of Operation
9-18	522	4900	1.94	4.33	599	311	2130	44
9-19	599	5254	1.94	3.15	616	320	2171	45
9-20	606	5415	1.82	2.88	613	321	2216	46
9-21	665	5867	1.72	2.29	629	325	2261	47
9-22	584	5088	1.69	3.53	599	312	2327	48
9-23	000	-	-	-	-	-	-	-
9-24	361	3625	1.73	4.36	524	293	2378	50
9-25	590	5450	1.94	2.89	607	317	2408	51
9-26	601	5488	2.01	2.98	615	317	2430	52
9-27	606	5440	2.06	3.23	619	320	2443	53
9-28	598	5325	2.11	3.37	619	317	2449	54
9-29	553	4954	2.01	3.97	614	320	2446	55
9-30	465	4190	2.00	3.67	589	314	2433	56
10-1	422	3792	2.01	3.54	562	315	2413	57
10-2	543	4871	1.95	3.18	604	317	2379	58
10-3	643	5736	2.00	3.21	630	319	2347	59
10-4	648	5796	2.08	3.00	635	325	2305	60
10-5	664	5946	2.10	2.91	640	325	2257	61
10-6	646	5673	2.04	2.79	630	324	2206	62
10-7	372	3450	2.09	4.63	564	314	2151	63
10-8	360	3400	2.04	5.30	565	320	2097	64
10-9	473	4415	1.99	4.40	598	317	2044	65
10-10	577	5244	2.03	3.21	620	323	1994	66
10-11	619	5577	2.09	2.84	628	326	1922	67
10-12	614	5467	2.17	3.00	628	324	1902	68
10-13	622	5583	2.12	3.11	635	324	1922	69
10-14	600	5442	2.03	3.13	629	320	1953	70
10-15	543	4944	2.12	3.88	615	323	2012	71

*Since last boiler wash

69

TABLE 11

AVERAGE DAILY COMBUSTION PARAMETERS

UNIT 2

Date	Steam Flow 1000 lb/hr	Oil Flow gal/hr	Fuel Sulfur %	Boiler O2-%	AH In-Temp. °F	AH Out-Temp. °F	Additive Ratio gal oil/gal add.	Days* of Operation
9-18	630	5683	1.94	2.86	625	353	2387	72
9-19	622	5604	1.94	2.83	627	354	2406	73
9-20	619	5583	1.82	2.96	624	355	2424	74
9-21	678	6050	1.72	2.35	646	359	2440	75
9-22	666	5925	1.69	2.25	640	363	2431	76
9-23	506	4638	1.76	3.73	595	348	2471	77
9-24	438	4013	1.73	3.34	570	343	2484	78
9-25	627	5658	1.94	2.49	635	359	2496	79
9-26	635	5679	2.01	2.29	632	359	2506	80
9-27	614	5500	2.06	2.39	625	354	2516	81
9-28	543	4900	2.11	3.23	604	347	2530	82
9-29	630	5619	2.01	2.79	631	358	2642	83
9-30	634	5681	1.99	2.56	633	358	2539	84
10-1	562	5029	1.90	3.00	617	356	2542	85
10-2	593	5354	1.95	3.37	627	355	2502	86
10-3	674	6129	2.00	2.56	646	359	2550	87
10-4	678	6046	2.08	2.43	647	360	2548	88
10-5	676	6117	2.10	2.33	649	360	2444	89
10-6	665	5950	2.04	2.53	646	360	2554	90
10-7	622	5602	2.09	3.06	639	361	2554	91
10-8	558	5008	2.04	3.38	619	353	2552	92
10-9	604	5615	1.99	3.12	636	361	2550	93
10-10	649	5846	2.03	2.78	645	361	2550	94
10-11	669	6067	2.09	2.52	650	365	2628	95
10-12	662	5917	2.17	2.60	647	364	2535	96
10-13	682	5992	2.12	2.66	651	365	2527	97
10-14	651	5794	2.08	2.72	637	350	2510	98
10-15	630	5337	2.12	3.39	620	345	2499	99

*Since last boiler wash

TABLE   12

AVERAGE DAILY COMBUSTION PARAMETERS

UNIT 3

Date	Steam Flow 1000 lb/hr	Oil Flow gal/hr	Fuel Sulfur %	Boiler O_2-%	AH Temp.-In $^{\circ}F$	AH Temp.-Out $^{\circ}F$	Additive Ratio gal oil/gal add.	Days* of Operation
10-6	551	5029	1.52	3.83	515	307	2107	1
10-7	596	5415	1.54	3.21	566	318	2118	2
10-8	527	4902	1.67	3.37	558	316	2375	3
10-9	624	5704	1.83	3.01	586	325	2385	4
10-10	653	5875	1.97	2.51	588	331	2395	5
10-11	662	6092	2.09	2.25	591	335	2502	6
10-12	556	5092	2.24	3.11	571	334	2550	7
10-13	635	5708	2.20	2.74	591	331	2597	8
10-14	643	5754	2.15	2.62	598	328	2645	9
10-15	514	4826	2.18	3.34	571	318	2691	10

*Since last boiler wash

71

TABLE 13

AVERAGE DAILY COMBUSTION PARAMETERS

UNIT 4

Date	Steam Flow 1000 lb/hr	Oil Flow gal/hr	Fuel Sulfur %	Boiler O2-%	AH Temp.-In °F	AH Temp.-Out °F	Additive Ratio gal oil/gal add.	Days* of Operation
9-18	620	5646	2.00	2.92	595	333	1976	15
9-19	654	5908	2.01	2.58	602	334	2070	16
9-20	637	5823	2.05	2.42	597	339	2016	17
9-21	657	5950	2.15	2.17	597	353	2176	18
9-22	635	5733	2.23	2.75	607	355	2171	19
9-23	567	5225	2.16	3.26	592	340	2092	20
9-24	479	4512	2.20	4.38	582	329	2038	21
9-25	605	5533	2.08	3.23	599	342	2006	22
9-26	606	5413	2.07	3.15	595	337	2009	23
9-27	588	5500	2.08	3.02	594	331	2002	24
9-28	510	4679	2.05	3.28	586	327	2002	25
9-29	510	4767	2.09	3.08	587	329	2021	26
9-30	595	5517	2.13	2.67	594	327	3505	27
10-1	548	5058	2.02	3.00	582	338	3630	28
10-2	566	5275	2.00	3.01	610	338	3641	29
10-3	646	5971	1.95	2.68	613	338	3846	30
10-4	645	5900	1.87	2.25	608	338	3581	31
10-5	663	6096	1.60	2.24	605	348	3404	32
10-6	635	5796	1.52	2.13	593	355	3233	33
10-7	587	5400	1.54	2.39	609	362	3337	34
10-8	450	4306	1.67	4.07	579	332	3425	35
10-9	592	5908	1.83	3.44	604	348	3497	36
10-10	612	5654	1.97	3.12	610	351	3560	37
10-11	639	5879	2.09	2.40	607	359	3793	38
10-12	644	5867	2.22	2.11	606	359	2581	39
10-13	654	5946	2.20	2.38	603	367	2557	40
10-14	643	5796	2.15	2,90	625	363	2502	41
10-15	569	5278	2.18	3.51	624	351	2419	42

*Since last boiler wash

72

TABLE   14

FUEL OIL SPECIFICATIONS

Date	Boiler	BTU/lb	Ash %	S %	C %	H %	N %	Cl %	Na ppm	K ppm	Mg ppm	Ca ppm	Ni ppm	Mn ppm	Fe ppm	V ppm
9-18	1	18,581	.14	1.91	85.9	12.4	.79	.01	64	2	153	8	48	2	9	212
9-18	2	18,586	.11	2.00	85.5	13.8	.40	.02	72	1	110	6	45	1	7	203
9-18	4	18,670	.13	1.99	85.9	13.6	.30	.01	59	2	133	8	45	2	6	207
9-19	1	18,587	.13	1.96	85.7	13.2	.40	0.0	55	1	136	7	35	2	8	231
9-19	2	18,653	.11	1.99	86.1	13.1	.30	0.0	48	7	113	6	49	1	7	203
9-19	4	18,672	.12	2.00	86.2	12.2	.24	0.0	47	1	129	7	35	2	6	223
9-25	1	18,633	.14	2.01	85.1	11.2	.35	0.0	-	-	-	-	-	-	-	-
9-25	2	18,670	.12	1.93	84.8	11.2	.20	0.0	-	-	-	-	-	-	-	-
9-25	4	18,628	.11	2.00	85.4	11.0	.30	0.0	-	-	-	-	-	-	-	-
10-02	1	18,571	.14	1.91	85.9	12.0	.27	.02	66	2	160	8	52	2	8	235
10-02	2	18,584	.10	2.02	85.7	11.5	.28	.02	41	2	160	5	76	2	9	212
10-02	4	18,846	.11	1.94	85.8	12.1	.27	.02	61	1	110	5	45	1	6	216
10-09	1	18,641	.13	1.94	85.8	11.8	.33	.02	53	1	190	7	81	2	8	165
10-09	2	18,620	.11	1.96	85.5	12.2	.34	.02	50	2	130	6	84	1	7	169
10-09	3	18,646	.15	1.92	85.6	11.8	.33	.02	56	2	260	9	81	2	3	224
10-09	4	18,555	.12	1.96	85.4	12.3	.27	.02	36	2	180	6	84	1	1	182
10-15	1	18,658	.11	2.04	86.0	12.1	.21	.02	42	4	170	7	42	1	5	160
10-15	2	18,538	.10	2.05	86.0	12.2	.20	.03	36	2	140	5	54	1	8	144
10-15	3	18,773	.09	2.11	85.8	12.4	.18	.02	39	2	150	5	53	1	7	175
10-15	4	18,501	.09	2.14	86.0	12.4	.17	.02	40	3	120	6	55	1	9	176

TABLE   15

FUEL ADDITIVE ANALYSIS - METALS

Date	Na ppm	K ppm	Mg %	Ca ppm	Ni ppm	Mn ppm	Fe ppm	V ppm
9-18	1180	260	25.51	8390	3	2081	923	N.D.
9-20	1130	240	25.93	6270	8	2008	1014	N.D.
9-25	1120	250	25.97	7210	4	1948	965	N.D.
10-02	1000	260	25.98	7300	2	1930	1160	N.D.
10-09	900	250	25.95	7700	3	1890	1190	N.D.
10-15	1000	240	26.05	7700	3	1980	1190	N.D.

N.D. - less than 1 ppm

from the stack effluent near the point of discharge. Simultaneous documentation of the combustion parameters was accomplished, as well as the daily acquisition of oil and additive samples.

Since the samples of emitted materials were taken over a short time span with each 24-hour day, and the emissions from the boilers varied over a wide range during each day, it was beneficial to use these data to predict the quantity of ejected materials on a continuous real-time basis. Statistical techniques were used in making these predictions, in particular was the multiple stepwise regression analysis using emission test data and simultaneous operational combustion parameters. A regression analysis was used to quantify the relationship between a dependent variable, y, and one or more independent variables, x_j. The model with regression coefficients, β_j, is written as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p + E$$

A stepwise regression method was used for the analysis.

The stepwise regression procedure is a modification to forward selection regression. Independent variables are entered until a satisfactory regression equation is obtained. Independent variables are inserted in order according to their partial correlation coefficient. At each stage in the regression the independent variables previously entered are re-examined. The test statistic or partial F criterion for each variable in the regression is evaluated and compared with a pre-selected percentage point of the appropriate F distribution. Any independent variable providing a non-significant contribution is removed from the model. This process is continued until no more independent variables are added or deleted. Through this procedure, an independent variable important at an early stage

75

can be dropped because of relationships between it and other independent variables brought into the equation at a later stage.

At each step the variables are removed and/or entered into the equation according to the F value criteria. The variable with the smallest F value is removed from the equation if the F-to-remove is less than the chosen lower limit. If no value meets this criterion, the variable with the largest F value is entered into the equation if the F-to-enter is larger than the chosen limit. This allows selectivity of the variables in the equation in as many steps as there are variables.

An analysis of variance (ANOVA) is used to test the null hypothesis that the regression coefficients are zero. That is, the F value is used to test the statistical significance of the regression equation.

The standard error of estimates, which is the square root of the deviations mean square, provides a measure of how closely the regression model fits the data. Since the purpose is to find a more accurate method of predicting y, the size of the standard error of estimates is of primary importance. The smaller the standard error of estimates, the better the regression equation fits the data.

The correlation coefficient, r, for a simple linear regression analysis indicates how closely the dependent variable, y, is related to the independent variable, x. The range of cases can be from r=0 where y is independent of x and there is no relationship between the variables to r=$\pm$1.0 where any change in x is accompanied by a proportionate change in y. The multiple correlation coefficient, R, is a measure of the joint relationship of all the independent parameters, x_j, to the dependent parameter y.

The adjusted R^2 value is used to estimate the fraction of the variance of y that is attributable to the regression. An ideal regression model would have an adjusted R^2 value equal to 1.0. The adjusted R^2 value is translated as:

$$\text{Adjusted } R^2 = 1 - (MSD/MST)$$
$$\text{Where} \quad MSD = \frac{\Sigma(y-\hat{y})^2}{n-p-1}$$
$$MST = \frac{\Sigma(y-\bar{y})^2}{}$$

Particulate Model

Multiple regression analyses were performed using emission rates of specific materials derived from emission tests and simultaneous operational and combustion parameters. Each emission test was considered to be one data point. For the particulate discharge regression analysis, forty-six data points were available. Independent variables consisted of: oil flow, boiler oxygen content, fuel sulfur content, additive ratio, (gallons of oil/gallons of additive), and days of operation since the last boiler wash. Since this was a stepwise regression analysis, the results were documented after each parameter was entered, with decreasing order of consequence. The lowest standard error appeared after oil flow, gallons of oil/gallons of additive, and boiler oxygen content had been entered.

Particulate Sulfate Model

Particulate sulfate emissions were correlated with the same parameters as particulate emissions. Fiftyfour data points were analyzed (soot blow test data were eliminated from the particulate prediction analysis but not from the particulate sulfate prediction analysis). The lowest standard error appeared after oil flow, gallons of oil/gallons of additive,

days of operation since the last boiler wash, and boiler oxygen content had been entered.

Sulfur Dioxide Model

Sulfur dioxide emission rates were correlated with the weight rate of fuel sulfur entering the firebox. Forty-six data points were available.

Total Sulfate Model

Total sulfate emission data were correlated with oil flow, boiler oxygen content, gallons of oil/gallons of additive, fuel sulfur content, and days of operation since the last boiler wash. Forty-six modified Method 6 test results were available. The lowest standard error appeared after all the parameters had been entered.

Summary of Regression Coefficients

The summary of regression coefficients for the prediction models is shown on Table 16. Units are lb./hr. for filterable particulate, sulfur dioxide, and total sulfate; percent of filterable particulate for particulate sulfate. The standard error of estimates in each case is 15% or less of the mean value, indicating reasonable, but not exceptional, correlation.

Emission Estimates

The models were applied to the actual data in the form of hourly averages. However, fuel sulfur content and gallons of oil/gallons of additive were not available hourly, therefore representative daily values were substituted. Since particulate emissions during soot blowing were approximately 40%

78

higher than during normal operation, a factor was inserted into the parameter data files which caused the particulate rate to be multiplied by a 1.4 whenever soot blowing was performed. The hourly emission rates were summed on a daily basis for correlation with 24-hour ground-level concentration measurements. The results of these summations are shown in Figures 14, 15, 16, 17, and 18 in the form of average hourly rates each day for particulate, particulate sulfate, total sulfate, acid sulfate, and sulfur dioxide, respectively. These graphical presentations reflect the day when Unit 1 was out of service due to an economic outage (Day 6) and the period when Unit 3 came on-line after an extended maintenance outage (following Day 19).

DIURNAL EMISSION PROFILE

The diurnal analyses of emission estimates for particulate, particulate sulfate, total sulfate, and sulfur dioxide are presented in Figures 19, 20, 21, 22, respectively.

INVESTIGATION OF THE RELATIONSHIP OF SULFATE FORMATION TO COMBUSTION PARAMETERS

Several individual operational and combustion parameters were investigated in order to gain knowledge of primary sulfate formation in these combustion furnaces. The high variability of sulfate emissions observed is probably due to a complex interaction of specific variables. The most likely causes of high sulfate emissions are high oxygen levels, high sulfur and metals content of the oil, burner and boiler configuration, cleanliness of boiler internals, degree of air leaks, and to a certain extent, the collection efficiency of the particulate collectors. In the case of these boilers, the burner and boiler configurations, fuel sulfur and metals content, and operation of the mechanical collectors are similar between boilers. The oxygen levels are variable but in all cases are

79

TABLE 16

SUMMARY OF EMISSION PREDICTION MODELS

	Y-Intercept	Oil Flow gal/hr	Fuel S %	Boiler O_2 %	Additive Ratio oil/addi-tive	Days of Operation	Multiple R	Adjusted R^2	Standard Error of Estimates
Filterable Particulate Mean,92.5 lb/hr	-15.2	+.028	-	+4.9	-.021	-	.91	.81	14.1
Particulate Sulfate Mean,47.5% of Particulate	+25.7	-.002	-	+2.0	+.009	+.12	.72	.47	6.6
Sulfur Dioxide Mean,1893 lb/hr	+492.3	+.145*	-	-	-	-	.89	.78	202.0
Total Sulfate Mean,114.0 lb/hr	+115.1	+.033	+16.1	+20.1	-.008	-.18	.87	.73	17.5

* Multiplied times % Fuel Sulfur

80

PARTICULATE EMISSION ESTIMATE

24-HOUR AVERAGE OF PLANT AGGREGATE TOTAL

FIGURE 14

PARTICULATE SOLUBLE SULFATE EMISSION ESTIMATE

24-HOUR AVERAGE OF PLANT AGGREGATE TOTAL
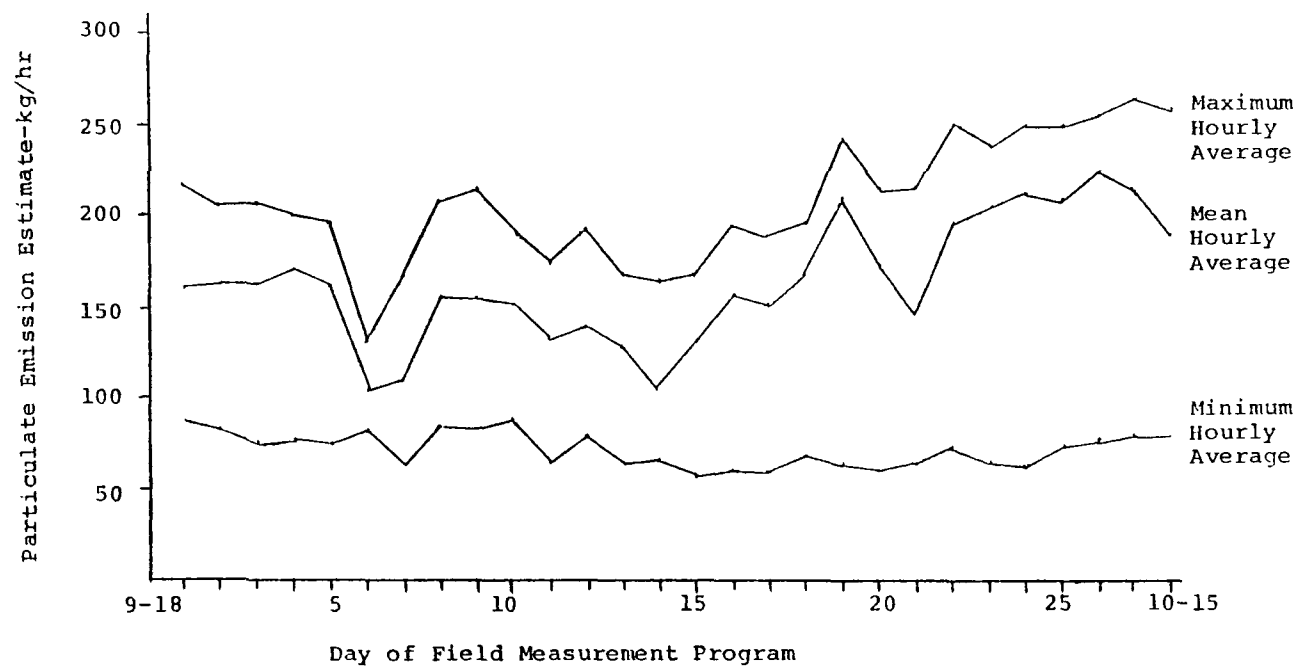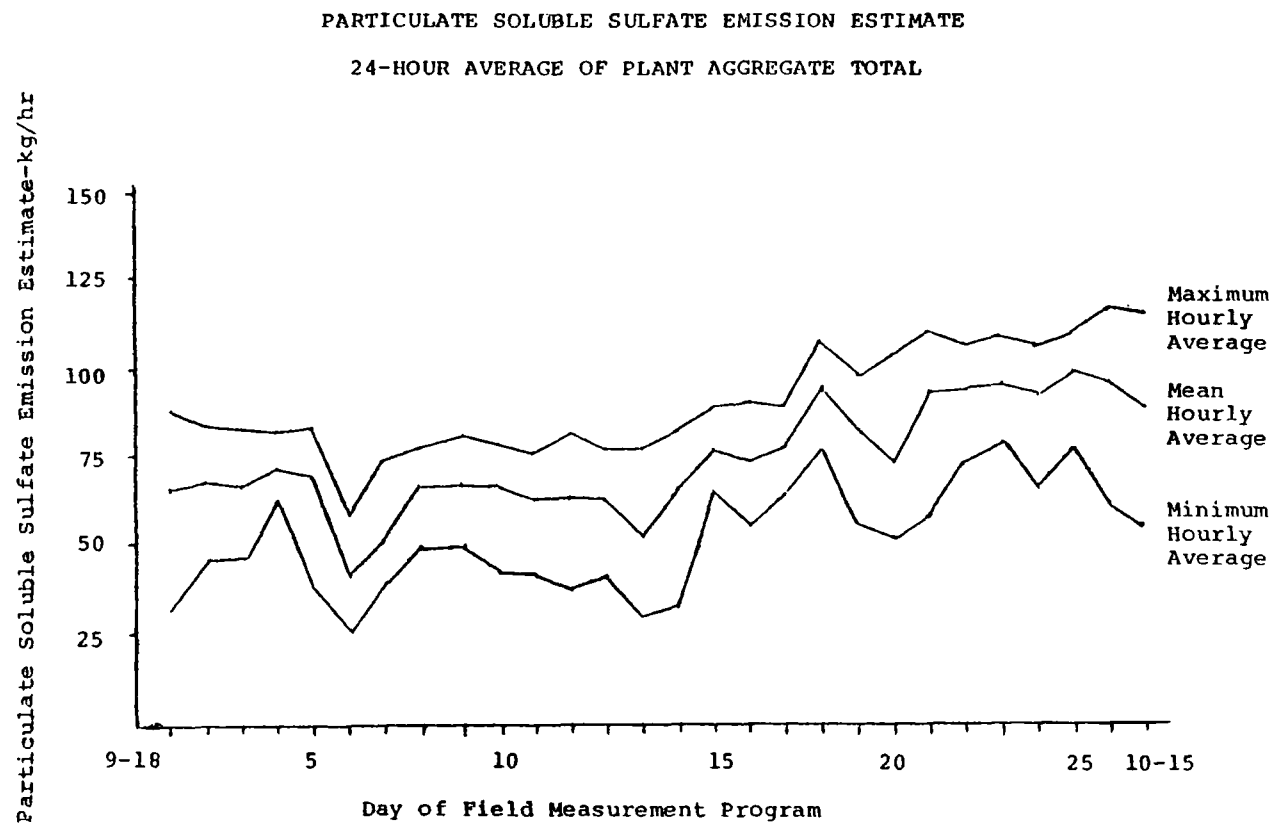
FIGURE 15

TOTAL SOLUBLE SULFATE EMISSION ESTIMATE

24-HOUR AVERAGE OF PLANT AGGREGATE TOTAL

Day of Field Measurement Program

FIGURE 16

ACID SULFATE EMISSION ESTIMATE

24-HOUR AVERAGE OF PLANT AGGREGATE TOTAL

Day of Field Measurement Program

FIGURE 17

84

SULFUR DIOXIDE EMISSION ESTIMATE

24-HOUR AVERAGE OF PLANT AGGREGATE TOTAL

FIGURE 18

DIURNAL ANALYSIS OF EMISSION ESTIMATE

PARTICULATE
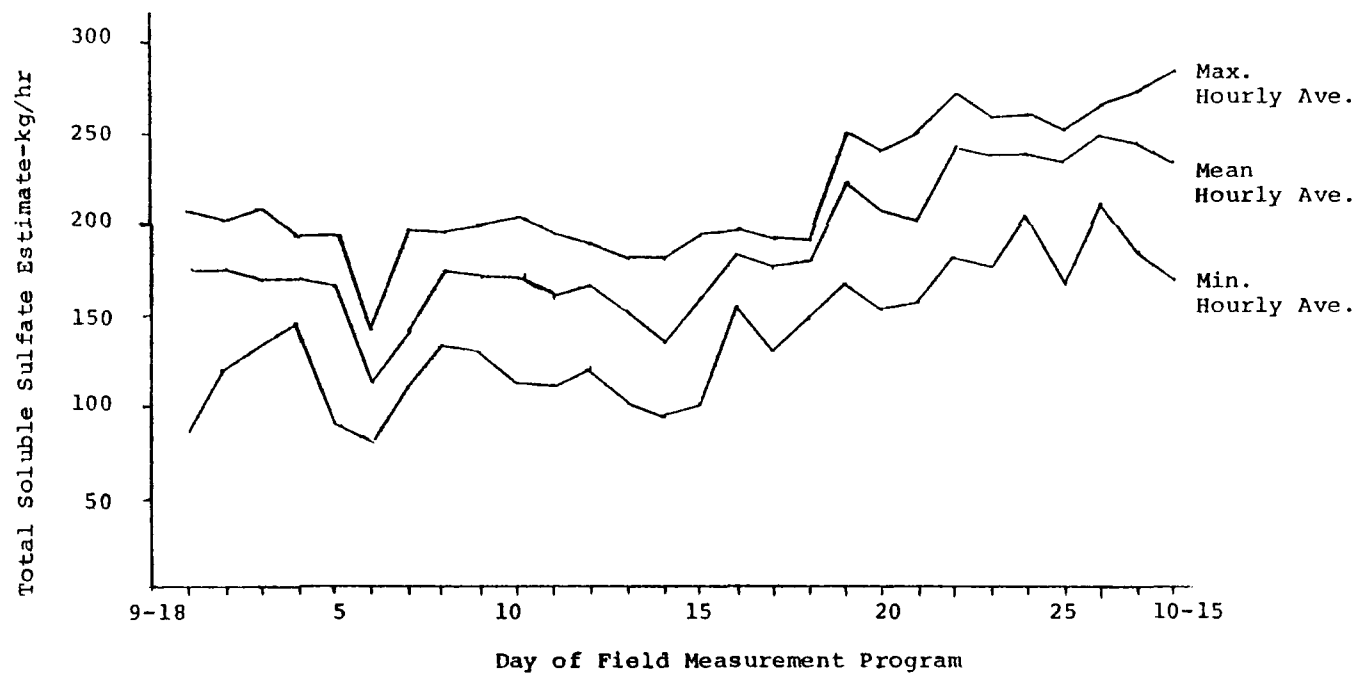
28-DAY AVERAGE OF PLANT AGGREGATE TOTAL
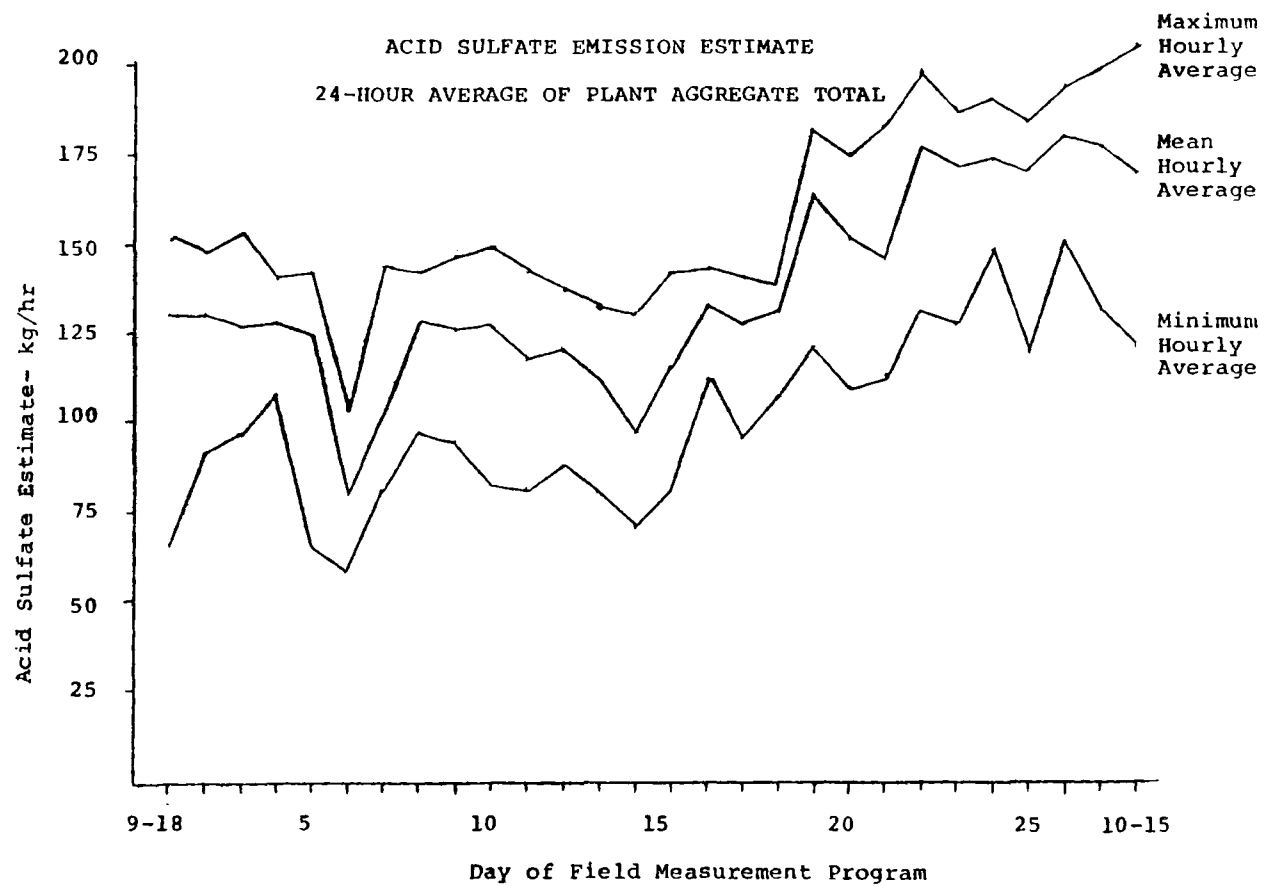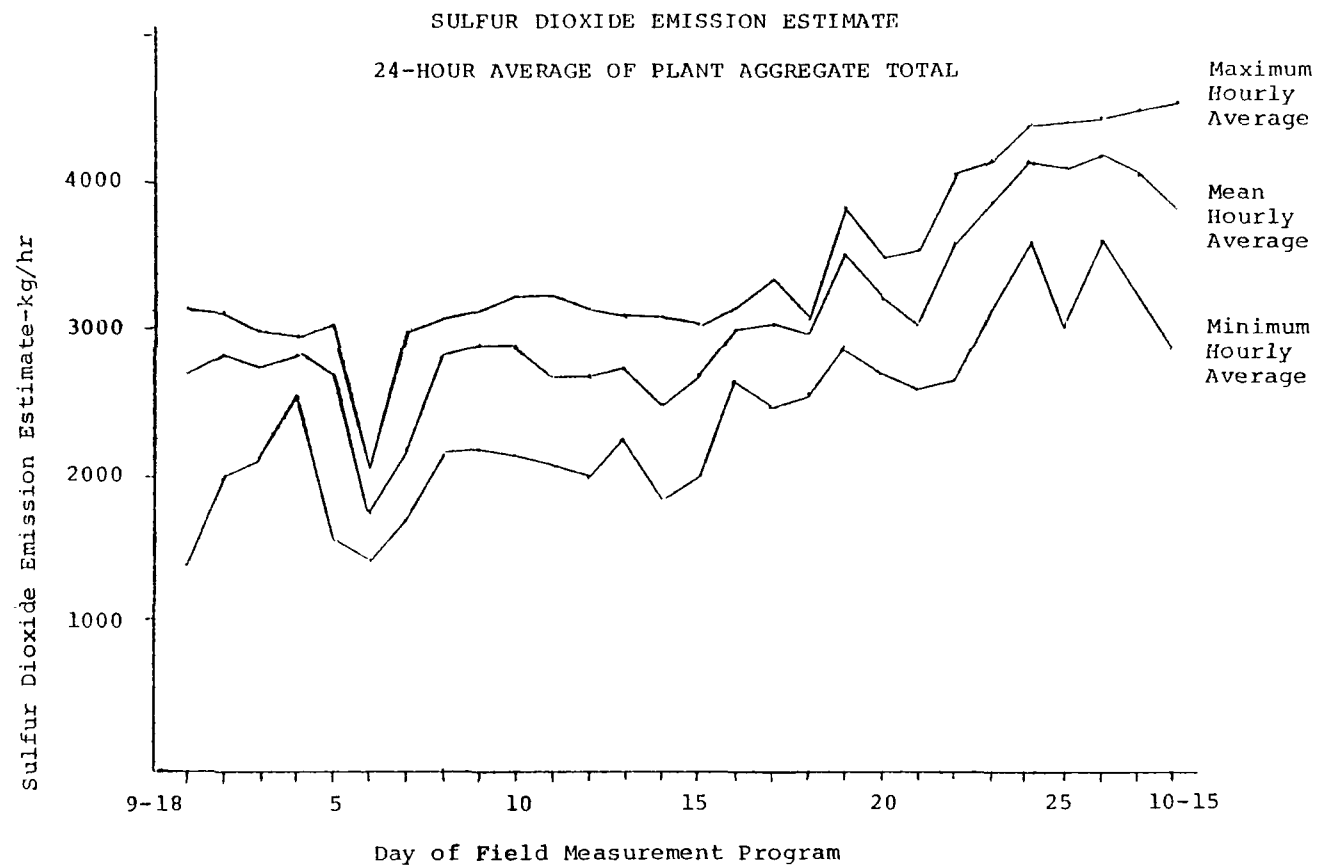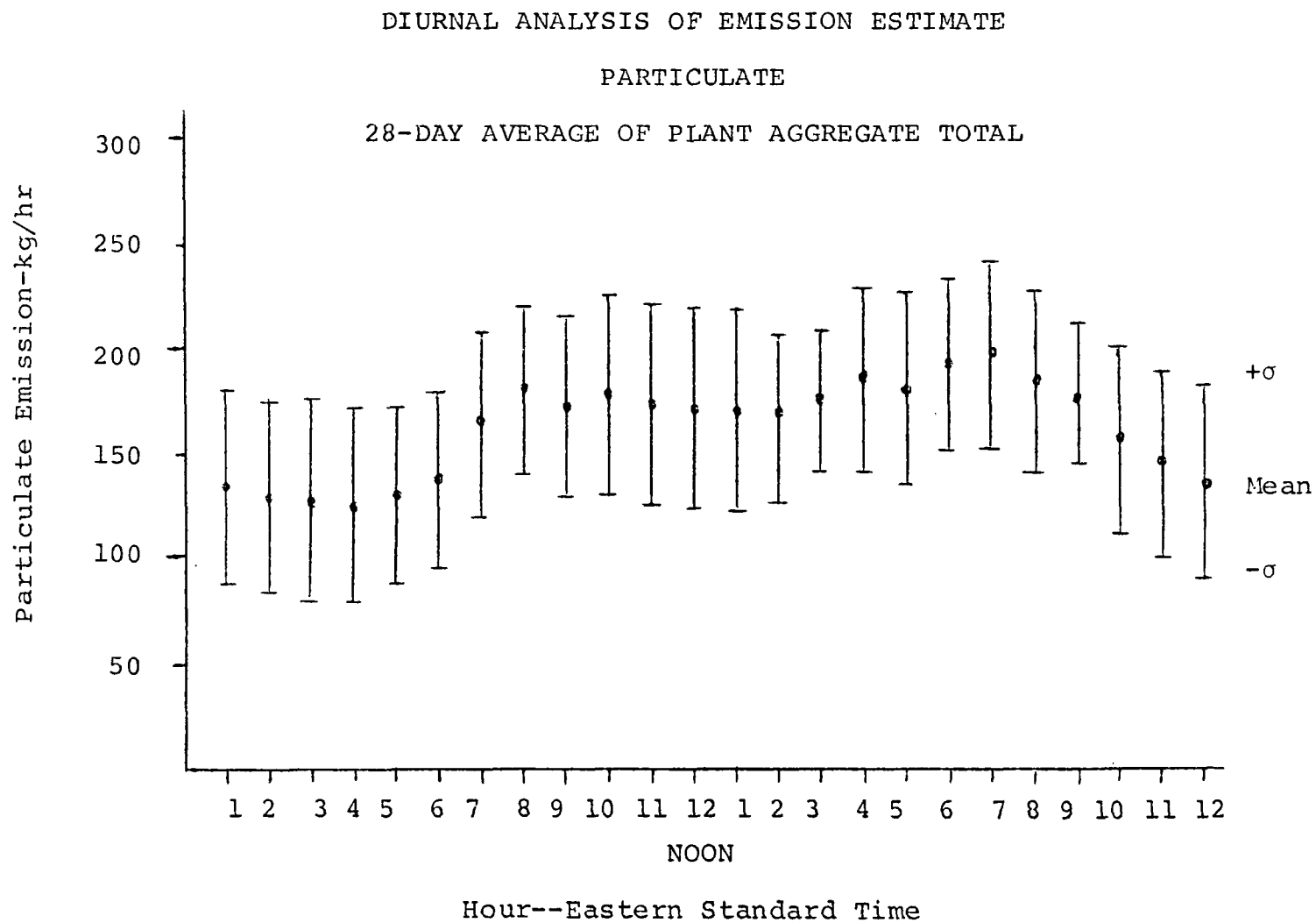
FIGURE 19

