Volume 3-Chapter 3

AIR RESOURCES

Minnesota Environmental Quality Board
Regional Copper-Nickel Study
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REGIONAL COPPER-NICKEL STUDY REPORT OUTLINE

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A NOTE ABOUT UNITS

This report, which in total covers some 36 chapters in 5 volumes, is both international and interdisciplinary in scope. As a result, the problem of an appropriate and consistent choice of units of measure for use throughout the entire report proved insurmountable. Instead, most sections use the system of units judged most common in the science or profession under discussion. However, interdisciplinary tie-ins complicated this simple objective, and resulted in the use of a mix of units in many sections. A few specific comments will hopefully aid the reader in coping with the resulting melange (which is a reflection of the international multiplicity of measurement systems):

1) Where reasonable, an effort has been made to use the metric system (meters, kilograms, kilowatt-hours, etc.) of units which is widely used in the physical and biological sciences, and is slowly becoming accepted in the United States.

2) In several areas, notably engineering discussions, the use of many English units (feet, pounds, BTU's, etc.) is retained in the belief that this will better serve most readers.

3) Notable among the units used to promote the metric system is the metric ton, which consists of 2,205 pounds and is abbreviated as mt. The metric ton (1,000 kilograms) is roughly 10% larger (10.25%) than the common or short ton (st) of 2,000 pounds. The metric ton is quite comparable to the long ton (2,240 pounds) commonly used in the iron ore industry. (Strictly speaking, pounds and kilograms are totally different animals, but since this report is not concerned with mining in outer space away from the earth's surface, the distinction is purely academic and of no practical importance here).

4) The hectare is a unit of area in the metric system which will be encountered throughout this report. It represents the area of a square, 100 meters on a side (10,000 m^2), and is roughly equivalent to $2\frac{1}{2}$ acres (actually 2.4710 acres). Thus, one square mile, which consists of 640 acres, contains some 259 hectares.

5) Where electrical energy is converted to thermal units, a conversion factor of 10,500 BTU/kWH is used. This means that the energy lost to waste heat in a central power plant is included, assuming a generating efficiency of 32.5%.

The attached table includes conversion factors for some common units used in this report. Hopefully, with these aids and a bit of patience, the reader will succeed in mastering the transitions between measurement systems that a full

reading of this report requires. Be comforted by the fact that measurements of time are the same in all systems, and that all economic units are expressed in terms of United States dollars, eliminating the need to convert from British Pounds, Rands, Yen, Kawachas, Rubles, and so forth!

Conversions for Common Metric Units Used in the Copper-Nickel Reports

1 meter (m)	=	3.28 feet = 1.094 yards
1 centimeter (cm)	=	0.3937 inches
1 kilometer (km)	=	0.621 miles
1 hectare (ha)	=	10,000 sq. meters = 2.471 acres
1 square meter (m^2)	=	10.764 sq. feet = 1.196 sq. yards
1 square kilometer (km^2)	=	100 hectares = 0.386 sq. miles
1 gram (g)	=	0.037 oz. (avoir.) = 0.0322 Troy oz.
1 kilogram (kg)	=	2.205 pounds
1 metric ton (mt)	=	1,000 kilograms = 0.984 long tons = 1.1025 short tons
1 cubic meter (m^3)	=	1.308 yd^3 = 35.315 ft^3
1 liter (l)	=	0.264 U.S. gallons
1 liter/minute (l/min)	=	0.264 U.S. gallons/minute = 0.00117 acre-feet/day
1 kilometer/hour (km/hr)	=	0.621 miles/hour
1 kilowatt-hour (kWH)	=	10,500 BTU (for production of electricity at 32.5% conversion efficiency)
degrees Celsius (^oC)	=	(5/9)(degrees Fahrenheit -32)

Standard Abbreviations.

ha - hectare
st - short ton of 2,000 lb
lt - long ton of 2,240 lb
mt - metric ton of 2,205 lb
mtpy - metric ton(s) per year

ppm - parts per million
ppb - parts per billion
um - micron or 10^{-6} meters
% - percent by weight unless otherwise noted

ELEMENT	SYMBOL	ELEMENT	SYMBOL	ELEMENT	SYMBOL
Actinium	Ac	Holmium	Ho	Rhenium	Re
Aluminum	Al	Hydrogen	H	Rhodium	Rh
Americium	Am	Indium	In	Rubidium	Rb
Antimony	Sb	Iodine	I	Ruthenium	Ru
Argon	Ar	Iridium	Ir	Samarium	Sm
Arsenic	As	Iron	Fe	Scandium	Sc
Astatine	At	Krypton	Kr	Selenium	Se
Barium	Ba	Lanthanum	La	Silicon	Si
Berkelium	Bk	Lawrencium	Lw	Silver	Ag
Beryllium	Be	Lead	Pb	Sodium	Na
Bismuth	Bi	Lithium	Li	Strontium	Sr
Boron	B	Lutetium	Lu	Sulfur	S
Bromine	Br	Magnesium	Mg	Tantalum	Ta
Cadmium	Cd	Manganese	Mn	Technetium	Tc
Calcium	Ca	Mendelevium	Md	Tellurium	Te
Californium	Cf	Mercury	Hg	Terbium	Tb
Carbon	C	Molybdenum	Mo	Thallium	Tl
Cerium	Ce	Neodymium	Nd	Thorium	Th
Cesium	Cs	Neon	Ne	Thulium	Tm
Chlorine	Cl	Neptunium	Np	Tin	Sn
Chromium	Cr	Nickel	Ni	Titanium	Ti
Cobalt	Co	Niobium	Nb	Tungsten	W
Copper	Cu	Nitrogen	N	Uranium	U
Curium	Cm	Nobelium	No	Vanadium	V
Dysprosium	Dy	Osmium	Os	Xenon	Xe
Einsteinium	Es	Oxygen	O	Ytterbium	Yb
Erbium	Er	Palladium	Pd	Yttrium	Y
Europium	Eu	Phosphorus	P	Zinc	Zn
Fermium	Fm	Platinum	Pt	Zirconium	Ar
Fluorine	F	Plutonium	Pu		
Francium	Fr	Polonium	Po		
Gadolinium	Gd	Potassium	K		
Gallium	Ga	Praseodymium	Pr		
Germanium	Ge	Promethium	Pm		
Gold	Au	Protactinium	Pa		
Hafnium	Hf	Radium	Ra		
Helium	He	Radon	Rn		

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Volume 3-Chapter 3 AIR RESOURCES

3.1 INTRODUCTION AND SUMMARY OF FINDINGS

3.1.1 Introduction

The atmosphere surrounding the earth is a complex, dynamic, often unpredictable medium whose composition and movement have profound effects on the geophysical and biological systems which it envelopes. Increasingly, it is apparent that this atmosphere is a natural resource in the same sense that water, timber, and valuable minerals are natural resources. Though it possesses a vast ability to absorb insults in the form of pollutants injected as a result of man's activities, this ability is not infinite. For one pollutant after another, indications are appearing that the atmosphere's assimilative capacity is being strained. Further, by the nature of the global movement of air masses, when careless use of the atmosphere is made in one location, the penalties may be paid by persons and other living things hundreds and even thousands of kilometers removed.

In this context, the prospect for a major new industrial development in northeastern Minnesota to recover copper and nickel clearly raises the potential for major impacts on the atmosphere. It is the purpose of this report to assess the nature and magnitude of these potential impacts.

3.1.1.1 Basic Issues--In the context of air resources, a variety of concerns arise over potential copper-nickel development. Broadly, these concerns can be classed as relating to human health, water quality, aquatic and terrestrial ecosystems, and legal standards. Some of the issues of concern to Minnesotans in each of these areas are briefly outlined below.

In terms of human health, certain pollutants may potentially be emitted to the atmosphere, intentionally or purely accidentally, which may impare the health of individuals inhaling them. In terms of copper-nickel development, principal potential emissions of concern include sulfur (primarily as gaseous SO_2), total suspended particulates, copper, nickel, cobalt, and mineral fibers. Other elements of concern (should they appear in the ore in greater quantities than seem likely to be present according to available information) include arsenic, lead, mercury, and cadmium. This report estimates possible changes in the atmospheric concentrations of these constituents, and the health implications of these changes are discussed in the chapter on public health, Volume 5-Chapter 2.