DIURNAL ANALYSIS OF EMISSION ESTIMATE

PARTICULATE SOLUBLE SULFATE

28-DAY AVERAGE OF PLANT AGGREGATE TOTAL
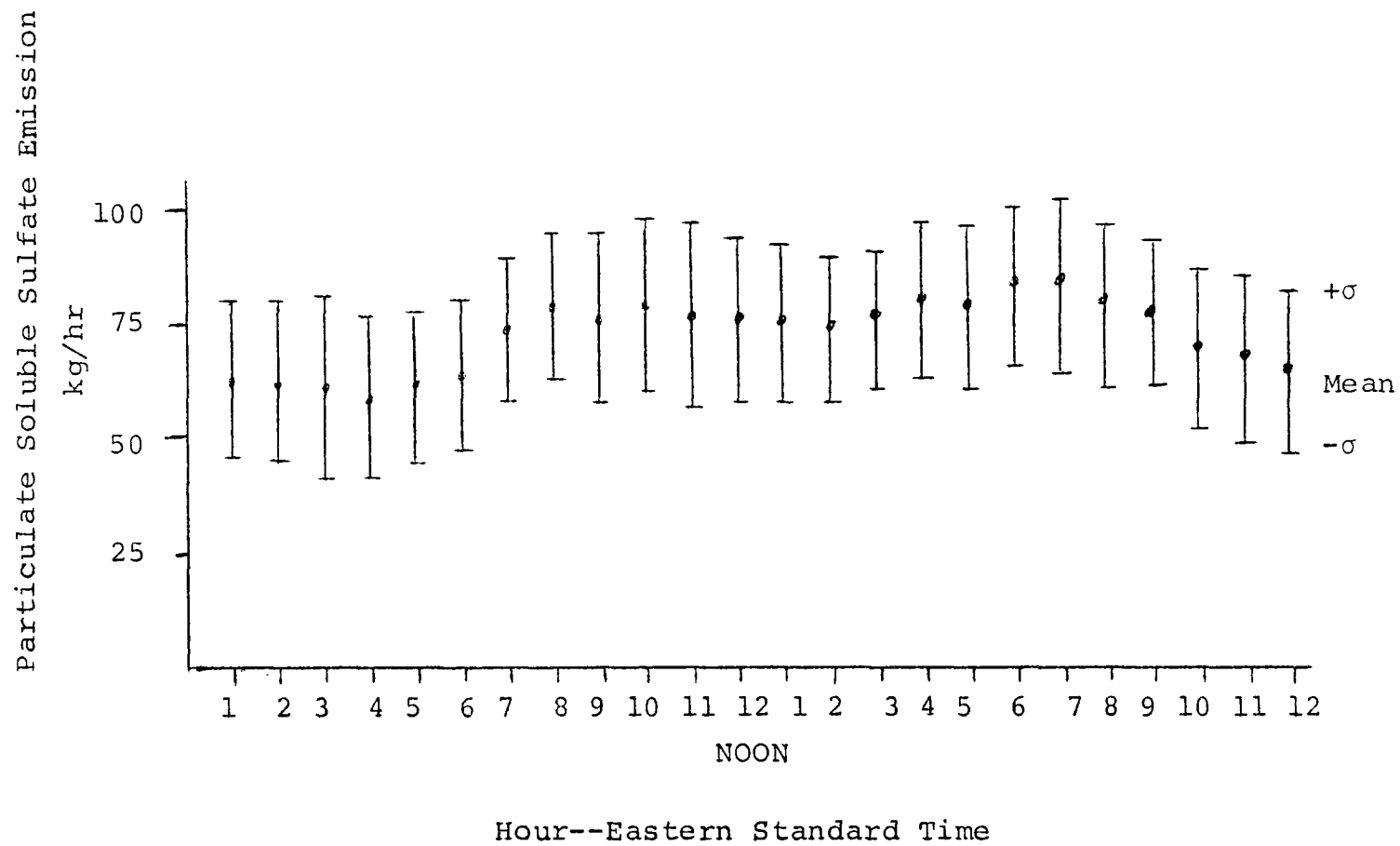
FIGURE 20

DIURNAL ANALYSIS OF EMISSION ESTIMATE

TOTAL SOLUBLE SULFATE

28-DAY AVERAGE OF PLANT AGGREGATE TOTAL

Hour--Eastern Standard Time
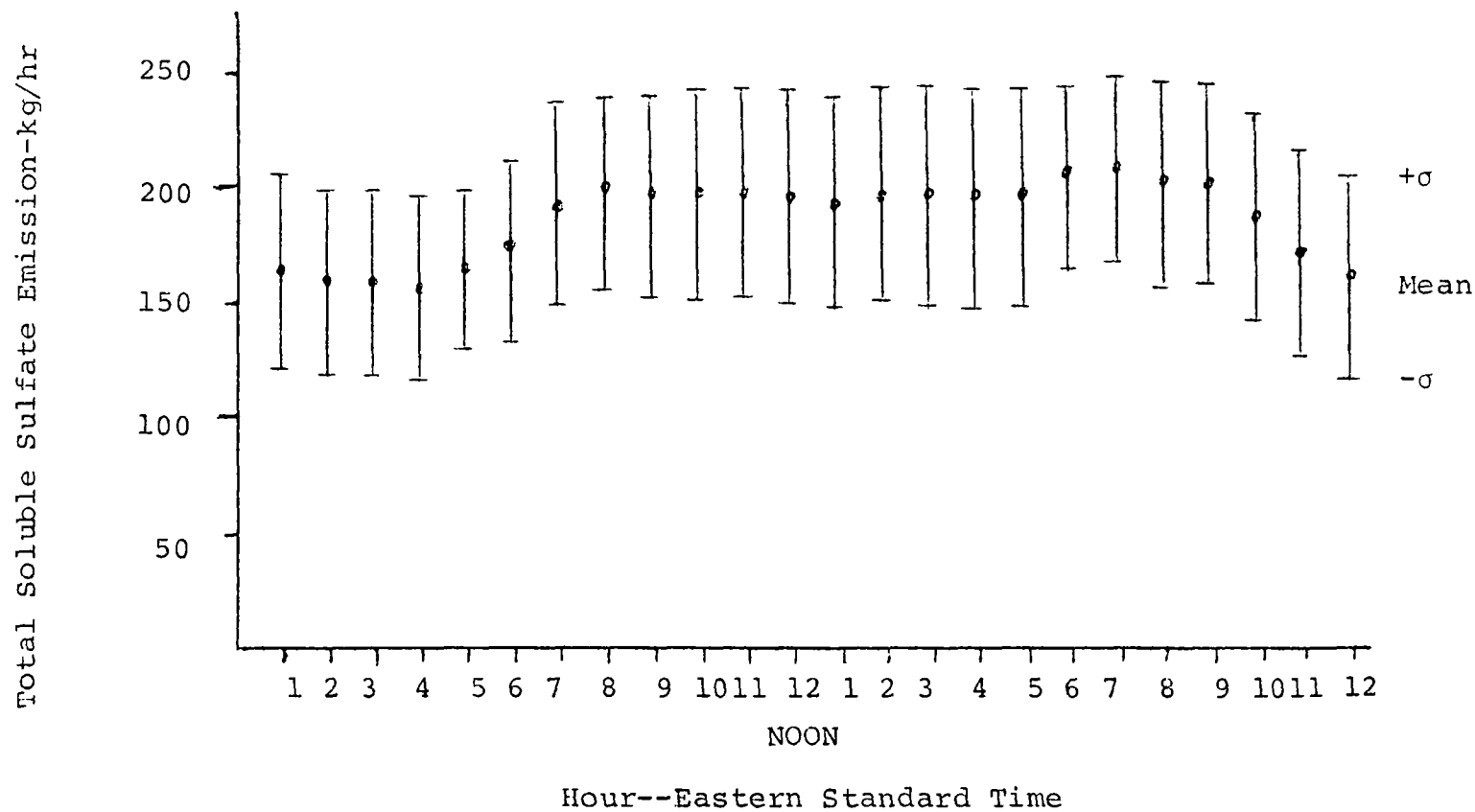
FIGURE 21

DIURNAL ANALYSIS OF EMISSION ESTIMATE

SULFUR DIOXIDE

28-DAY AVERAGE OF PLANT AGGREGATE TOTAL

Hour--Eastern Standard Time
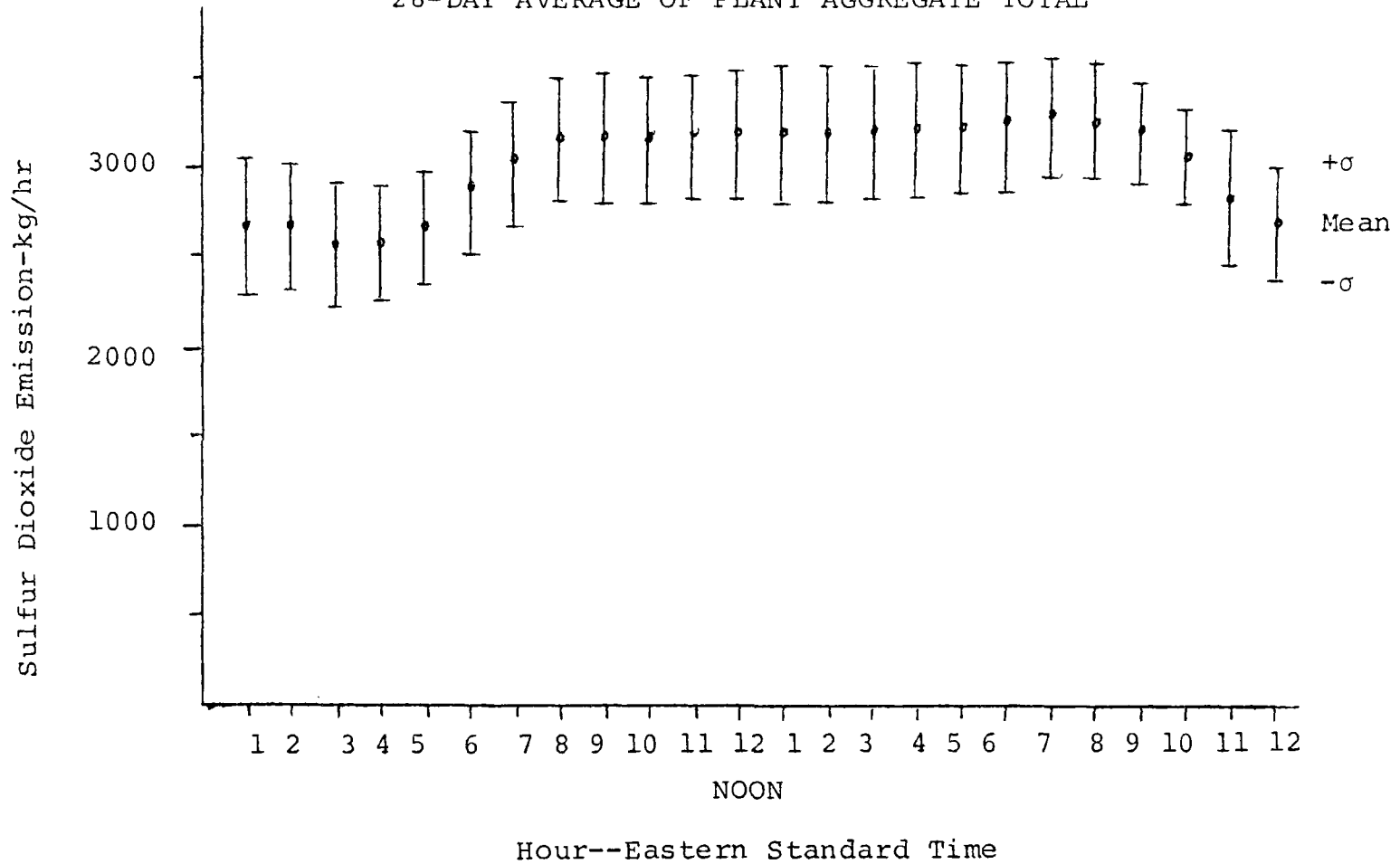
FIGURE 22

too high to demonstrate a distinct change in sulfate emissions from time to time. The ratio of sulfate emissions to total sulfur oxides ($100 \times \overline{SO_4}/SO_2 + \overline{SO_4}$) was the indicator used because it reduces bias caused by the variance of fuel sulfur.

Vanadium content of the fuel is known to be a contributory cause of sulfate formation by catalysis. However, there is no way of knowing how much vanadium is in the fuel continuously, or even how much is in the boiler in the form of ash deposits at any given time. Therefore, vanadium concentration in the stack gas, measured simultaneously with the sulfate measurements, determined the vanadium factor relating to sulfate formation.

The number of days of operation since the last boiler wash is a relative indicator of the condition of the boiler internal surfaces. The effect may be that longer operation confers more ash buildup, therefore more sulfate formed by catalysis. However, a magnesium fuel additive is used in the boilers for corrosion control; some literature cites that a magnesium oxide layer on the boiler internals with the use of the additive (Reid, 1971), will deactivate the catalytic ash deposits (Barrett, 1966). Work has shown as much as 50% less sulfate emitted when magnesium additives were used on boilers firing low sulfur, low vanadium fuel oil that had previously not used additives (Boldt and Laube, 1978).

The operational characteristics such as burner and atomizer condition, air supply controls, boiler casing and duct condition affect the extent of sulfate formation. The investigations of sulfate ratio, compared to operational parameters, was limited to 2 individual boilers to minimize interferences. The boilers with the largest numbers of data points were Units 2 and 4; a sum of Unit's 2 and 4 data comprised a third set.

The results of regression analyses which compare the operational parameters to the sulfate ratio are shown in Table 17 (explanation of the regression terms can be found in Section 4). The most significant relationship exists between sulfate and the concentration of vanadium in the stack gas. Consistent y-intercepts, slopes, correlation coefficients, and standard error of estimates are observed between the three data sets (see Figure 23). Obviously this relationship overshadows any variations among the other parameters.

Weaker relationships appear with additive ratio (gallons oil/ gallons additive) and days of operation, but they are apparent only when the data from two boilers are combined. These relationships are essentially straight lines between two data points, since the data are clustered for each boiler (see Figures 24 and 25). These data suggest that if more additive is injected into the flame, less sulfate is emitted, all other parameters remaining equal. The mechanism of this reduction could be either enhanced collection of magnesium sulfate in the mechanical collectors, or a long-term deactivation of catalytic surfaces by magnesium oxide.

TABLE 17

SUMMARY OF REGRESSION ANALYSES
$(SO_4/SO_4+SO_2$ X 100) AS DEPENDENT VARIABLE

Independent Variable	Units of Independent Variable	Y-Intercept	Slope	R	Adjusted R^2	Standard Error of Estimates
Fuel Sulfur						
Unit 2	%	− .44	+2.15	.69	.45	.43
Unit 4	%	+4.28	− .18	.07	−.08	.57
(Unit 2+4)	%	+3.60	+ .05	.02	−.03	.64
Stack Gas Temperature						
Unit 2	°C	+1.89	+ .01	.23	−.01	.58
Unit 4	°C	+ .66	+ .02	.41	.10	.52
(Unit 2+4)	°C	+3.95	− .00	.04	−.03	.64
Boiler Oxygen Content						
Unit 2	%	+4.02	− .22	.35	.07	.55
Unit 4	%	+4.46	− .17	.28	−.00	.55
Unit 2+4)	%	+4.23	− .21	.29	.05	.61
Additive Ratio						
Unit 2	1000 gal/gal	−13.86	−7.00	.40	.10	.54
Unit 4	1000/gal/gal	+ 5.06	− .30	.09	−.07	.57
Unit 2+4)	1000 gal/gal	+ 1.93	+ .60	.46	.19	.56
Days of Operation						
Unit 2	days	− 6.54	+ .13	.47	.17	.52
Unit 4	days	+ 1.77	+ .07	.21	−.04	.56
(Unit 2+4)	days	+ 4.40	+ .01	.45	.17	.57
Vanadium Concentration						
Unit 2	mg/m^3	+ 2.02	+ .36	.77	.55	.42
Unit 4	mg/m^3	+ 2.58	+ .31	.69	.41	.49
(Unit 2+4)	mg/m^3	+ 2.20	+ .36	.73	.50	.47

92

UNIT 2

Regression
2.0202+.3563V
R=.7725
Adjusted R^2=.5463
Std. Error=.4201

UNIT 4

Regression
2.5783+.3099V
R=.6872
Adjusted R^2=.4063
Std. Error=.4936

UNIT 2 + 4

Regression
2.1994+.3550V
R=.7273
Adjusted R^2=.5028
Std. Error=.4716

Ratio $SO_4 / SO_2 + SO_4$ X 100

Vanadium Concentration in Stack Gas - mg/m^3

FIGURE 23

93

UNIT 2

Regression
-13.8635+.0070R
R=.3960
Adjusted R^2=.1006
Std. Error=.5428

UNIT 4

Regression
5.0596-.0003R
R=.0907
Adjusted R^2=-.0744
Std. Error=.5658

UNIT 2 + 4

Regression
1.9340+.0006R
R=.4643
Adjusted R^2=.1885
Std. Error=.5641

Ratio $SO_4 / SO_2 + SO_4$ X 100

Additive Ratio - R - Gal. Fuel Oil/ Gal. Additive

FIGURE 24

94

FIGURE 25

SECTION 5

AIR QUALITY

TOTAL SUSPENDED PARTICULATES

For several years the New York State Department of Environ-
mental Conservation has operated a high volume sampler network
in the Albany area. The results of several of those stations
are shown in Table 18. The Cohoes Station is located across
the Hudson River from Troy; the Colonie Station is located at
the Albany Airport; the Castleton Station is located just South
of the Albany Steam Station on the East side of the river.

All reporting stations show a general declining trend in TSP
over the years. Particulate concentrations at the downtown
Albany Station decreased by 50% during the period (1966-1978).
Rensselaer, Troy, and Schenectady show a slight increase, then
a continued decrease through the 1970's.

PARTICLE SIZE

Experiments to determine particle size were conducted through-
out the test period. They were operated at the base site and
site 5 (one day run at site 1) every even day beginning on
September 18 and concluding on the 14th of October.

The procedure for the collection of the various size particles
involved the use of a multi-stage cascade impactor manufactured
by Sierra Instruments, Inc. This separates suspended particu-
lates into six size fractions based on flow rates.

TABLE 18

Long Term Total Suspended Particulate Concentrations
Annual Geometric Means ($\mu g/m^3$)

Station/Station Number

Year	Rensselaer 4101-02	Downtown Albany 0101-03	Troy 4102-02	Cohoes 0102-01	Colonie 0153-03	Schenectady 4601-02	Castleton 4124-01
1966	-	82	62	-	-	87	-
1967	-	87	57	69	-	-	72
1968	-	73	52	68	-	62	59
1969	66	64	46	53	-	59	-
1970	72	70	45	61	-	60	51
1971	75	67	51	-	-	64	-
1972	77	59	52	-	-	62	43
1973	74	57	55	61	55	72	34
1974	62	51	53	-	51	64	39
1975	54	50	46	63	52	52	39
1976	46	41	39	56	42	46	32
1977	42	42	36	-	44	45	31
1978	40	37	33	-	43	41	30

Source: NYSDEC

Stage	Cut-off Size at 40 CFM (Microns)
1	>7.2 u
2	7.2-3.0
3	3.0-1.5
4	1.5-0.95
5	0.95-0.49
6	0.49>

The daily particle size distributions were plotted on lognormal probability graph paper. The cumulative weights (%) are plotted against the cut-off size (um) for that stage. The daily mass median diameters were then read off the curve to give the results shown in Table 19. The arithmetic averages of the mass median diameter for the base site and site 5 were 0.59 microns and 0.65 microns respectively. The one day operation at site 1 resulted in a mass median diameter of 0.70 microns. Various scatter type plots were done. The variables being mass diameter, total suspended particles on the back-up filter, $SO_4^=$, nephelometer values and total suspended particles on the high volume sampler filter.

At site 5 a correlation between $SO_4^=$ and the particle size range of 0-.49u (6th stage) was observed. At the base site, however, there does not appear to be any simple relationship between these two. A possible explanation of this could be that the downwash at the base site caused large particles of sulfate to be retained on the hi-vol filters, thus increasing $SO_4^=$ and negating the correlation between $SO_4^=$ and particle size. A possible explanation for the correlation appearing at site 5 is most likely due to the fact that the larger sulfate particles would have dropped out before reaching the monitoring system, indicating a very local plant effect. If this is the case then site 5 was representative of the long distance transport particles of small size and slow settling velocities.

The results of the Energy Dispersive X-ray (EDX) laboratory
results of the dichotomous filters have not yet been provided
by the EPA's laboratory in Research Triangle Park. Thus, any
conclusions drawn betweeen cascade sizing and hi-vol filters is
tentative.

Studies by Mezaros (1970), Whitby (1978), Tanner and Marlow
(1977) have indicated that the great majority of airborne ($SO_4^=$
is in the particulate size range of 0.01-0.5 um. Mezaros
(1978) has reported the results of a field test in which 90% of
the total sulfate mass measured at a rural site had a diameter
less than 0.6 um.

The size data reported by these authors suggest two things.
First, they are of a size to affect visibility, and second,
they could be capable of being transported great distances be-
fore gravitational settling out occurs. In this study if the
association between hi-vol filter data and cascade filter mass
holds true, then a portion of the emitted $SO_4^=$ particulate is of
sufficient size to settle out within short distances of the
plant. This is a tentative conclusion requiring further effort
to verify this.

SULFUR DIOXIDE

Long term SO_2 data is contained in Table 21. These data were
provided by NYSDEC; stations not previously identified are the
Town of Bethlehem, located on Highway 9W South of the City of
Albany and West of the Albany Steam Station and the Town of
Hudson, located about 23 miles South of Albany.

These long term data indicate there are geographical variations
in the data. The area along the Hudson River to the North of
the Albany Steam Station shows higher values of SO_2 than the
rural stations at Bethlehem and Hudson. For most of these

TABLE 19

CASCADE IMPACTOR RESULTS

BASE SITE

Microgroms per cubic meter

DATE		STAGE						MASS MEDIAN DIAMETER (MICRONS)
		1	2	3	4	5	6	
Sept.	18	4.995	0.000	0.000	0.000	0.000	9.445	-
	20	4.327	2.308	2.019	2.308	3.967	9.304	0.88
	22	0.799	2.542	1.452	1.162	0.290	8.207	0.56
	24	0.000	0.124	0.000	0.000	0.062	0.062	1.00
	26	2.143	6.017	2.225	5.852	0.330	14.177	1.10
	28	1.183	2.644	2.853	1.740	2.296	11.967	0.41
	30	2.102	3.083	2.102	2.102	2.382	12.611	0.49
Oct.	02	1.392	2.435	1.739	2.157	4.453	13.011	0.42
	04	0.917	1.975	1.482	1.834	3.034	10.018	0.54
	06	3.018	0.000	0.000	0.000	0.000	44.264	-
	08	0.448	0.448	0.179	0.089	0.089	1.881	0.32
	10	0.480	0.320	0.080	0.160	0.000	2.882	0.14
	12	5.824	8.659	5.058	5.977	11.494	31.341	0.72
	14	1.010	1.534	1.243	1.243	1.476	7.460	0.55

CASCADE IMPACTOR RESULTS

SITE 5

Micrograms per cubic meter   * Located at Site 01

DATE		STAGE						MASS MEDIAN DIAMETER (MICRONS)
		1	2	3	4	5	6	
Sept.	18	0.644	1.611	1.095	1.353	1.933	3.157	0.94
	20	0.851	1.914	1.276	1.701	2.836	2.056	1.20
	22	1.556	1.738	0.549	0.091	0.914	12.438	0.13
	24	0.000	0.000	0.000	0.000	0.000	0.000	0.00
	26	1.022	1.294	0.749	2.520	0.681	0.000	2.20
	28	1.136	2.248	1.748	2.060	0.874	10.927	0.44
	30	1.043	1.780	0.798	0.859	1.412	7.120	0.42
Oct.	02	1.245	1.805	1.866	2.178	4.107	9.645	0.56
	04	0.713	1.485	1.069	1.604	0.000	9.360	0.26
	06							
	08	0.318	0.572	0.000	0.254	0.381	3.113	0.20
	10	5.255	7.434	3.204	2.627	4.101	15.124	0.94
	*12	*7.307	*9.150	*5.003	*5.727	*10.993	*30.611	*0.70
	14	0.186	0.327	0.000	0.000	0.340	0.340	0.49

100

TABLE 20

DICHOTOMOUS SAMPLER RESULTS

Micrograms per cubic meter

DATE		BASE SITE		SITE 5	
		$<3.5\mu$	$>3.5\mu$	$<3.5\mu$	$>3.5\mu$
Sept.	18			3.1	23.4
	20	33.7	16.8	2.0	15.9
	22	12.8	9.8	6.1	21.2
	24	15.0	05.0	3.6	19.3
	26	11.1	16.5	9.2	24.8
	28	16.7	17.8	24.0	1.8
	30	12.8	06.1	14.8	0.0
Oct.	02	12.3	12.3	23.0	0.0
	04	13.2	4.8	20.9	0.0
	06	5.0	0.7	18.4	0.0
	08	0.0	0.0	6.1	3.3
	10	14.6	3.9	40.3	0.0
	12	27.4	14.5	*58.2	* 0.0
	14	3.6	1.7	9.2	1.6

* Located at Site 01

TABLE 21

Long Term Sulfur Dioxide Concentration
Annual Means (ppm)

Year	Rensselaer 4101-02	Downtown Albany 0101-03	Troy 4101-02	Cohoes 0102-01	Schenectady 4601-05	Bethlehem 0151-01	Hudson 1001-02
1970	0.020	-	-	-	-	-	-
1971	0.020	-	-	-	-	-	-
1972	0.019	-	-	-	0.018	-	-
1973	0.017	0.021	-	-	0.016	-	-
1974	0.018	0.018	0.008	0.014	0.014	-	0.006
1975	0.014	0.017	0.007	0.011	0.013	-	0.006
1976	0.014	0.016	0.005	0.011	0.013	0.008	0.003
1977	0.016	0.014	0.007	0.010	0.015	-	0.004
1978	0.016	0.016	0.011	0.008	0.014	-	0.005

Source: NYSDEC

stations there is insufficient data available to ascertain long term trends in the SO_2 data.

The diurnal variation in ambient SO_2 concentration during the study period is shown in Figures 26 and 27. Two of the sites (site 4 and 6) showed very little variation in SO_2. This indicates that these stations were not affected to a great extent by nearby SO_2 sources. The low levels at sites 4 and 6 also sustain this conclusion.

The base site was affected by the Albany Steam Station's effluent but only to a limited extent. There was a slight maximum around 0800. This was probably due to inversion breakup or fumigation effects.

Four of the sites showed considerable diurnal variations. These stations indicated a diurnal maximum before or during noon. The increases generally began around 0800, or the time of the morning inversion breakup. The diurnal decrease was usually achieved by around 1600-1800 with the onset of the evening stable conditions.

This sustains the supposition that the sites were influenced by industrial sources only during part of the day. Until the time of inversion breakup, most of the sites were not greatly affected by the plant, as the surface stable conditions retarded the dispersion of industrial SO_2 emissions. Either they were contained in the surface stable layer or else there was sufficient plume buoyancy to rise above the surface stable layer.

PHOTOCHEMICAL POLLUTANTS

Photochemical pollutants, nitric oxide (NO), nitrogen dioxide (NO_2), and ozone (O_3) were measured in the Albany area during this study. Table 22 contains historical data collected in
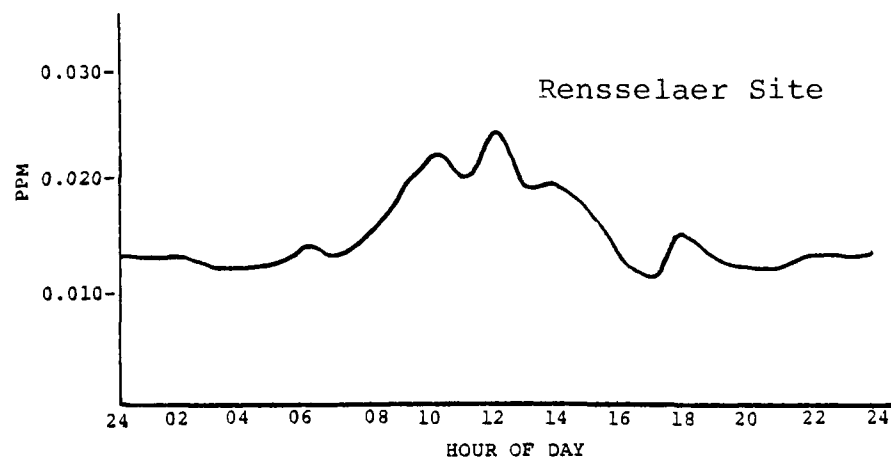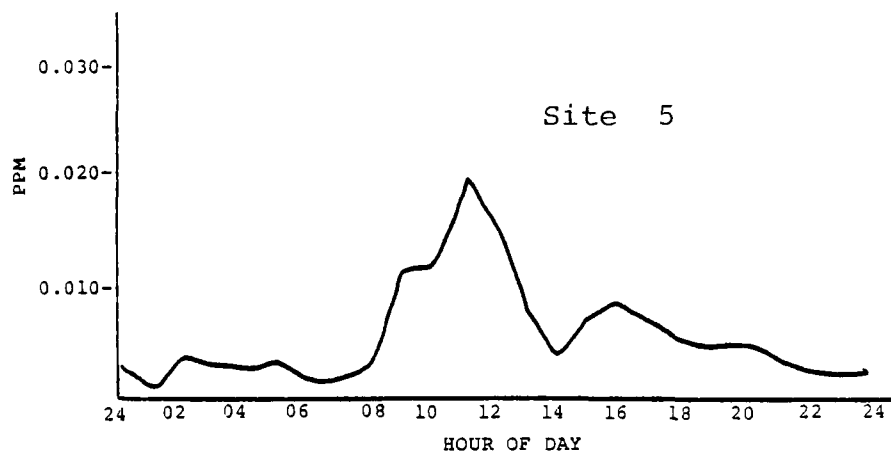
FIGURE 26
SO$_2$ DIURNAL VARIATION

Site 1

Site 5

Rensselaer Site

104

FIGURE 27

SO$_2$ DIURNAL VARIATION

105
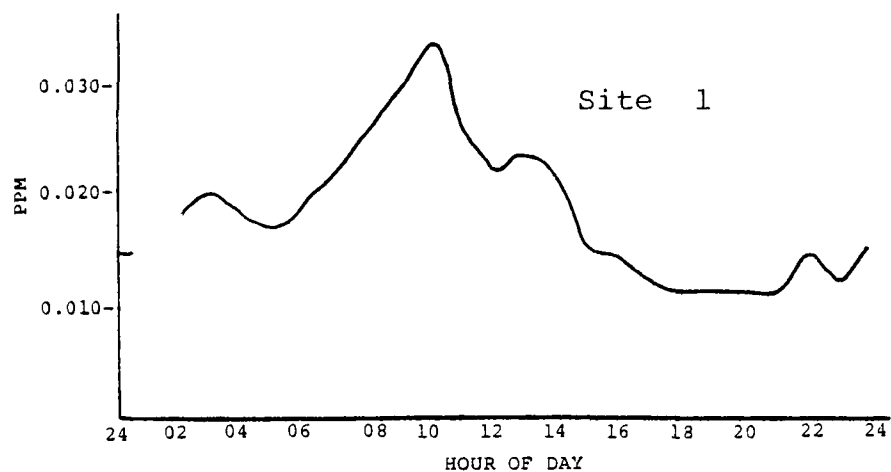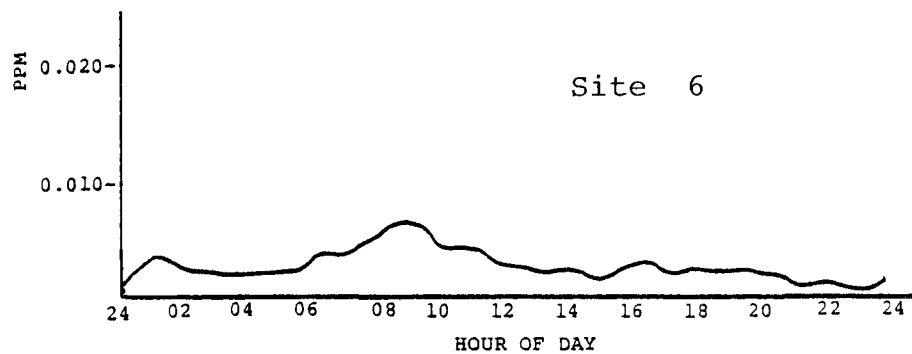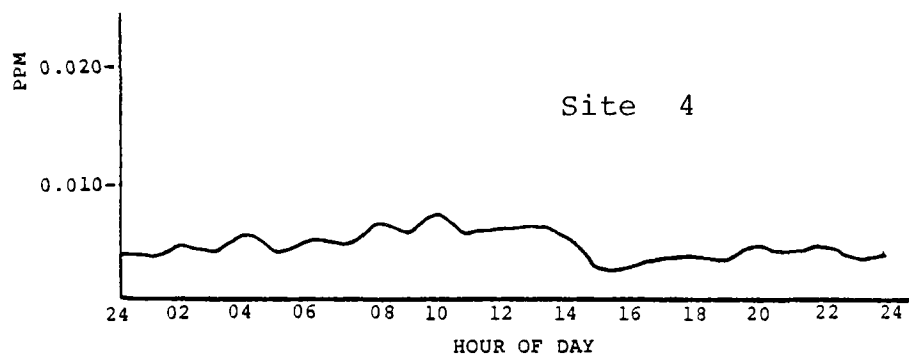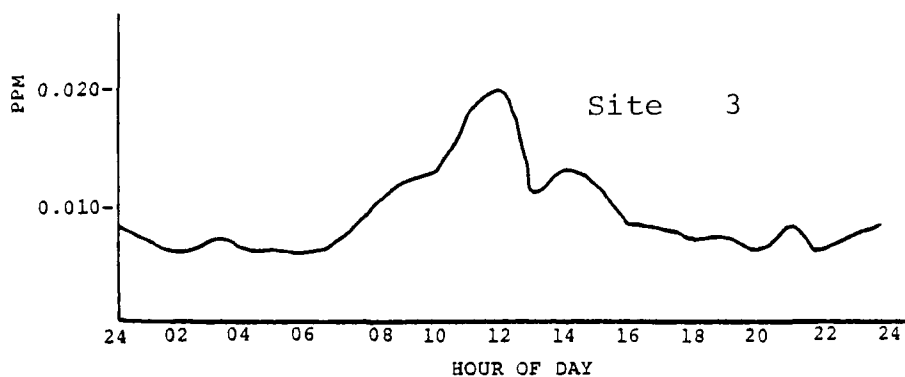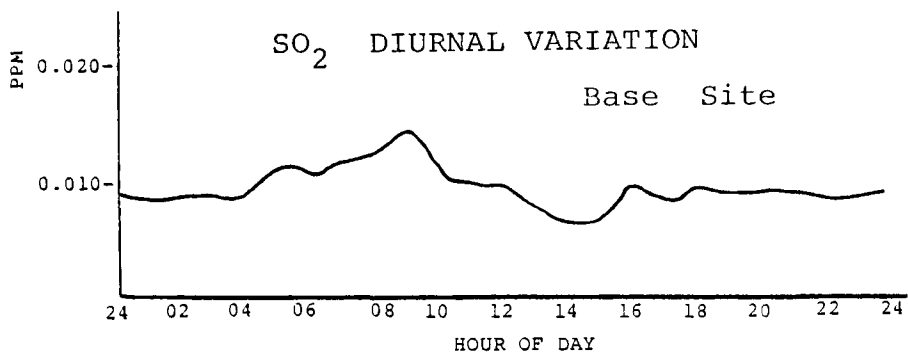
the Albany area by the NYSDEC. Also included in this table are total hydrocarbons (HC) measured by flame ionization at Rensselaer.

TABLE 22

LONG TERM PHOTOCHEMICAL POLLUTANT CONCENTRATIONS

ANNUAL AVERAGE (ppm)

	Rensselaer (4101-02)				Schenectady (4601-05)		
Year	NO	NO_2	O_3	HC	NO	NO_2	O_3
1971	–	–	–	2.81	–	–	–
1972	–	.013	–	2.45	–	.023	–
1973	.014	.018	.022	–	.027	.021	.022
1974	.015	.018	.017	2.74	.034	.019	.019
1975	.011	.015	.022	2.83	.024	.017	.017
1976	.010	.016	.023	3.08	.019	.016	.020
1977	.012	.014	.022	–	.018	.014	.022
1978	.013	.015	.022	–	.017	.017	.029

Source: NYSDEC

The hydrocarbons could be emitted from the numerous tank farms in the area, from leaks and tanker-to-bulk storage and transfer operations. During the study period a small refinery on the South side of the Port of Albany began start-up operations. Thus, there could have been an additional source of hydro- carbons. The Albany Steam Station itself is surrounded by numerous bulk storage tanks for petroleum products. The NYSDEC stopped monitoring for hydrocarbons in early 1977, therefore no hydrocarbon-data was available for the test period.

These pollutants have long been known to exhibit a characteristic diurnal variation. This diurnal variation has been observed at various locations by Renzetti and Romanovsky (1956), Leighton (1961), U.S. Public Health Service (1965) and by the California Department of Health (1966).

During the study period the NO and NO_2 concentrations exhibited a double maximum double minimum diurnal variation at the four monitoring stations with NO_x monitoring equipment. These two pollutants had maximums during the early morning near sunrise, and later in the early evening after sunset. Ozone concentrations did not begin to increase until after the morning NO_x maximum. Ozone decreased in the late afternoon with the decrease in sunlight.

Various models have been published to explain this diurnal relationship. A simplified model is:

$$N_2 + O_2 \longrightarrow 2 \ NO \qquad \text{(Combustion)}$$
$$2 \ NO + O_2 \longrightarrow 2 \ NO_2$$
$$NO_2 + hy \longrightarrow NO + O \qquad \text{(Sunlight)}$$
$$O + O_2 + M \longrightarrow O_3 + M \qquad \text{(Non-methane hydrocarbons)}$$
$$O_2 + NO \longrightarrow NO_2 + O_2$$
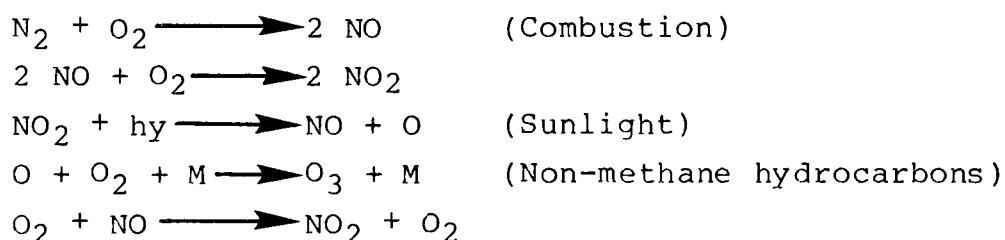
The formation of NO_2 proceeds directly from the plant emissions of NO into the atmosphere. The presence of sunlight (hy), together with a suitable catalyst (M), usually taken to be reactive hydrocarbons, results in the formation of O_3. With the decline in sunlight in the late afternoon, the formation of O_3 decreases and available O_3 reacts to form NO_2, thus decreasing O_3 and causing a NO_2 peak in the early evening.

These pollutant measurements showed a variation from one day to the next. For the most part, the ambient concentrations could be described as a series of consecutive pulses or spikes.

While there was no significant change in the NO trend at three of the sites, the base site showed a decreasing trend during the study period. Both NO_2 and O_3 showed no change in trend during the study period at any of the sites. A summary of the data is contained in Table 23.