A variety of water quality concerns are raised in terms of air resource impacts since the atmosphere acts as a transport medium, depositing pollutants onto the land surface surrounding an emission source. The pollutants can then be washed into local rivers and lakes by rainfall. Direct deposition onto water surfaces may also be an important input mechanism. As before, the major constituents of concern here include sulfur (as sulfate), copper, nickel, and cobalt. Also of potential concern are arsenic, lead, mercury, and cadmium. This report will focus on potential changes in the input rates of these constituents to the land and water surfaces from potential copper-nickel developments. The water quality impacts which might result are discussed in the chapter on water resources, Volume 3-Chapter 4.

A variety of terrestrial and aquatic concerns (in addition to concerns specific to human health) arise as a result of potential changes of ambient concentrations and deposition rates for certain pollutants. The implications for terrestrial ecosystems of possible concentration increases in atmospheric pollutants are assessed in the terrestrial biology report, Volume 4-Chapter 2. The possible

effects of increased deposition rates for heavy metals, particularly copper, onto soil surfaces are also discussed there. The aquatic biological effects of altered water quality as a result of surface deposition increases are assessed in the chapter on aquatic biology, Volume 4-Chapter 1.

Finally, the existence of various legal standards specifying limits for air emissions and maximum concentrations of various pollutants provides a reference framework for discussion. Standards, of course, exist to protect many of the resources mentioned above. Since standards are explicitly stated in terms of emission rates and ambient concentrations, the potential for exceedances of various standards may be discussed directly in this report. Sections 3.7 and 3.8, particularly, address the regulatory question in the context of ambient concentrations of SO_2 and particulates. The ability of a copper-nickel operation, particularly a smelter, to meet existing standards can be assessed based on the discussion of emission control technology presented in the chapter on smelter/refinery technology, Volume 2-Chapter 4.

Throughout the impact assessment discussions in this report, the range of impacts implied by a range of emission rates are presented. The various emission rates can, in turn, be related to the practices and control technologies employed as part of any copper-nickel development. Thus, the effectiveness of various mitigating measures emerges automatically from the various impact assessment discussions.

3.1.1.2 Basic Approach--To address the various concerns noted above, a simple 3-step approach was adopted by the Regional Copper-Nickel Study:

1) Characterize Air Resources: The present nature of air resources in northeastern Minnesota prior to copper-nickel development is assessed.

Projections are also made for the future (1985) to forecast conditions in the absence of copper-nickel development. Both meteorology/climatology and air quality are examined in some detail (sections 3.3, 3.4, and 3.5).

2) Simulate Copper-Nickel Sources: A set of hypothetical emission models are created to simulate the types and amounts of pollutants which may be emitted to the atmosphere by copper-nickel developments. A range of models are presented to reflect the application of various mitigating methods to the mining developments (section 3.6).

3) Assess Copper-Nickel Impacts: The changes in air quality resulting from the hypothetical copper-nickel emission sources are assessed using predictive atmospheric dispersion models. Changes are compared to existing and projected conditions and to legal standards to assess the magnitude of predicted changes (sections 3.7 and 3.8).

For more detailed information in these various areas, the interested reader is referred to the following reference documents:

Characterization Reports

Ashbrook, P. 1978. Ambient concentrations of mineral fibers in air and water in northeastern Minnesota.

Eisenreich, S.J., G.J. Hollod and S. Langevin. 1978. Precipitation chemistry and atmospheric deposition of trace elements in northeastern Minnesota.

Eisenreich, S.J., S.A. Langevin and J.D. Thornton. 1978. Metal composition and size distribution of atmospheric particulate matter in remote northeastern Minnesota.

Endersen, G.W. and D. Feeney. 1979. Particulates in northeastern Minnesota, regional characterization.

Ritchie, I. 1978. Copper-Nickel Study Region point source emissions inventory for particulate and sulfur dioxide emissions.

Seltz, J. and M. West. 1976. Air quality program operations manual.

Thingvold, D.A., R.W. Mustalish, B. Honetschlager and D.T. Feeney. 1979. Characterization of water resources of the Copper-Nickel Study Area.

Watson, B.F. 1978a. The climate of the Copper-Nickel Study Region of northeastern Minnesota. Part A: The long-term climatological record.

Watson, B.F. 1978b. The climate of the Copper-Nickel Study Region of northeastern Minnesota. Part B: Weather during the Project 1976-1978.

Wilson, J.C., K.T. Whitby, V.A. Marple and J.E. McCormack. 1979. Characteristics and origins of coarse particles in the air of northeastern Minnesota.

Copper-Nickel Source Simulations

Coleman, R.T., Jr. 1978. The behavior of minor and trace elements in a smelter treating copper-nickel concentrates from the Minnesota Duluth Gabbro Complex.

Iwasaki, I., K.A. Smith, P.L. Gleder. 1978. Mineral processing studies-dust generation.

Volume 2, Chapter 2 of this report: Mineral Extraction.

Volume 2, Chapter 3 of this report: Mineral Processing.

Volume 2, Chapter 4 of this report: Smelting and Refining.

Copper-Nickel Impacts

Ashbrook, P. 1979. Impacts of fugitive dust emissions from a model copper-nickel mine and mill.

Endersen, G.W. 1979. Short-range dispersion of sulfur dioxide from a smelter complex.

Ritchie, I.M. 1979. A regional approach to analyzing the atmospheric impacts of copper-nickel smelting in northeastern Minnesota (thesis in preparation).

3.1.2 Summary of Findings

The major findings presented in detail in this chapter are outlined below. Although the Duluth area is considered briefly in terms of a potential smelter location, the bulk of the discussions focus on the Regional Copper-Nickel Study

Area (Study Area) shown in Figure 1, and more generally on the Air Quality Study Region surrounding the Study Area.