There is some indication by Larson et al. (1978) and Penkett et al. (1978) that elevated O_3 levels can be influencial in the conversion of SO_2 to SO_4. Larson et al. reported the following oxidation rate could be significant when $O_3 ->0.050$ ppm and pH ≤ 5:

$$d \, [SO_4^=] \quad = k_4 K_{HO_3} \, P_{O_3^-} \, [HSO_3^-] \, [H^+] \, -0.01 \pm 0.02$$

with $k_4 = (4.4 \pm 2.0) \times 10^4 \, M^{-0.9}S^{-1}$

$K_{HO} = 0.0123 \, M \, atm^{-1}$, both at $298°K$

TABLE 23

NO, NO_2, O_3 Concentrations (ppm)

	NO		NO_2		O_3	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Site 1	0.020	0.035	0.022	0.025	–	–
Rensselaer	0.009	0.009	0.010	0.007	0.004	0.008
Site 3	0.012	0.043	0.013	0.010	–	–
Base	0.021	0.017	0.007	0.009	0.014	0.015

FIGURE 28
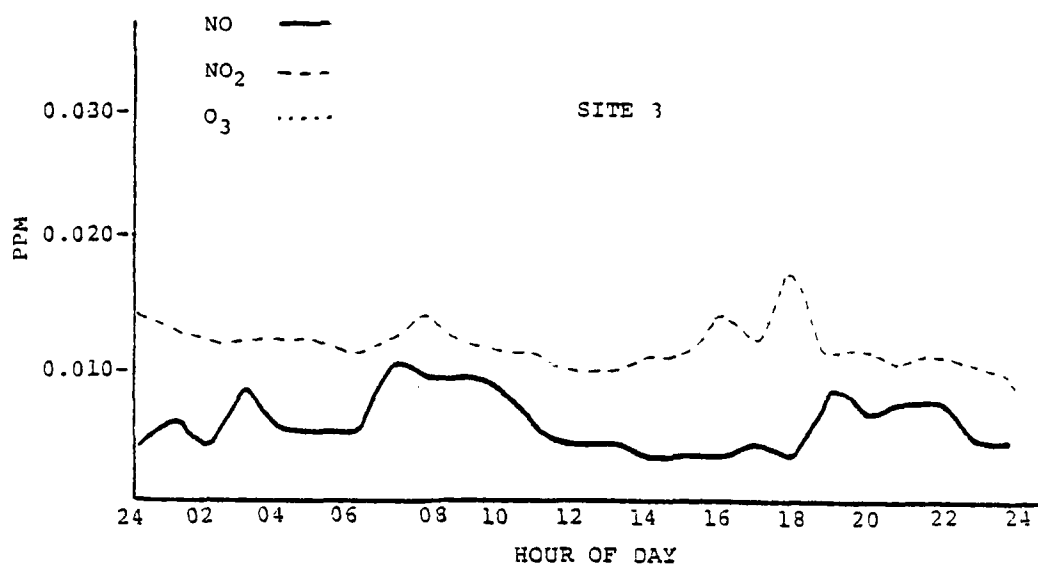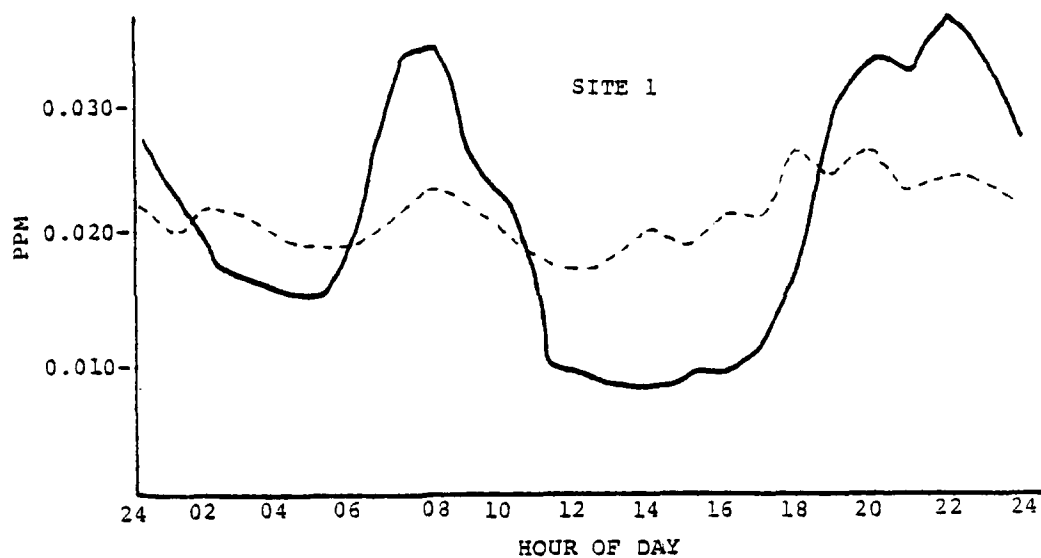
Photochemical Pollutant Diurnal Variation

FIGURE 29
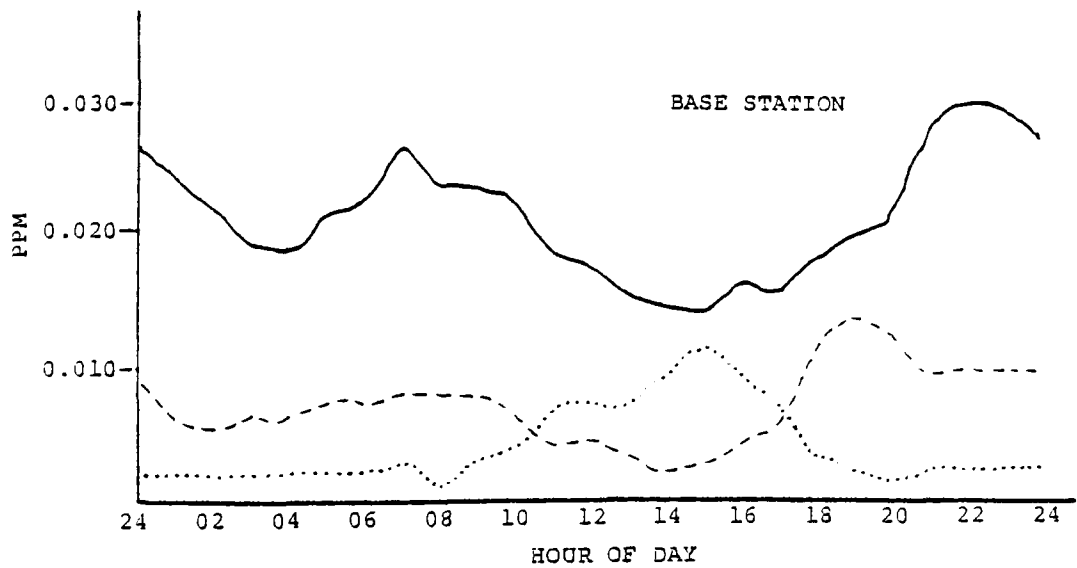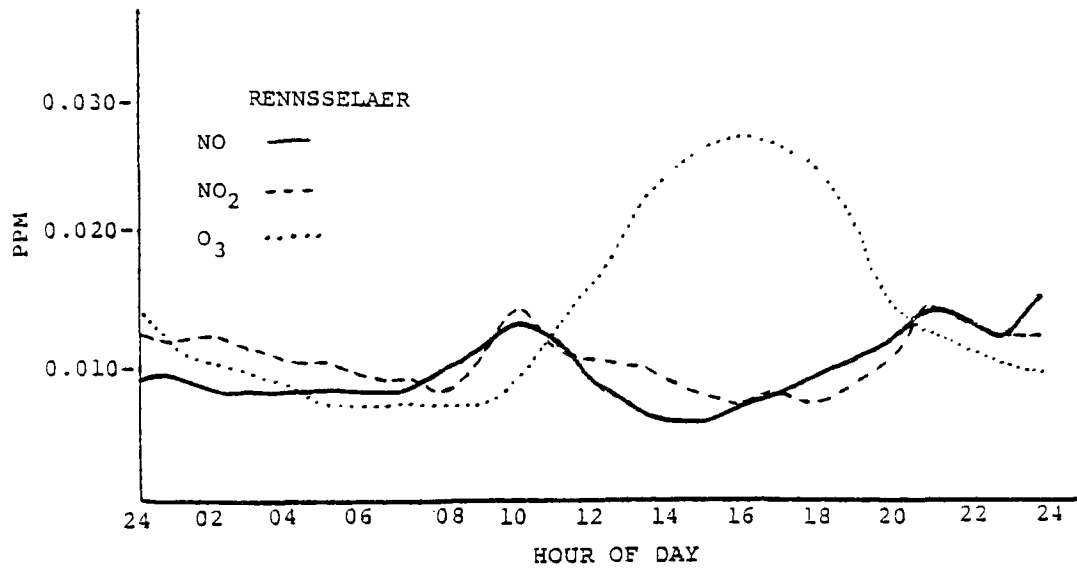
Photochemical Pollutant Diurnal Variation

The diurnal variation experienced in the ozone concentrations suggests that if this were a factor in SO_2 to $SO_4^=$ conversion in the Albany area, it would be limited to a few hours of the day. That is, O_3 would most likely affect $SO_4^=$ levels during the 1200 to 1800 time priod.

CARBON MONOXIDE

Carbon monoxide was not measured as part of this experiment. However, some CO data is available from the NYSDEC. Table 24 contains long term CO data.

TABLE 24

LONG TERM CARBON MONOXIDE CONCENTRATIONS
ANNUAL AVERAGE (ppm)

| | Station/(Station Number) | |
Year	Rensselaer (4101-02)	Schenectady (4601-05)
1970	2.5	-
1971	2.8	-
1972	2.7	3.0
1973	2.8	2.5
1974	2.5	2.0
1975	1.3	1.2
1976	0.9	1.1
1977	0.7	0.9
1978	0.5	0.8

Source: NYSDEC

In a study by Kuhlman et al. (1978) it has been suggested that the presence of CO decreases the rate of formation of airborne $SO_4^=$ particulate. The CO was considered by Kuhlman et al. to compete with SO_2 for the available OH^- radical thus retarding

112

the formation of H_2SO_4. There are insufficient data to test this hypothesis in this study.

SULFATE ANALYSIS

The long term (1975-1978) $SO_4^=$ distributions for monitoring stations run by the NYSDEC in Troy and in downtown Albany are shown in Figure 29. This figure indicates that the $SO_4^=$ tends to have a log-normal distribution as would be expected for ambient particulate concentrations. The slopes of the two curves appear to be the same, suggesting the same sample variance. The same variance suggests that the causes of variation at these two locations may be the same. The geometric means determined from these distributions are 10.4 ug/m^3 for downtown Albany and 8.1 ug/m^3 for Troy. This difference of 2.3 ug/m^3 suggests local source effect(s).

The long term trend in $SO_4^=$ is contained in Table 25. This table contains a summary of available $SO_4^=$ data collected over a 13-year period. In the Albany-Troy-Schenectady area there appears to be a slowly changing oscillation with a wavelength of about 8 or 9 years and an amplitude of about 4 ug/m^3. However, data from New Rochelle near New York City and Massena in upstate New York near the Canadian border do not show this oscillation. If this is true then this would suggest that the Albany-Troy-Schenectady area possesses some uniqueness apart from either downstate New York or Northern upstate New York.

A comparison of Albany to Troy and Schenectady indicates that Albany has higher values of $SO_4^=$ than either Troy or Schenectady. The only exceptions being Troy in 1973 and Schenectady in 1966. A comparison of Troy to Schenectady shows that Troy was greater than Schenectady 4 times and Schenectady greater than Troy 6 times. This suggests a local source/sink phenomena

113

$SO_4^=$
1975-1978

——— Downtown Albany

·········· Troy

Cummulative Frequency of Occurance

FIGURE 30

114
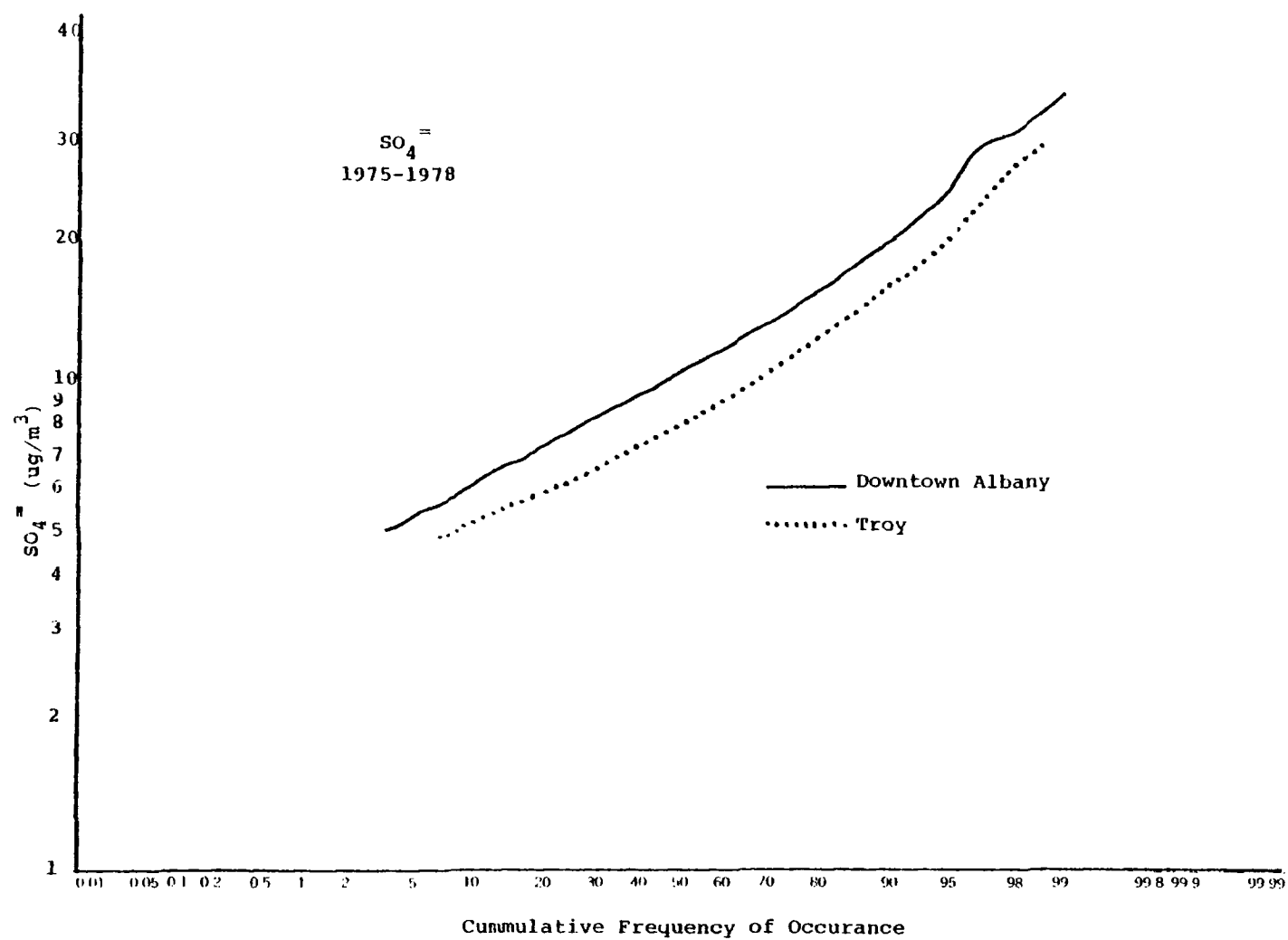
TABLE 25

Annual Variation in $SO_4^=$
Geometric Mean (ug/m^3)

Year	0101-03 Downtown Albany	4102-02 Troy	4601-02 Schenectady	5904-02 New Rochelle	4402-05 Massena	1302-04 Poughkeepsie
1966	10.9	10.3	11.4	13.3	-	-
1967	10.2	8.5	-	12.9	-	-
1968	8.9	8.4	7.3	11.6	3.8	-
1969	9.1	7.7	8.1	11.1	6.3	-
1970	8.9	7.1	7.3	10.5	5.1	-
1971	9.6	7.8	8.3	10.2	5.7	-
1972	12.0	10.4	10.9	9.0	6.3	-
1973	10.5	11.0	10.0	8.1	6.3	8.8
1974	11.7	10.2	11.0	8.9	5.6	10.3
1975	13.0	10.7	9.8	10.9	5.7	11.0
1976	11.6	9.2	9.1	-	7.7	8.9
1977	9.9	7.9	8.6	8.9	7.4	7.6
1978	8.3	6.8	7.0	7.4	7.0	-

Source: NYSDEC

115

in the Albany area. Long range transport should not produce
consistently higher geometric means at Albany.

Tables 26 and 27 contain data on the seasonal variation of $SO_4^=$
for downtown Albany and for Troy. As might be expected, down-
town Albany has consistently higher values than Troy. There
appears to be a slight double maximum-double minimum seasonal
variation. The months of April and September are the minimum
months with the summer and winter periods being somewhat
higher. The 75% values indicate that large values of $SO_4^=$ are
more likely during the summer months than any other time of the
year. The differences between the 50 percentiles and the 75
percentiles are minimal during spring and fall and greater dur-
ing the summer and winter. This is especially true for Albany
during the summer. This suggests that there is more likely to
be greater differences from one day to the next in the summer
than in the winter.

Figure 30 and Tables 26 and 27 suggest that the data could be
described as an average level with pulses occurring from time
to time. Seasonally these pulses appear to be more frequent in
the summer rather than the rest of the year. It is these pul-
ses that account for the seasonal shift in the monthly average
level in $SO_4^=$. These long term data are collected on the one
day in six cycle therefore it is difficult to discuss sustained
elevated $SO_4^=$ episodes.

$SO_4^=$ data collected during the test period shows a geometric
distribution similar to that observed for the longer period of
record. The pulse character of the data can be seen in Figures
31 and 32. The period of record from September 18 to October
15 contained two significant pulses as well as several lesser
pulses. The two main pulses occurred on September 21 and
October 12. In both cases the synoptic situation was similar.
There was an elongated high pressure area running along the

TABLE 26

Seasonal Variation in $SO_4^=$ ($\mu g/m^3$)

Downtown Albany
Period of Record: 1975 - 1978

Cumulative Frequency

	Minimum	25%	50%	75%	Maximum	Sample Size
Jan	4.7	7.7	10.5	15.0	57.0	20
Feb	5.6	9.8	12.0	15.6	23.1	15
Mar	5.0	8.5	11.0	14.0	19.2	20
Apr	3.8	6.6	8.2	10.8	26.2	20
May	3.2	7.9	11.3	14.7	20.3	21
Jun	5.2	9.3	12.5	17.4	68.6	17
Jul	2.4	7.8	12.3	17.8	24.8	17
Aug	4.3	7.7	11.5	21.2	31.5	19
Sep	4.7	7.0	9.0	11.6	35.0	18
Oct	5.2	7.5	11.0	14.1	20.4	18
Nov	4.0	7.8	10.7	13.1	16.2	19
Dec	4.5	8.4	9.6	10.5	14.5	20
Total Period	4.3	7.8	10.4	14.0	68.6	224

TABLE 27

Seasonal Variation in $SO_4^=$ ($\mu g/m^3$)

Troy, New York

Period of Record: 1975-1978

Cumulative Frequency

	Minimum	25%	50%	75%	Maximum	Sample Size
Jan	4.2	6.7	9.0	11.8	18.3	20
Feb	6.6	8.6	9.7	12.0	19.0	15
Mar	4.8	6.2	8.0	10.1	16.4	22
Apr	4.9	5.7	7.0	9.2	20.8	18
May	5.2	7.4	9.1	11.7	17.8	21
Jun	3.7	8.5	10.0	12.4	25.3	19
Jul	3.1	5.2	9.3	12.7	23.3	21
Aug	5.6	7.7	9.9	16.8	32.7	16
Sep	3.1	5.6	6.7	8.3	30.7	16
Oct	3.3	5.0	7.6	11.0	14.7	16
Nov	4.2	6.0	7.4	8.8	14.6	18
Dec	5.6	6.7	7.6	8.5	10.2	15
Total Period	3.1	6.2	8.1	11.2	32.7	217

Source: NYSDEC

Atlantic Coast with a cold front in the vicinity of the Great Lakes. This was accompanied by a flow aloft of Southwest winds. Local winds were from the South on both days. Thus, while the Albany Steam Station might have influenced monitoring stations to the North, it could not have influenced the Southern stations and their pulse is obviously due to some other source or sources. It is interesting to observe on the October 12 case that the Southern stations had higher concentrations than the Northern sites.

This feature of elevated $SO_4^=$ concentrations on the rear side of anticyclones or high pressure areas has also been observed by Y.S. Chung (1978). Chung noted these phenomena in Ontario and in Western Canada. He specifically mentions the case of May 17-18, 1975 when Southern Ontario was under the influence of a retreating high pressure area and an advancing cold front. Maximum values of both $SO_4^=$ and O_3 were observed.

FIGURE 31

DAILY SO$_4$ CONCENTRATIONS
Sep. 18 - Oct. 15, 1978

Site 1

Site 3

Site 4
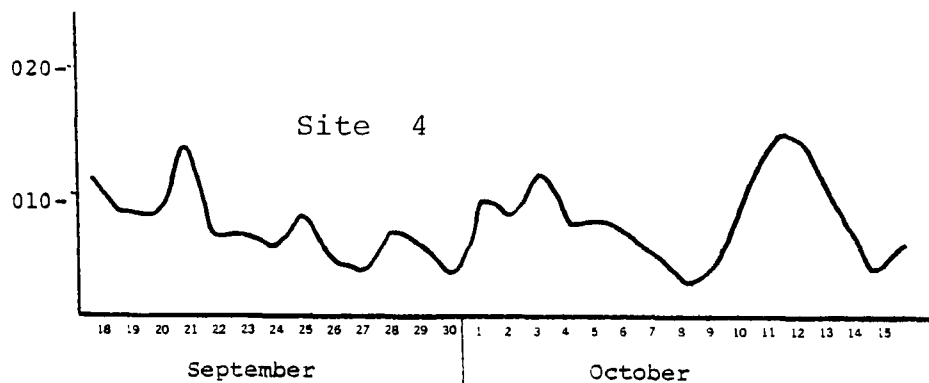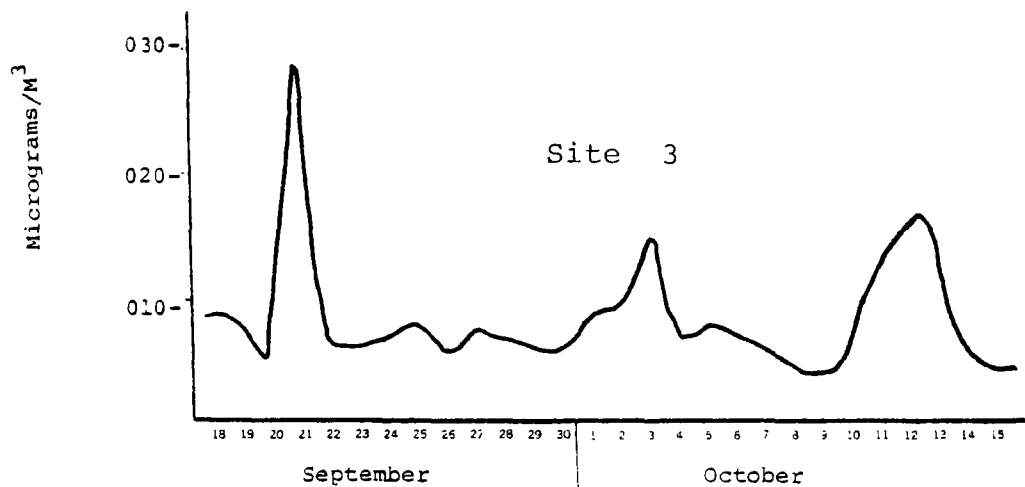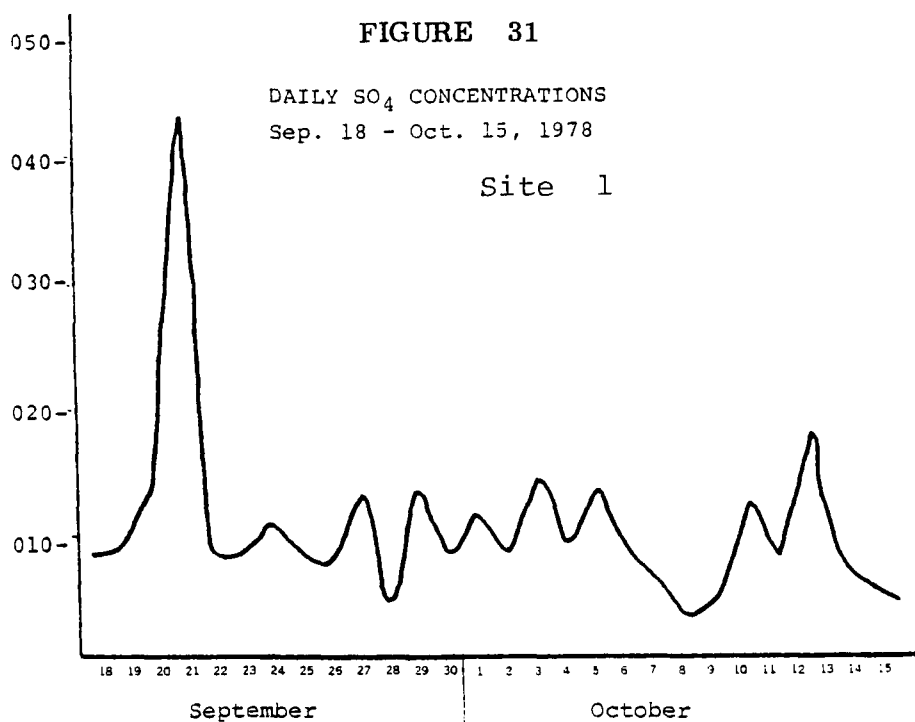
FIGURE 32

DAILY SO$_4$ CONCENTRATIONS
Sep. 18 - Oct. 15, 1978

Site 5

September | October

Site 6

September | October

Base Site

September | October

Micrograms/M^3
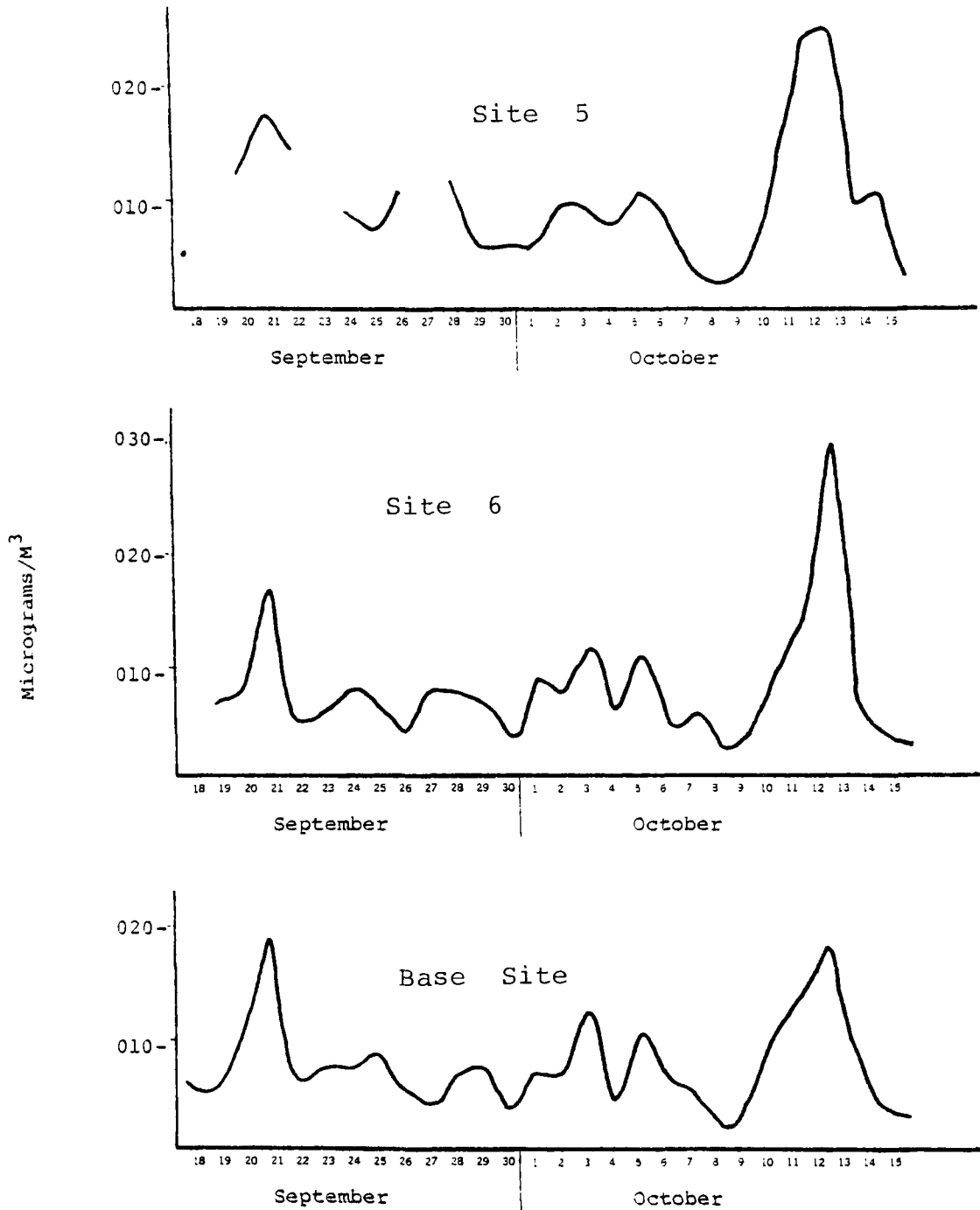
SECTION 6
METEOROLOGY

CLIMATE

The climate is representative of the humid continental type
prevailing in the Northeastern United States. The general cir-
culation of the atmosphere brings a variety of different air
masses into the region. Cold dry air masses are brought in
from the Northern interior of the continent. Warm, humid air
is transported from the Gulf of Mexico and adjacent waters. At
times air is transported in from the North Atlantic producing
cool, cloudy and damp weather conditions (NOAA, 1977).

Many storms and frontal systems moving eastward across the con-
tinent pass through or in close proximity to the State of New
York. Two principal storm tracks can be identified. One storm
track moves from the Great Lakes area Northeast along the St.
Lawrence River valley. The second storm track is offshore and
moves Northeast generally parallel to the coast (Klein, 1957).

A trough of cyclogenesis, centered over the Virginia capes
extends Northeastward offshore along the coast. During the
September-October time frame this activity is at a minimum.
Conversely, the Appalachian Mountains are a center for the
formation of high pressure areas, particularly in October
(Klein, 1957).

DAILY SYNOPTIC SITUATION

For the study period the daily weather maps prepared by the
National Weather Service were examined primarily with interest
in the Northeast United States. A summary of the synoptic
situation for each day is continued in Table 28.

TABLE 28
DAILY SYNOPTIC SITUATION

Sept. 17   High pressure area centered over Quebec, Canada, with
           a stationary front running from the Great Lakes
           across Pennsylvania and Maryland.

Sept. 18   High pressure area centered over Quebec, Canada, with
           a stationary front East-West over central Pennsyl-
           vania.

Sept. 19   High pressure area in Canada with stationary front
           from the Great Lakes to the Atlantic with cyclo-
           genesis in Pennsylvania.

Sept. 20   Advancing cold front in Great Lakes with high pres-
           sure area over New England.

Sept. 21   Advancing cold front along St. Lawrence River Valley
           with retreating high pressure area centered over
           Virginia and North Carolina.

Sept. 22   Frontal passage during night with cold front along
           Eastern seaboard. High pressure area over Great
           Lakes.

Sept. 23   High pressure area over New England.

Sept. 24   Advancing cold front over Great Lakes with high
           pressure area over New England.

Sept. 25   Frontal passage during night with cold front along
           the Atlantic seaboard. High pressure area over Great
           Lakes.

Sept. 26   High pressure area over New England.

Sept. 27   Advancing cold front over Great Lakes with retreating
           high pressure area over Nova Scotia.

Sept. 28   Cold front centered over New York State running from
           mouth of St. Lawrence River Southwest through
           Kentucky. High pressure area over Great Lakes.

Sept. 29   High pressure area over New England.

Sept. 30   High pressure area over New England. Advancing cold
           front over Great Lakes.

TABLE 28

Oct. 1   Advancing cold front over Eastern Great Lakes. High
          pressure area retreating towards Iceland.

Oct. 2   Frontal passage during night with cold front over
          Nova Scotia. High pressure ridge extending from
          Hudson Bay South through Great Lakes.

Oct. 3   Advancing cold front over Great Lakes. High pressure
          ridge along Atlantic seaboard.

Oct. 4   Advancing cold front over Eastern Great Lakes with
          warm front over St. Lawrence River.

Oct. 5   Frontal passage with cold front in New England.
          Advancing cold front vicinity of Great Lakes.

Oct. 6   Remnants of decaying cold front offshore in
          Atlantic. Advancing cold front with front running
          North-South over central New York State.

Oct. 7   Cold front passed with front over Quebec-Nova
          Scotia. High pressure area over Great Plains.

Oct. 8   High pressure area centered over Mississippi River.

Oct. 9   Advancing high pressure area centered over West
          Virginia.

Oct. 10   High pressure area centered over Virginia capes with
          a cold front running East-West over Southern Canada.

Oct. 11   High pressure area over Maine. Weak front running
          from Hudson Bay across New York State into the
          Atlantic.

Oct. 12   High pressure ridge along Atlantic seaboard with
          advancing cold front area Great Lakes.

Oct. 13   Cold front running Southwest from Maine to Arkansas.
          Rain following frontal passage along entire front.

Oct. 14   Slow moving cold front running Southwest from Boston
          to Atlanta accompanied by rain.

Oct. 15   Cold front offshore in Atlantic. Advancing low pres-
          sure area approaching Great Lakes.

Oct. 16   Low pressure area over Ohio with high pressure area
          approaching Great Lakes.

During the study period the usual pattern was for a series of cold fronts to advance generally westerly from the Great Lakes through the study area. A series of seven such fronts were in the area and/or passed through the Albany area during the study period.

WINDS

The annual wind pattern as observed at the Albany airport shows a prevailing southerly wind with secondary maximums in the North and West Northwest. Seasonally there is a shift in this pattern. During the winter months of December through March, the prevailing winds are from the West Northwest. During the months of April through November, the southerly winds are prevailing. This is especially true during the summer months of June, July and August.

The wind frequency distribution for Albany airport, Rensselaer (Port of Albany), base station, and Niagara Mohawk meteorological tower all show similar patterns for the study period. All stations show a southerly maximum with secondary maximums generally out of the North to Northwest.

Concurrent winds among these stations show a strong comparison indicated by Figure 33. One of these figures was prepared for each day during the study period. This indicates that wind direction at one station is generally similar to wind direction at another. Moreover, when the shift from essentially down valley flow to up valley flow occurs, it occurs at all stations at about the same time.

For the study period, valley winds, as a general rule, were not observed. By valley winds, it is meant the diurnal shift in wind direction from up valley during the day shifting to down valley during the night. Most of the wind shifts that were

125

FIGURE 33

date   October 09

hour	upper	WIND lower	DIRECTION base	REN	ALB	site 5
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						

observed were associated with synoptic weather features. During frontal passages, the general pattern was for the wind direction to shift from South to North. By about the second day after a frontal passage, the winds would shift back to South again. Local features tended to impose some perturbation on this basic North-South flow.

UPPER ATMOSPHERIC MEASUREMENTS

The average diurnal temperature profile for the study period is contained in Table 29 and Figure 34. There was only one temperature sounding for the 0400 time frame, therefore, it is not included. In addition, the 1300 sounding for September 23 appears to be an anomalous sounding and is not included in the average diurnal presentation.

The upper air diurnal pattern appears to be similar to that defined by the Niagara Mohawk meteorological tower. Stable conditions are observed at night and unstable conditions during the day. Radiation cooling at the surface results in the formation of a surface stable layer by 1900. The diurnal ΔT data indicates this surface inversion is during the 1700-1800 time period. This surface inversion extends through the first 500 feet AGL as measured from the Hudson River bottom land. Another stable layer also forms during the early evening. This second layer lies immediately above the surface stable layer. This second layer may be thought of as an extension of the surface layer and extends from about 500 feet to 1500 feet AGL. This layer is generally isothermal.

As indicated in Table 29, by shortly after sunrise the atmosphere has become almost isothermal up through 3000 feet AGL. The Niagara Mohawk tower shows the transition from stable to unstable takes place rather quickly (Table 30). During the

TABLE 29
AVERAGE DIURNAL TEMPERATURE ALOFT ($^{\circ}$C)
ALBANY STEAM PLANT
PERIOD OF RECORD: Sept. 22, 1978-Oct. 15, 1978

Time (EST	Surface	Height Above Ground (ft)						Number Soundings
		500	1000	1500	2000	2500	3000	
0100	11.5	11.9	12.1	12.1	11.3	11.0	10.5	6
0400	-	-	-	-	-	-	-	-
0700	7.9	8.5	8.7	8.4	8.6	8.1	7.6	6
1000	13.3	10.9	9.5	8.3	7.0	5.7	3.9	6
1300	16.0	14.0	12.6	11.1	10.4	9.8	9.9	5
1600	16.6	1 .3	14.2	12.8	11.9	11.0	10.2	9
1900	13.5	14.7	14.2	14.2	12.5	11.4	10.7	7
2200	11.9	13.7	13.6	13.0	12.4	11.5	11.1	7

FIGURE 34
AVERAGE DIURNAL
TEMPERATURE PROFILES
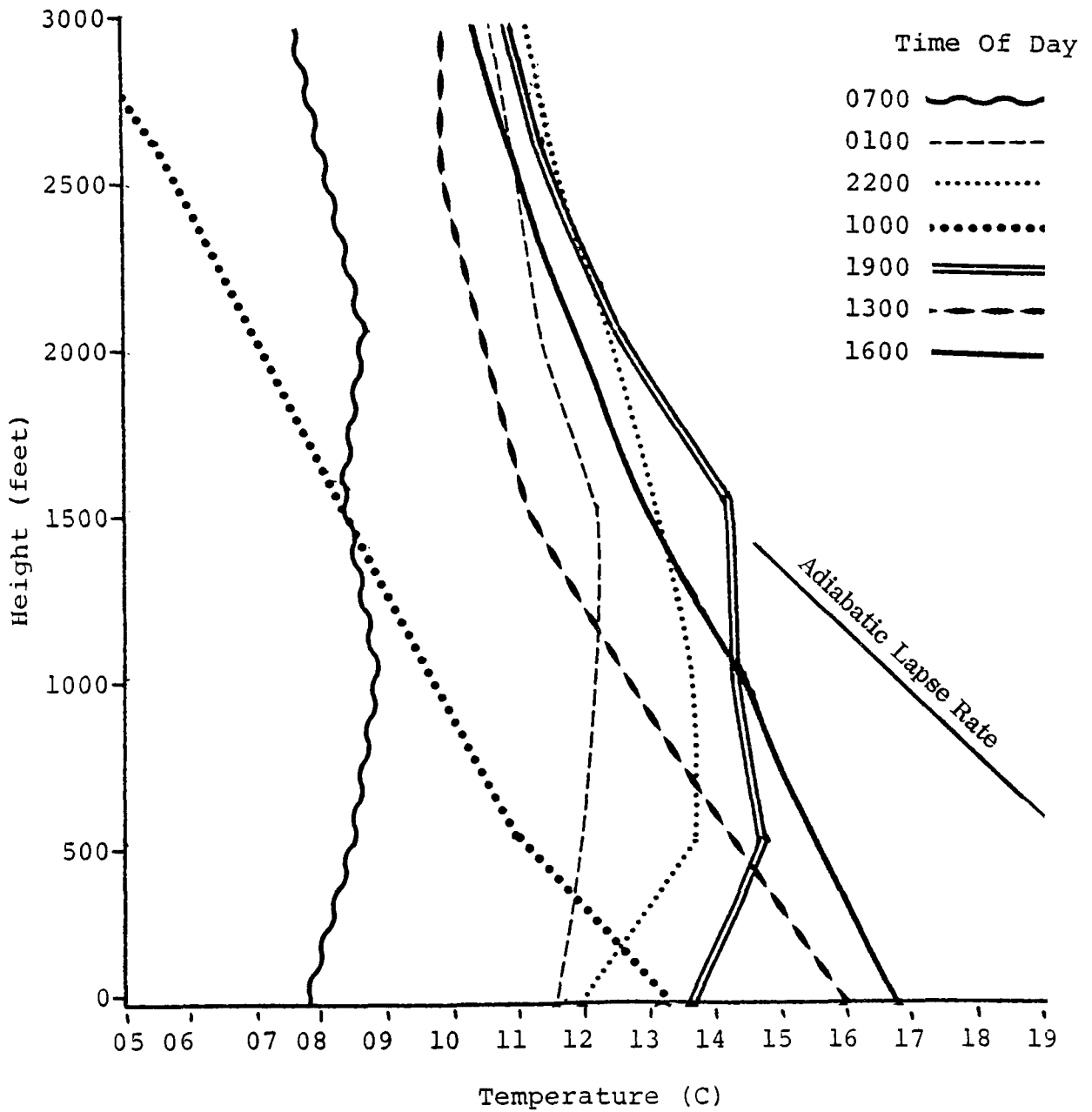
day the lower 3000 feet of the atmosphere is unstable once the
morning inversion breakup takes place.

The significance of this is that the plume is emitted into
stable air from early evening through the morning inversion
breakup. Consequently the contents of the plume would be dis-
persed slowly during the night and would have a minimal impact
during these hours.

From the pibal wind frequency tables it can be seen that the
wind did change in regard to height. The wind speed at the
ground had a very high percentage of occurrences at the lower
speeds (0-18 mph). The 1000 foot level had most of its wind
speeds in the 4-31 mph range, the 2000 foot in the 8-38 mph
range, and the 3000 foot level in the 13-38 mph range. The
wind direction remained constant with height during northerly
winds. During southerly winds, as height increased, the winds
shifted toward the West. This can clearly be seen from Figure
35. Tables 31, 32 and 33 summarize the upper air wind pat-
terns.

From Table 34 it can be observed that there were definite
diurnal patterns with regard to upper air temperatures. This
can be seen clearly by looking at the day of October 12. At
0100 a stable condition exists, by 1008 this stable condition
has become unstable allowing mixing of the atmosphere, at 1322
the atmosphere has become adiabatic, at 1533 it was becoming
stable, and, at 1906 it had become very stable. This condition
existed through 2155, and by 0100 the atmosphere had become
isothermal.

VISIBILITY

It has been recognized for many years that degradation of visi-
bility can be caused by air pollution. However, air pollution

130

TABLE 30

FREQUENCY DISTRIBUTION OF STABILITY CLASS
NIAGARA MOHWAK METEOROLOGICAL TOWER
PERIOD OF RECORD: SETP. 17, 1978-OCT. 16, 1978
PASQUILL STABILITY CLASS (delta-T method)

Hour	A	B	C	D	E	F	G	Missing	Valid hours
1	0	0	1	4	14	8	2	1	29
2	0	0	1	8	11	9	1	0	30
3	0	0	1	6	15	7	1	0	30
4	0	0	2	4	17	7	0	0	30
5	0	0	0	11	12	5	2	0	30
6	0	0	1	8	15	4	1	1	29
7	0	0	1	15	8	6	0	0	30
8	6	3	1	14	6	0	0	0	30
9	20	1	3	6	0	0	0	0	30
10	22	3	1	4	0	0	0	0	30
11	23	4	2	1	0	0	0	0	30
12	24	3	2	1	0	0	0	0	30
13	24	3	1	2	0	0	0	0	30
14	25	1	1	2	1	0	0	0	30
15	23	0	3	3	1	0	0	0	30
16	16	6	0	7	1	0	0	0	30
17	1	1	3	22	3	0	0	0	30
18	0	0	0	10	20	0	0	0	30
19	0	0	0	5	17	7	1	0	30
20	0	0	0	5	18	4	3	0	30
21	0	0	0	9	12	6	3	0	30
22	0	0	0	6	16	5	3	0	30
23	0	0	0	6	12	9	3	0	30
24	0	0	1	6	11	8	4	0	30
Totals	184	25	25	165	210	85	24	2	718

NOTE: STABILITY CATEGORIES TAKEN FROM NRC SAFETY GUIDE 1.23

TABLE 31

UPPER AIR PROGRAM DATA LOG

NIAGARA MOHAWK

DATE	TIME EST	OBSERVATION			BASE		1000'		2000'		3000'		TOWER PASQUILL STABILITY CLASS
		PIBAL	SONDE	DOUBLE	DIR	SPEED	DIR	SPEED	DIR	SPEED	DIR	SPEED	
9/22/78	1432		x		180	08.0	034	09.3	037	25.3	046	30.9	D
9/22/78	1555		x		350	06.0	021	30.8	046	21.2	*	*	D
9/23/78	1000		x		030	04.0	012	06.9	019	05.5	194	07.4	A
9/23/78	1300		x		040	04.0	036	13.0	*	*	*	*	B
9/24/78	1000	x			194	05.0	206	13.8	238	11.9	279	07.4	D
9.25.78	0735		x		150	04.0	*	*	*	*	*	*	E
9/25/78	1750	x			180	03.0	306	09.2	*	*	*	*	E
9/25/78	1006	x			290	20.0	334	35.6	344	31.1	330	40.5	B
9/25/78	1320	x			315	12.0	348	09.6	358	08.7	349	21.1	B
9/25/78	1540	x			270	12.0	319	40.6	331	21.9	345	26.9	D
9/26/78	0720	x			360	03.0	019	06.8	*	*	*	*	C
9/26/78	0951		x		050	05.0	045	06.9	351	04.4	035	07.2	A
9/26/78	1314	x			360	05.0	034	01.9	336	01.2	295	10.6	B
9/26/78	1611	x			100	05.0	234	04.1	246	05.7	278	09.8	D
9/27/78	0726		x		185	03.0	195	18.4	202	34.4	*	*	D
9/27/78	1019	x			180	10.0	197	24.9	200	20.1	218	14.7	A
9/27/78	1338	x		x	180	11.0	265	17.9	260	34.2	249	12.5	B
9/27/78	1552	x		x	170	12.0	*	*	*	*	*	*	D
9/28/78	0731	x			300	03.0	237	04.4	*	*	*	*	D
9/28/78	1016		x		320	20.0	324	40.7	329	14.6	328	42.8	A
9/28/78	1255	x			300	11.0	324	23.9	354	24.2	005	26.8	A
9/28/78	1605		x	x	320	14.0	037	39.8	040	56.3	047	26.5	D
9/29/78	0730		x		340	03.0	334	12.8	357	08.5	357	08.0	E
9/29/78	1015	x			330	02.0	349	07.3	004	11.1	024	10.1	B
9/29/78	1420	x			360	03.0	059	07.7	350	04.7	339	11.3	C
9/29/78	1608		x	x	090	02.0	133	03.3	140	03.2	107	07.6	E

* INDICATES THAT THE PIBAL WAS OBSCURED FROM VIEW

TABLE 31

UPPER AIR PROGRAM DATA LOG

NIAGARA MOHAWK

DATE	TIME EST	PIBAL	OBSERVATION SONDE	OBSERVATION DOUBLE	BASE DIR	BASE SPEED	1000' DIR	1000' SPEED	2000' DIR	2000' SPEED	3000' DIR	3000' SPEED	TOWER PASQUILL STABILITY CLASS
9/30/78	0730		x		190	04.0	194	34.8	210	39.1	*	*	D
9/30/78	1000	x			180	15.0	206	19.0	*	*	*	*	A
9/30/78	1350	x			180	18.0	196	12.1	212	17.5	222	24.7	B
10/01/78	0955	x			180	13.0	101	04.7	212	42.2	211	47.3	C
10/01/78	1316	x			180	13.0	212	24.0	221	26.2	236	23.7	D
10/01/78	1543		x		220	05.0	236	13.4	251	11.2	281	13.7	E
10/02/78	0730		x		330	07.0	009	23.7	*	*	*	*	E
10/02/78	1005	x			350	10.0	014	29.9	018	34.5	019	19.8	D
10/02/78	1306	x			350	08.0	010	05.9	009	14.1	006	18.7	A
10/05/78	1306		x		180	09.0	240	03.2	*	*	*	*	A
10/05/78	1619		x	x	180	08.0	268	12.7	262	23.2	251	27.7	D
10/05/78	1924		x		210	04.0	165	19.9	183	34.0	186	31.6	E
10/05/78	2215		x		140	04.0	167	26.0	173	39.2	194	35.2	E
10/06/78	0158		x		240	03.0	169	15.1	162	21.7	*	*	E
10/06/78	0415	X			180	05.0	*	*	*	*	*	*	E
10/06/78	0704	x			180	05.0	167	25.0	170	34.3	202	26.5	D
10/06/78	1005	x			140	04.0	189	08.5	*	*	*	*	D
10/06/78	1315	x			140	11.0	203	07.0	*	*	*	*	C
10/06/78	1532		x	x	200	06.0	077	12.2	078	09.2	081	13.9	D
10/06/78	1902		x		270	02.0	310	13.2	299	14.7	289	23.4	E
10/06/78	2210		x		220	02.0	235	10.7	272	19.2	301	19.8	F
10/07/78	0040		x		220	04.0	254	09.8	279	18.4	302	24.0	E
10/07/78	0430	x			210	03.0	*	*	*	*	*	*	E
10/07/78	0700			x	200	04.0	295	39.3	*	*	*	*	E
10/07/78	1003		x	x	090	03.0	078	07.0	013	33.5	*	*	D
10/07/78	1310		x	x	290	08.0	002	18.2	020	16.9	012	16.4	C
10/07/78	1615		x		320	12.0	334	23.3	333	21.8	338	20.5	D

* INDICATES THAT THE PIBAL WAS OBSCURED FROM VIEW

TABLE 31

UPPER AIR PROGRAM DATA LOG

NIAGARA MOHAWK

DATE	TIME EST	OBSERVATION			BASE		1000'		2000'		3000'		TOWER PASQUILL STABILITY CLASS
		PIBAL	SONDE	DOUBLE	DIR	SPEED	DIR	SPEED	DIR	SPEED	DIR	SPEED	
10/07/78	1902		x		330	04.0	326	27.5	327	35.5	329	65.2	E
10/07/78	2154		x		210	02.0	314	15.3	296	30.6	327	33.5	E
10/08/78	0040		x		240	01.0	319	23.4	326	24.4	331	30.3	E
10/08/78	0433	x			300	04.0	337	24.2	*	*	*	*	E
10/08/78	0711			x	330	03.0	029	18.5	030	68.5	033	53.8	D
10/08/78	1002			x	330	08.0	031	22.6	021	17.9	026	32.2	A
10/08/78	1310	x			290	08.0	305	29.3	314	29.1	332	18.2	C
10/08/78	1602	x			300	08.0	323	22.4	318	35.6	319	35.2	D
10/08/78	1907	x			330	05.0	341	26.8	335	24.8	336	44.5	E
10/08/78	2225	x			300	02.0	334	28.1	344	27.4	348	31.7	E
10/09/78	0045	x			280	02.0	335	25.4	347	23.9	003	18.0	E
10/09/78	0430	x			230	02.0	325	25.7	335	27.9	340	27.0	E
10/09/78	0712			x	210	02.0	*	*	*	*	*	*	E
10/09/78	1006			x	300	08.0	035	48.0	030	57.2	026	82.0	A
10/09/78	1324			x	330	09.0	032	11.5	050	18.3	032	19.5	A
10/09/78	1604		x	x	330	06.0	056	10.6	033	11.9	018	35.5	E
10/09/78	1923		x		210	03.0	309	04.7	293	09.9	282	15.5	F
10/09/78	2205		x		180	04.0	221	15.5	269	25.3	297	28.5	F
10/10/78	0500		x		190	04.0	239	19.2	269	47.6	*	*	F
10/10/78	0455	x			170	04.0	250	13.8	301	21.9	*	*	E
10/10/78	0705	x			180	06.0	248	12.2	305	27.5	*	*	D
10/10/78	1006			x	180	06.0	281	14.0	*	*	*	*	B
10/10/78	1256	x			100	10.0	248	11.2	327	07.0	314	19.2	C
10/10/78	1611		x	x	300	05.0	027	15.0	022	22.4	017	29.9	D
10/10/78	1900		x		280	02.0	341	17.4	329	19.5	310	23.0	E
10/10/78	2206		x		200	01.0	348	14.9	329	15.8	345	23.2	E
10/11/78	0050		x		250	03.0	037	15.3	356	15.9	338	21.5	F

*INDICATES THE PIBAL WAS OBSCURED FROM VIEW

134

TABLE 31

UPPER AIR PROGRAM DATA LOG

NIAGARA MOHAWK

DATE	TIME EST	OBSERVATION			BASE		1000'		2000'		3000'		TOWER PASQUILL STABILITY CLASS
		PIBAL	SONDE	DOUBLE	DIR	SPEED	DIR	SPEED	DIR	SPEED	DIR	SPEED	
10/11/78	0445	x			190	03.0	192	25.0	359	17.3	*	*	E
10/11/78	0651	x			180	03.0	206	13.7	190	08.4	204	07.9	D
10/11/78	1005	x			180	12.0	198	10.7	215	17.7	197	11.4	B
10/11/78	1336			x	180	14.0	261	13.3	248	22.5	*	*	C
10/11/78	1602	x			160	14.0	192	13.6	*	*	*	*	E
10/11/78	1905		x		190	06.0	187	29.5	198	34.0	201	32.1	E
10/11/78	2155		x		180	05.0	202	27.0	212	37.0	208	35.8	E
10/12/78	0100		x		180	03.0	200	25.4	196	32.7	213	37.5	E
10/12/78	0440	x			170	07.0	199	27.5	*	*	*	*	E
10/12/78	0710			x	170	07.0	*	*	*	*	*	*	D
10/12/78	1008		x	x	175	12.0	269	28.6	278	36.7	*	*	A
10/12/78	1322		x	x	170	13.0	269	26.7	263	21.6	270	22.7	C
10/12/78	1553		x	x	180	14.0	269	33.2	284	26.3	302	11.2	D
10/12/78	1906		x		180	06.0	212	33.5	207	18.4	216	15.0	E
10/12/78	2155		x		180	04.0	196	35.4	198	24.0	233	14.1	E
10/13/78	0100		x		180	06.0	201	31.9	227	26.1	240	39.3	E
10/13/78	0450	x			240	05.0	199	34.3	202	50.6	*	*	E
10/13/78	0719	x			170	08.0	*	*	*	*	*	*	D
10/13/78	1010			x	175	14.0	262	20.1	*	*	*	*	B
10/13/78	1327			x	310	07.0	063	07.6	092	07.0	322	04.0	D
10/13/78	1550	x			330	04.0	017	14.8	353	16.4	316	13.6	E
10/14/78	1311	x			210	03.0	186	228	196	45.9	*	*	D
10/15/78	1020		x		300	15.0	312	17.4	338	14.7	*	*	A
10/15/78	1316		x		310	12.0	329	34.0	329	45.8	327	62.5	D
10/15/78	1520	x			337	24.7	336	21.0	339	20.6	330	28.0	D

*INDICATES THE PIBAL WAS OBSCURED FROM VIEW

135

TYPICAL PIBAL TRAJECTORY

N

W

E

1000

2000

3000
Height (feet)

4000

5000

▼ 1 minute intervals   6000

S
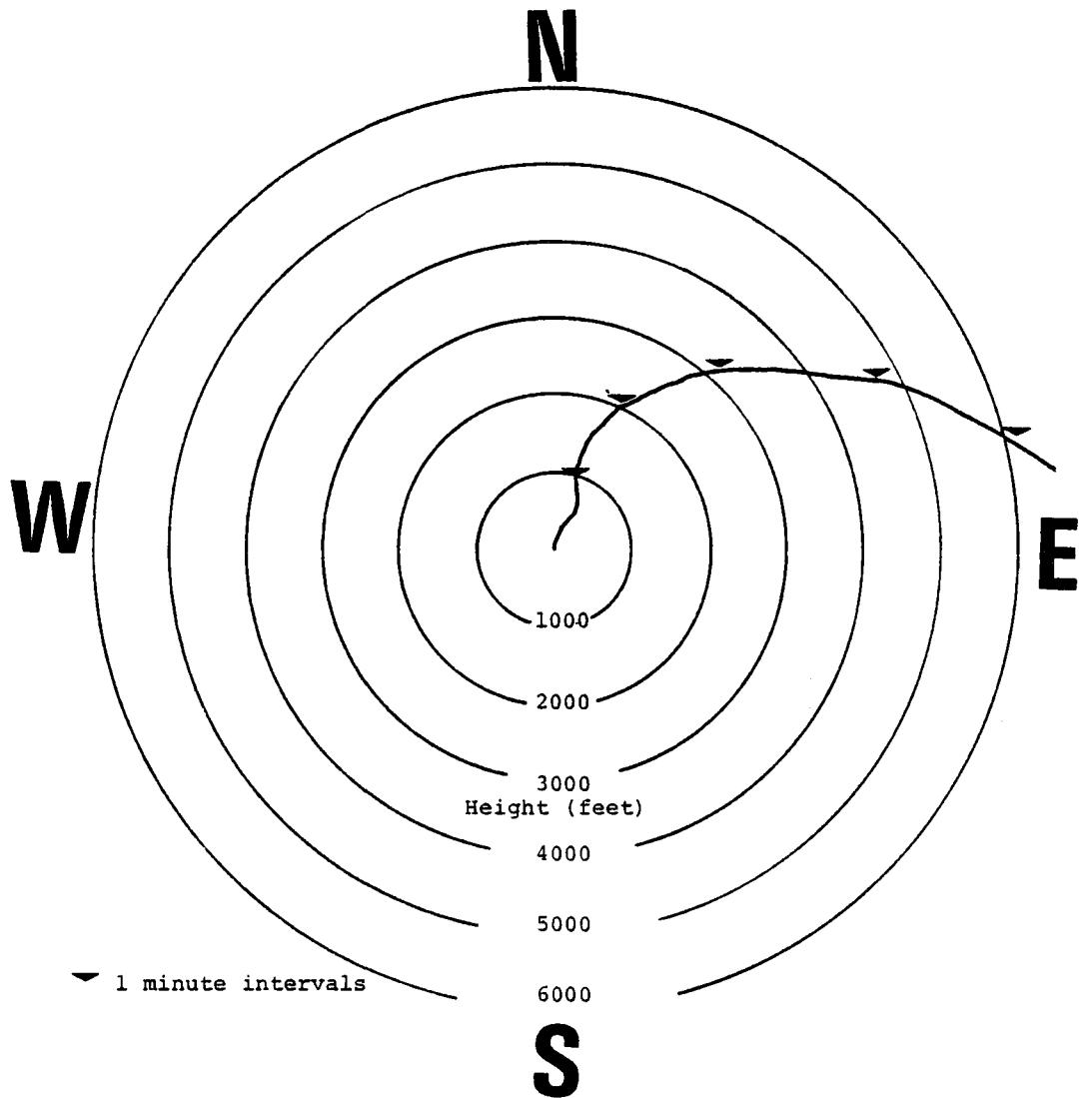
FIGURE 35

TABLE 32
SUMMARY OF MEAN WIND DIRECTIONS AND SPEEDS

	BASE	1000'	2000'	3000'
NORTHERLY				
Direction	341.4	10.2	001.6	349
Direction S.D.	24.5	31.5	26.0	49.4
Speed	7.9	18.3	21.8	27.2
Speed S.D.	6.1	12.0	18.5	18.8
SOUTHERLY				
Direction	183.4	201.3	211.4	226.6
Direction S.D.	13.8	63.3	58.2	61.1
Speed	7.3	20.1	25.5	24.0
Speed S.D.	4.3	8.9	9.5	11.1
WESTERLY				
Direction	268.9	324	331.2	336.8
Direction S.D.	36.5	55.5	51.3	29.6
Speed	6.2	21.2	23.17	28.2
Speed S.D.	5.0	10.2	11.5	14.3
EASTERLY				
Direction	96.6	205	237.7	233
Direction S.D.	5.7	62.7	93.7	110.6
Speed	5.7	6.2	5.3	12.2
Speed S.D.	4.0	4.3	1.9	6.2

Categories include summation of soundings coincident with ground level wind direction within that quadrant.

137

TABLE 33

FREQUENCY DISTRIBUTION OF WIND SPEED & DIRECTION

PIBAL OBSERVATIONS
30 FEET

| WIND DIRECTION | WIND SPEED MPH | | | | | | | | | | |
	0-3	4-7	8-12	13-18	19-24	25-31	32-28	39-46	47	MISS	TOTAL
349-11 N	1.90	1.90	1.90								5-71
12-33 NNE		0.95									0.95
34-56 NE		1.90									1.90
57-58 ENE											0.00
79-101 E	1.90	0.95	0.95								3.81
102-123 ESE											0.00
124-146 SE		1.90	1.90								2.85
147-168 SSE		0.95	0.95								1.90
169-191 S	4.76	15.14	7.61	7.61							35.24
192-213 SSW	5.71	3.81									9.52
214-236 SW	1.90	1.90									3.81
237-258 WSW	2.86	0.95									3.81
259-281 W	2.86		0.95								3.81
282-303 WNW	1.90	1.90	4.76	0.95	0.95						10.48
304-326 NW		0.95	2.86	0.95	0.95						5.71
327-348 NNW	2.86	4.76	1.90		0.95						10.48
MISSING											
TOTAL	26.67	38.09	21.90	10.48	2.86						100.00

138

TABLE 33

FREQUENCY DISTRIBUTION OF WIND SPEED & DIRECTION

PIBAL OBSERVATIONS
1000 FEET

WIND DIRECTION	WIND SPEED MPH										
	0-3	4-7	8-12	13-18	19-24	25-31	32-28	39-46	47	MISS	TOTAL
349-11 N		1.90		0.95	0.95						4.76
12-33 NNE		1.90	1.90	2.86	0.95	1.90					9.52
34-56 NE	0.95	0.95	0.95	1.90				0.95	0.95		6.67
57-58 ENE		2.86	0.95								4.76
79-101 E		0.95									0.95
102-123 ESE											0.00
124-146 SE	0.95										0.95
147-168 SSE					0.95	1.90					2.86
169-191 S			0.95	0.95	0.95	0.95					4.76
192-213 SSW		0.95	1.90	2.86	2.86	5.71	3.81				18.09
214-236 SW		0.95	0.95	1.90							4.76
237-258 WSW	0.95	0.95	2.86	0.95	0.95						6.67
259-281 W			0.95	2.86	0.95	1.90	0.95				7.62
282-303 WNW					0.95			0.95			1.90
304-326 NW		0.95	0.95	2.86	1.90	2.86		1.90			11.43
327-348 NNW			0.95	2.86	2.86	2.86	1.90				11.43
MISSING											6.67
TOTAL	2.86	12.38	13.33	20.95	14.28	18.09	6.67	3.81	0.95	6.67	100.00

TABLE 33

FREQUENCY DISTRIBUTION OF WIND SPEED & DIRECTION

PIBAL OBSERVATIONS
2000 FEET

WIND DIRECTION	WIND SPEED MPH										
	0-3	4-7	8-12	13-18	19-24	25-31	32-28	39-46	47	MISS	TOTAL
349-11 N		1.92	2.88	3.85	0.96						9.62
12-33 NNE		0.96	0.96	1.92	0.96		1.92		0.96		7.69
34-56 NE				0.96	0.96	0.96			0.96		3.85
57-58 ENE			0.96								0.96
79-101 E		0.96									0.96
102-123 ESE											0.00
124-146 SE	0.96								0.96		1.92
147-168 SSE					0.96						0.96
169-191 S			0.96				1.92	0.96			3.85
192-213 SSW				1.92	1.92		3.85	2.88	0.96		11.54
214-236 SW				0.96		1.92					2.88
237-258 WSW		0.96	1.92		0.96						3.85
259-281 W				0.96	2.88	0.96	1.92		0.96		7.69
282-303 WNW			0.96	0.96	0.96	1.92					4.81
304-326 NW					0.96	1.92	0.96				3.85
327-348 NNW	0.96	0.96		2.88	4.81	2.88	0.96	0.96			12.50
MISSING											21.15
TOTAL	1.92	5.77	8.65	14.42	16.34	10.58	11.54	4.81	4.81	21.15	100.00

TABLE 33

FREQUENCY DISTRIBUTION OF WIND SPEED & DIRECTION

PIBAL OBSERVATIONS
3000 FEET

WIND DIRECTION	0-3	4-7	8-12	13-18	19-24	25-31	32-28	39-46	47	MISS	TOTAL
349-11 N			0.94	1.89	0.94	0.94					4.72
12-33 NNE			0.94	0.94	1.89	0.94	0.94		1.89		7.56
34-56 NE		0.94		0.94		1.89					5.77
57-58 ENE											0.00
79-101 E				0.94							0.94
102-123 ESE		0.94									0.94
124-146 SE											0.00
147-168 SSE											0.00
169-191 S						0.94					0.94
192-213 SSW		1.89	0.94			0.94	3.77		0.94		8.49
214-236 SW				2.83	1.89						4.72
237-258 WSW			0.94			0.94		0.94			2.83
259-281 W		0.94	0.94	0.94	0.94						3.77
282-303 WNW			1.89	0.94	2.83	0.94					6.60
304-326 NW		0.94		0.94	1.89		0.94				4.72
327-348 NNW			0.94	0.94	2.83	4.72	1.89	2.83	1.89		16.04
MISSING											33.96
TOTAL	0.00	5.66	7.54	11.32	13.20	12.26	7.54	3.77	4.71	33.96	100.00

TABLE 34

TEMPERATURE (C°) CHANGE WITH HEIGHT @ BASE SITE

DATE	TIME (est)	GROUND	500	1000	HEIGHT (ft) 1500	2000	2500	3000
10/07/78	0040	06.6	07.3	07.3	07.8	06.4	05.2	04.2
10/07/78	1003	13.2	11.6	10.7	09.9	08.6	08.0	
10/07/78	1310	16.1	13.0	12.0	10.6	09.8	08.7	07.2
10/07/78	1615	12.1	10.1	08.7	07.2	06.8	05.7	04.2
10/07/78	1902	08.8	07.9	06.8	06.0	05.0	03.8	02.8
10/07/78	2154	05.8	09.0	09.1	08.6	07.7	06.5	05.5
10/08/78	0400	04.9	08.8	08.5	08.6	07.4	06.2	05.1
10/09/78	1604	13.7	12.0	11.2	09.4	08.4	07.3	06.3
10/09/78	1923	06.0	11.7	11.6	11.0	10.0	09.1	09.0
10/09/78	2205	04.9	07.0	10.6	10.6	09.9	08.7	07.9
10/10/78	0050	03.6	05.2	09.9	09.6	09.1	09.0	08.4
10/10/78	1611	19.9	19.2	18.0	16.5	16.	15.2	13.9
10/10/78	1900	16.6	19.5	18.8	18.0	16.9	16.4	15.8
10/10/78	2206	14.3	16.2	16.0	15.5	15.4	14.7	14.9
10/11/78	0050	14.3	16.0	14.5	15.3	14.3	14.2	13.5
10/11/78	1905	17.4	17.7	16.6	15.6	14.4	13.2	12.1
10/11/78	2155	16.3	15.7	14.2	13.3	12.3	11.4	10.6
10/12.78	0100	13.7	13.2	12.2	11.8	11.2	11.6	11.4
10/12/78	1008	18.2	15.0	13.8	12.9	11.6	10.7	
10/12/78	1322	20.4	18.7	17.5	15.7	14.8	13.8	17.7
10/12/78	1553	22.7	21.6	20.6	19.2	18.4	18.0	17.0
10/12/78	1906	14.8	17.6	17.9	17.8	16.7	15.5	14.9
10/12/78	2155	41.8	16.2	15.5	14.9	15.6	15.4	15.1
10/13/78	0100	16.1	16.1	16.1	16.2	16.2	15.8	14.9
10/15/78	1020	08.0	05.9	02.5	-0.2	-2.9	-5.7	-7.3
10/15/78	1316	09.0	08.0	07.2	06.0	04.7	03.9	03.0

TABLE 34

TEMPERATURE (C^o) CHANGE WITH HEIGHT @ BASE SITE

DATE	TIME (EST)	GROUND	500	1000	HEIGHT (FT) 1500	2000	2500	3000
9/22/78	1432	16.0	15.1	13.2	11.8	10.6	10.4	10.8
9/22/78	1555	15.2	15.4	15.1	15.4	14.9	14.1	14.8
9/23/78	1000	13.5	12.1	11.2	10.6	10.3	10.2	09.2
9/23/78	1200	21.0	13.5	10.4	08.6			
9/24/78	0724	01.8	07.1	06.6	05.4	04.6	04.1	03.6
9/25/78	0735	11.5	11.4	12.2	12.3	11.7	10.4	09.6
9/26/78	0951	07.9	04.7	03.8	02.5	1.2	-0.5	-1.6
9/27/78	0726	07.1	07.3	07.8	07.0	08.8	09.4	10.1
9/28/78	1016	18.8	16.0	14.7	14.1	12.9	11.6	10.1
9/28/78	1605	15.0	13.2	12.5	11.3	10.2	9.0	09.0
9/29/78	0730	03.8	04.3	05.5	06.0	05.5	04.6	03.7
9/29/78	1608	15.8	14.0	13.4	12.0	11.1	09.0	08.2
9/30/78	0730	09.5	08.0	07.9	08.6	08.6	08.2	07.4
10/1/78	1543	17.8	17.0	16.2	15.4	14.5	13.4	12.2
10/2/78	0730	13.9	13.0	12.6	11.2	12.4	12.2	11.4
10/5/78	1306	18.6	15.5	13.2	11.4	12.4	12.2	11.1
10/5/78	1619	16.0	14.7	13.3	11.9	10.8	09.8	09.6
10/5/78	1924	15.6	14.2	14.2	13.9	13.3	12.4	11.3
10/5/78	2215	14.8	14.5	13.5	13.0	12.3	11.8	12.0
10/6/78	0158	14.8	13.6	13.0	11.8	10.8	10.3	10.5
10/6/78	1902	15.6	15.0	13.7	12.4	11.3	09.5	08.5
10/6/78	2210	12.3	17.0	16.2	14.9	13.4	11.6	11.3

is not the only cause for decreased visibility. Atmospheric moisture is considered to play a significant role in visibility reduction. This has been reported on by Wright (1935, 1939), Junge (1963), Buma (1960) and Winkler (1973). Moreover, the size of atmospheric particles likely to adversely influence visibility is small. Horvath and Charlson (1969) reported the optically important aerosols to be a narrow range centered about a diameter of 0.50 um.

The importance of relative humidity on visibility can be seen in Figure 36 representing measurements at Newburgh, NY (Reiss and Eversole, 1978). This location is South of Albany along the Hudson River about 80 km North of New York City.

Visibility data in the Albany area has the log-normal distribution mentioned by Reiss and Eversole (1978). The Albany data also shows a seasonal variation as seen in Table 35. This table was compiled from the 3-hourly observations contained in the Local Climatological Data (LCD) for Albany and includes observations with precipitation. This seasonal variance is a widespread phenomena with much of New England experiencing low visibilities during the summer months. This is partially due to the shift to southerly winds brought about by the northward shift of the Azores High.

This table shows a rather abrupt shift in visibility between September and October. September is one of the worst months for visibility and October is one of the better months.

During the study period, visibilities were measured at the Base site and at Site 5 by nephelometers. The values presented here are in units of b_{scat} which is approximately inversely proportional to visibility. The diurnal variation in b_{scat} is shown in Figure 37. The base site was found to have somewhat better visibility than Site 5. This suggests that Site 5 was more

144

FIGURE   36
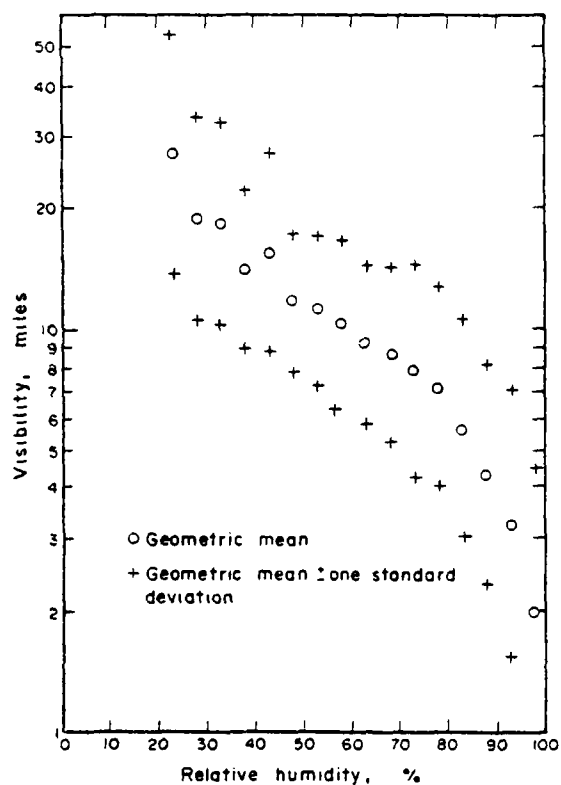
Dependence of daytime (15Z, 18Z, 21Z) visibility on relative humidity at Newburgh, NY (1948-1970) for observations in which no precipitation was observed (all wind directions). (Reiss and Eversole, 1978)

TABLE 35

ALBANY AIRPORT VISIBILITY (Miles)

1977

Cumulative Frequency of Occurrence

	25%	50%	75%
Jan	6.8	11.9	20.8
Feb	6.7	10.5	19.9
Mar	9.0	14.8	25.0
Apr	9.7	22.3	33.3
May	9.1	25.0	32.8
June	6.4	13.9	28.2
July	6.1	14.1	30.3
Aug	5.1	9.6	25.0
Sep	3.8	9.7	27.3
Oct	9.0	14.4	24.4
Nov	7.2	13.8	24.2
Dec	5.8	12.5	19.2
Annual	6.7	13.8	27.4

likely affected by the fine particle emissions than the close-in base site. Moreover both locations showed a diurnal variation consisting of a double maximum-double minimum. The lowest minimum in visibility occurs about the time of the morning inversion breakup. The higher maximum in visibility occurs in the mid afternoon. The other inflection points occur about midnight and about 0400-0500.

Assuming that b_{scat} is directly proportional to airborne particulate mass loading, then the dust loading experienced by a monitoring station is not uniform throughout the day. This suggests that the greatest impact to a 24-hour hi-vol filter could occur about 0900 each morning. Moreover, the minimum particulate loadings are experienced when O_3 shows a diurnal maximum. There appears to be an SO_2 maximum about the same time as the maximum particulate loading and a minor SO_2 minimum about the same time as the minimum particulate loading at Site 5.

The results of ground-level concentration of sulfate were compared to simultaneous b_{scat} values for the base site and Site 5 (see Figure 38). The relationship is evident that sulfate concentration increases significantly as the scattering coefficient increases. Since b_{scat} is the inverse of distance that a specified amount of light can travel through a particulate suspension, this indicates an inversely proportional relationship between visibility and sulfate concentration.

Figure 37

DIURNAL NEPHELOMETERS
VALUES

148
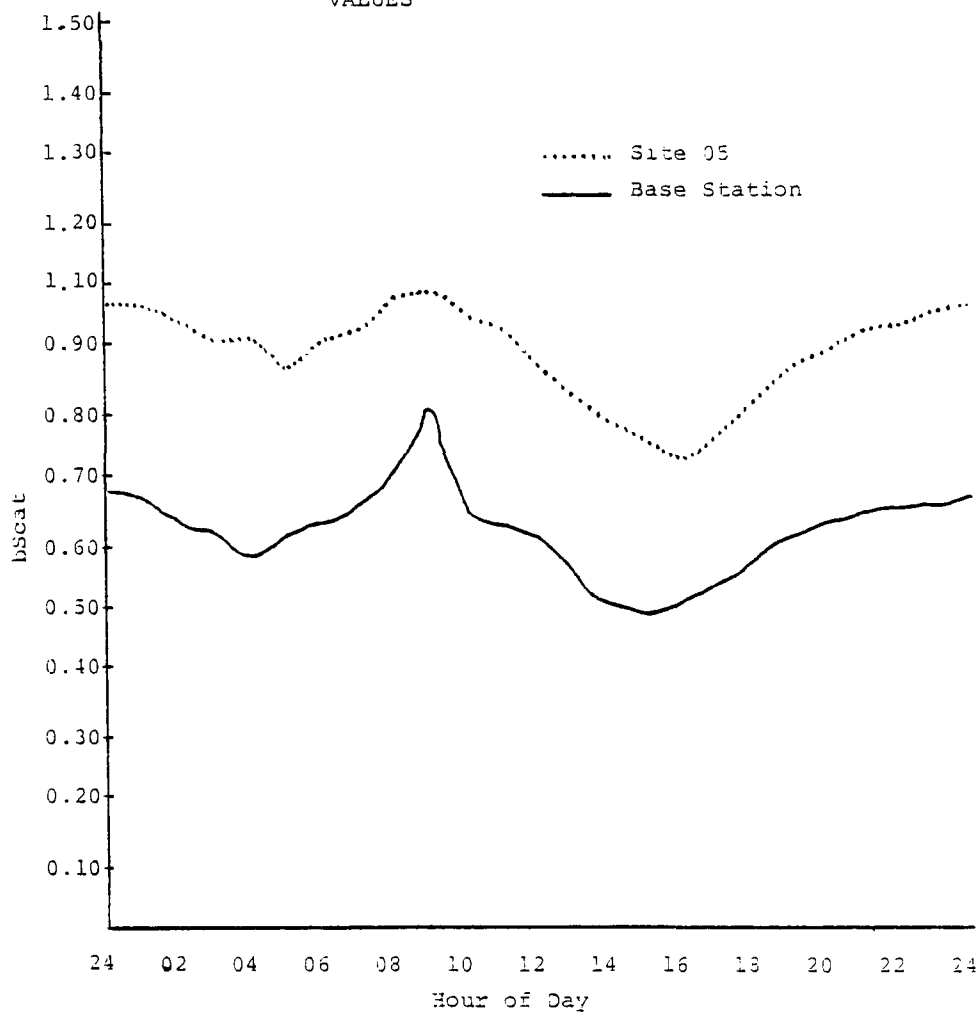
FIGURE 38

SULFATE/SCATTERING COEFFICIENT

BASE SITE AND SITE 5

$Site\ 5\ -\ b_{scat}\ (10^{-4}\ m^{-1})\ -\ 24$-Hour Average

$Base\ Site\ -\ b_{scat}\ (10^{-4}\ m^{-1})\ -\ 24$-Hour Average

149
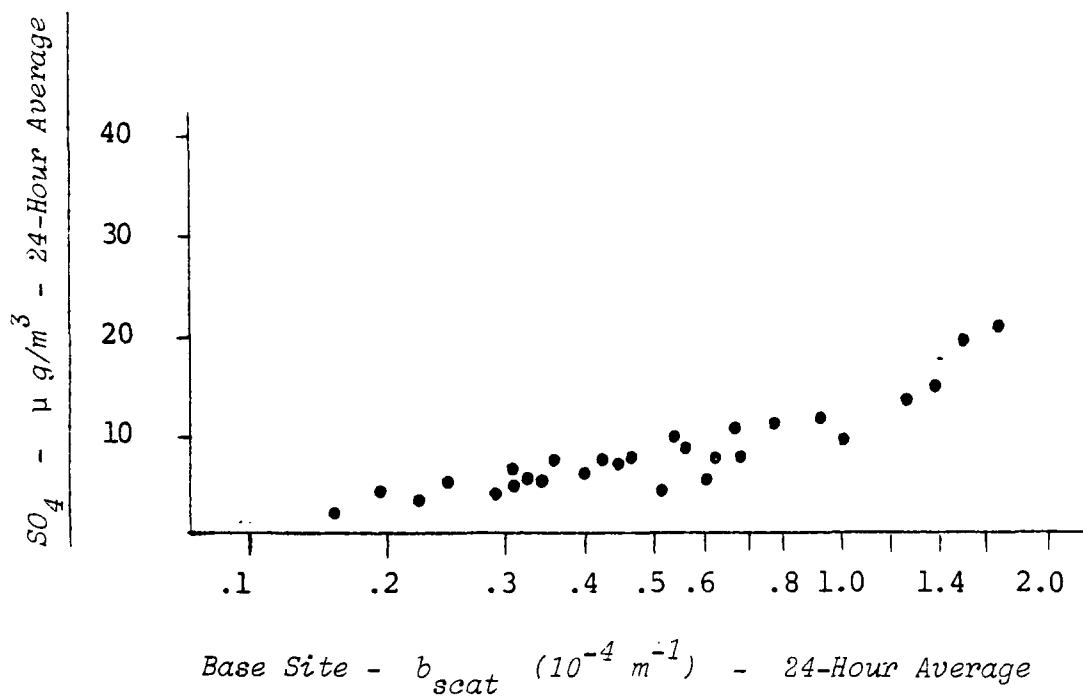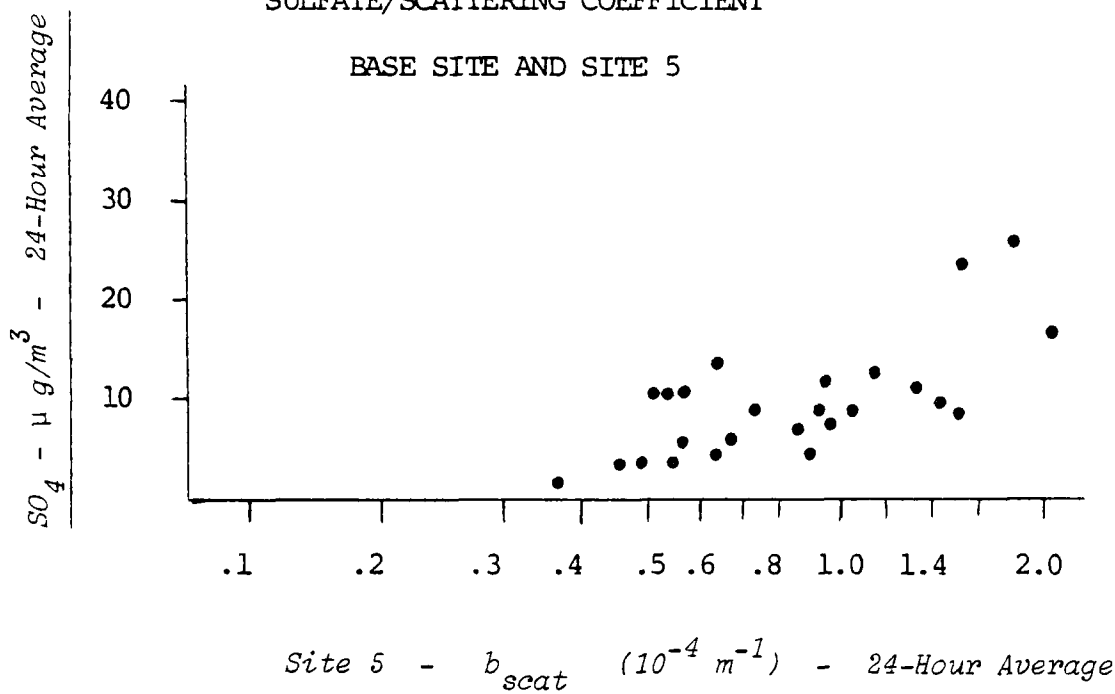
SECTION 7

RELATIONSHIPS BETWEEN AIR QUALITY AND METEOROLOGY

DAILY POLLUTANT DISTRIBUTION

The 24-hour average SO_2 and $\overline{\overline{SO_4}}$ concentrations were plotted on maps for each day and isopleths or lines of equal concentrations were constructed. Sulfur dioxide was selected due to its anthropogenic source implications.