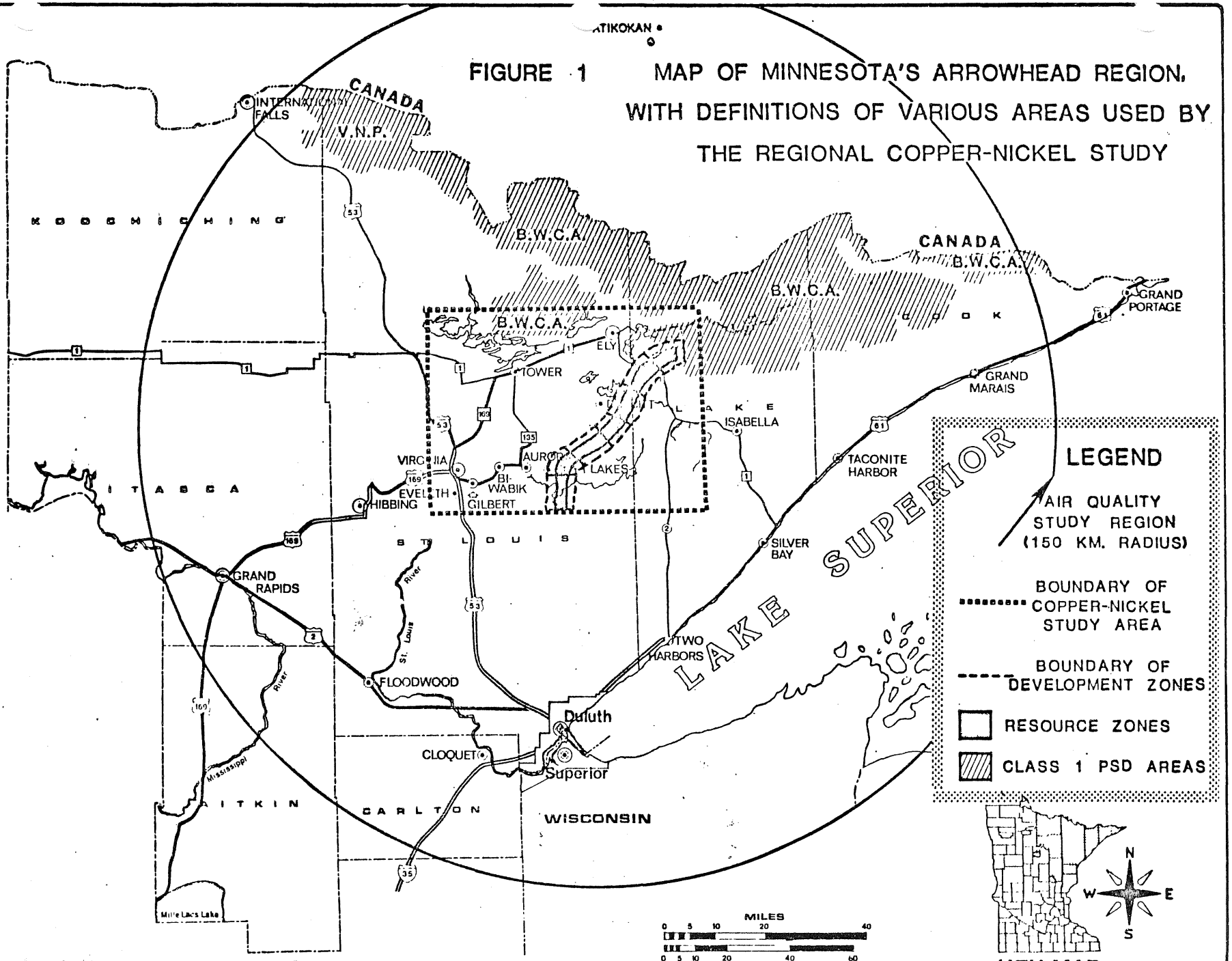
Figure 1

3.1.2.1 Climatology/Meteorology--The climate of the Study Area is characterized by cold winters and warm summers. The area is far enough east for atmospheric circulation to bring sufficient rain to allow the climax vegetation to be forest. Precipitation in the Study Area averages from 700 mm (27.6 in.) in the southwest to 760 mm (29.9 in.) in the northeast. Pan evaporation measured at Hoyt Lakes shows a mean seasonal value of 725 mm (28.5 in.) while actual lake evaporation ranges around 470 mm (18.5 in.). Clearly, lake inputs exceed evaporative losses by over 200 mm (7.9 in.) across the region on the average. The bulk of the precipitation typically occurs during the period June to September, with roughly half of the annual precipitation occurring at that time.

During the 1976-78 field monitoring study period, dryer than normal conditions were experienced in 1976, with wetter than normal conditions in 1977. Average annual precipitation at Babbitt is 726.4 mm (28.6 in.). For the 12-month period from April 1 of 1976, the total precipitation there was 389 mm (15.3 in.), which is only 53% of normal. For the 12-month period beginning April 1, 1977, precipitation was 933 mm (36.7 in.) which is 128% of normal.

The wind distribution and annual wind rose at Hibbing, which is generally representative of the Study Area, are shown in Figures 2 and 2A. Northwesterly winds predominate in the winter months, with the southeasterly component becoming more prominant in the summer and early autumn. Mean monthly wind speeds vary from 7.8 to 10.4 mph at Hibbing, with an annual mean of 9.1 mph.

FIGURE 1 MAP OF MINNESOTA'S ARROWHEAD REGION, WITH DEFINITIONS OF VARIOUS AREAS USED BY THE REGIONAL COPPER-NICKEL STUDY



MEQB REGIONAL COPPER-NICKEL STUDY

Figures 2 and 2A

The Area is characterized by extreme temperature variations between summer and winter. In Hibbing the monthly mean temperature in January (the coldest month) is -15.4°C (4.3°F) while the warmest month, July, has a mean temperature of 18.7°C (65.7°F). Small lakes and ponds in the Area are normally ice covered from early November to mid-April with large lakes being frozen over from late November to the end of April.

3.1.2.2 Air Quality--The air quality in the Study Area as a whole is quite good, although portions of the region along the eastern end of the Mesabi Iron Range are non-attainment areas for particulates. 24-hour TSP concentrations in excess of the 260 ug/m^3 primary ambient standard were measured at Virginia and Hibbing during the course of the Study.

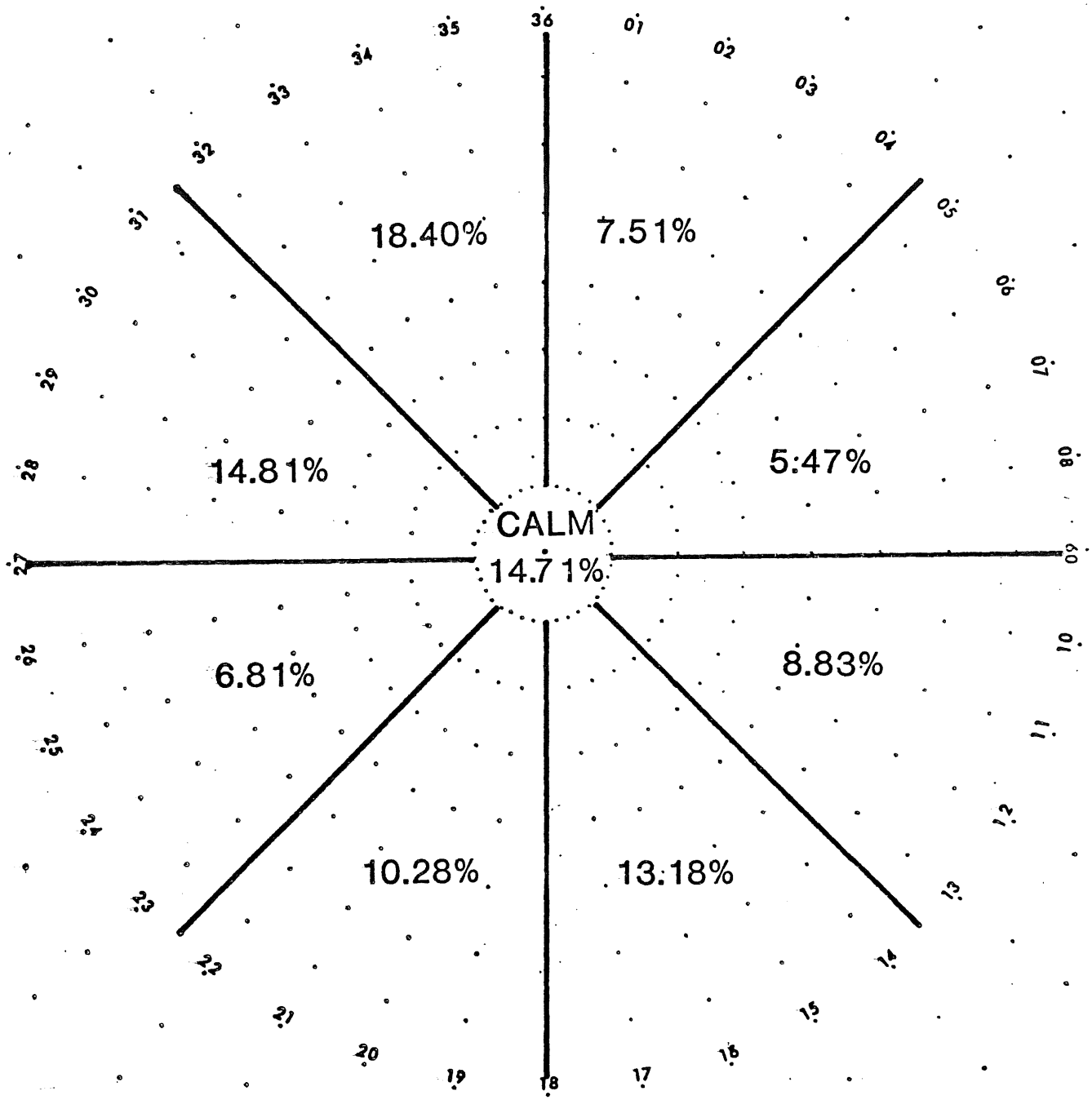
The point source emission inventory for the air quality study region lists total annual SO_2 emissions of 84,820 mtpy for 1975-76 with projections for 196,700 mtpy by 1985, an increase of 132%. For particulates, 1975-76 annual emisions of 92,540 mtpy are expected to decline 38% to 57,740 mtpy by 1985. The SO_2 emission increases are principally due to growth in the power generation industry and the conversion of the taconite industry from natural gas to coal. The expected decline in particulate emissions is attributable to improved control efforts, notably at the Reserve Mining taconite operation in Silver Bay.