These daily maps showed that gradients in the observed SO_2 and SO_4 concentrations could be constructed. While the confidence in these patterns could be subject to question, the fact remains that gradient patterns could be constructed. The implications that can be drawn is there are local effects (sources and sinks) in the SO_2 and $\overline{\overline{SO_4}}$ in the Albany area. The fact that at times the nature of the SO_2 and $\overline{\overline{SO_4}}$ patterns were different indicates that other factors besides SO_2 alone is involved in the resulting $\overline{\overline{SO_4}}$ concentrations. The fact that gradients in SO_2 could be constructed is not surprising as isopleths have been constructed for such things as b_{scat} (Lutrick, 1971) and SO_2 (Turner, 1964).

DAILY SO_4 ISOPLETH CHARTS

The isopleths that are located on the following pages have been drawn using the daily $\overline{\overline{SO_4}}$ (sulfate) values at the six monitoring stations. The isopleths all represent observed sulfate concentrations in micrograms per cubic meter.

DIFFUSION MODELING

A diffusion model was used to estimate the plant's contribution to the ambient concentration measured at each of the monitoring

FIGURE 39
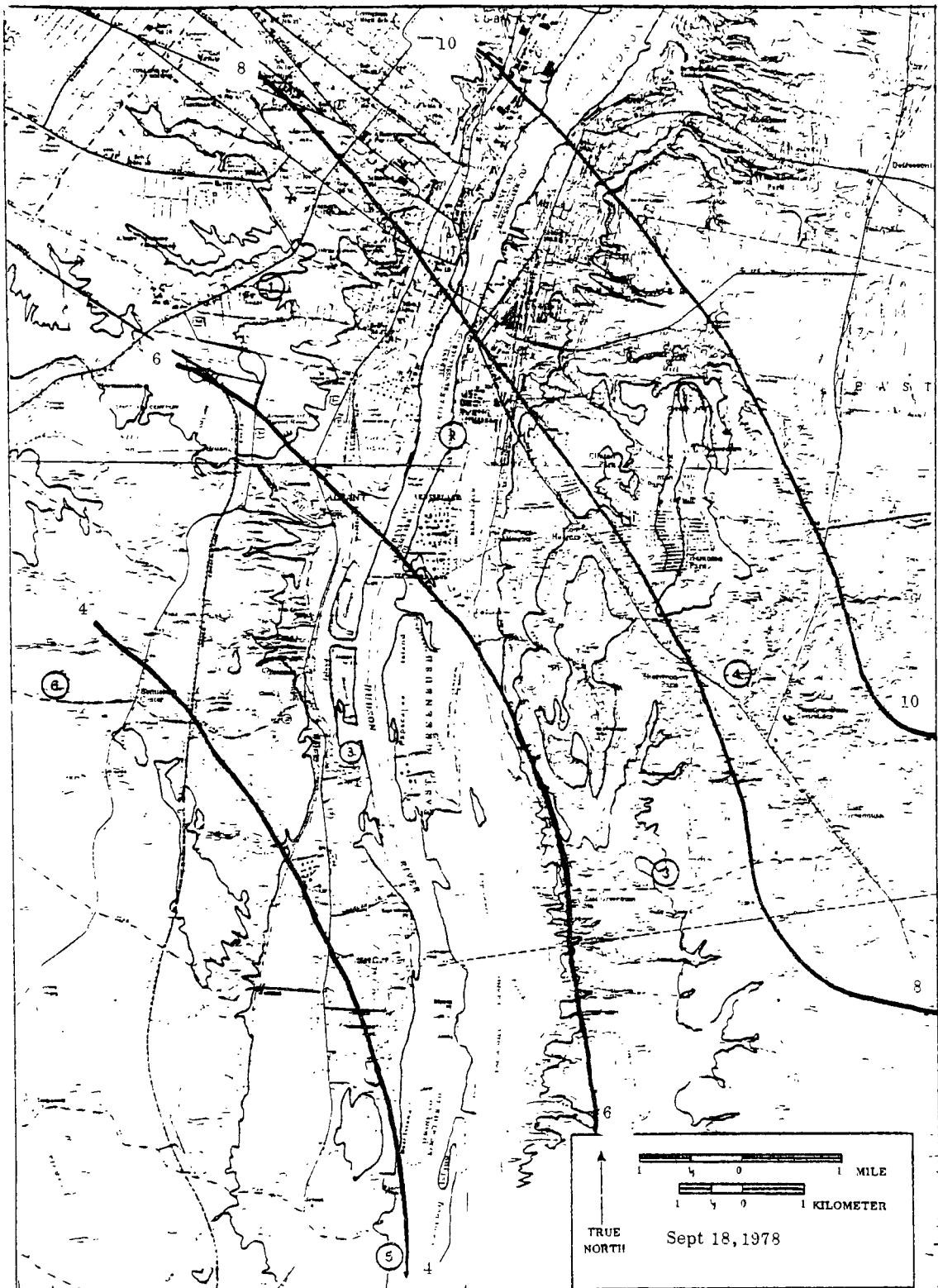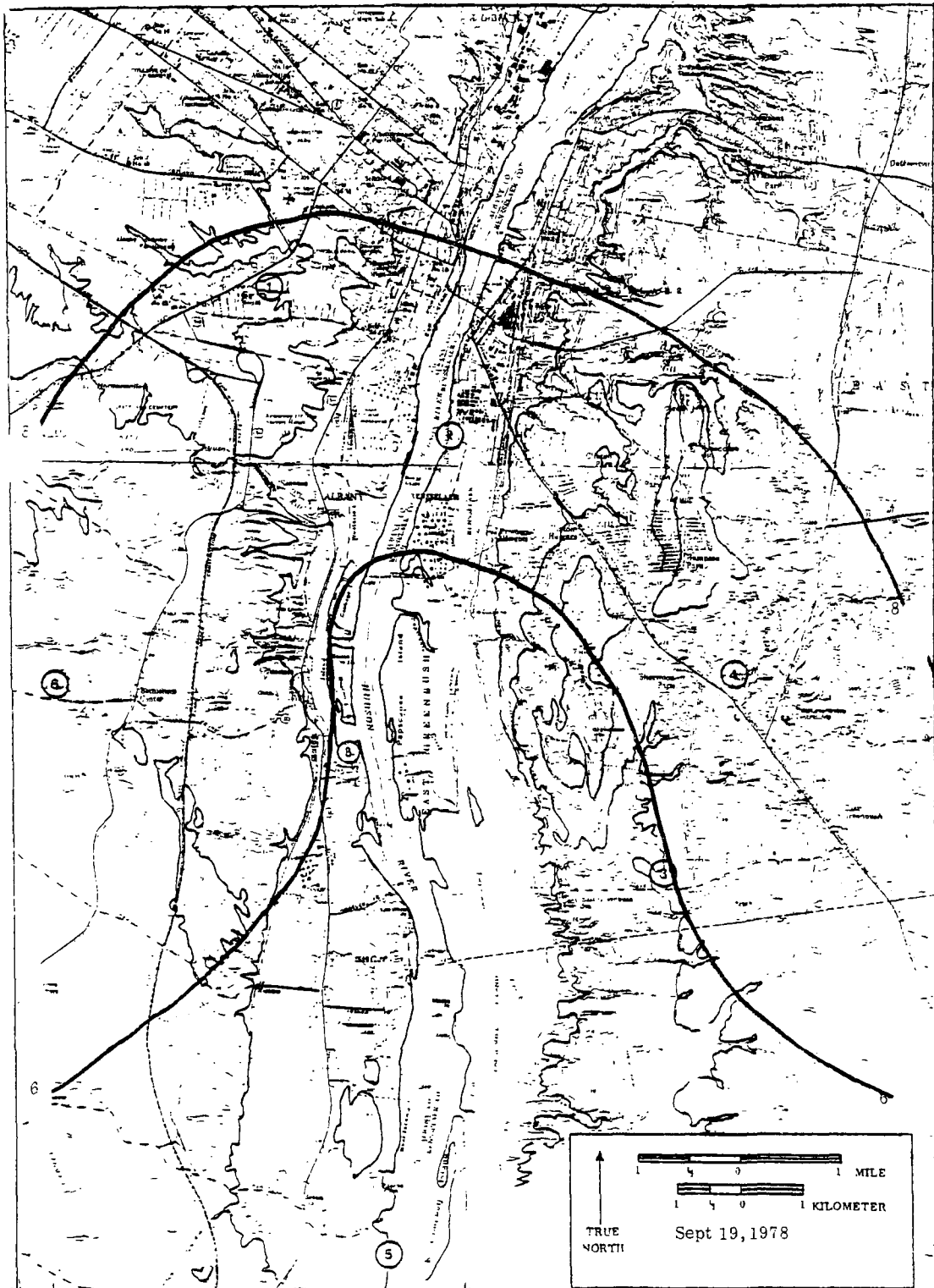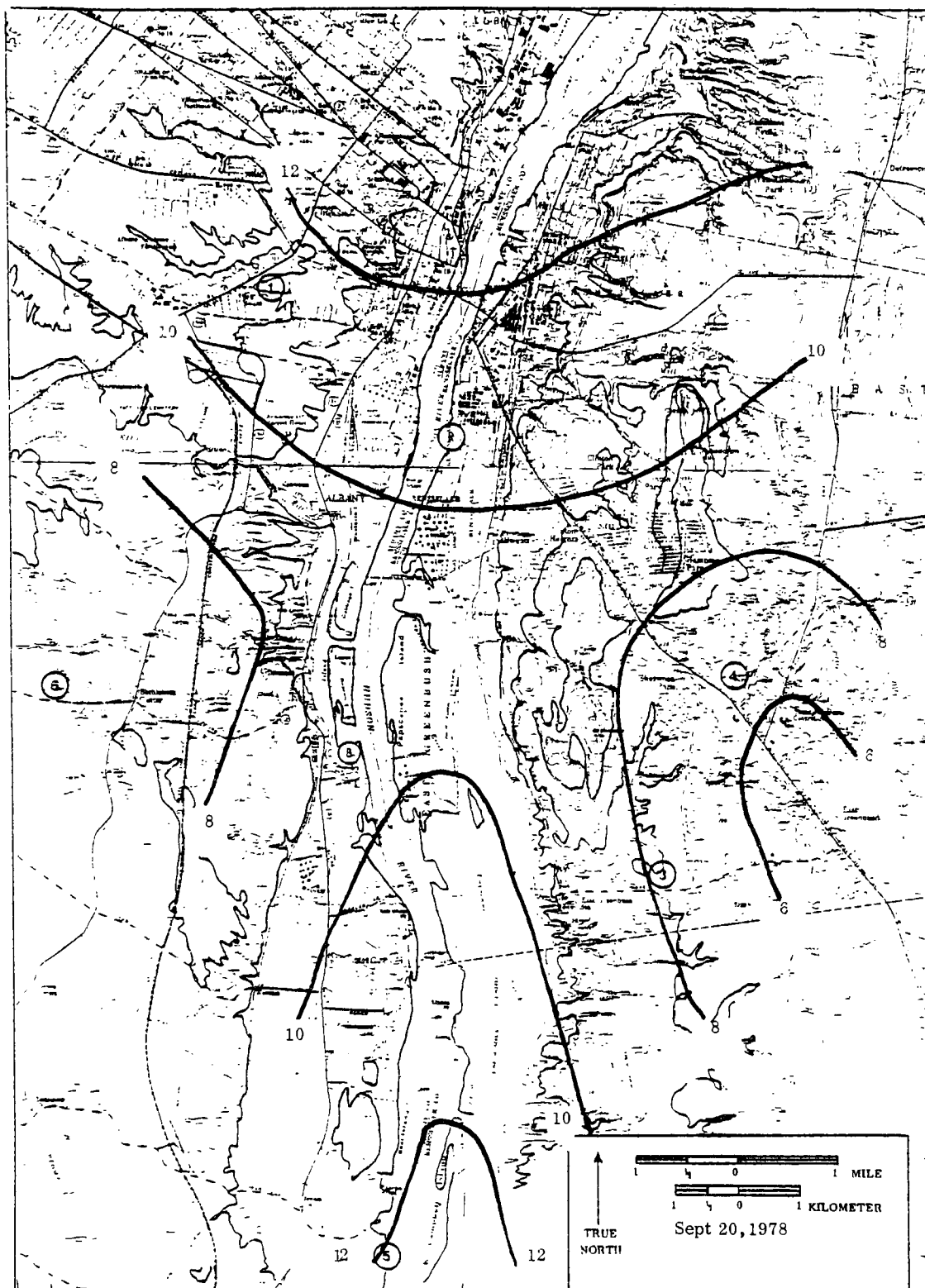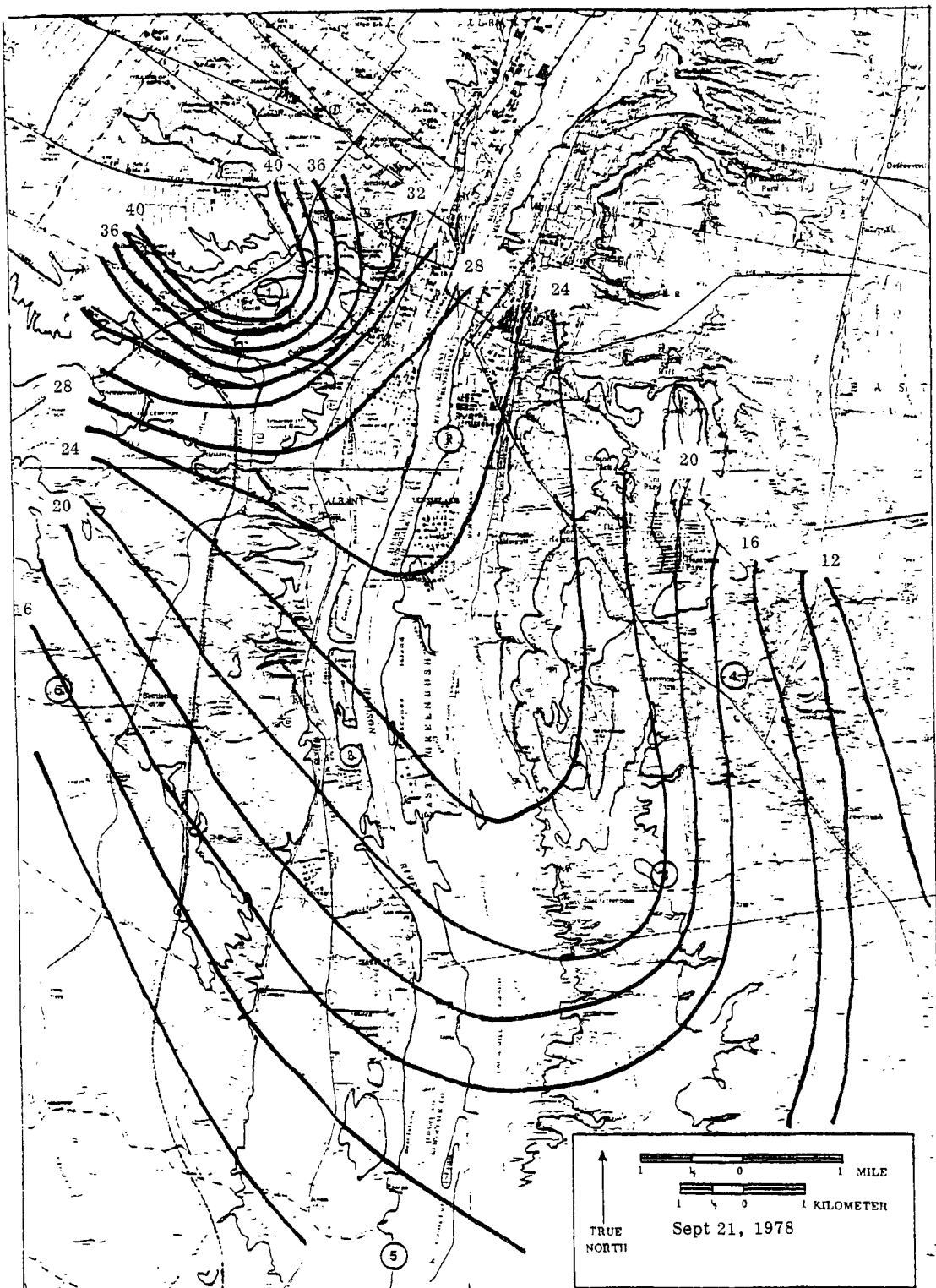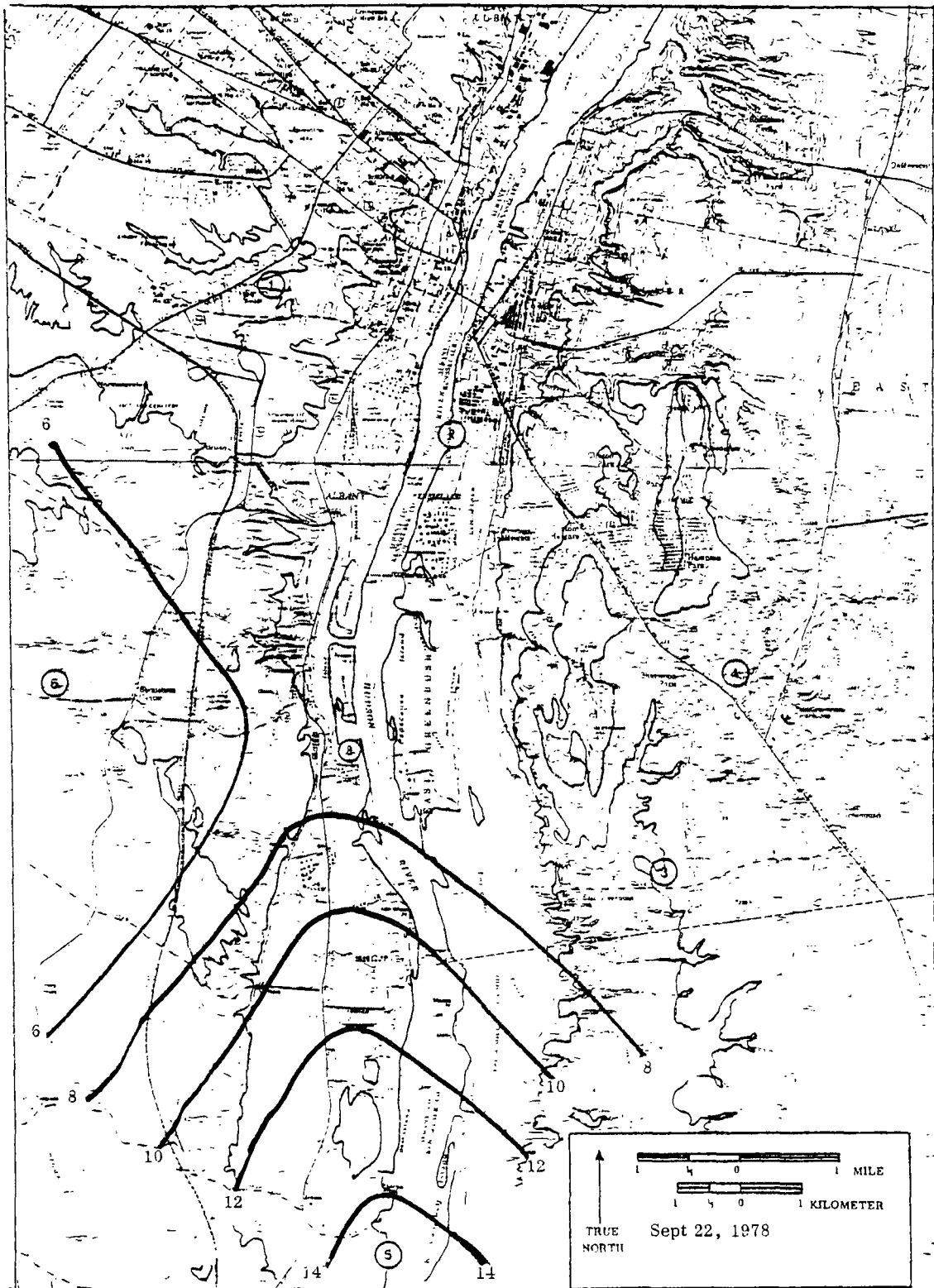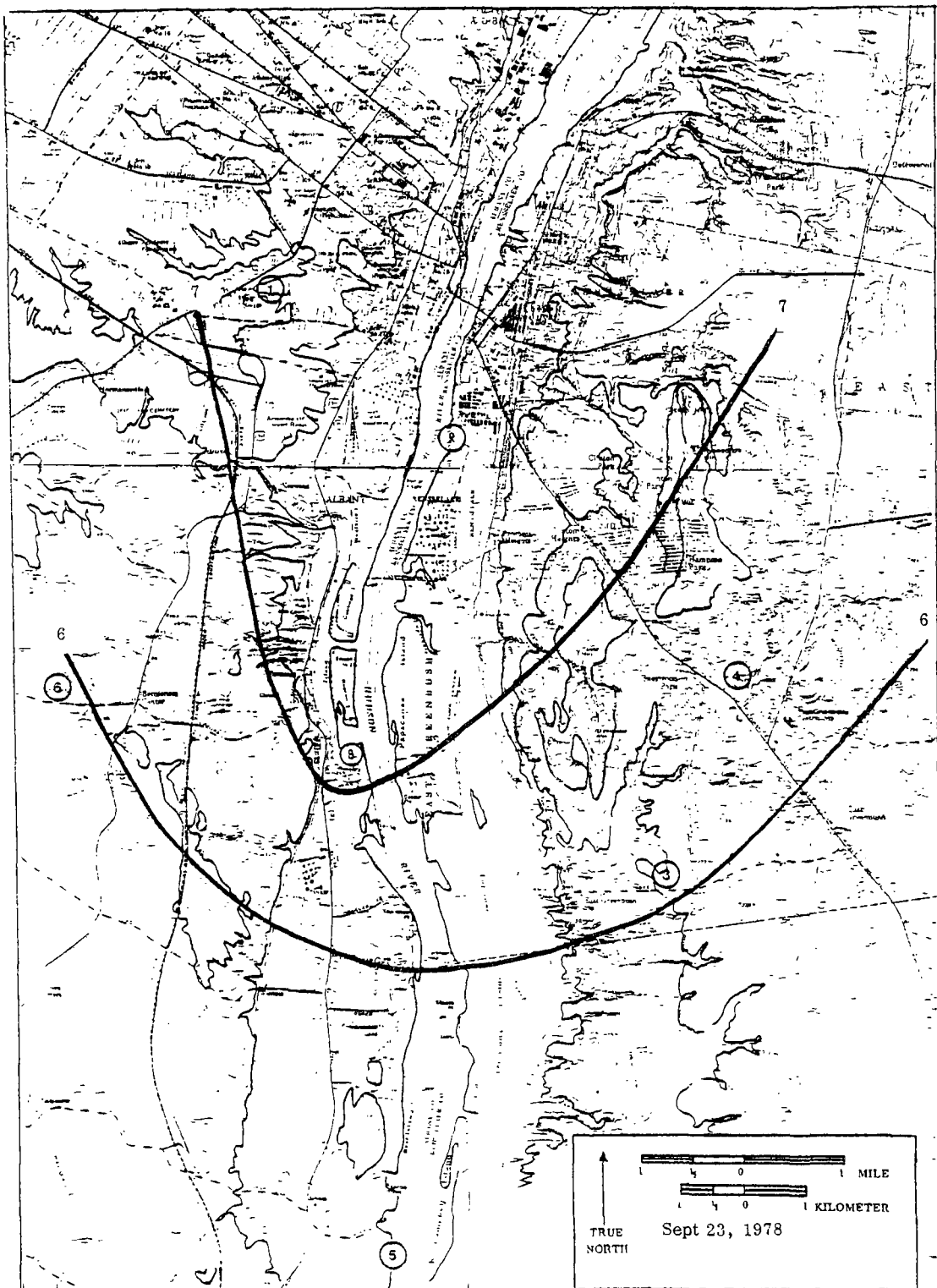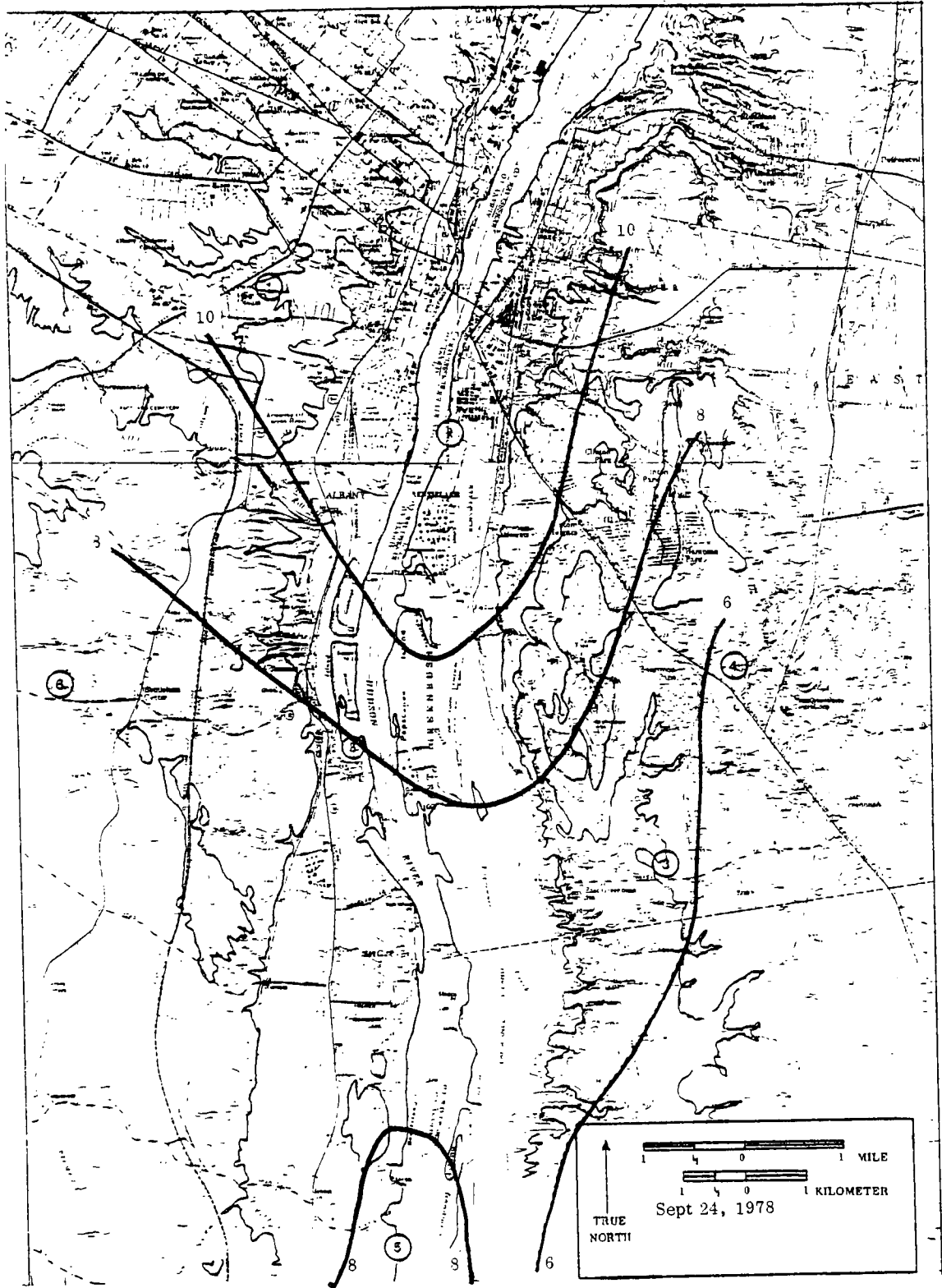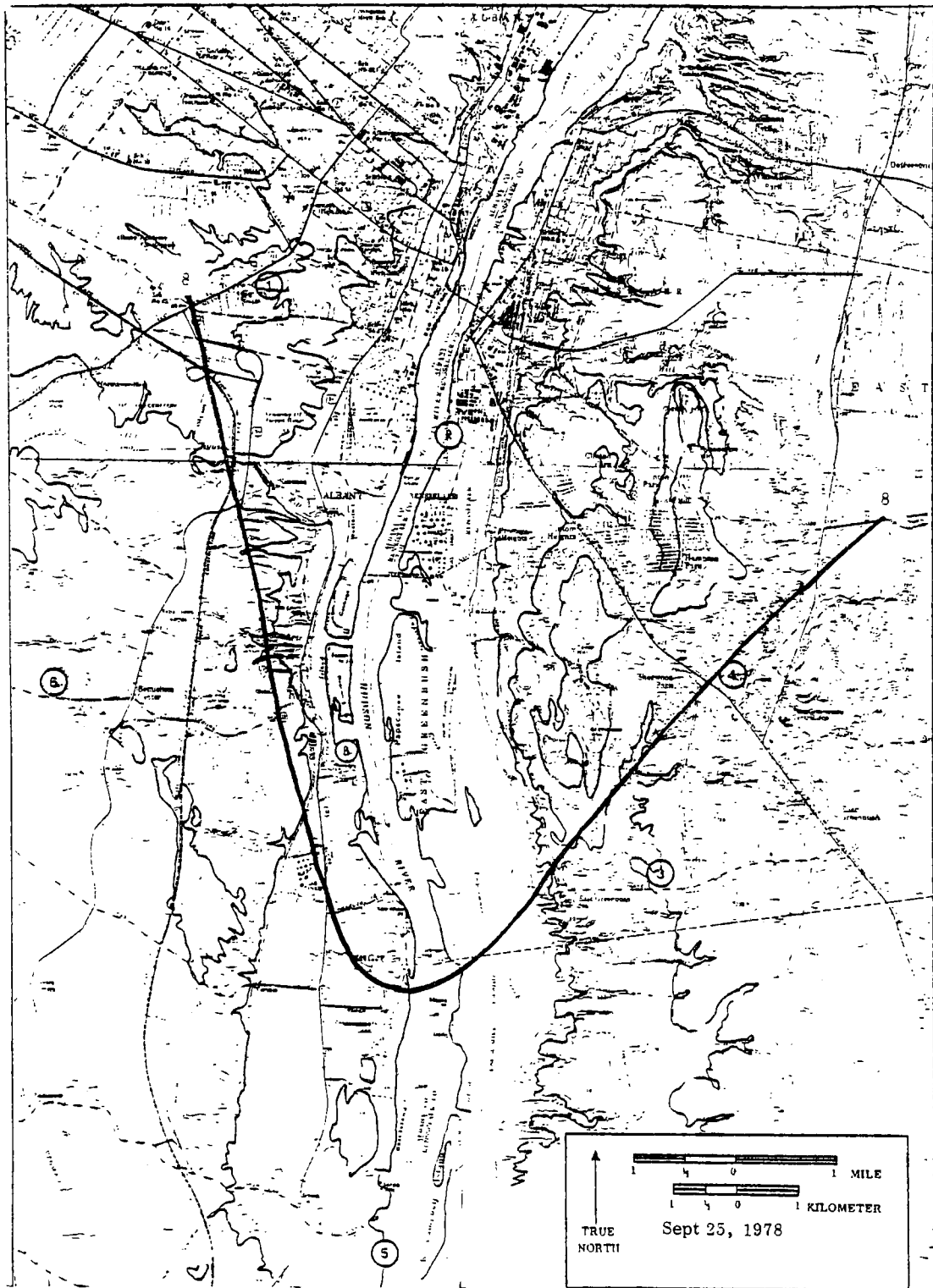
TRUE
NORTH

Sept 18, 1978

1 ¼ 0 1 MILE

1 ¼ 0 1 KILOMETER

151

FIGURE 39

Sept 19, 1978

152

FIGURE 39

Sept 20,1978

153

FIGURE   39

Sept 21, 1978

154

FIGURE 39

Sept 22, 1978

155

FIGURE   39

Sept 23, 1978

TRUE
NORTH

FIGURE 39

Sept 24, 1978

157

FIGURE 39

TRUE
NORTH

Sept 25, 1978

158

FIGURE 39

Sept 26, 1978

159

FIGURE 39

Sept 27, 1978

TRUE
NORTH

FIGURE   39

Sept 28, 1978

TRUE NORTH

FIGURE   39

Sept 29, 1978

162

FIGURE 39

Sept 30, 1978

163

FIGURE 39

TRUE NORTH   OCT 01, 1978

164

FIGURE   39

FIGURE 39

Oct 3, 1978

TRUE NORTH

166

FIGURE 39

Oct 4,1978

TRUE NORTH

FIGURE   39

FIGURE   39

TRUE
NORTH   Oct 6, 1978

FIGURE   39

Oct 7, 1978

TRUE
NORTH

FIGURE 39

TRUE
NORTH

Oct 8, 1978

1   ½   0   1   MILE

1   ½   0   1   KILOMETER

171

FIGURE   39

TRUE
NORTH   Oct 9, 1978

172

FIGURE 39

Oct 10, 1978

TRUE
NORTH

173

FIGURE 39

Oct 11, 1978

174

FIGURE   39

FIGURE 39

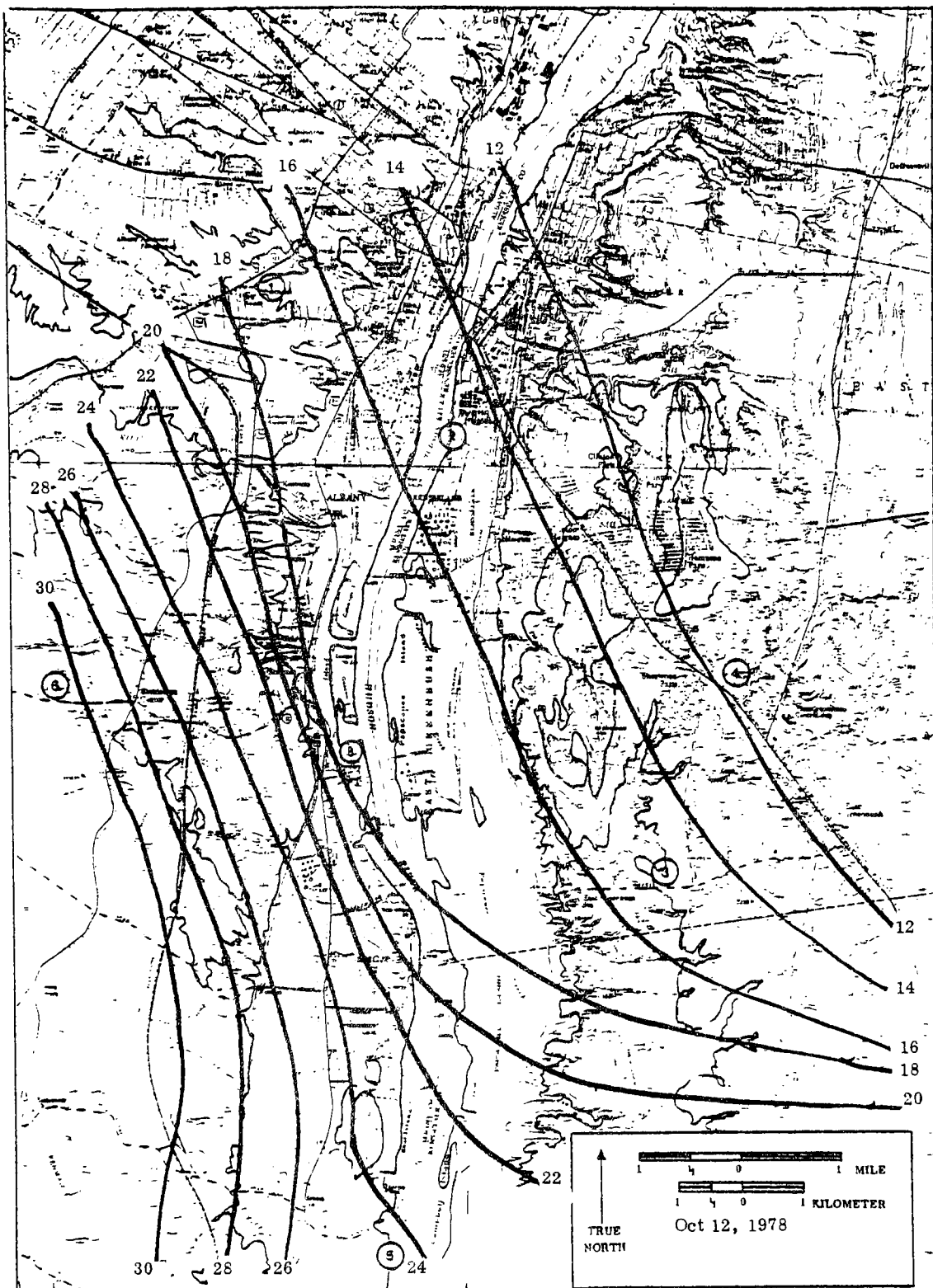

TRUE
NORTH   Oct 13, 1978

FIGURE   39

FIGURE 39

Oct 15, 1978
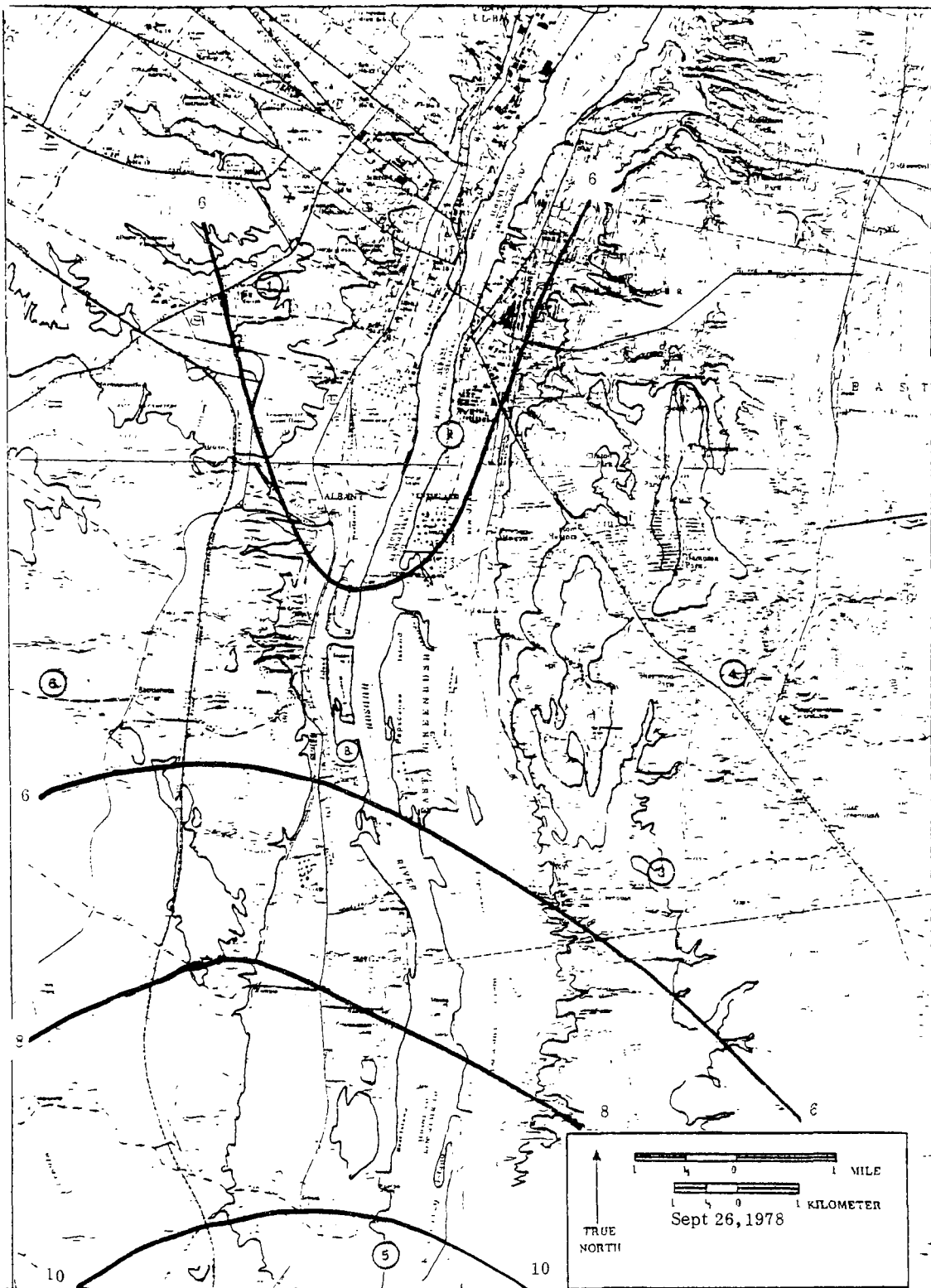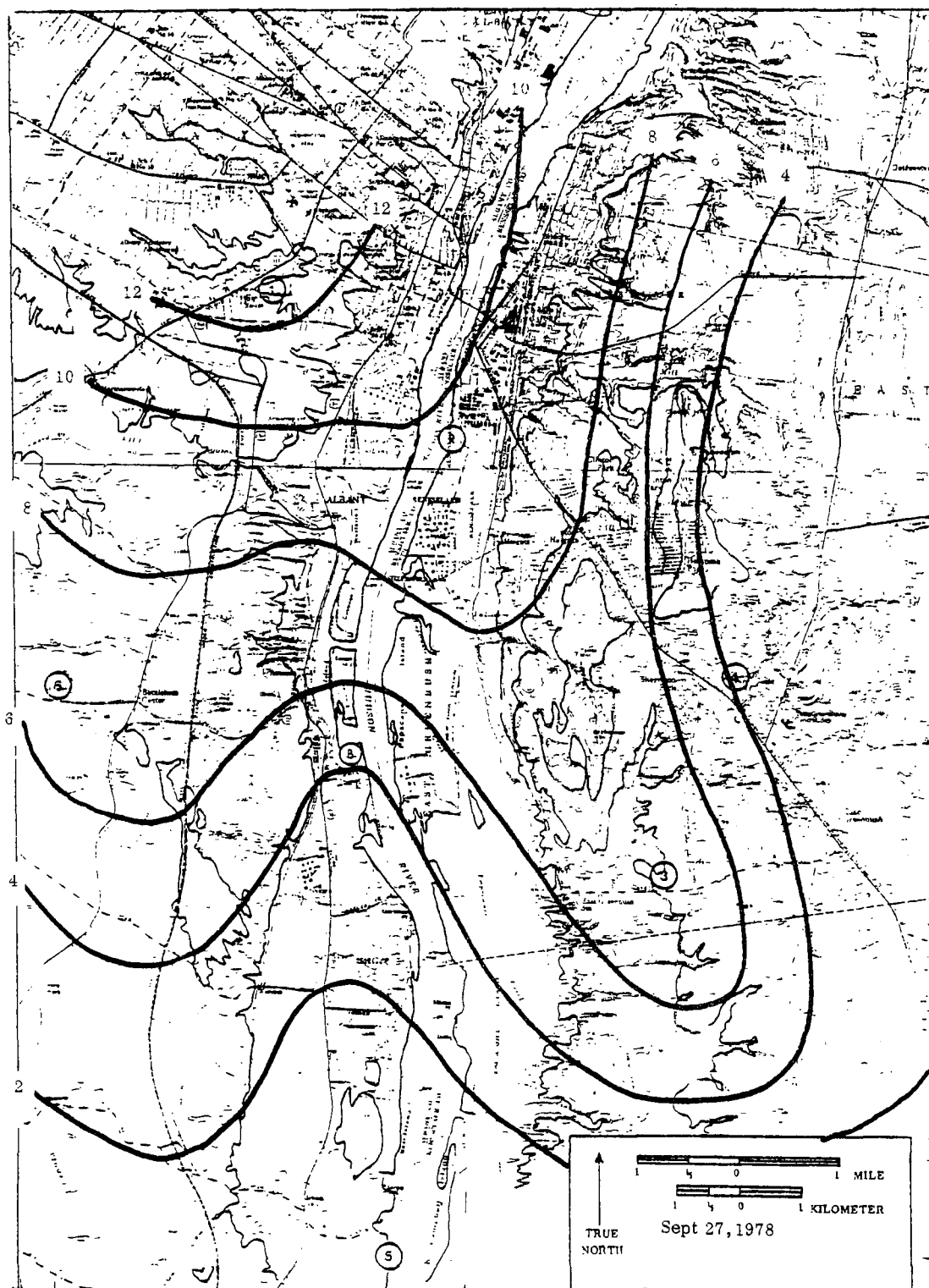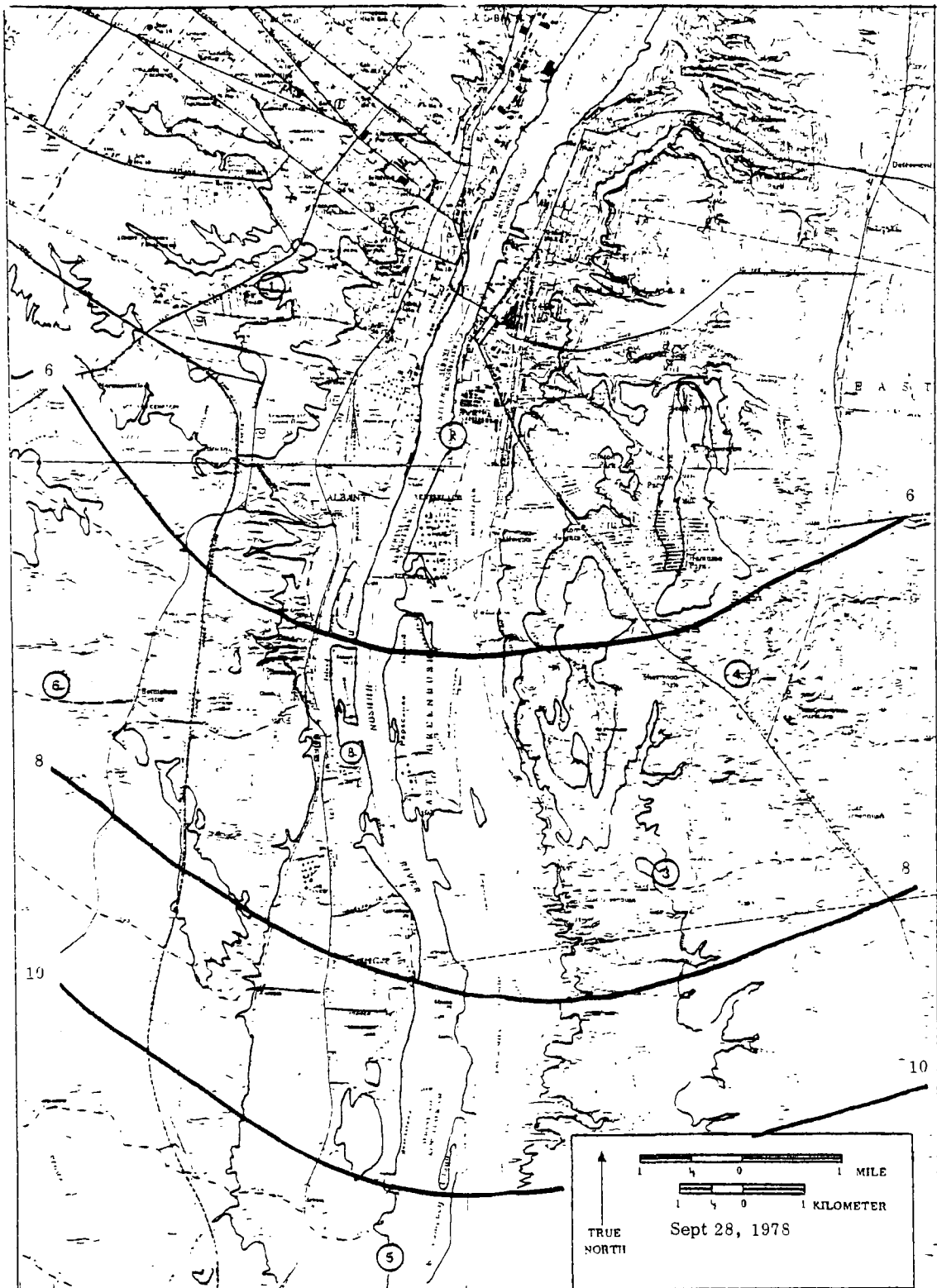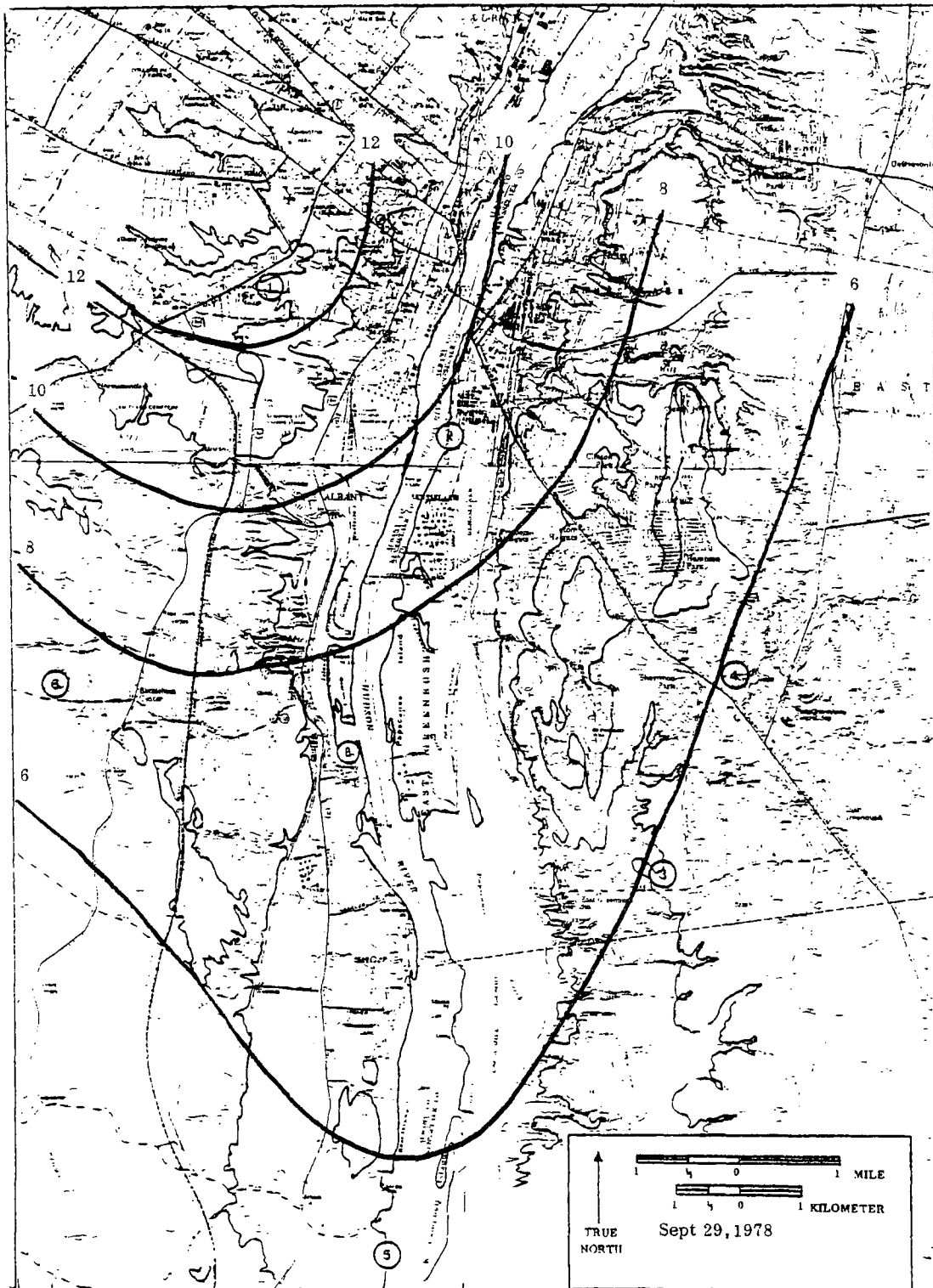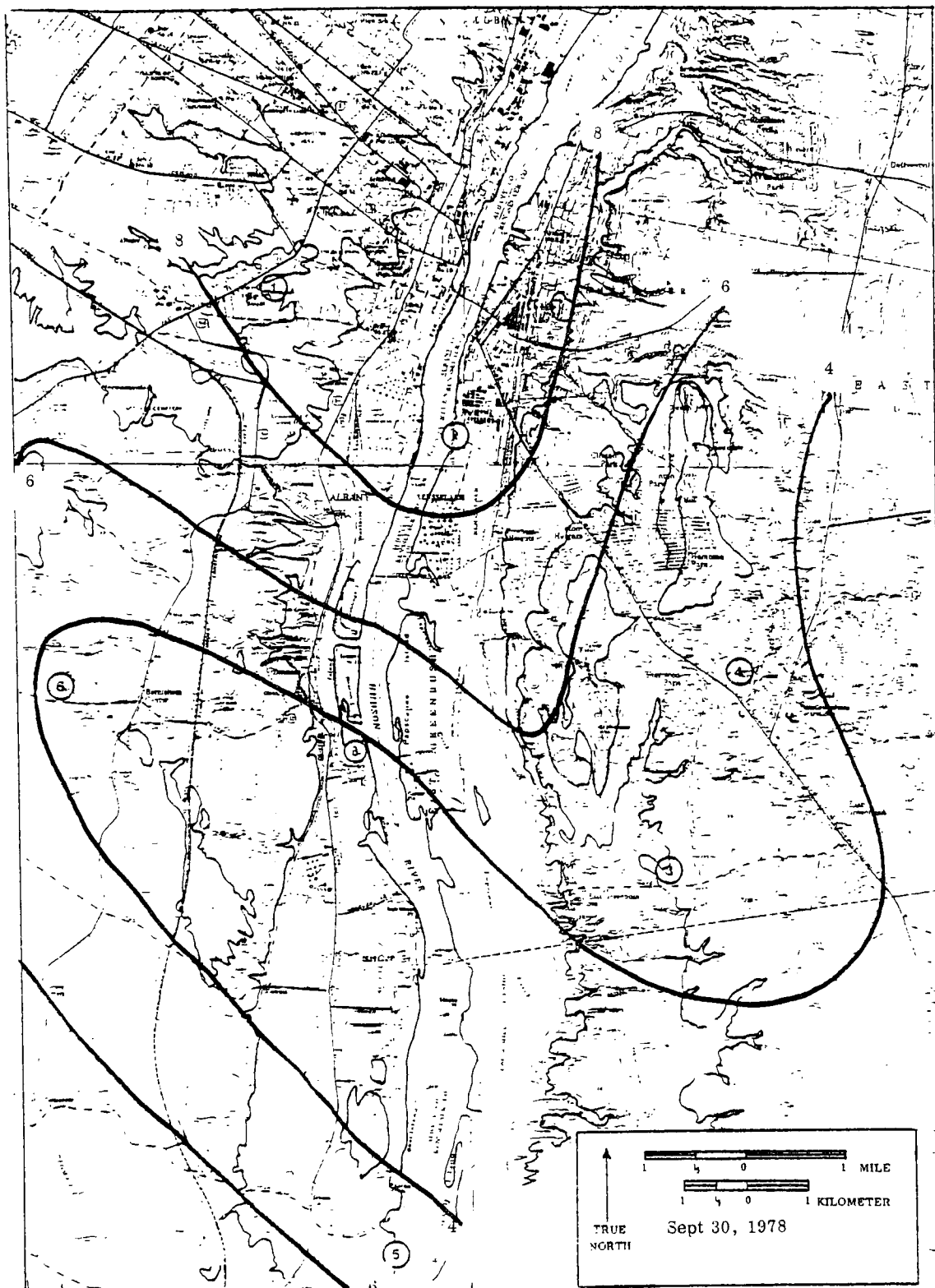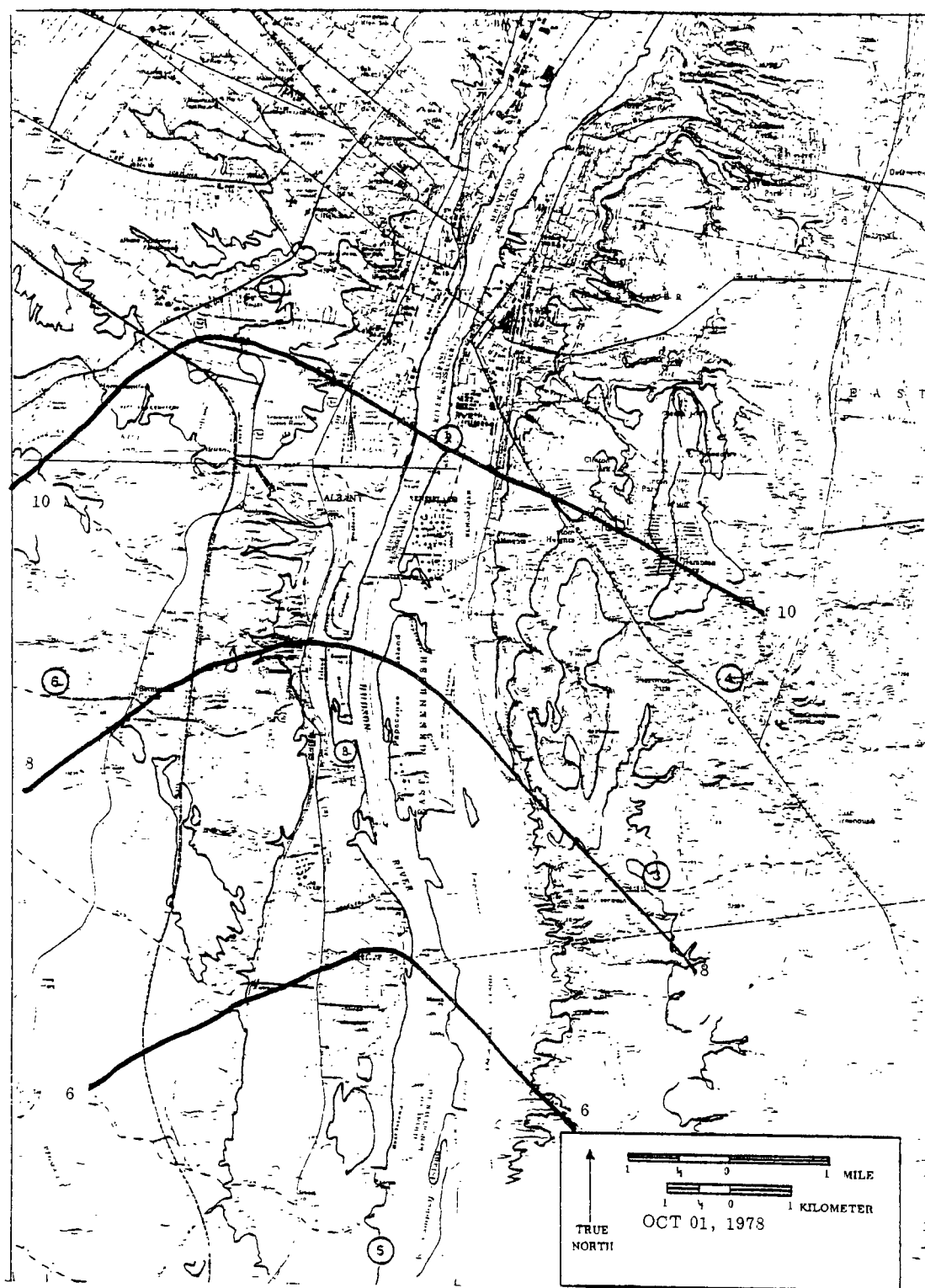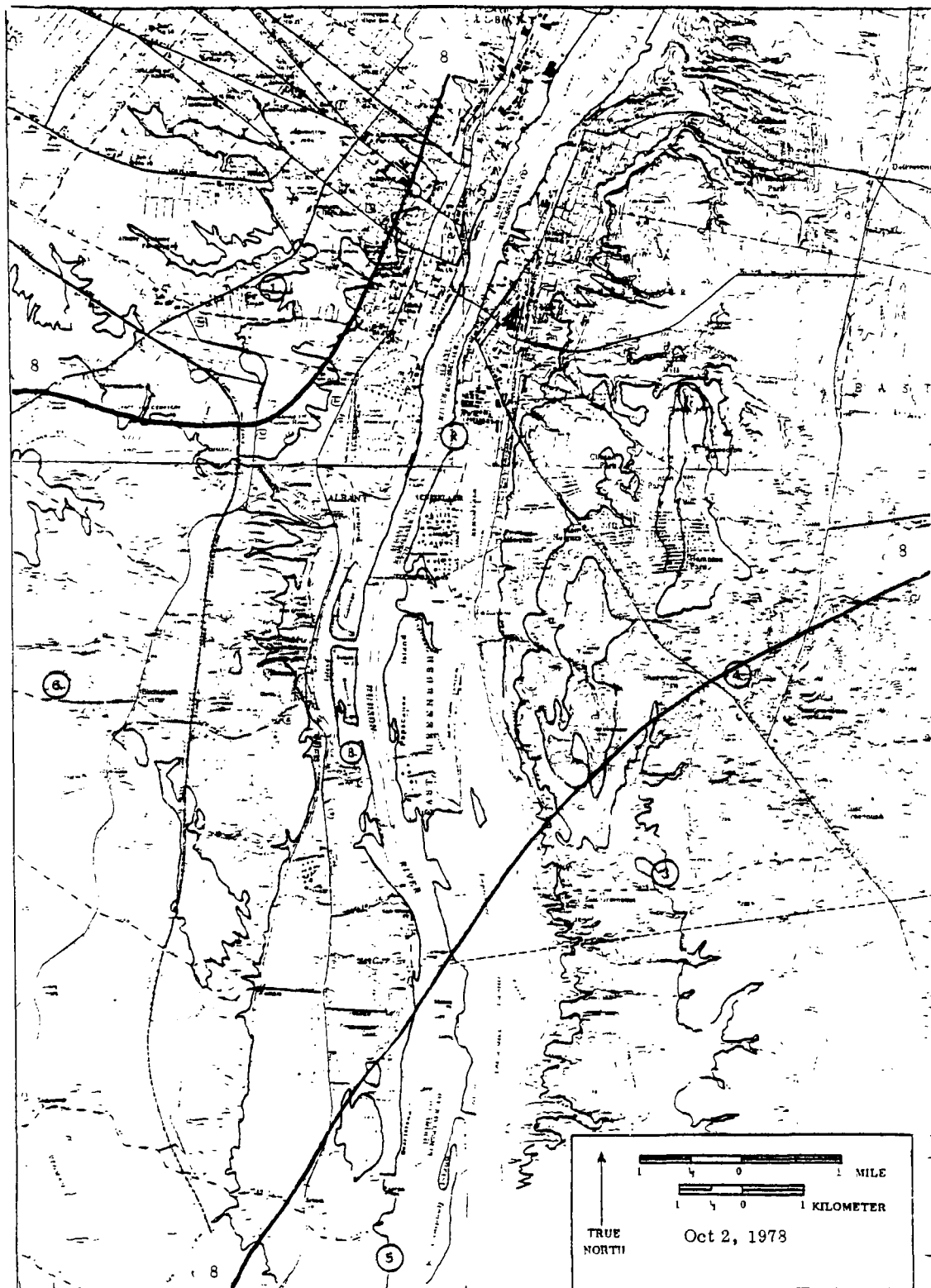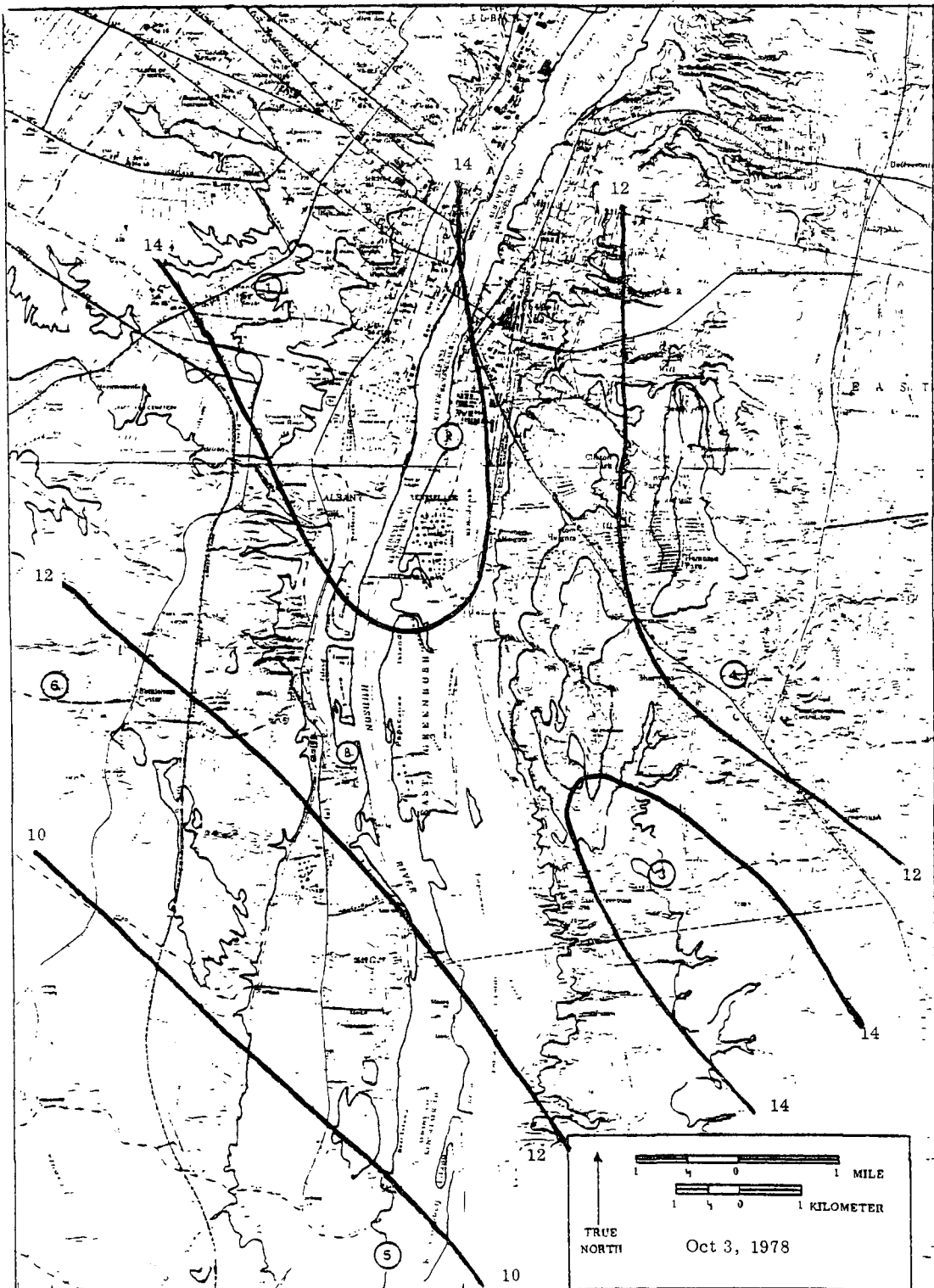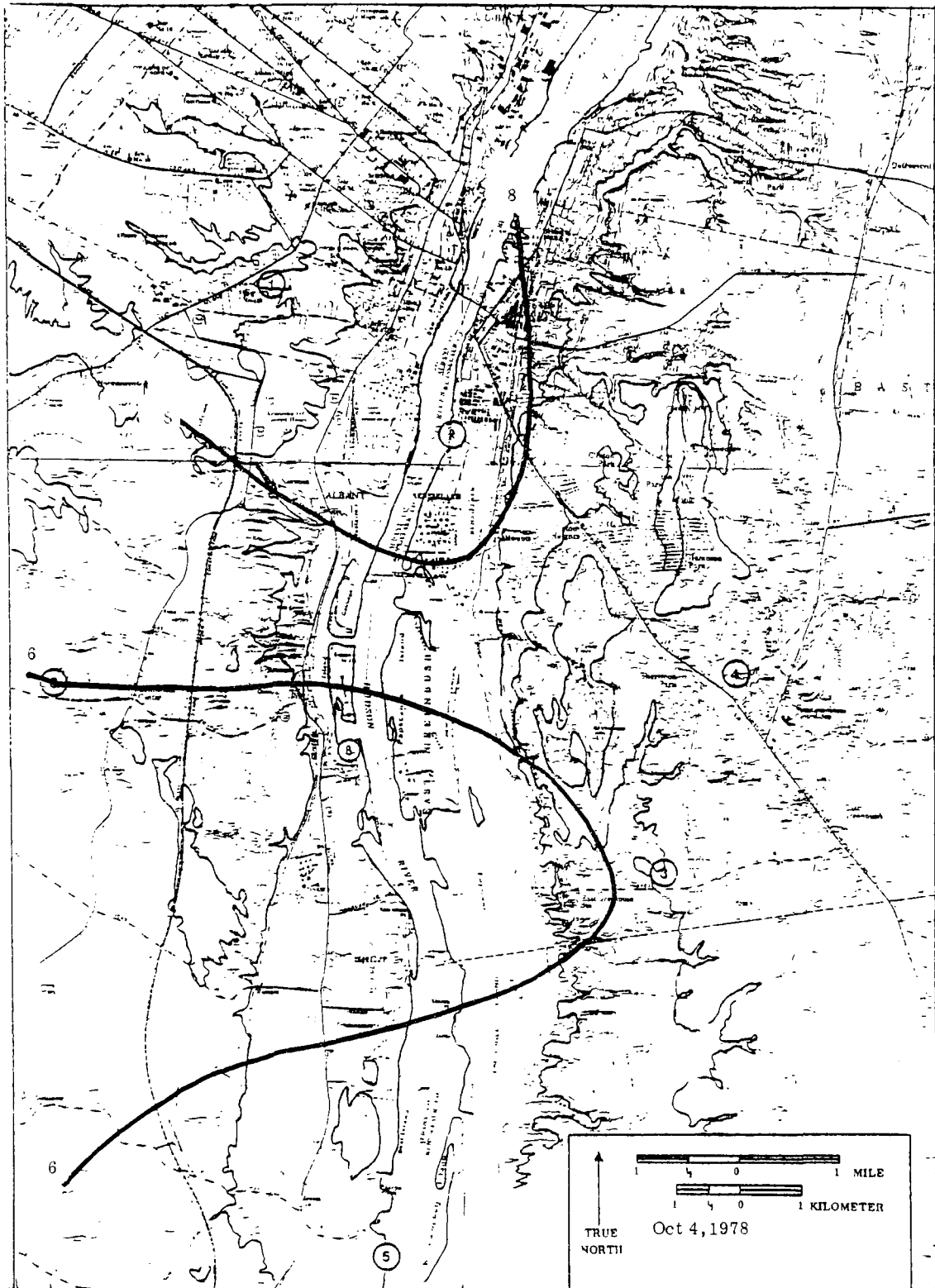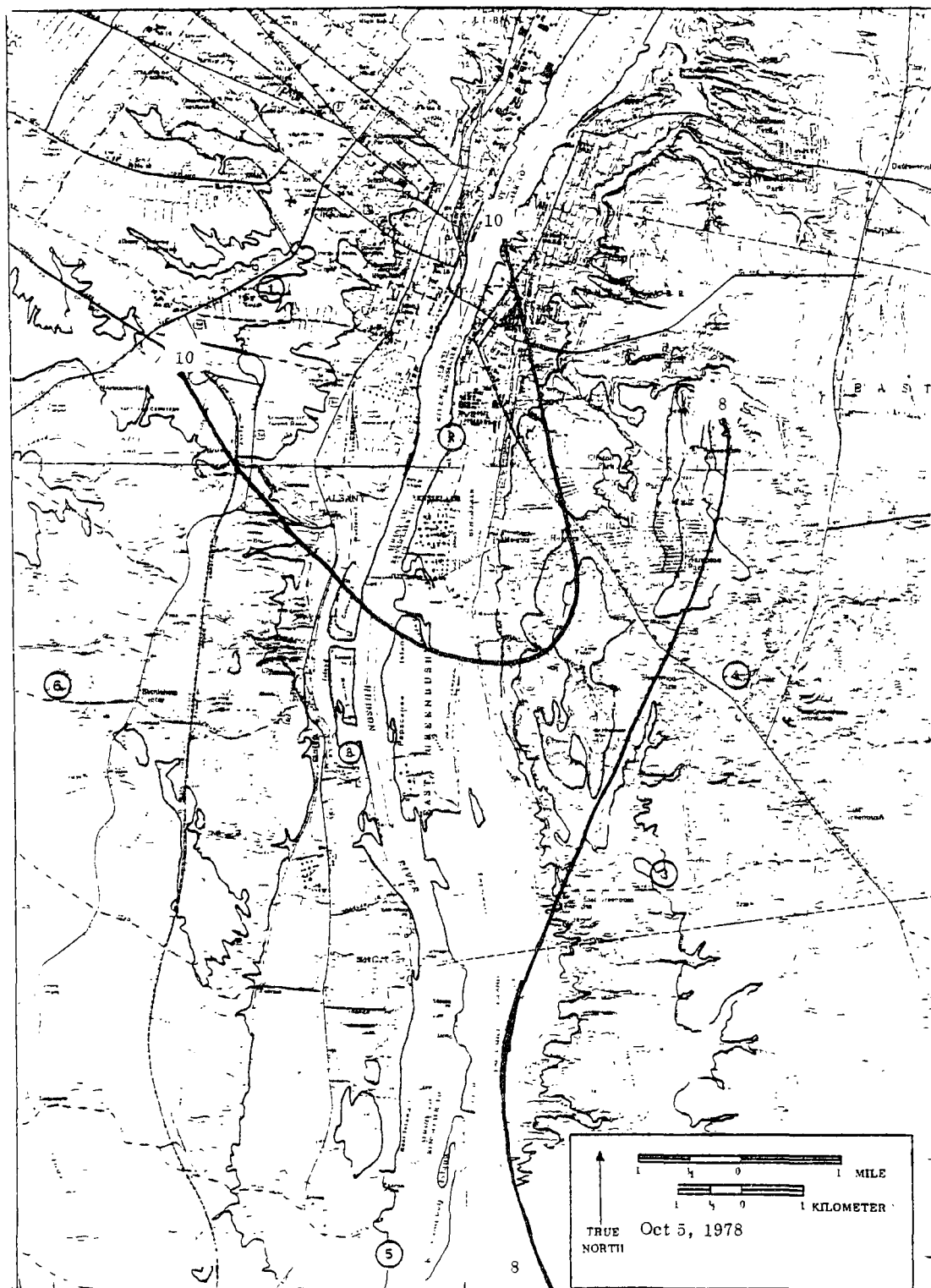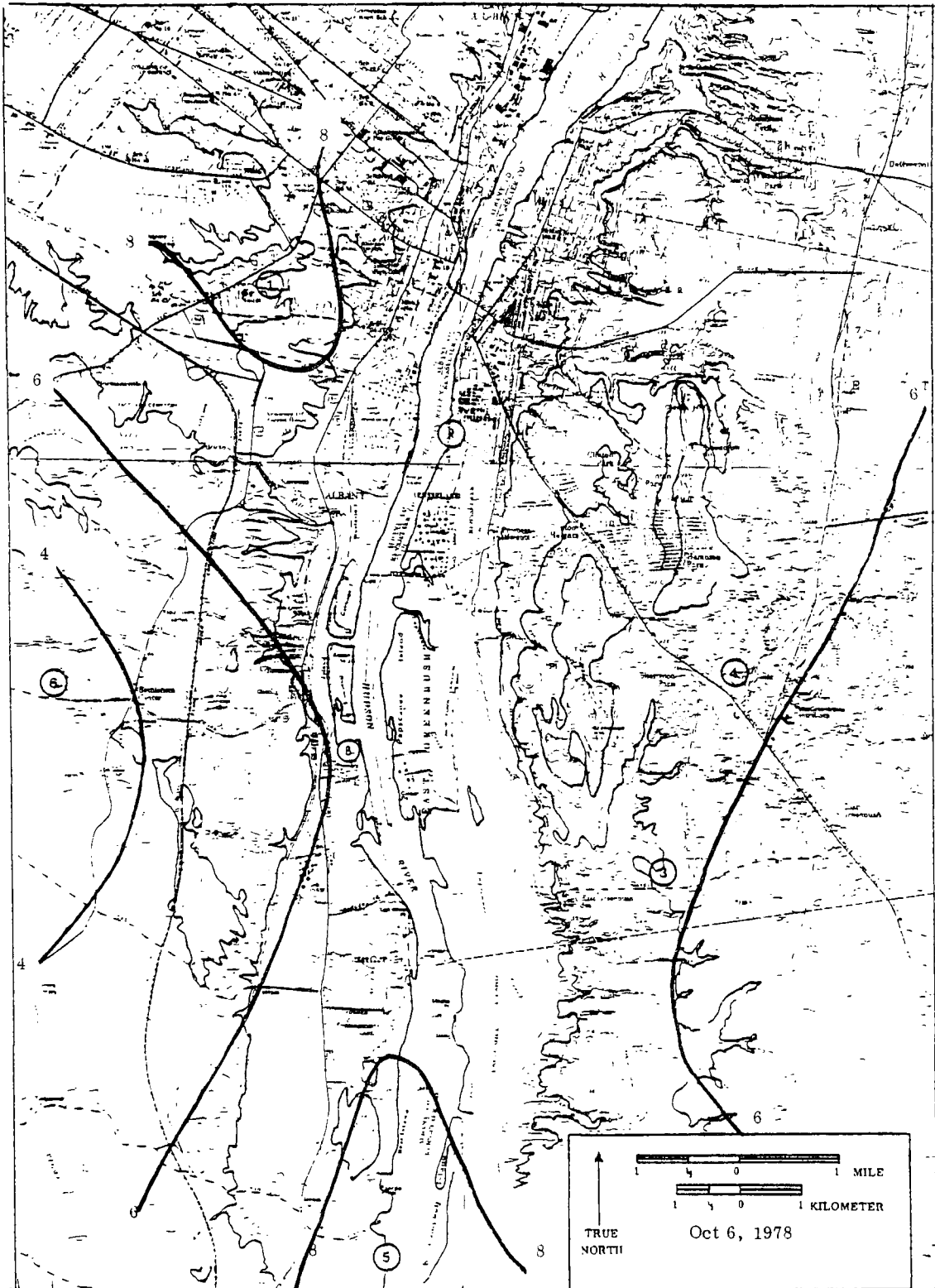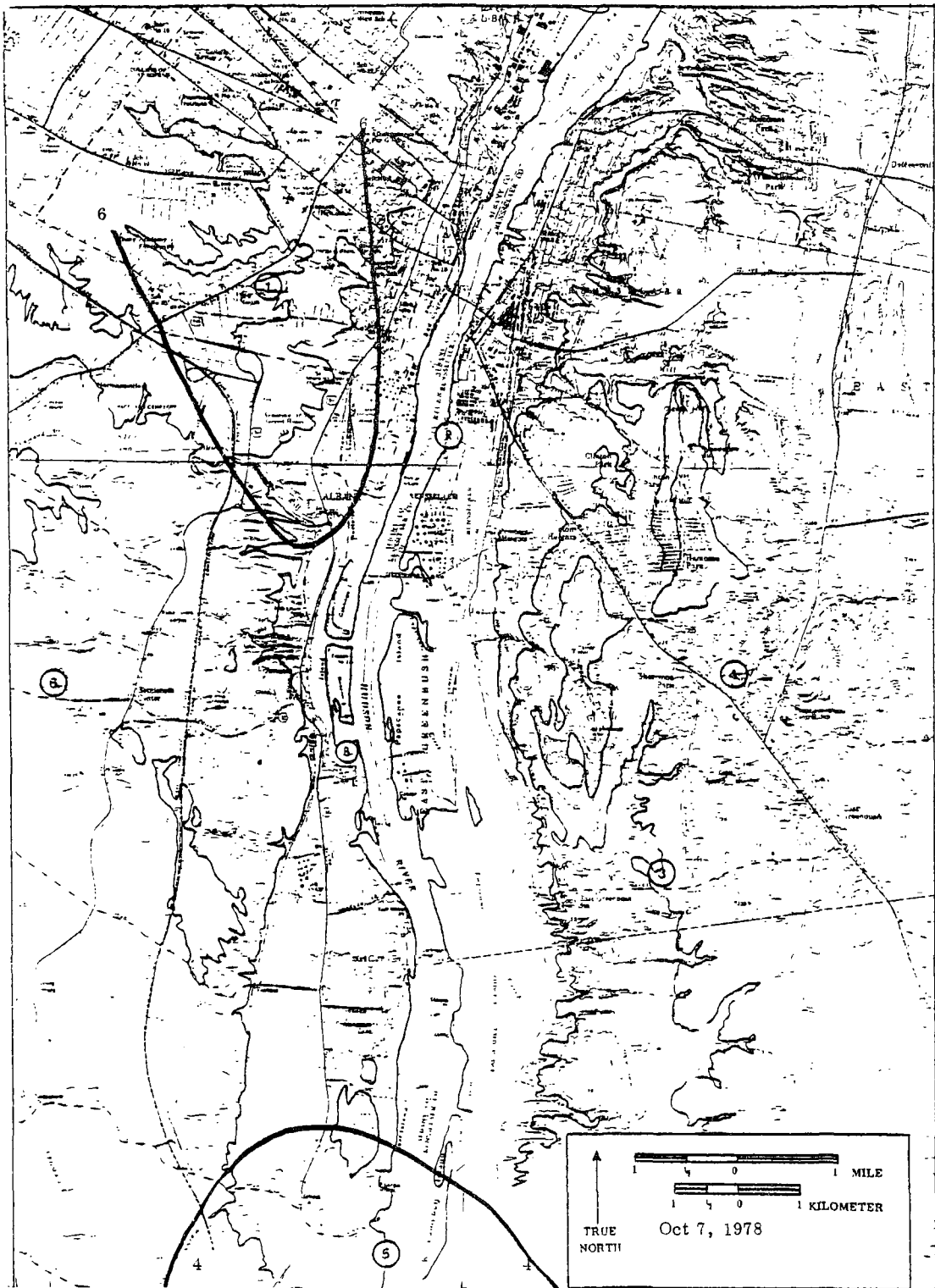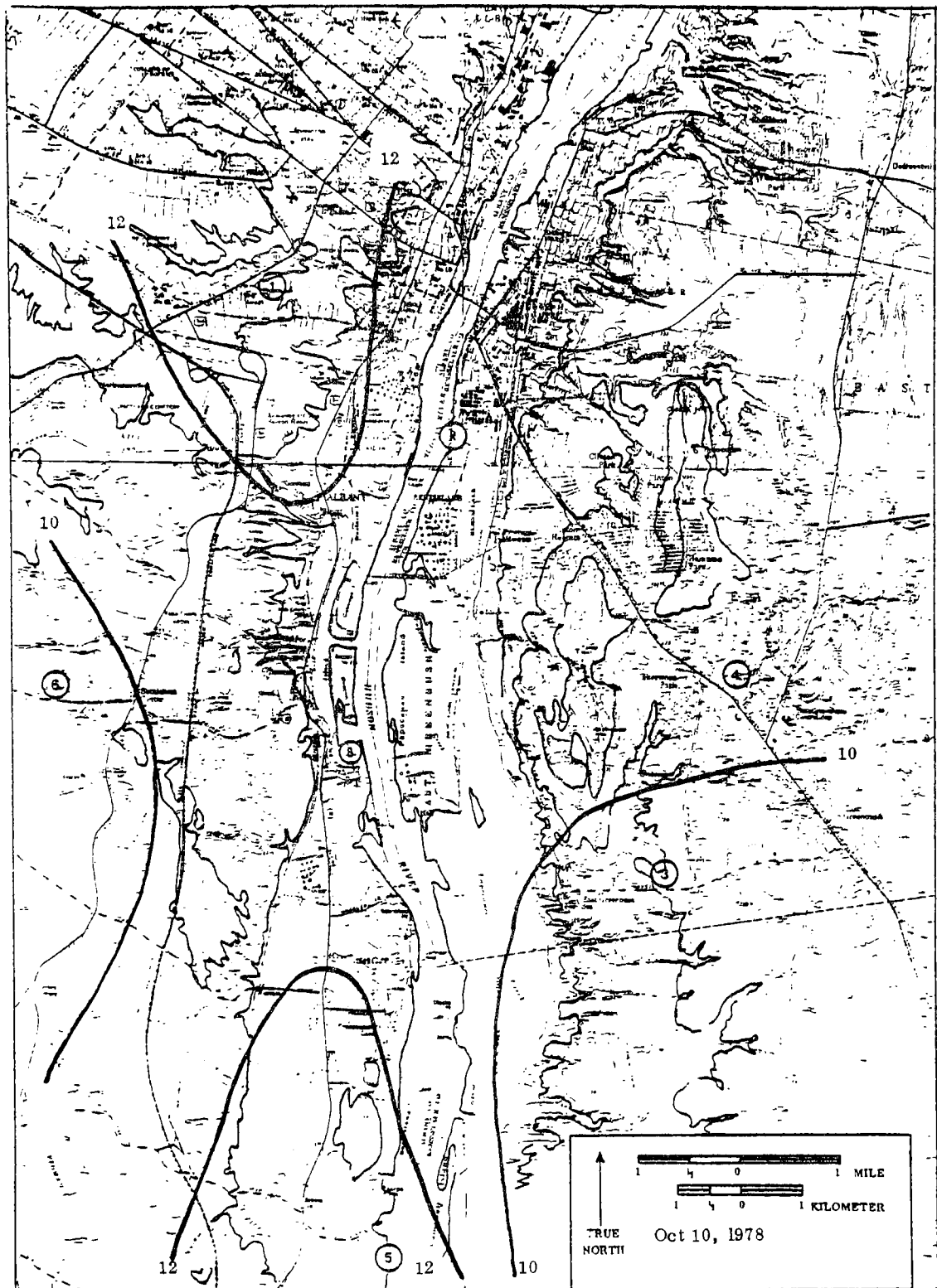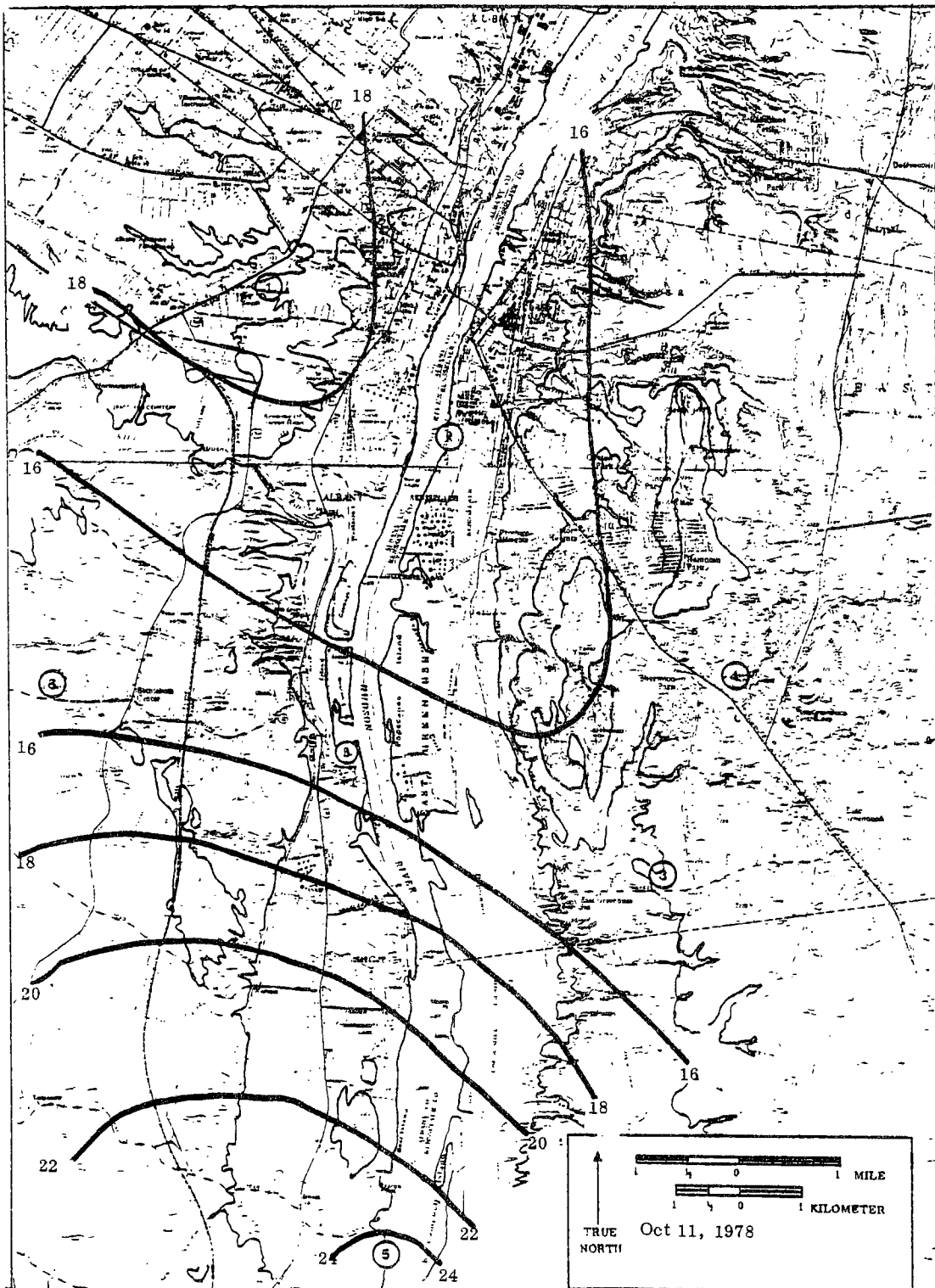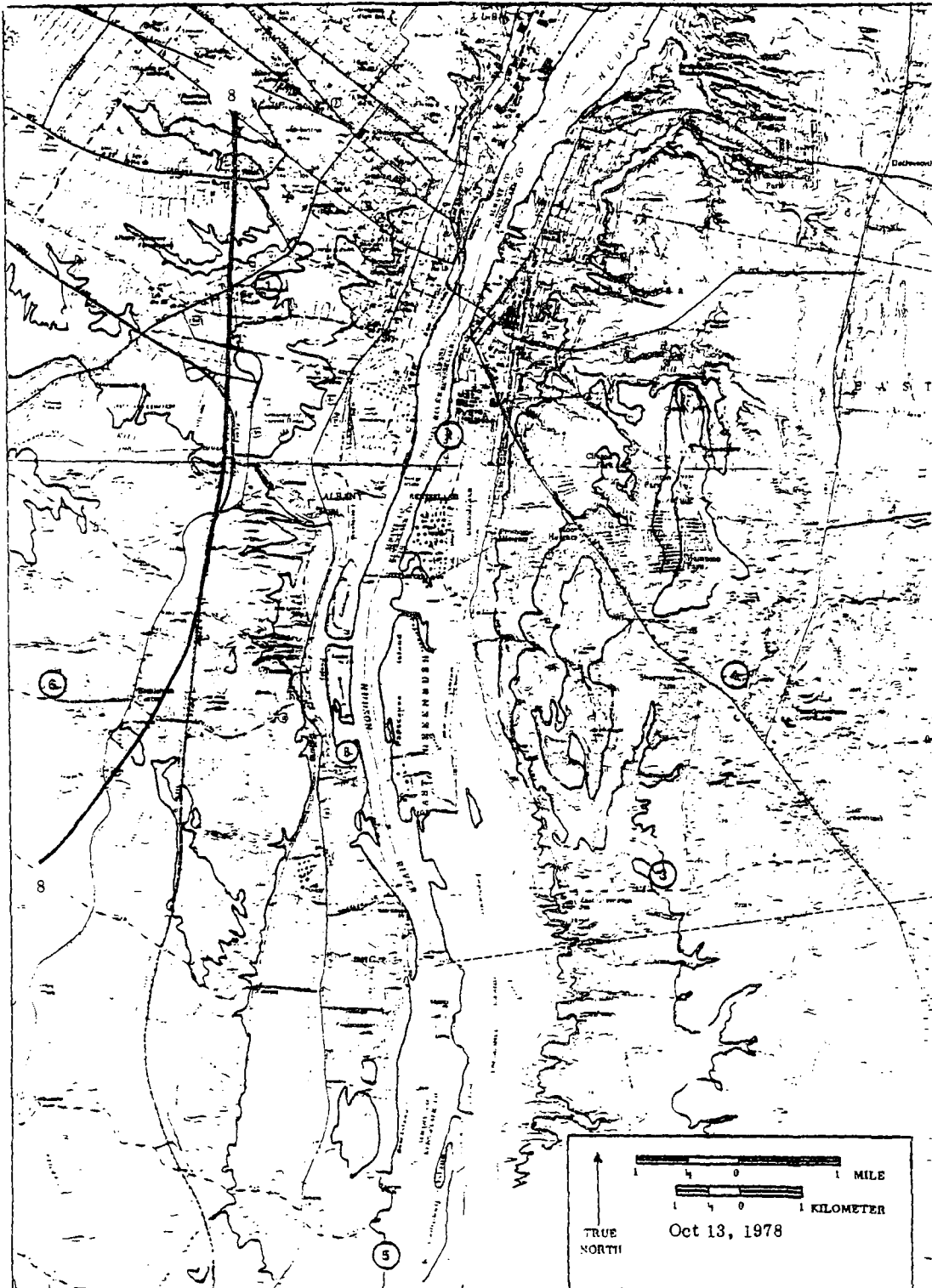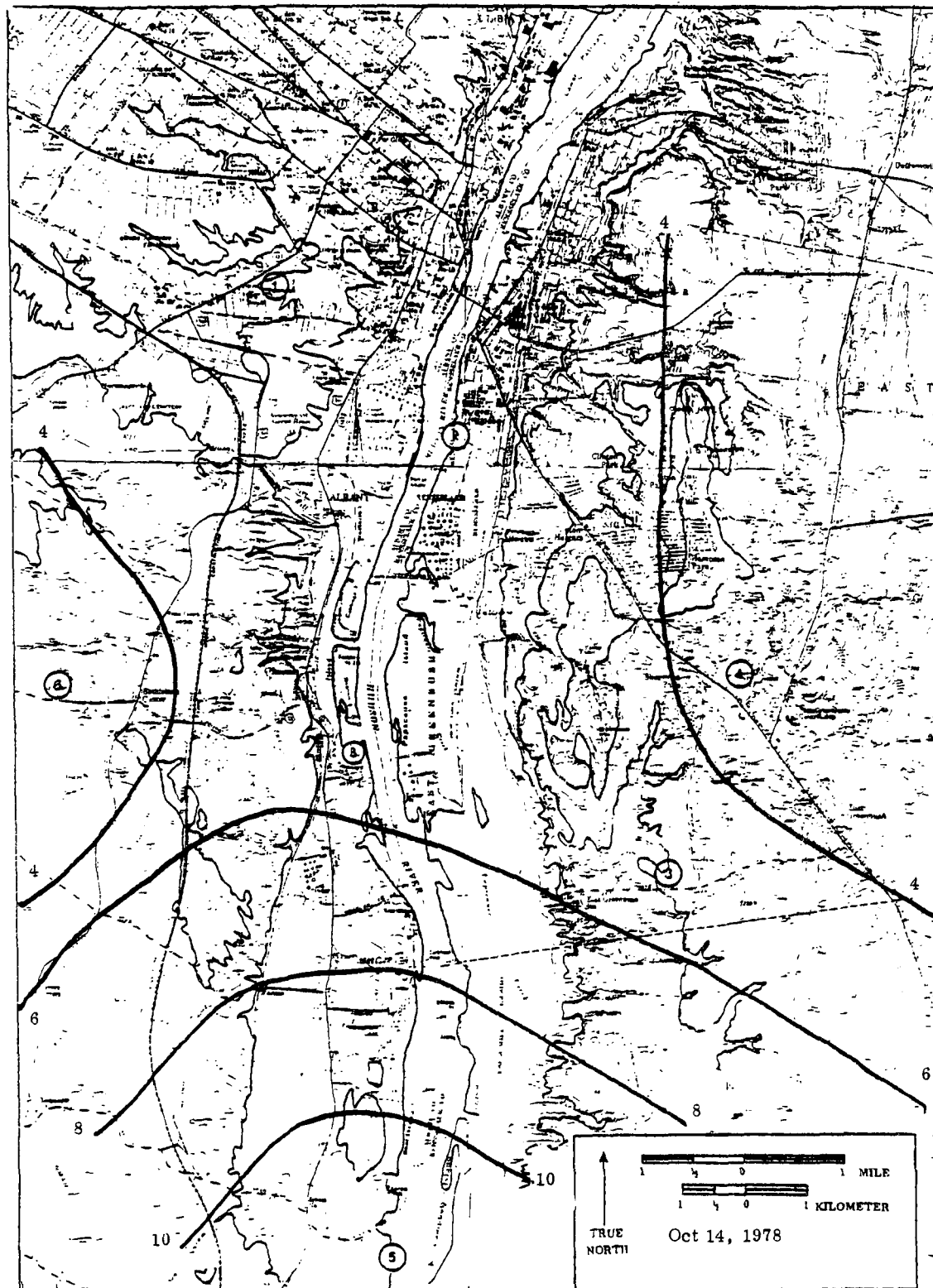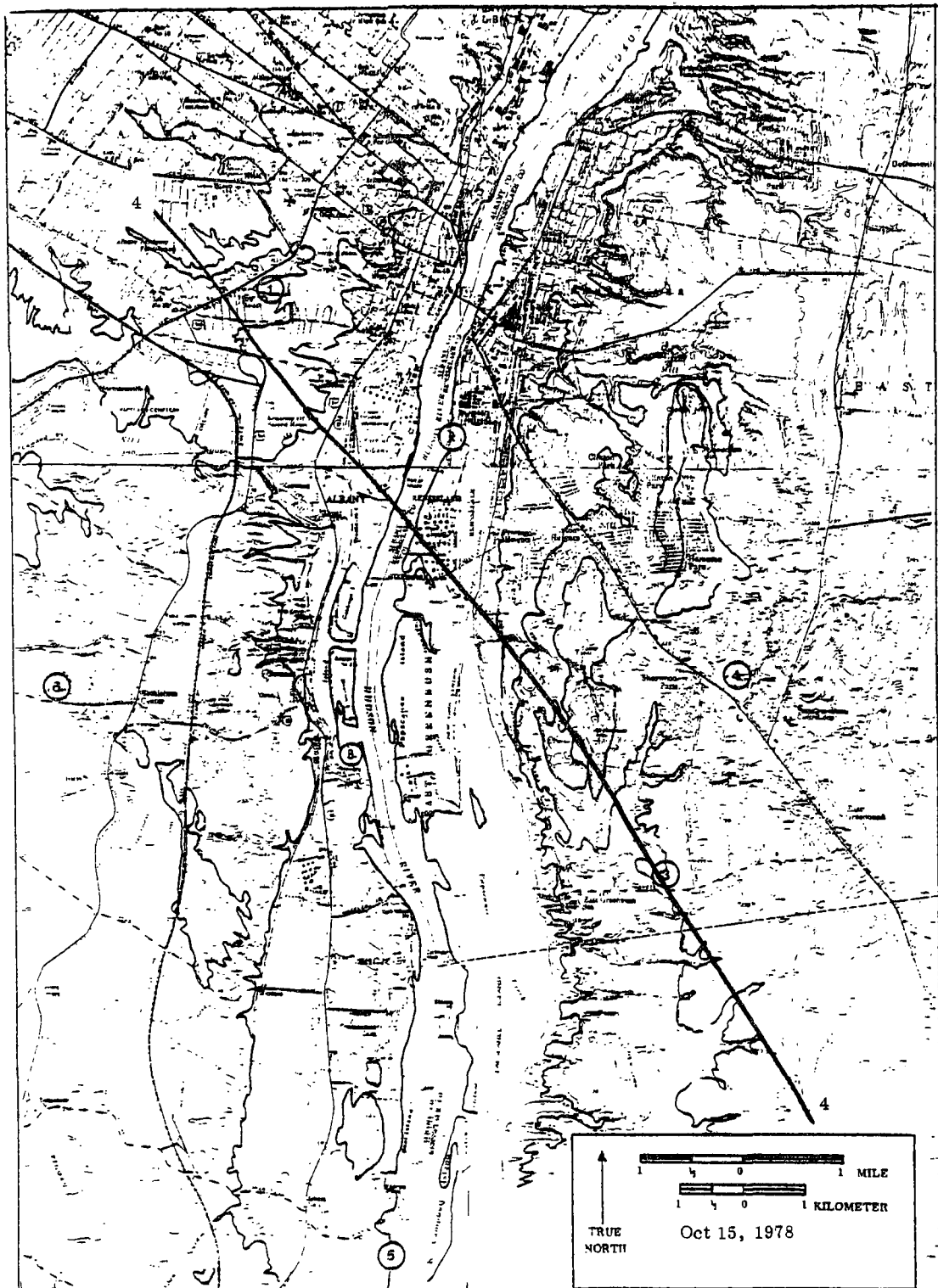
locations. The objective of this analysis was not model veri-
fication, but to obtain a general estimate of the plant's im-
pact at these locations during the study period.