At the present time, ambient SO_2 concentrations in the region are below the detection level of 5.24 ug/m^3 for the continuous SO_2 analyzer located at the isolated Fernberg site in the northeastern part of the Study Area. Based on predicted concentrations using a gaussian dispersion model with the point sources

FIGURE 2

WIND DISTRIBUTION % FREQUENCY BY OCTANTS

HIBBING (1964 - 1973 DATA)



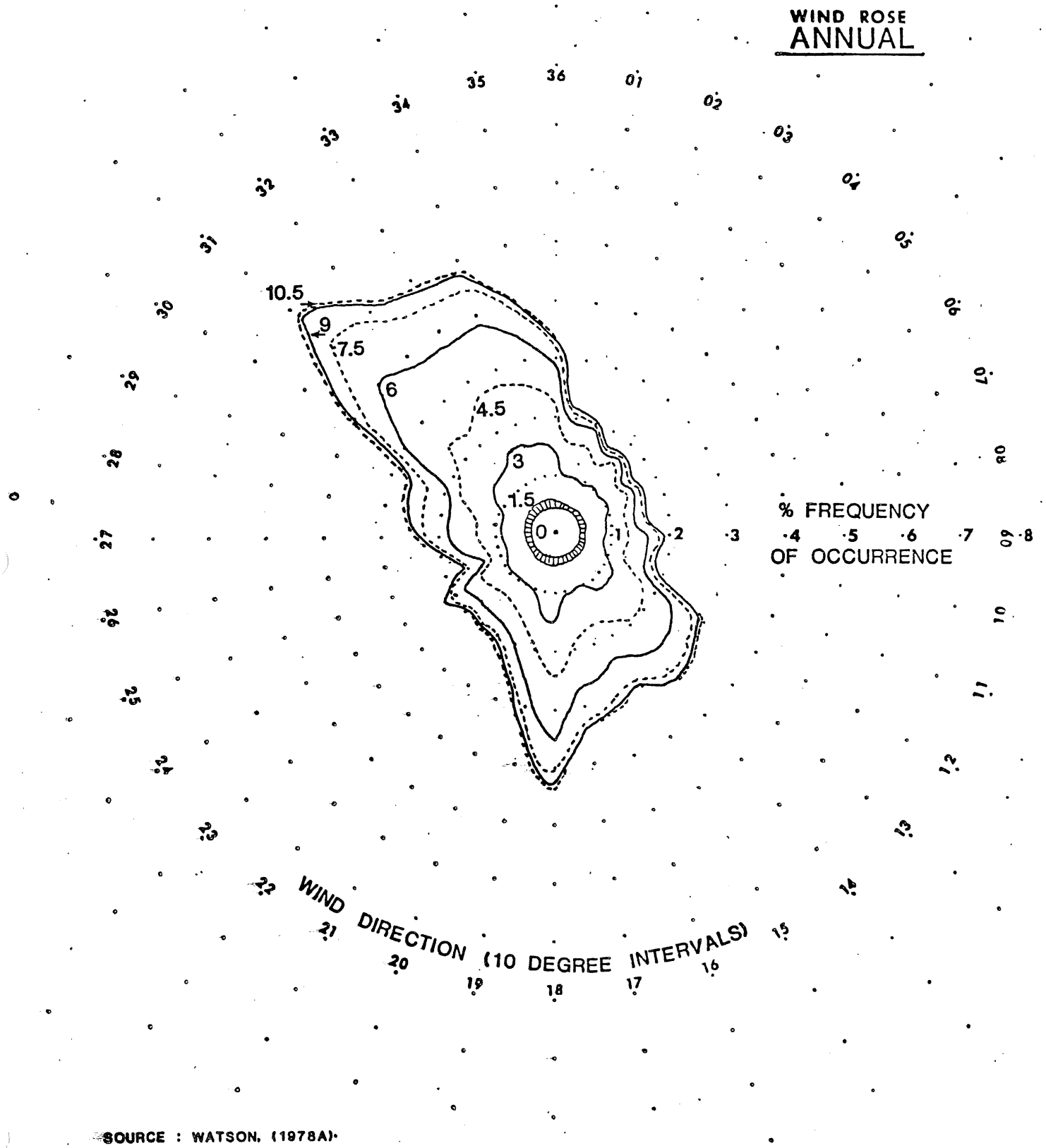
SOURCE : WATSON, (1978A).

FIGURE 2A

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



SOURCE : WATSON, (1978A).

in the baseline emissions inventory, a regional mean annual SO_2 concentration of 1.1 ug/m^3 was calculated. The highest calculated annual mean at any site was 3.3 ug/m^3. Based on expected growth in the region, the regional and highest annual means are predicted to increase to 2.3 ug/m^3 and 5.6 ug/m^3, respectively, by 1985.

In terms of modeled 24-hour SO_2 concentrations from local sources, the maximum predicted value for 1977 is 52 ug/m^3. This is predicted to increase to 78 ug/m^3 in 1985 (exclusive of copper-nickel development). The allowed 24-hour PSD (Prevention of Significant Deterioration) Class II increment of 91 ug/m^3 is not predicted to be exceeded at any of the modeled receptor sites. However, the more stringent Class I increment of 5 ug/m^3 which is applicable in the BWCA and Voyageurs National Park is predicted to be exceeded at several sites with projected non-copper-nickel growth. Because of the projected increases in SO_2 emissions in and near the Study Area, high-sensitivity continuous monitoring SO_2 stations should be established along the Iron Range between Hibbing and Birch Lake. The information provided by these stations would be invaluable in validating air quality models and in developing a management plan pertaining to protection of the Class I PSD increment.

Measured values of ambient sulfate (total sulfur expressed as sulfate) in the region averaged from 1 to 2 ug/m^3. Modeling of local SO_2 sources indicates that more than 99% of this total cannot be accounted for by sources within the region, indicating long-range transport from outside the region is an important sulfate source in the Study Area.

This is further supported by deposition data. Geometric mean annual deposition rates from bulk deposition samplers at 4 sites in the area ranged from 12.4 to

15.4 kg/ha/yr. Modeling of local sources indicates that, although local sources dominate dry deposition, they account for only 10-20% of the total observed deposition. Again, long-range transport from remote sources is indicated as the dominant cause of sulfate deposition in the Area, with wet deposition playing the major input role. Given expected national increases in sulfur emissions, regional deposition of sulfate may well increase by a factor of 2 or more by 1985. Specific forecasts cannot be made with confidence due to lack of information on the source of this sulfur. A monitoring and modeling program should be undertaken in the Area as soon as possible to resolve this problem. The program should be designed to determine annual, seasonal, monthly, and event deposition rates for sulfate, and also for nitrates. The resulting information will aid in understanding the varying deposition rates and sources of these important acid-generating compounds.

Background particulate concentrations in the Study Area are typically 10 to 11 ug/m^3 for geometric annual means at undisturbed locations. These values increase to 15 to 30 ug/m^3 in small towns and adjacent to existing mining operations. In larger population centers, values range from 36 ug/m^3 in Hibbing to 54 ug/m^3 in Virginia, which is near several mining operations. Local concentrations near sources can be quite high for short periods. The maximum observed 24-hour concentration at the Dunka Road site, for example, was 243 ug/m^3. During the $1\frac{1}{2}$ year course of the monitoring program, 3 readings greater than the primary standard (2 in Virginia, 1 in Hibbing) and 18 readings greater than the secondary standard were observed in the region. The effect of taconite mining in the Study Area became apparent during the 1977 taconite workers' strike. Average TSP values during the strike were at least 45% lower than pre-strike values for all monitoring sites.

Modeling of point emission sources in the region indicates that their contribution to observed particulate levels is quite small, typically a fraction of a percent. Area sources in the region appear to dominate the existing TPS levels. Modeling further predicts that annual PSD increments do not appear to be in jeopardy based on projected 1985 development. However, new particulate sources in the region may lead to exceedances of the allowable 24-hour PSD increment in Class II areas. No presently projected developments (exclusive of copper-nickel mining) are close enough to Class I areas to cause predicted exceedances of the increment in these areas.

The atmospheric concentrations of several elements of concern were measured. Table 1 summarizes and compares the results for the region as a whole and for the remote background site at Fernberg Road to data from other remote and urban areas. For the Study Area, iron levels are considered high (above 1,000 ng/m^3) while levels of silicon, aluminum, potassium, and sulfur are intermediate (100-1,000 ng/m^3). The remaining elements are low (10-100 ng/m^3) or very low (less than 10 ng/m^3). Of course, certain spatial patterns are apparent as expected. Lead, for which automobile exhaust emissions constitute a major source, averaged 10-20 ng/m^3 at background sites and 100-200 ng/m^3 at sites associated with population centers. Iron also showed significant enhancement near population and industrial centers.

Table 1

Particulate deposition studies focused on deposition rates for a variety of elemental constituents of concern in the context of copper-nickel development. Table 2 presents the bulk deposition rates measured in the Study Area expressed as regional averages. The rates for many elements were below the detection

Table 1. Elemental concentrations in air particulates for northeastern Minnesota compared to remote and urban areas worldwide (in ng/m^3).

ELEMENT	Urban	Remote	NORTHEASTERN MINNESOTA	
			Fernberg	Region Average[a]
Al	190-4,000	2-450	100	240-299
Si	670-60,000	130-7,500	455	910
K	200-5,000	10-300	110	163
Ti	18-500	1-50	16	29-56
Sr	---	---	.3	2-5
Rb	---	---	.1	.7-2
Mn	10-200	0.2-20	6	15-19
Ga	---	---	.4	.3-2
Fe	250-10,000	4-800	376	1,048
Ni	2-200	0.4-10	1	2-4
Ge	---	---	.2	.04-2
V	20-600	0.5-20	.8	.5-11
P	50-200	5-100	33	50
Cr	2-100	0.1-15	11	4-10
Ba	---	---	15	30
Co	0.2-20	0.1-14	.6	2-8
Cu	10-1,000	0.1-100	5	6-12
Zn	30-3,000	0.03-100	76	22
Cl	70-7,063	9-2,000	19	34-83
Sn	---	---	2	1-5
W	---	---	4	.7-7
As	1-40	0.3-5	2	4-7
Ca	150-20,000	10-2,500	201	320
S	2,000-10,000	800-13,000	729	692
Sb	---	---	2	.6-4
Pb	20-3,000	0.3-200	19	58
Br	6-700	.5-8	5	15
Hg	.2-11	.06-4	.2	.2-3
Cd	.3-100	0.01-4	2	.8-9

SOURCE: Eisenreich, Hollod and Langevin (1978).

[a]Where a range is shown, the lower average resulted from including not-detectable data as zero, while the higher average was arrived at by omitting not-detectable data. The data shown here include the Duluth site.

limits. For comparison, rates measured over Lake Superior and Lake Michigan are also shown. Of particular interest are the deposition rates for Cu (0.011 kg/ha/yr) and Ni (less than .014 kg/ha/yr) since these may be associated with emissions from a copper-nickel smelter.

Table 2

Measurements of the ambient concentrations of mineral fibers in the Study Area revealed total fiber concentrations ranging from 10,000 to 40,000 fibers/m^3. Excluding chrysotile, which may have been due to contamination in the filter paper used for sampling, values ranged from 7,500 to 35,000 fiber/m^3. From 10-50% of this concentration was composed of fibers identified as amphibole. About half of the fibers were neither chrysolite or amphibole but consisted of other minerals. For comparison, it is noted that measurements in the vicinity of Reserve's processing plant in Silver Bay revealed concentrations of total fibers ranging from 200,000 to almost 500,000 fiber/m^3 with amphibole consistently accounting for 50% or more of the total.

3.1.2.3 Source Simulation Models--To simulate the possible emissions from various aspects of a copper-nickel development, a series of source models were generated. The two principal emissions modeled were SO_2 and particulates.

The only major SO_2 source unique to the development of a copper-nickel industry is a smelter. The emission models used are based on a facility capable of producing 100,000 mtpy of copper plus nickel metal. Both low level fugitive emissions and stack emissions were modeled. Figure 2B schematically illustrates the sources of these smelter emissions. Three models reflecting successively improved SO_2 control systems were used with the final model, option 3, reflecting

Table 2. Summary comparison of atmospheric deposition of trace elements (kg/ha/yr).

ELEMENT	NORTHEASTERN MINNESOTA A	LAKE SUPERIOR B	LAKE SUPERIOR C	LAKE MICHIGAN D
Al	.85	---	1.6	.86
Fe	1.08	1.18	1.9	.48
Zn	.057	---		.19
Cu	.011	.045	.097	.021
Ni	-.014	---	.024	---
Pb	.077	.079	.17	.11
Cd	.003	.007	.006	.002
As	-.011	---	---	---
Ca	-11.3	4.0	4.2	14
Mg	-11.3	.68	1.0	2.7
Na	3.5	1.8	---	1.9
K	3.5	1.6	---	1.1
Cl	-13	---	---	---
SO_4	14.4	27	---	15

A-Bulk deposition data. A minus(-) indicates the average is less than the value shown.
B-Eisenreich, Hollod and Langevin (1978).
C-IJC (1977).
D-Eisenreich (1978).

the best state of the art control technology. Table 3 summarizes the annual emission rates for the 3 models. The facility is assumed to operate 24 hours per day for 350 days every year. Figure 3 places the total modeled SO_2 emissions into context by comparison with the emissions from a variety of other sources.

Figures 2B and 3, Table 3

In terms of particulate emissions, much less data is available on which to base emission estimates. The three SO_2 models given above are reduced to two particulate models, with the option 1 and 2 models assumed to result in the same particulate emissions. No attempt was made to create models which were representative of emissions meeting existing performance standards as was done for SO_2. In fact, greater control (possibly reducing total emissions by an order of magnitude or more) is expected to be feasible than the control reflected in the best of the two models given here. With these qualifications the 2 emission models are summarized in Table 4. The table also presents a model for the composition of the particulates, assuming they have the same composition as the concentrate fed to the smelter. Figure 4 places these models in context with other particulate sources in the region.

Table 4 and Figure 4

The only other emissions model used for impact assessment is a mine and processing model representing the particulate emissions from area sources associated with an open pit mining and milling operation producing 20 X 10^6 mtpy of ore. The model is pictured late in the operating life of the facility when the mine and associated waste disposal areas have their maximum extent. Table 5 summarizes the estimated range of emissions from various operations and lists the