The model used was a Gaussian model (Turner, 1970) that used
the Brigg's plume rise formulae (Briggs, 1969 and 1972). The
specific form of the Gaussian equation used was equation 3.1 by
Turner (1970). Topography and horizontal distances from cen-
terline were used. Stability was determined by the T measure-
ments taken on the Niagara Mohawk tower. The stability classi-
fication scheme in Safety Guide 1.23 (NRC, 1972) was used to
convert the ΔT measurements to stability classes. Wind speed
and direction measurements from the tower were also used. The
pollutant was considered as being chemically and physically
inert and that plume loss by deposition did not occur.

Hour-by-hour calculations were made for each of the ambient
monitoring locations other than the Base Station. These hourly
concentrations were then averaged to obtain the estimated 24-
hour average plant contribution at each monitoring station.

A difficulty was encountered in the modeling estimates. The
problem is determining a reliable estimate of the background
concentration. No unique method for estimating background was
considered to be universally applicable in this study. The im-
portance of background can be best understood if each observed
concentration is considered as a sum of its components. That
is:

$$\chi \, obs \quad = \chi \, plant \, + \chi \, ols \, + \chi \, lrt$$

where: $\chi \, obs$ = observed ambient concentration

$\chi \, plant$ = concentration increment due to source

$\chi \, ols$ = concentration increment due to other

local sources

$\chi \, lrt$ = concentration increment due to long range

transport

The background concentration at any station is the sum of χols and χlrt. The value χlrt is probably uniform at the stations used in this study, but χols is not uniform at each station. Therefore, a uniform background concentration is difficult to apply to all stations.

In this study it was noticed that the winds rarely carried the plant plume towards Site 6. Thus, one attempt of estimating background was to consider the observed concentration at Site 6 as an estimate of the background concentration. Table 36 provides an analysis when Site 6 is used as an estimate of background. The values presented are values obtained from the following ratio:

$$\frac{\chi \; Plant}{\chi \, obs \, = \, (\chi \, ols \, + \, \chi \, lrt)}$$

What Table 36 suggests is that the plant increment in this study was a small value compared to the two relatively larger values of observed and background. Thus, any reasonable error in either of the two is probably of equal or greater magnitude than the plant's increment. This is a condition that exists for both SO_2 and $SO_4^=$ as indicated by the Site 1 data.

ANALYSIS OF AIR QUALITY MEASUREMENTS

A statistical analysis of variance was performed, using the combination of the (upper level) tower wind direction data and the ground-level air quality measurements. The analysis of

TABLE 36
RATIO OF ESTIMATED TO OBSERVED
(LESS SITE 6) 24-HOUR CONCENTRATIONS
CUMULATIVE PERCENT

Range Of Ratio	Rensselaer SO_2	Site 5 SO_2	Site 1 SO_2	Site 1 $SO_4=$
<0.0001	50.0	59.1	32.1	48.0
0.0001-0.0099	54.1	63.6	35.7	56.0
0.01-0.09	70.8	72.7	64.3	68.0
0.1-0.9	100.0	81.8	89.3	100.0
>1.0	100.0	100.8	100.0	100.0

variance tests is the difference between the means of two or more groups for significance. The sulfate, vanadium, and sulfur dioxide measurements were used as observations (or data points), while the site designation and the wind direction were used as groups. The variance ratio σ_x^2/σ_y^2 (or F value) was the criterion for testing the null hypothesis: that the means of the observations were the same in both groups.

Since the prevailing wind direction travelled the line of the Hudson Valley, North to South or South to North on 21 days of the 28 day program, the measurements made at the North and South sites (Sites 1 and 5) were used exclusively. A site was designated downwind when the wind blew toward that site ($\pm$ 45°) fourteen hours or more on a particular day. The complementary site was designated upwind, and non-affected sites were designated neutral.

A two-way analysis of variance was performed on the observations using site designation and wind direction groupings. The result of the analysis of variance is as follows:

SULFUR DIOXIDE

	Degrees of Freedom	F Value
Site	1	18.90**
Wind	2	3.33*
Site x Wind	2	1.61
Error	46	

VANADIUM

	Degrees of Freedom	
Site	1	34.75**
Wind	2	10.29**
Site x Wind	2	9.52**
Error	44	

182

<u>SULFATE</u>

	Degrees of Freedom	F Value
Site	1	.13
Wind	2	.74
Site x Wind	2	6.04**
Error	44	

*Significant at the 5% level

**Significant at the 1% level

The results of the analysis of variance for vanadium and sulfate are significant for the interaction of wind direction and site designation. The results indicate sulfur dioxide significance due to site designation and wind direction, but the interaction does not indicate significance. This means that the effects of site designation and wind direction are additive. To illustrate, the population mean of sulfur dioxide concentration, without regard to site designation or wind direction is u. When all sulfur dioxide values at a particular site are grouped together, the mean value becomes u + a. When all sulfur dioxide values are grouped under a particular wind direction, the mean becomes u + B. If the effect is additive, then the mean of all sulfur dioxide values at a particular site, when the wind is in a particular direction, is u + a + B. This leads one to the conclusion that sulfur dioxide fits a relatively simple model, which shows that the concentration is related to wind direction, regardless of whether the measurement was made upwind or downwind of the plant.

The results of the interaction of site designation and wind direction are significant with respect to sulfate and vanadium concentration. This indicates a more complex relationship between the population and the groupings than the one described above. In order to assess the significance of this relationship, a further one-way analysis of variance was performed

183

for each designated site using the sulfate and the vanadium
populations. Results are as follows:

Site 1

	Degrees Of Freedom	F Value SO$_4$	F Value Vanadium
Wind	2	5.26*	16.15**
Error	25		

Site 5

	Degrees Of Freedom	F Value SO$_4$	F Value Vanadium
Wind	2	2.21	1.64
Error	22		

*Significant at the 5% level
**Significant at the 1% level

The significant F values at Site 1 indicate that a definite
repeatable relationship exists between wind direction and
ground-level sulfate and vanadium concentrations.

Non-significant F-values at Site 5 indicate that concentrations
on the upwind days are not necessarily higher or lower than the
concentrations on downwind days. The mean concentrations pre-
sented on Table 37 clarify these results.

TABLE 37

SITE ANALYSIS

MEAN CONCENTRATIONS

	Site 1	Site 5
Sulfate - ug/m^3		
Downwind	15.504	6.940
Upwind	6.063	12.410
Sulfur Dioxide - ug/m^3		
Downwind	63.537	20.154
Upwind	28.352	13.727
Vanadium - ug/m^3		
Downwind	.0605	.0099
Upwind	.0162	.0085

It is clear that the concentration of sulfate is much higher at Site 5 when Site 5 is the upwind site than at Site 1 when Site 1 is the upwind site. The implication is that a considerable amount of sulfate material is carried from other, possibly distant, sources with the air movement from South to North. Both sulfur dioxide and vanadium concentrations, however, are at relatively low levels at Site 5 on both upwind days and downwind days. This indicates less contribution of sulfur dioxide and vanadium than sulfate from other emission sources.

The distributions of these air quality measurements are reflected in Figures 40 through 43; also shown are the relationships between sulfate and vanadium, and between sulfate and sulfur dioxide. The high sulfate and low vanadium values at Site 5-upwind (see Figure 41), show that while vanadium levels are quite low, sulfate levels are moderate-to-high and are independent from vanadium levels. A similar relationship exists between sulfate and sulfur dioxide measurements upwind at this site (see Figure 42); these results show apparent independence of sulfate from sulfur dioxide. Downwind measurements at Site

FIGURE 40

SULFATE/VANADIUM AT SAMPLING SITE

SOUTH OF EMISSION SOURCE

SITE 5

Downwind Days

Upwind or Neutral Days

186
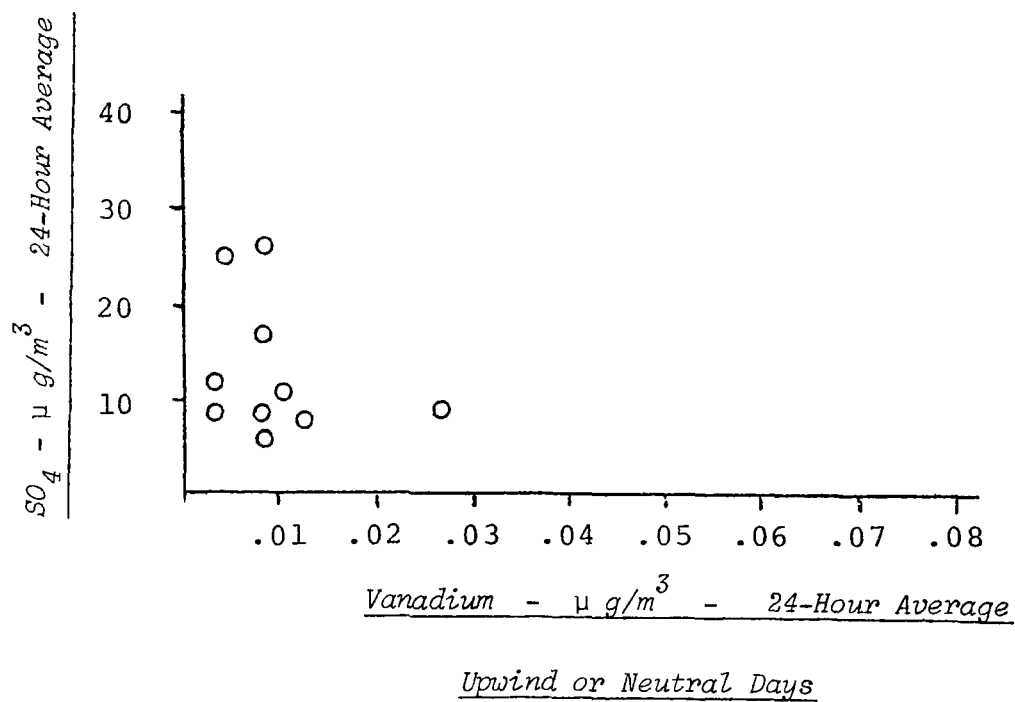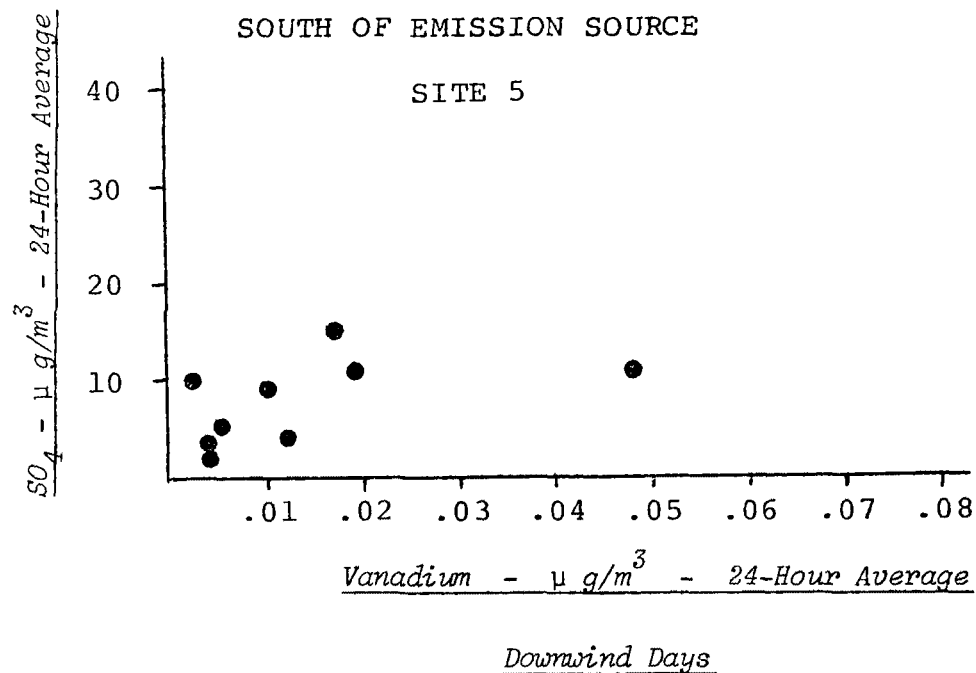
FIGURE 41

SULFATE/SULFUR DIOXIDE AT SAMPLING SITE

SOUTH OF EMISSION SOURCE

SITE 5

Downwind Days

Upwind or Neutral Days
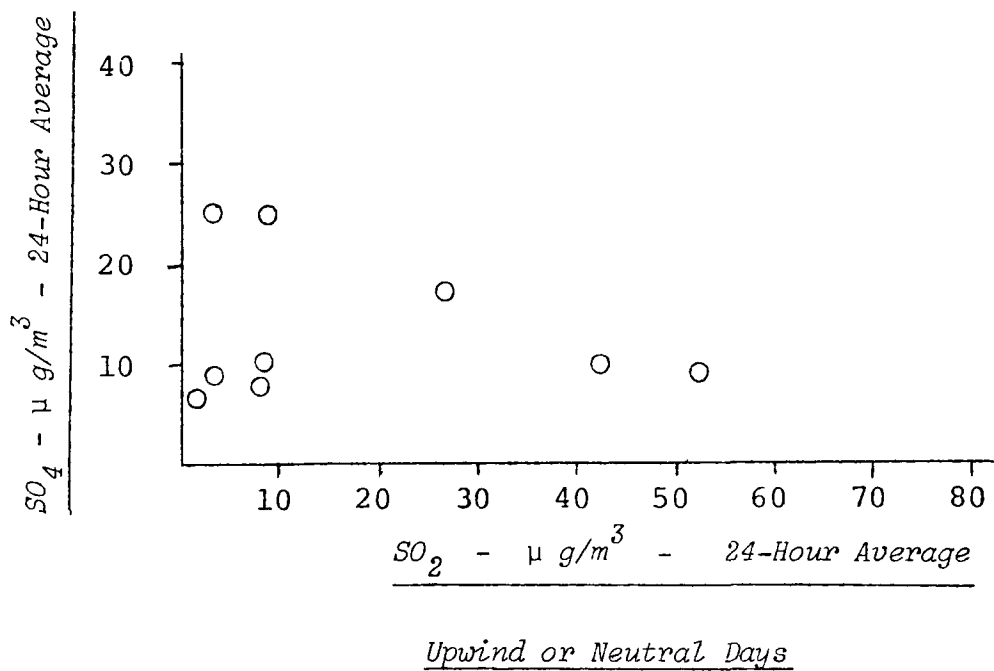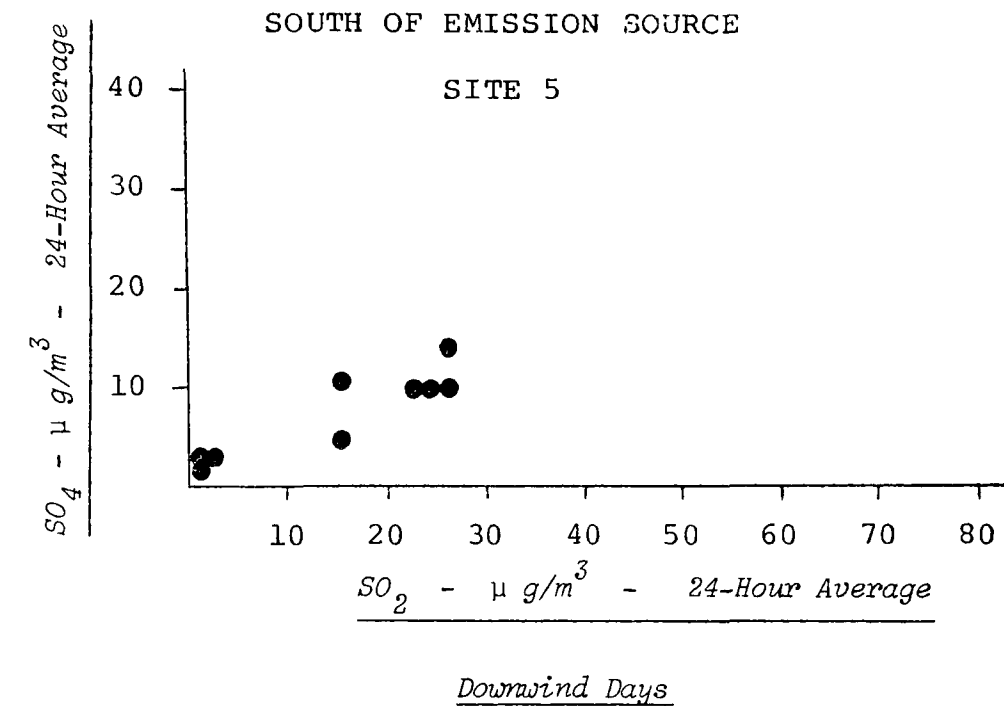
FIGURE 42