FIGURE 2B SOURCES OF STACK AND FUGITIVE EMISSIONS IN A SMELTER

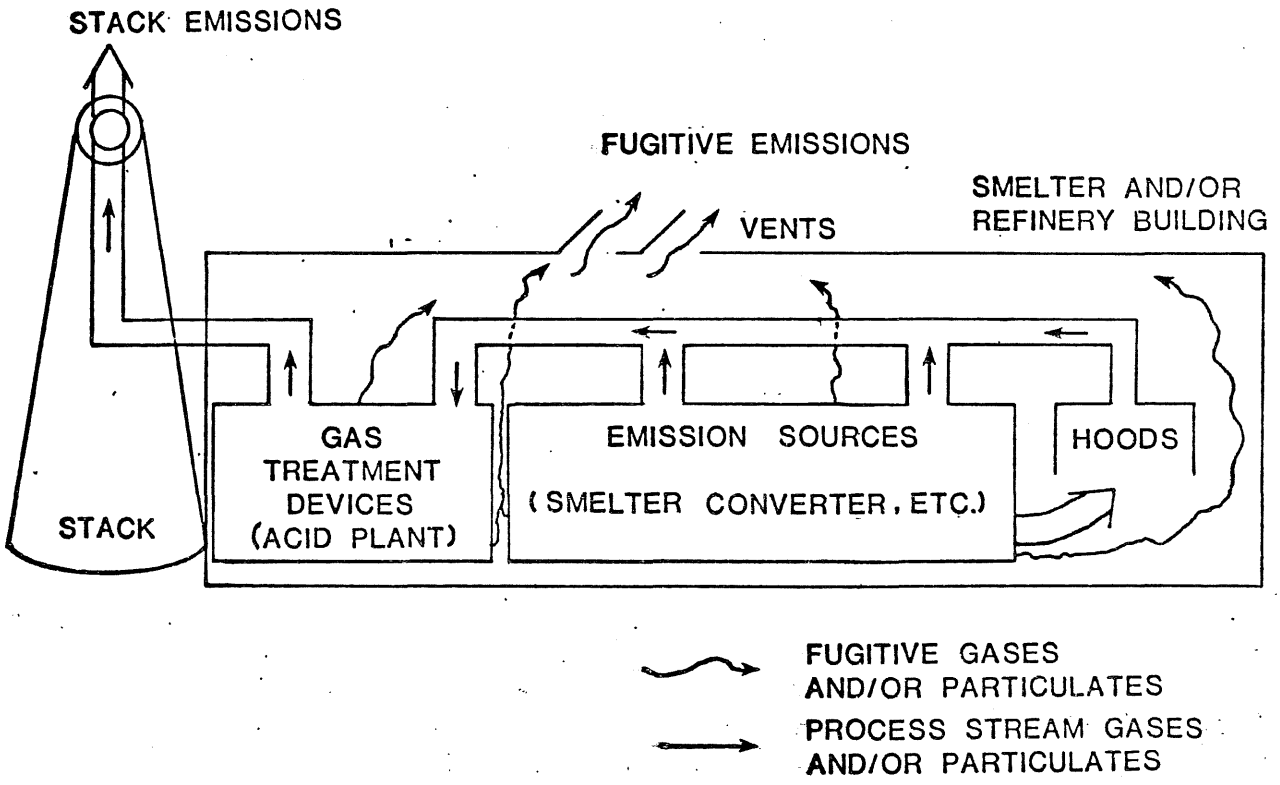
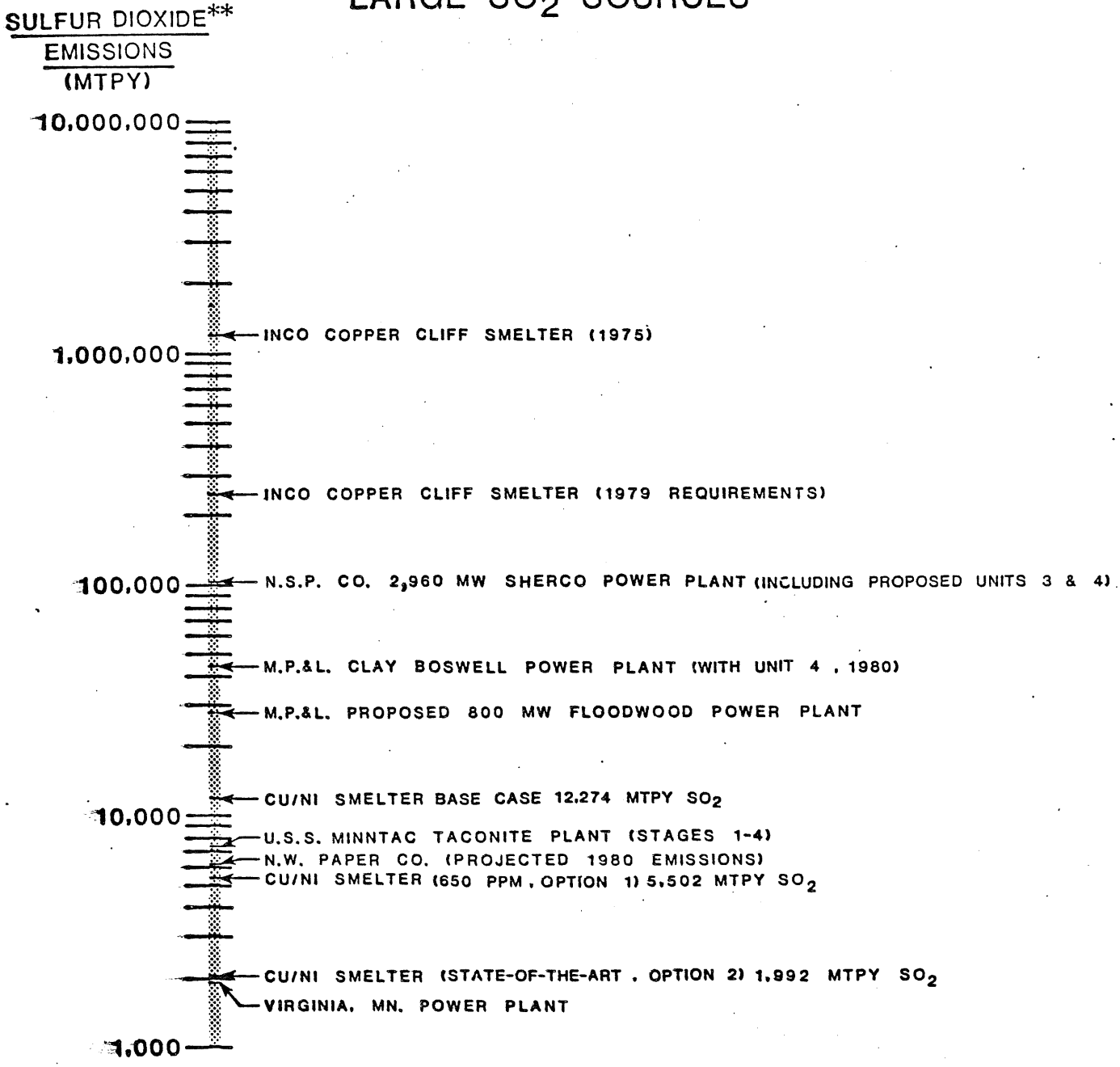


FIGURE 3

SUMMARY OF MODELED FLASH SMELTER SO_2 EMISSIONS* AND EMISSIONS FROM OTHER LARGE SO_2 SOURCES



*VALUES INCLUDE STACK PLUS FUGITIVE EMISSIONS

**VALUES SHOWN ARE MTPY OF SO_2 WHICH IS TWICE THE AMOUNT OF SULFUR

Table 3. Summary of SO_2 emissions from three control models for a smelter complex producing 100,000 mtpy of copper plus nickel metal.[a]

MODEL VARIATIONS	ANNUAL SO_2 EMISSIONS IN MTPY (and gm/sec)		
	Fugitive Emissions mtpy (gm/sec)	Stack Emissions mtpy (gm/sec)	Total Emissions mtpy (gm/sec)
Base[b]	990(31)	11,284(358)	12,274(389)
Option 1[c]	990(31)	4,512(143)	5,502(174)
Option 2[d]	990(31)	1,002 (32)	1,992 (63)

[a]All models assume normal operating conditions (see Volume 2-Chapter 4 for further details). The large number of figures shown are included for computational reasons only (for consistency in an overall mass balance).

[b]Acid plant control of strong SO_2 gas to 650 ppm SO_2, plus redirection of weak SO_2 gas with secondary hooding.

[c]Same as b plus scrubbing of collected weak SO_2 gas to 650 ppm SO_2.

[d]Same as c with acid plant control of strong SO_2 gas to 300 ppm SO_2, plus scrubbing of acid plant tail gas and collected weak SO_2 gas to 143 ppm SO_2.

Table 4. Summary of particulate emissions and composition from two control models for a smelter complex producing 100,000 mtpy of copper plus nickel metal.

MODEL	ANNUAL PARTICULATE EMISSIONS (mtpy) Stack	Fugitive	Total
Base Case	2,385	1,500	3,885
Option 1-Option 2	358	1,500	1,858

Particulate Composition[a]

CONSTITUENT	DISTRIBUTION[c]
Cu	13.8%
Ni	2.6%
S	25.9%
As	.004%
Cd	.004%
Co	.13%
Be	.00006%
Pb	.006%
Hg	.00001%
Zn	.11%
Fe(sulfides)	30%
Sb	.0002%
Cl	.011%
F	.0004%
SiO_2	15.5%
Al_2O_3	3.4%
MgO	2.6%
CaO	1.6%
Other[b]	4.3%
	100%

[a]The model assumes the particulates have the composition of the mill concentrate, as presented in the smelter/refinery discussion (Volume 2-Chapter 4, Section 4.7.2.8). Normal operating conditions are assumed.

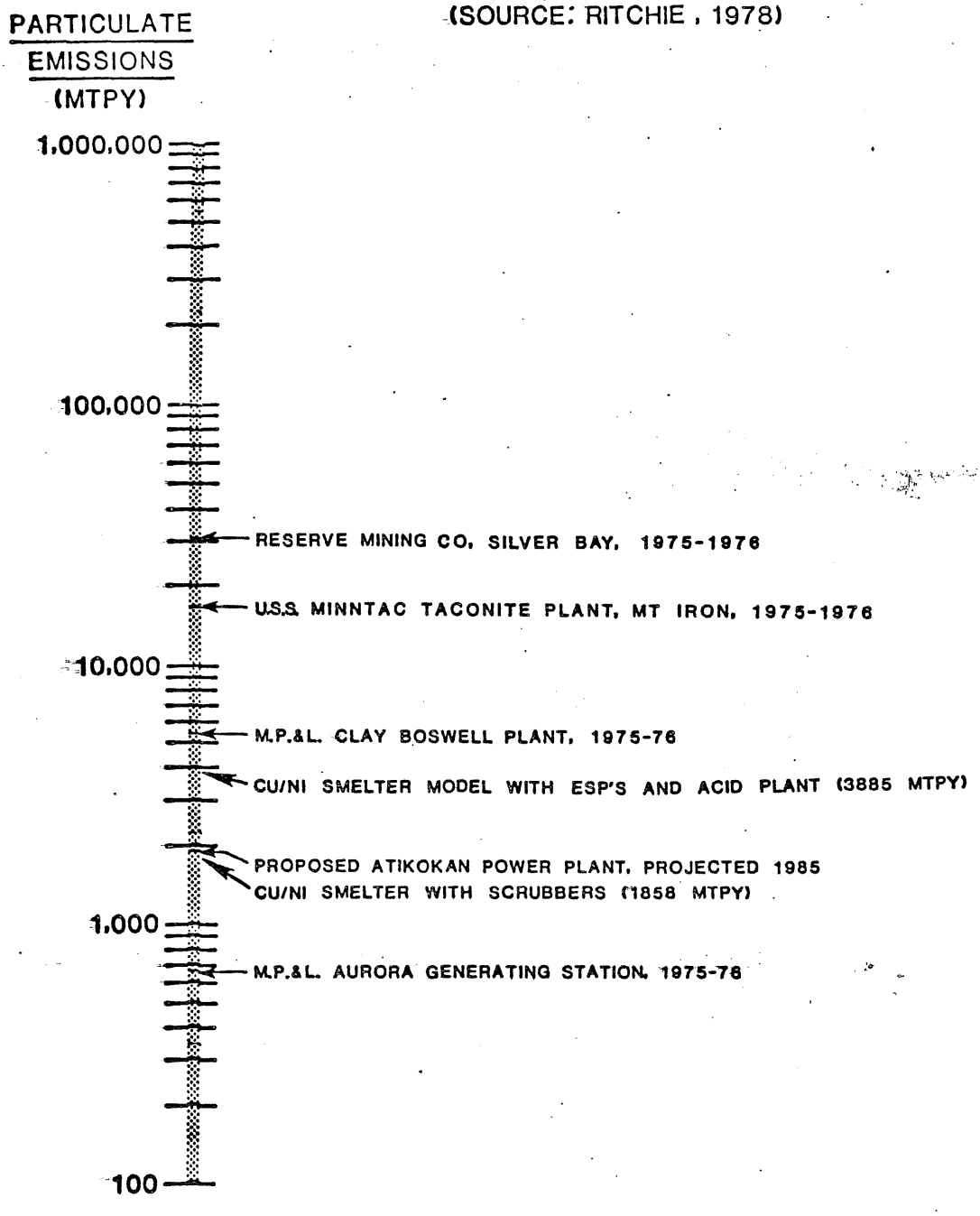
[b]Includes oxides of Na, K, Ti, P, Mn, Cr, and Fe.

[c]Weight percent.

FIGURE 4

SUMMARY OF MODELED FLASH SMELTER TOTAL PARTICULATE EMISSIONS AND EMISSIONS FROM OTHER LARGE PARTICULATE SOURCES

(SOURCE: RITCHIE , 1978)



value used for modeling purposes. In addition, based on bench scale tests of tailing, as well as concentrate, all processing products are assumed to contain 10^9-10^{10} mineral fibers per gram for modeling air quality impacts.

Table 5

3.1.2.4 Copper-Nickel Impacts--Employing the various copper-nickel source simulation models just summarized, dispersion modeling was used to assess the possible air quaity impacts on the region. The results indicate that in terms of ambient air quality, regional annual average increases due to the new sources are small with respect to existing levels and are not expected to exceed ambient or PSD increments, provided a smelter is not located too close to a Class I region. The 24-hour concentration predictions posed the greatest potential for exceeding the standards. The results of the 24-hour modeling simulations are thus stressed. The reader is referred to the following sections of the Copper-Nickel Study Report for detailed information on the public health and welfare significance of air quality impacts associated with copper-nickel development:

- try 4.3.4 instead

Volume 3-Chapter 4, section 4.3.5--Water Quality

Volume 4-Chapter 1, section 1.7--Aquatic Biology

Volume 4-Chapter 2, section 2.9--Terrestrial Biology

Volume 5-Chapter 2, sections 2.9 and 2.10--Public Health

For SO_2, there does not appear to be a problem with the 24-hour PSD increment being exceeded in Class II areas under normal operating conditions even with the base case smelter. Short range modeling simulations indicate that maximum concentrations, where the stack plume touches down, range from 50 to 90 ug/m^3 for the base case smelter under the worst meteorological conditions. This ignores

Table 5. Summary of estimated fugitive dust emissions from area sources associated with a copper-nickel mine and mill.[a]

OPERATION	ESTIMATED RANGE OF EMISSIONS (mtpy)	ESTIMATE USED FOR MODEL (mtpy)	PERCENT OF TOTAL	COMMENTS
Mine				
1) Blasting	1.5-1,600	10	0.4	Assumes 100 mtpy as a midpoint estimate and 10% of dust escapes the pit.
2) Hauling	840-4,200	2,100	74.8	Assumes dust control of 50%.
3) Waste rock dumping	8-400	10	0.4	Uses most recent MRI formula.
4) Waste rock piles erosion	2.4-400	60	2.1	Uses most recent MRI formula (silt content = 0.5%).
Mill				
5) Ore storage	2-210	10	0.4	Assumes 95% control.
6) Conveyors dumping on surge pile	1-100	10	0.4	Assumes 90% control.
7) Crushing/grinding	200-20,000	500	17.9	Based on Minntac's new plant (stage 3) and discussion with MPCA.
8) Tailing basin	0-480	100	3.6	Assumes 80% of basin under water.

[a]Assumes an open pit mine producing 20 X 10^6 mtpy of ore and removing 26 X 10^6 mtpy of waste rock. Estimates are for particulates less than 30 um.