SULFATE/VANADIUM AT SAMPLING SITE

NNW OF EMISSION SOURCE

Downwind Days

Upwind or Neutral Days
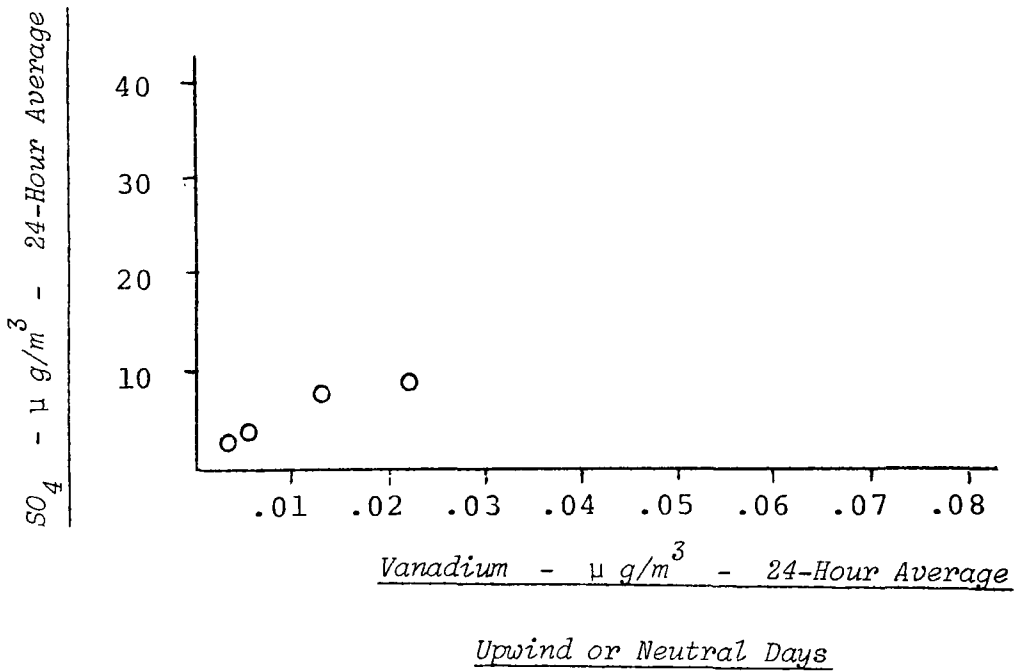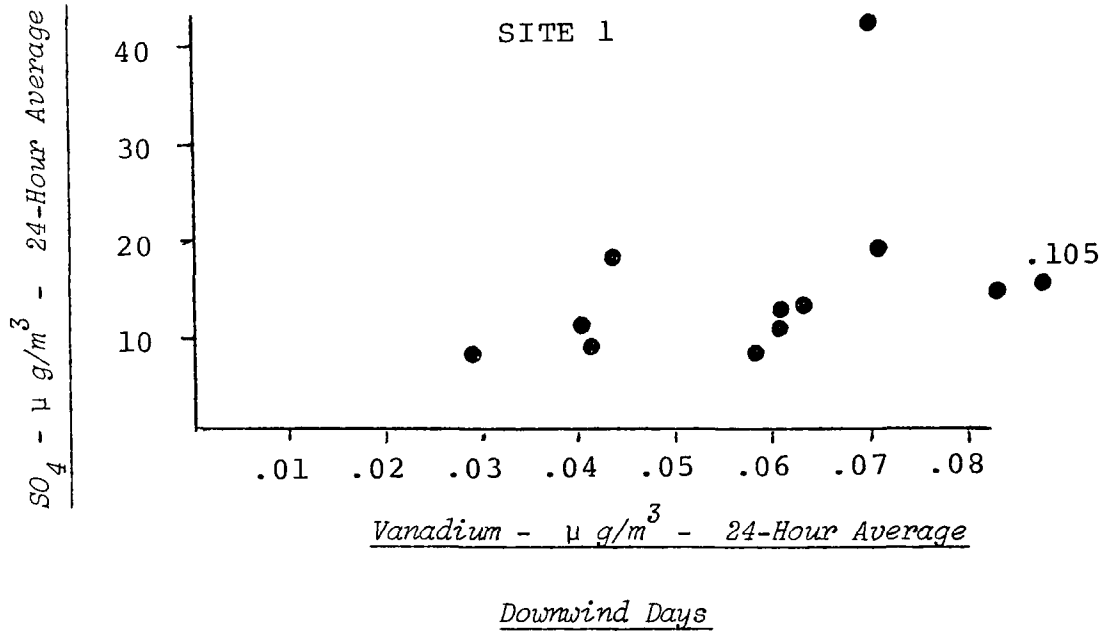
FIGURE 43

SULFATE/SULFUR DIOXIDE AT SAMPLING SITE

NNW OF EMISSION SOURCE

Downwind Days

Upwind or Neutral Days
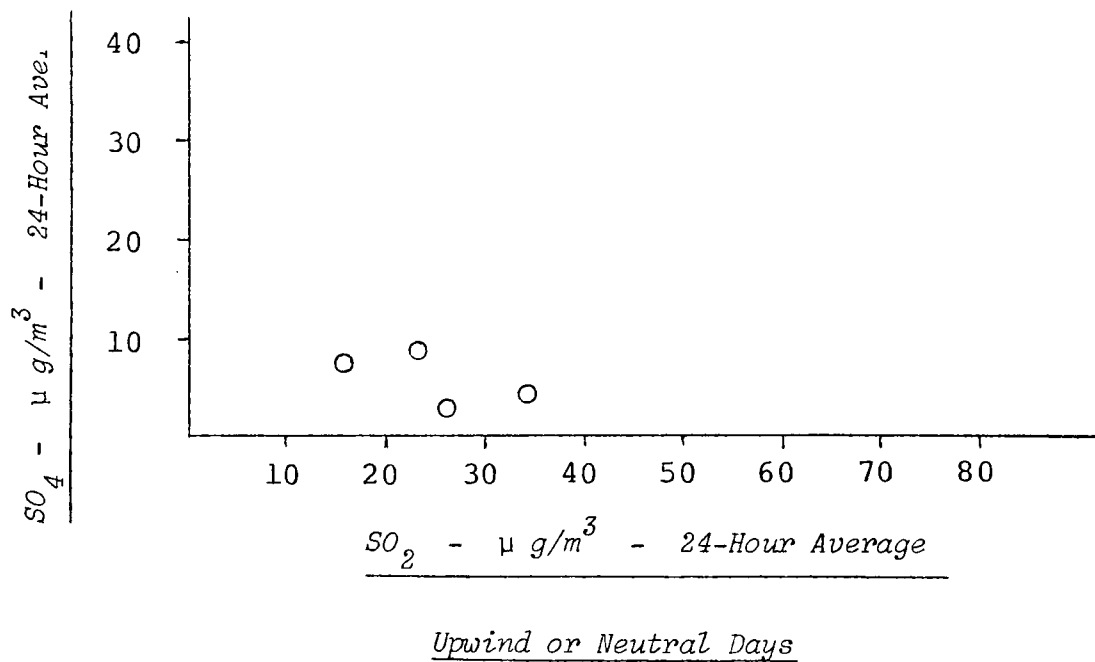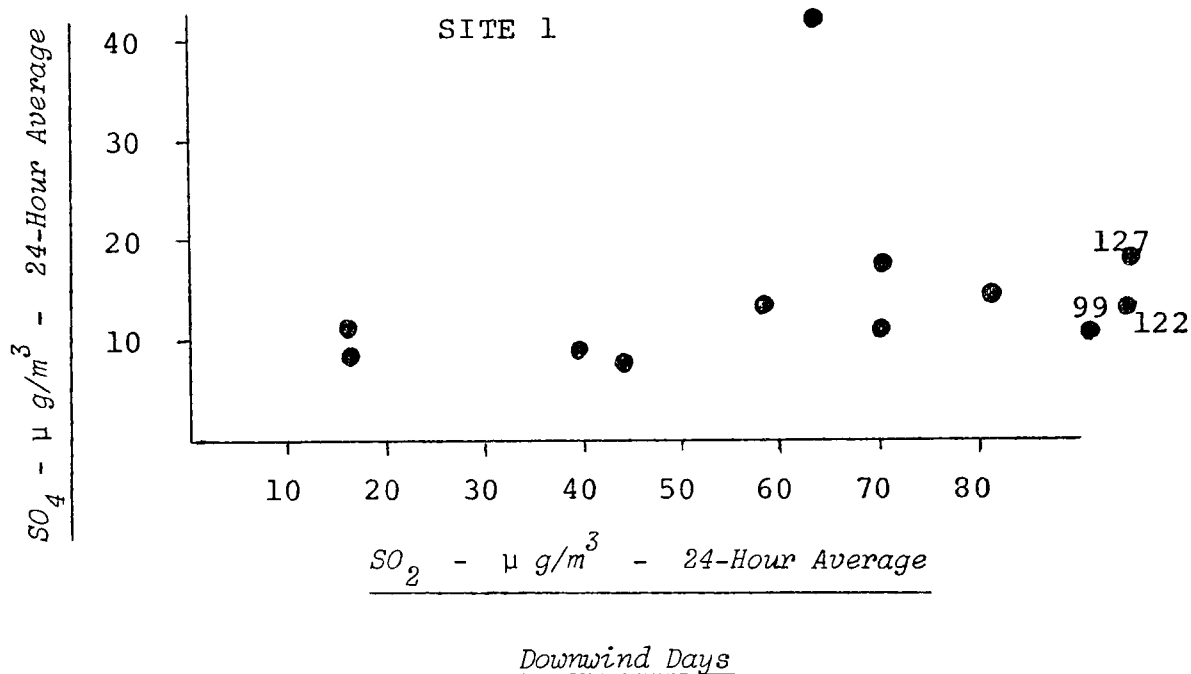
5 result in proportional relationships between sulfate and vanadium and between sulfate and sulfur dioxide. This supports the conclusion that the downwind sulfate, vanadium, and sulfur dioxide originate from the same source(s).

Upwind measurements at Site 1 reflect low-to-moderate sulfate levels, quite low vanadium levels (see Figure 43) and moderate sulfur dioxide levels (see Figure 44). Too few data points are available to draw any conclusions about the relationship between parameters under these conditions.

Downwind measurements at Site 1 show moderate-to-high levels of all three parameters, reflecting the high sulfate upwind values (at Site 5) plus the plant contribution. A proportional relationship exists between sulfate and both sulfur dioxide and vanadium on downwind days, suggesting that all three parameters originate at the same source(s).

Sulfate materials are transported from other sources in moderate quantities, while vanadium and sulfur dioxide are not. Since vanadium is a solid metal, usually present in combustion effluent in a higher oxide state, or as a vanadate combined with sodium, its weight probably causes it to settle to the ground soon after emission. Sulfur dioxide gas disperses with time, at a rate strongly influenced by local meteorology. Although it is not known exactly how far the background sulfate observed in this experiment had travelled prior to reaching the study area, it was of sufficient duration to cause dispersion of any attendant sulfur dioxide and deposition of attendant vanadium.

AIR QUALITY ANALYSIS OF UPWIND-DOWNWIND MEASUREMENTS

The examination of (upper level) tower wind direction measurements resulted in the determination that certain sites

190

(primarily sites 1 and 5) could be assigned the status upwind
or downwind, relative to the plant, during a major number of
days. The following definitions were necessary in order to
assign the designations: (1) whenever the wind movement
travelled along a course from the plant to a particular site,
within tolerance limits, more than 12 hours in any day, that
site was termed downwind that day and (2) whenever the wind
movement travelled along a coarse from a particular site to the
plant, within tolerance limits, more than 12 hours, and the
downwind hours were zero, that site was termed upwind. Data
was reduced using wind directional tolerances of 45°, 20°, and
10°. The wide 45° tolerance resulted in fifteen days where the
criteria were met; 20° tolerance resulted in six days and 10°
tolerance resulted in three days.

Four measurement parameters were identified, because of their
emission qualities: particulates (TSP), sulfur dioxide, vana-
dium, and sulfates. The upwind-downwind values of these para-
meters are shown on Tables 38, 39 and 40.

The mean downwind air quality measurements show a significant
increase over the mean upwind measurements; this increase will
be referred to as the "plant contribution" in this discussion.
The relationships between wind direction tolerance limits (45°,
20°, 10°) and plant contribution were significant for emission
parameters sulfate and TSP, but not for vanadium and sulfur
dioxide. In other words, the plant contribution of sulfate and
TSP was higher when the wind was less variable. The mean plant
contribution to downwind sulfate levels was 11.3% at a 45° wind
variance, and 53.4% at a 10° wind variance. The TSP trends
were similar although not quite as dramatic: plant contribu-
tion of 12.4% at a 45° wind variance and 20.7% at a 10° wind
variance.

191

TABLE 38

AMBIENT TSP MEASUREMENTS UPWIND-DOWNWIND OF EMISSION SOURCE

Date	Downwind Site Hrs.		Upwind Site Hrs.		Downwind TSP ($\mu g/m^3$)	Upwind TSP ($\mu g/m^3$)	Difference (DW-UW) ($\mu g/m^3$)	Difference % of Downwind TSP
Wind Directional Tolerance = 45°								
9-18	5	23	1	24	43.0	39.4	3.6	8.5
9-20	1	24	5	24	45.8	42.0	3.8	8.2
9-21	1	19	5	17	62.9	47.6	15.3	24.3
9-22	5	23	1	24	36.5	39.1	-2.6	-7.2
9-24	1	22	5	22	36.2	25.2	11.0	30.3
9-28	3	16	6	16	34.9	76.2	-41.3	-119
9-30	1	22	5	22	41.1	24.8	16.3	39.7
10-2	5	19	1	21	31.4	32.3	-0.1	-0.3
10-4	1	13	5	15	39.8	21.0	18.8	47.2
10-5	1	19	5	19	42.8	30.1	12.7	29.7
10-6	1	18	5	19	25.7	16.0	9.7	37.7
10-8	5	23	1	24	4.0	11.4	-7.4	-186
10-11	1	22	5	23	73.9	48.8	25.1	-340
10-12	1	23	5	23	76.0	72.3	3.7	4.8
10-15	5	24	1	24	10.3	18.2	-7.9	76.2
Mean		21		21	40.3	36.3	5.0	
σ		3		3	19.9	19.1	15.5	
Wind Directional Tolerance = 20°								
9-18	5	15	1	19	43.0	39.4	3.6	8.5
9-20	1	20	5	18	45.8	42.0	3.8	8.2
9-21	1	18	5	17	62.9	47.6	15.3	24.3
9-22	5	20	1	21	36.5	39.1	-2.6	-7.2
9-24	1	21	5	17	36.2	25.2	11.0	30.3
9-30	1	16	5	16	41.1	24.8	16.3	39.7
Mean		18		18	44.3	36.4	7.9	
σ		2		2	9.9	9.3	7.5	
9-21	1	16	5	14	62.9	47.6	15.3	24.3
9-22	5	17	1	20	36.5	39.1	-2.6	-7.2
9-30	1	13	5	13	41.1	24.8	16.3	39.7
Mean		15		16	46.9	37.2	9.7	
σ		2		4	14.1	11.5	10.7	

TABLE 39

AMBIENT SULFUR DIOXIDE MEASUREMENTS UPWIND-DOWNWIND OF EMISSION SOURCE

Date	Downwind Site Hrs.		Upwind Site Hrs.		Downwind SO_2 ($\mu g/m^3$)	Upwind SO_2 ($\mu g/m^3$)	Difference (DW-UW) ($\mu g/m^3$)	Difference % of Downwind SO_2
Wind Directional Tolerance = 45°								
9-18	5	23	1	24	14.6	29.2	-14.6	-100
9-20	1	24	5	24	56.5	10.3	46.2	81.7
9-21	1	19	5	17	61.9	26.1	35.8	57.9
9-22	5	23	1	24	26.1	15.3	10.8	3.9
9-24	1	22	5	22	69.1	52.1	17.0	24.6
9-28	3	16	6	16	30.6	21.7	8.9	29.0
9-30	1	22	5	22	15.8	00.0	15.8	100
10-2	5	19	1	21	25.0	23.1	1.9	7.4
10-4	1	13	5	15	39.1	7.6	31.5	80.6
10-5	1	19	5	19	21.5	7.6	13.9	64.7
10-6	1	18	5	19	44.3	3.3	41.0	92.6
10-8	5	23	1	24	00.0	27.1	-27.1	--
10-11	1	22	5	23	26.5	8.7	17.8	67.2
10-12	1	23	5	23	70.4	3.3	67.1	95.4
10-15	5	24	1	24	1.1	35.1	34.0	-3136
Mean		21		21	33.5	18.0	20.0	
σ		3		3	22.8	14.4	23.8	
Wind Directional Tolerance = 20°								
9-18	5	15	1	19	14.6	29.2	-14.6	-100
9-20	1	20	5	18	56.5	10.3	46.2	81.7
9-21	1	18	5	17	61.9	26.1	35.8	57.9
9-22	5	20	1	21	26.1	15.3	10.8	3.9
9-24	1	21	5	17	69.1	52.1	17.0	24.6
9-30	1	16	5	16	15.8	00.0	15.8	100
Mean		18		18	40.7	22.2	18.5	
σ		2		2	24.6	18.1	21.1	
Wind Directional Tolerance = 10°								
9-21	1	16	5	14	61.9	26.1	35.8	57.9
9-22	5	17	1	20	26.1	15.3	10.8	3.9
9-30	1	13	5	13	15.8	00.0	15.8	100
Mean		15		16	34.6	13.8	20.8	
σ		2		4	24.2	13.1	13.2	

193

TABLE 40

AMBIENT VANADIUM MEASUREMENTS UPWIND-DOWNWIND OF EMISSION SOURCE

Date	Downwind Site Hrs.		Upwind Site Hrs.		Downwind Vanadium ($\mu g/m^3$)	Upwind Vanadium ($\mu g/m^3$)	Difference (DW - UW) ($\mu g/m^3$)	Difference % of Downwind Vanadium
Wind Directional Tolerance = 45°								
9-18	5	23	1	24	0.005	0.033	-0.028	-505
9-20	1	24	5	24	0.063	0.003	0.060	95.4
9-21	1	19	5	17	0.070	0.008	0.062	88.5
9-22	5	23	1	24	0.017	0.013	0.004	19.7
9-24	1	22	5	22	0.061	0.003	0.058	94.9
9-28	3	16	6	16	0.024	0.004	0.020	85.2
9-30	1	22	5	22	0.058	0.008	0.050	86.6
10-2	5	19	1	21	0.010	0.022	-0.012	-122
10-4	1	13	5	15	0.041	0.012	0.029	70.5
10-5	1	19	5	19	0.083	0.010	0.073	87.6
10-6	1	18	5	19	0.029	0.008	0.021	72.4
10-8	5	23	1	24	0.002	0.003	-0.001	-50
10-11	1	22	5	23	0.071	0.004	0.067	93.8
10-12	1	23	5	23	0.043	0.008	0.035	81.1
10-15	5	24	1	24	0.004	0.005	-0.001	-31.6
Mean		21		21	0.035	0.010	0.029	
σ		3		3	0.028	0.008	0.032	
Wind Directional Tolerance = 20°								
9-18	5	15	1	19	0.005	0.033	-0.028	-505
9-20	1	20	5	18	0.063	0.003	0.060	95.4
9-21	1	18	5	17	0.070	0.008	0.062	88.5
9-22	5	20	1	21	0.017	0.013	0.004	19.7
9-24	1	21	5	17	0.061	0.003	0.058	94.9
9-30	1	16	5	16	0.058	0.008	0.050	86.6
Mean		18		18	0.046	0.011	0.030	
σ		2		2	0.027	0.011	0.036	
Wind Directional Tolerance = 10°								
9-21	1	16		14	0.070	0.008	0.062	88.5
9-22	5	17		20	0.017	0.013	0.004	19.7
9-30	1	13		13	0.058	0.008	0.050	86.6
Mean		15		16	0.048	0.010	0.038	
σ		2		4	0.028	0.003	0.031	

Sulfur dioxide contribution was 45-60% and vanadium contribution was 65-80%, apparently independent of wind variance degree. The summary of upwind-downwind measurements is shown in Table 42.

Since the plant emission rates of total sulfates and particulates were approximately equal, it is not surprising that the mean contributions to the ambient levels were also approximately equal. Difference in TSP levels (downwind minus upwind) was 5, 8, and 10 ug/m^3 when the wind variance was 45°, 20°, and 10°, respectively. Likewise, difference in total sulfate levels were 1.4, 6, and 12 ug/m^3 at the respective wind variances. Difference in vanadium concentration was 0.030 ug/m^3, or beween 0.3% and 0.6% of the plant-contributed TSP. This fraction is lower than the vanadium fraction in the plant particulate emissions by a factor of 10, possibly due to rapid deposition of metallic vanadium. The downwind minus upwind measurement of sulfur dioxide was 20 ug/m^3. Neither vanadium nor sulfur dioxide measurements indicate a susceptibility to increased ground-level concentrations due to low wind direction variance.

The first consideration to these mean values is the observation that sulfate and total particulates travel a narrow corridor when wind direction is steady. The mean values do not, however, indicate the extreme variability in plant contribution even with wind direction tolerance of 20° (-64% to +60% of downwind sulfate levels). Less variability occurs at a wind variance of 10° (34% to 60% of downwind concentration), but in this case only three values are included. Wind tolerances of 45° show a negative plant sulfate contribution on 40% of the days observed. Apparently upper winds and atmospheric stability were important factors on those days.

195

TABLE 41

AMBIENT SULFATE MEASUREMENTS UPWIND-DOWNWIND OF EMISSION SOURCE

Date	Downwind Site Hrs.		Upwind Site Hrs.		Downwind $SO_4^=$ ($\mu g/m^3$)	Upwind $SO_4^=$ ($\mu g/m^3$)	Difference (DW − UW) ($\mu g/m^3$)	Difference % of Downwind $SO_4^=$
Wind Directional Tolerance = 45°								
9-18	5	23	1	24	5.0	8.2	−3.2	−63.6
9-20	1	24	5	24	13.8	12.0	1.8	12.6
9-21	1	19	5	17	43.2	17.3	25.9	59.9
9-22	5	23	1	24	14.4	7.8	6.6	46.1
9-24	1	22	5	22	11.0	8.8	2.2	19.5
9-28	3	16	6	16	6.9	7.5	−0.6	−8.9
9-30	1	22	5	22	8.8	5.8	3.0	33.7
10-2	5	19	1	21	9.3	8.6	0.7	7.5
10-4	1	13	5	15	9.1	8.0	1.1	12.7
10-5	1	19	5	19	13.9	11.0	2.9	30.0
10-6	1	18	5	19	8.2	8.9	−0.7	8.5
10-8	5	23	1	24	2.3	3.3	−1.0	−47.0
10-11	1	22	5	23	18.4	25.5	−6.1	−33.0
10-12	1	23	5	23	18.3	25.7	−7.4	−40.2
10-15	5	24	1	24	3.0	4.4	−1.4	−46.5
Mean		21		21	12.4	10.8	1.4	
σ		3		3	9.8	6.7	7.6	
Wind Directional Tolerance = 20°								
9-18	5	15	1	19	5.0	8.2	−3.2	−63.6
9-20	1	20	1	18	13.8	12.0	1.8	12.6
9-21	1	18	5	17	43.2	17.3	25.9	59.9
9-22	5	20	1	21	14.4	7.8	6.6	46.1
9-24	1	21	1	17	11.0	8.8	2.2	19.5
9-30	1	16	5	16	8.8	5.8	3.0	33.7
Mean		18		18	16.0	10.0	6.0	
σ		2		2	13.7	4.1	10.2	
Wind Directional Tolerance = 10°								
9-21	1	16	5	14	43.2	17.3	25.9	59.9
9-22	5	17	1	20	14.4	7.8	6.6	46.1
9-30	1	13	5	13	8.8	5.8	3.0	33.7
Mean		15		16	22.1	10.3	11.8	
σ		2		4	18.4	6.2	12.3	

196

TABLE 42

	Mean	σ	Wind Directional Tolerance	Downwind ($\mu g/m^3$)	Upwind ($\mu g/m^3$)	Difference (DW-UW) ($\mu g/m^3$)
TSP						
	X		45°	40.3	36.3	5.0
		X	45°	19.9	19.1	15.5
	X		20°	44.3	36.4	7.9
		X	20°	9.9	9.3	7.5
	X		10°	46.9	37.2	9.7
		X	10°	14.1	11.5	10.7
Vanadium						
	X		45°	0.035	0.010	0.029
		X	45°	0.028	0.008	0.032
	X		20°	0.046	0.011	0.030
		X	20°	0.027	0.011	0.036
	X		10°	0.048	0.010	0.038
		X	10°	0.028	0.003	0.031
SO_2						
	X		45°	33.5	18.0	20.0
		X	45°	22.8	14.4	23.8
	X		20°	40.7	22.2	18.5
		X	20°	24.6	18.1	21.1
	X		10°	34.6	13.8	20.8
		X	10°	24.2	13.1	13.2
$SO_4^=$						
	X		45°	12.4	10.8	1.4
		X	45°	9.8	6.7	7.6
	X		20°	16.0	10.0	6.0
		X	20°	13.7	4.1	10.2
	X		10°	22.1	10.3	11.8
		X	10°	18.4	6.2	12.3

These results reflect the concept that the plant does in fact
contribute sulfate and other materials to the ambient air
levels, but because of high background scatter and the use of
fixed monitoring sites, a very low confidence is assigned to
the magnitude of the contribution. In fact the standard devi-
ations in many cases (all cases of sulfate) exceed the mean.

STATISTICAL AMBIENT SULFATE PREDICTION ESTIMATES

Regression analysis was used to develop a statistic prediction
model for ambient sulfate concentrations. This methodology has
several advantages in that it allows available data to be used
to estimate ambient $SO_4^=$ concentrations in the study area.
While there is some advantages that result from this, there are
some points to be kept in mind. Any such prediction scheme
that results has a statistical, not a physical basis. Second,
the prediction scheme may not necessarily be equally applicable
at another location due to the statistical nature of the
scheme.

The statistical model was developed using stepwise multiple
regression. This involved fitting a set of independent vari-
ables to a single dependent variable. That is;

$$\hat{Y} = b_o + \sum_{i=1}^{n} b_i X_i + \epsilon \qquad\qquad \epsilon \sim NID (o, \sigma_e)$$

In this case, the dependent variable, Y, was the measured 24-
hour ambient sulfate concentrations downwind from the plant.
The following is a list of independent variables, measured
hourly and converted to 24-hour averages:

198

(1) Portion of 24-hour day that wind blew toward downwind
    site, %

(2) Wind speed, mph

(3) Downwind SO_2 concentration, ppm

(4) Downwind vanadium concentration, ug/m^3

(5) Average temperature profile (from tower measurement),
    °F/ft.

(6) Average wind persistence

(7) Average relative humidity

(8) Average nephelometer reading, b_{scat} ($10^{-4}m^{-1}$)

(9) Distance from plant to downwind site, km

(10) Average mixing height, m

(11) Total sulfate emission, kg/day

(12) Particulate emission, kg/day

(13) SO_2 emission, kg/day

(14) Background sulfate concentration, ug/m^3

A site was considered to be downwind if it was downwind from
the plant during any portion of a day. There could be more
than one downwind site during any day. The limits of daily
wind direction variability, designating a site as downwind,
were + 45° so that an adequate number of data points were
available. In this examination, background levels were taken
from the upwind or neutral site measurements.

The statistical model inserted the variables by priority, using
the most significant variables first, and so on in order of de-
creasing significance. The most significant variable in the
analysis was background sulfate; obviously the downwind sulfate
must be an incremental increase added to the background lev-
els. The most significant variable after background sulfate
was the percent of time the wind blew towards the downwind
site. In order of decreasing significance, the following vari-
ables were inserted: downwind SO_2, downwind vanadium, nephelo-
meter reading, distance downwind from plant, and particulate

TABLE 43

RESULTS OF MULTIPLE REGRESSION ANALYSIS

INDEPENDENT VARIABLE -- DOWNWIND $SO_4^=$

Parameter	Units	Coefficient	Value Necessary to alter $SO_4^=$ $\pm 1.0 ug/m^3$	Mean Value	Individual Correlation Coefficient
Y-Intercept	-	19.9	-	-	-
Downwind Hours	% of 24 - hour	+.02	50.0	57.4	.22
Downwind SO_2	ppm	-301.6	.003	.017	.32
Downwind Vanadium	$\mu g/m^3$	+55.8	.018	.038	.40
Nephelometer, 24 - hour average	b scat	-6.9	.145	.664	.79
Downwind Distance from plant	km	+2.2	.45	5.05	.04
Plant Emission, Particulate	kg/day	+.001	1000	3997	.05
Background $SO_4^=$	$\mu g/m^3$	+2.9	.345	7.95	.89
Downwind $SO_4^=$	$\mu g/m^3$	-	-	11.82	1.00

emission. The remaining variables caused an increase of the error term when inserted, therefore they were not included in the statistical model.

The resulting regression has a multiple correlation coefficient of .96, adjusted R^2 .89, and a standard error of estimates 2.43. The regression coefficients are shown on Table 43, and are presented with mean values, values necessary to alter downwind sulfate $\pm$ 1.0 ug/m^3, and the individual correlation coefficients. The inverse relationship between sulfate and SO_2 reflects the instances where high background sulfate levels were observed with low SO_2 values. Mean downwind sulfate concentration was 11.82 ug/m^3; mean upwind sulfate concentration was 7.95 ug/m^3. Standard deviation of the difference between the predicted and actual downwind values was 2.43 ug/m^3.

This statistical model uses the emission data and monitoring sites designated in this experiment, under those meteorological conditions that prevailed at the time. The statistical equation is not a universal relationship and may not be accurate under any other conditions or applications. The model is an accurate prediction of ambient sulfate concentrations within the limitations imposed by the data.

BIBLIOGRAPHY

Altshuller, A.P., April, 1976, Regional Transport and
    Transformation of Sulfur Dioxide to Sulfates in the U.S.,
    J.A.P.C.A., 26 (4), pg. 318-324.

Amdur, M.O., Lewis, T.R., Fitzhand, M.P. and Campbell, K.I.,
    July, 1972, Toxicology of Atmospheric Sulfur Dioxide Decay
    Products, AP-111, U.S. EPA, Research Triangle Park, NC 27711.

Babcock & Wilcox, 1978, Steam, 39th Edition, 161 East 42nd St.,
    New York, NY 10017.

Barrett, R.E., July, 1966, "High Temperature Corrosion Studies
    in an Oil-Fired Laboratory Combustor", ASME Paper 66-WA/CD-2.

Bogue, Donald J. and Beale, Calvin, L., 1961, Economic Areas of
    the United States, The Free Press of Glencoe, Inc.

Boldt, K.R., McMillan, William, Laube, A.H., June, 1978, A
    Study of Damaging Fallout from Oil-Fired Boilers, APCA Paper
    78-65.5, 71st Annual Meeting.

Bolin, Bert, Editor, 1971, "Air Pollution Across National
    Boundaries. The Impact on the Environment of Sulfur in Air
    and Precipitation. Sweden's Case Study for the United
    Nations' Conference on the Human Environment." Kungl
    Boktryckeriert P.A., Norstedt & Soner 710396, Stockholm.

Briggs, Gary A., 1969, Plume Rise, T1D-25075, AEC Critical
    Review Series Environmental Science Services Administration,
    Oak Ridge, Tennessee.

_____, July, 1972, Discussion on Chimney Plumes in
    Neutral and Stable Surroundings, Atmospheric Environment,
    Vol. 6, pg. 507-516.

Bruckman, L., June, 1977, "Suspended Particulate Transport",
    Paper 77-8.4, 70th Annual Meeting A.P.C.A., Toronto, Canada.

Buma, T.J., 1960, A Statistical Study of the Relationship
    Between Visibility and Relative Humidity at Leeuwarden,
    Bulletin of the American Meteorological Society, Vol. 41,
    pg. 357-360.

California Department of Public Health, Bureau of Air Sanita-
    tation, 1966, Oxides of Nitrogen in Air Pollution.

Cass, Glen R., 1979, on the relationship between sulfate air
    quality visibility with examples in Los Angeles, Atmospheric
    Environment, Vol. 13, No. 8, pg. 1,069-1,084.

Chaikivsky, M., and Siegmund, C.W., June, 1964, Low-Excess-Air
Combustion of Heavy Fuel Oil - High Temperature Deposits and
Corrosion, ASME paper 64-WA/CD-2.

Cheney, J.L., and Homolya, J.B., May, 1979, Sampling Parameters
for Sulfate Measurement and Characterization, Environmental
Science and Technology, Vol. 13, No. 5, pg. 584-588.

Chung, Y.S., 1978, The Distribution of Atmospheric Sulphates in
Canada and its Relationship to Long-Range Transport of Air
Pollutants, Atmospheric Environment, Vol. 12, pg. 1,471-1,480.

Code of Federal Regulations, Title 40, Part 60, Standards of
Performance for New Stationary Sources, Appendix A, Reference
Method 5

Code of Federal Regulations, Title 40, Part 60, Standards of
Performance for New Stationary Sources, Appendix A, Reference
Method 6.

Delaware, W., January, 1979, Personal Communication, New York
State Department of Environmental Conservation, 50 Wolf Road,
Albany, NY 12223.

Electrical World, 1977, Directory of Electric Utilities, 1977-
1978, 86th Ed., McGraw-Hill Book Company, 1221 Avenue of the
Americas, New York, NY 10020.

EPA, January, 1973, Nationwide Air Pollutant Emission Trends,
1940-1970, AP-115, OAQPS, Research Triangle Park, NC 27711.

Galvin, P.J., et al., May 1978, Transport of Sulfate to New York
State, ENV. SCI. & TECH., 12(5), 580-584.

Glaubitz, F., March, 1963, The Economic Combustion of Sulfur-
Containing Heating Oil - Part II: An Accounting of the
Operating Experiences with 1.0 Percent Excess Air, Combustion.

Horvath, H., and Charlson, R., 1969, The Direct Optical Measure-
ment of Atmospheric Air Pollution, American Industrial Hygiene
Association, Vol. 30, pg. 500-509.

Junge, C.E., 1963, Air Chemistry and Radioactivity, Academic
Press, New York, NY.

Klein, William H., 1957, Principal Tracks and Mean Frequences of Cyclones and Anticyclones in the Northern Hemisphere, Research Paper No. 40, U.S. Department Commerce, National Weather Service, National Climatic Center, Asheville, NC.

Kuhlman, Michael R., Fox, Donald, L., and Jeffries, Harvey E., 1978, The Effect of CO on Sulfate Aerosol Formation, Atmospheric Environment, Vol. 12, pg. 2,415-2,423.

Larson, Timothy V., Harike, Neil R., and Harrison, Halstead, 1978, Oxidation of Sulfur Dioxide by Oxygen and Ozone in Acqueous Solution: a kinetic study with significance to atmospheric rate processes, Atmospheric Environment, Vol. 12, pg. 1,597-1,611.

Leighton, P.A., 1961, Photochemistry of Air Pollution, Academic Press, New York.

Lutrick, D., 1971, MS Thesis, University of Washington, Seattle.

Meszaros, A., 1978, Size Distribution of Atmospheric Aerosol Particles Under Regional Background Conditions, Proceedings, 9th International Conference on Atmospheric Aerosols, Condensation, and Ice Nuclei, 1977, Galway, Ireland.

Meszaros, E., 1970, Seasonal and Diurnal Variations of the Size Distribution of Atmospheric Sulfate Particles, Tellus, Vol. 22, pg. 235-238.

National Research Council, 1978, Sulfur Oxides, National Academy of Sciences, Washington, DC.

Newman, L., Forrest, J., and Manowitz, P.B., 1974a, The Application of an Isotopic Ratio Technique to a Study of the Atmospheric Oxidation of Sulfur Dioxide in the Plume from a Coal-Fired Power Plant, Brookhaven National Laboratory, Upton, NY.

_____, 1974b, The Application of an Isotopic Ratio Technique to a Study of the Atmospheric Oxidation of Sulfur Dioxide in the Plume from an Oil-Fired Power Plant, Brookhaven National Laboratory, Upton, NY.

New York State Department of Environmental Conservation, 1976, Air Quality Report, Annual 1976, DAR-77-1, Division of Air Resources, 50 Wolf Road, Albany, NY 12223.

_____, 1977, Air Quality Report, Annual 1977, DAR-78-1, Division of Air Resources, 50 Wolf Road, Albany, NY 12223.

_____, 1978, Air Quality Report, Annual 1978, DAR-79-1, Division of Air Resources, 50 Wolf Road, Albany, NY 12223.

NOAA, January, 1977, Climate of New York, Climatography of the United States, No. 60, NOAA, National Climatic Center, Asheville, NC.

Nuclear Regulatory Commission, February, 1972, Safety Guide 1.23, Onsite Meteorological Programs, Washington, DC.

OAQPS, September, 1975, Position Paper on Regulation of Atmospheric Sulfates, EPA-450/2-75-007, U.S. EPA, Research Triangle Park, NC 27711.

Penkett, S.A., Jones, B.M.R., Brice, K.A., and Eggleton, A.E.J., 1978, The Importance of Atmospheric Ozone and Hydrogen Peroxide in Oxidizing Sulfur Dioxide in Cloud and Rain Water, Atmospheric Environment, Vol. 13, pg. 123-137.

Reese, J.T., Jonakin, J., and Caracristi, V.Z., 1965, Prevention of Residual Oil Combustion Problems by Use of Low Excess Air and Magnesium Additive, Journal of Engineering for Power, Transactions of ASME.

Reid, W.T., 1971, External Corrosion and Deposits - Boilers and Gas Turbines, American Elsevier Publishing Co.

Reiss, Nathan, M. and Eversole, Rae Ann, 1978, Rectification of Prevailing Visibility Statistics, Atmospheric Environment, Vol. 12, pg. 945-950.

Renzetti, N.A. and Romanovsky, J.C., 1956, AMA Archives of Industrial Health, Vol. 14, pg. 458.

Samson, P.J., et al., December, 1975, The Transport of Suspended Particulates as a Function of Wind Direction and Atmospheric Conditions, JAPCA, 25(12), 1232-1237.

Samson, P.J., 1978, Ensemble Trajectory Analysis of Summertime Sulfate Concentration in New York State, ATMOS. ENV. 12, 1889-1893.

Snedecor, G.W., and Cochran, W.G., 1967, Statistical Methods, The Iowa State University Press.

Tanner, R.L., and Marlow, W.H., 1977, Size Discrimination and Chemical Composition of Ambient Airborne Sulfate Particles by Diffusion Sampling, Atmospheric Environment, Vol. 11, pg. 1,143-1,150.

Thyler, Norman, March, 1962, Double Theodolite Pibal Evaluation by Computer, Journal of Applied Meteorology, Vol. 1, pg. 66-68.

Turner, D.B., 1964, A diffusion Model for an Urban Area, Journal of Applied Meteorology, Vol. 3, No. 1, pg. 83-91.

_____, 1970, Workbook of Atmospheric Dispersion Estimates, AP-26 EPA, Research Triangle Park, NC 27711.

Waggoner, A.P., Vanderpol, A.H., Charlson, R.J., Granat, L., Tragard, C., and Laisen, S., 1975, Sulfates as a Cause of Tropospheric Haze, Report AC-33, Dept. of Meteorology, University of Stockholm, Sweden, VDC 551.510 4:535.33.

Whitby, K.T., 1978, The Physical Characteristics of Sulfur Aerosols. Atmospheric Environment, Vol. 12, pg. 135-159.

Winkler, P., 1973, The Growth of Atmospheric Aerosol Particles as a Function of the Relative Humidity - II: an improved concept of mixed nuclei, Journal of Aerosol Science, Vol. 4, pg. 373-387.

Wright, H.L., 1935, Visibility and Atmospheric Suspensoids at Kew Observatory, Quarterly Journal of the Royal Meteorological Society, Vol. 65, pg. 411-439.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-80-109	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE IMPACT OF A PRIMARY SULFATE EMISSION SOURCE ON AIR QUALITY		5. REPORT DATE May 1980
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) K.R. Boldt, C.P. Chang, E.J. Kaplin, J.M. Stansfield, B.R. Wuebber		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS York Research Corporation Stamford, CT 06906		10. PROGRAM ELEMENT NO. 1AA603A AA-91 (FY-79)
		11. CONTRACT/GRANT NO. 68-02-2965
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Sciences Research Laboratory - RTP, NC Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE EPA/600/09

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A one-month study was carried out at an isolated oil-fired power plant in New York State to assess the impact of primary sulfate emissions on air quality. Emissions of total sulfate from the source varied from 22 kg/hr to 82 kg/hr per boiler with the sulfuric acid concentration averaging 74% of the total sulfate. Particulate emissions ranged from 12 kg/hr to 70 kg/hr per boiler with between 32% and 67% of the particle mass as water soluble sulfate. Vanadium was implicated as the driving force in the magnitude of the primary sulfate emissions. Measurements taken 5 km downwind of the plant indicated a source sulfate contribution of from 30% to 60% of the 24 hr average ambient levels.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Air pollution *Particles *Sulfates *Emission Electric power plants		13B 07B 10B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 227
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (Rev. 4-77)   PREVIOUS EDITION IS OBSOLETE