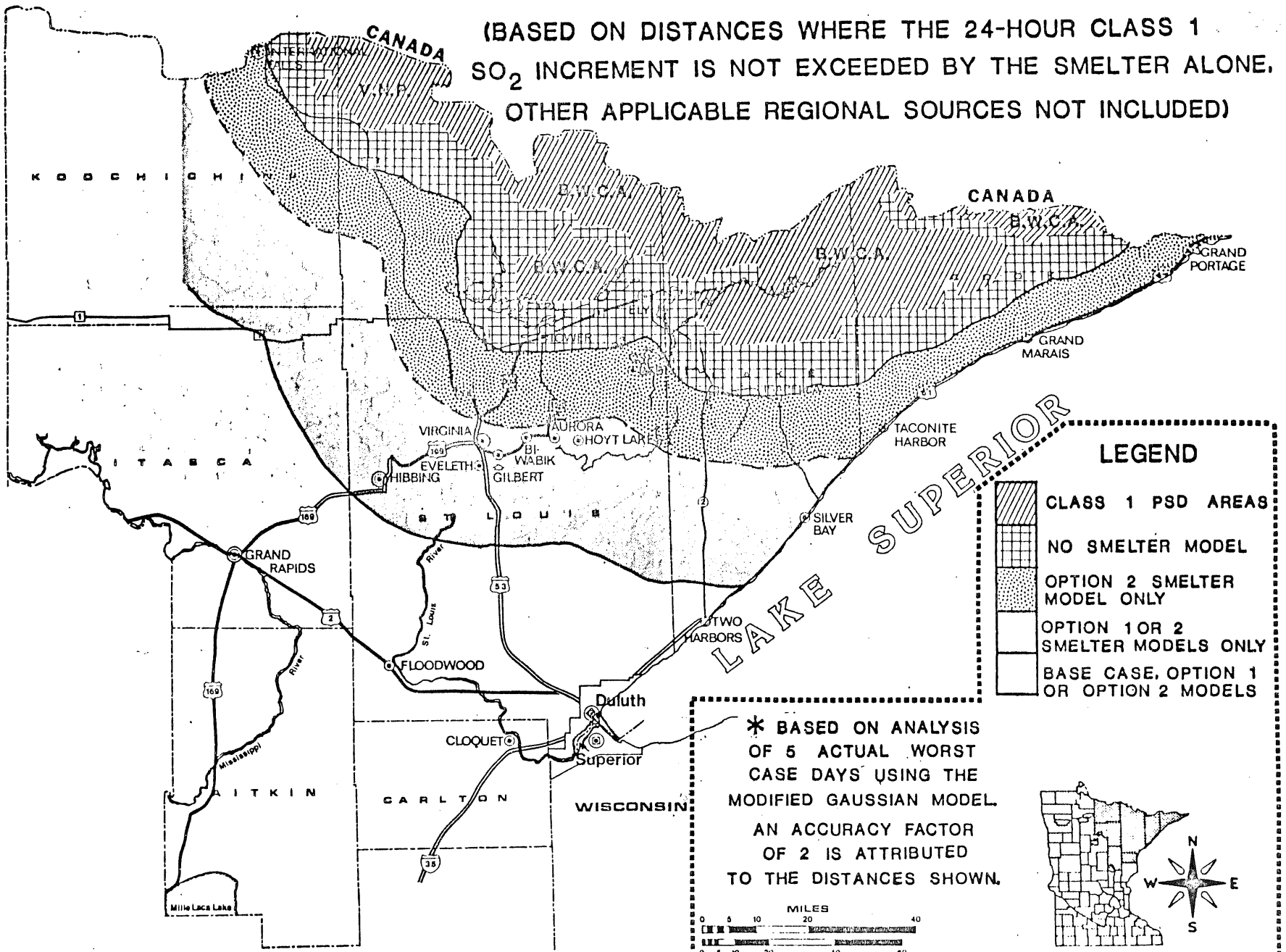
higher concentrations due to fugitives within roughly 1/4 to 1/2 km of the smelter location. These results are consistent with findings from the long range modeling as well. In terms of Class I PSD areas, the above results exceed the allowable increment of 5 ug/m^3 by a significant amount.

It is possible to create a generalized series of zones surrounding Class I areas which represent exclusion zones for the various smelter models. The results of this analysis are shown in Figure 5. None of the smelter models are expected to meet the allowable 24-hour Class I PSD increment for SO_2 if located within 10 to 20 km of a Class I area. Only the Option 2 model appears to meet the increment between 10 to 20 and 30 to 40 km, and the Base Case Model would require at least 70 to 80 km. A factor of 2 accuracy is attributed to the distance predictions here. Further, these conclusions do not factor in the contribution of new or expanded SO_2 sources other than from copper-nickel development. As mentioned previously, these other sources are projected to exceed the 24-hour Class I PSD increment without copper-nickel development. Therefore, the region along the Iron Range and on a line between existing and projected sources and the BWCA is not likely to be a viable location for a smelter or other large SO_2 sources. This conclusion is independent of the degree of air pollution control utilized unless exemptions allowed for by law are invoked. Thus, while SO_2 emission reduction is a very important factor in reducing ambient SO_2 concentrations, siting could be more important because of the need to evaluate overall changes in air quality caused both by copper-nickel sources and other existing and proposed sources in the region. The absolute need for a source may have to be the controlling factor affecting industrial siting in this region in the future.

Figure 5

FIGURE 5 SMELTER SITING ZONES* SURROUNDING CLASS 1 PSD AREAS

(BASED ON DISTANCES WHERE THE 24-HOUR CLASS 1 SO_2 INCREMENT IS NOT EXCEEDED BY THE SMELTER ALONE, OTHER APPLICABLE REGIONAL SOURCES NOT INCLUDED)



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The possibility of extremely high SO_2 concentrations occurring during short periods of time as a result of an accident or other upset at the smelter site was also modeled. The effect of the release of all the SO_2 generated in the smelter for a 3-hour period was used as a basis for two scenarios. The release was assumed to occur under worst case meteorological conditions and as stack emissions for one scenario and low level fugitive emissions for another, The maximum 3-hour SO_2 concentration for the stack scenario was predicted to be 1,800 ug/m^3 at about some 4 km downwind of the source. Values of 65,000 ug/m^3 at 1 km, 40,000 ug/m^3 at 4½ km, and 20,000 ug/m^3 at 10 km are predicted for the fugitive scenario.

The 3 smelter cases were also used to simulate regional average sulfate deposition. Based on a present regional average deposition of roughly 15 kg/ha/yr, the models predict increases of up to 15%, 6%, and 2% respectively for the Base Case, Option 1 and Option 2 models (using 9 selected receptor sites). Of course, ambient deposition is expected to increase in the future, possibly doubling by 1985 due to increased SO_2 emissions, thereby halving the increases noted above. Thus, the regional sulfate input from a smelter, especially a facility with state of the art control, is expected to be a minor contribution to total sulfate deposition. However, on a local scale, close to the smelter significant increases may occur. For example, a receptor site 5 km from the smelter location was modeled as having a 57% increase in sulfate deposition over the 1977 regional average using the base case smelter. This increase can be expected to compound the acid rain problem already thought to be affecting the region (see Volume 3-Chapter 4).

For particulates the findings for a smelter are rather similar to those for SO_2. Annual ambient concentration increases are not expected to pose a problem. For

24-hour concentrations under worst case meteorological conditions, values of 20-25 ug/m^3 may occur at 5 km from the site for the Base Case model. These fall to roughly 5 ug/m^3 at 25 km. Thus, there is the potential to exceed the Class I 24-hour TSP increment of 10 ug/m^3 if the smelter is located too close to a Class I zone. However, the SO_2 considerations discussed earlier place far more stringent conditions on possible sites, so TSP restrictions are not considered further.

The results of annual modeling of TSP concentration increases adjacent to a large mine and mill operation predict maximum annual geometric mean concentrations of 10-15 ug/m^3 from the facility. These levels occur within 1 km of the site, and fall to values in the range of 2-3 ug/m^3 at 3 km from the site. Extrapolating these results to 24-hour intervals indicates that this model might result in the Class II 24-hour PSD increment of 37 ug/m^3 being exceeded within 1 km of the facilities, and the Class I increment (10 ug/m^3) being exceeded within 10 km of the facility. Use of dust control methods to reduce the emissions below those used in the model would correspondingly reduce these distances.

Calculations were made of potential deposition rates of selected elements from smelter emissions. The predictions are only to be taken as general indicators due to the various assumptions required by the model. Assuming the particulates have the composition of the concentrate fed to the smelter, the deposition of copper at a receptor 5 km from the smelter site is predicted to be 600-700 gm/ha/yr for the Base Case Model. The values for Ni, Fe, and Co are respectively, 100-150 gm/ha/yr, 1,000-2,000 gm/ha/yr and 5-10 gm/ha/yr. These estimates are cut in half for the Option 1-Option 2 model. These are order of magnitude estimates only, but clearly the conclusions are that annual deposition rates for Cu and Ni may increase 1 to 2 orders of magnitude above present rates within 5 to 10 km of a smelter site. Sulfur and Fe deposition rates may double in this same vicinity.

Predictions of increased ambient fiber concentrations in the vicinity of a smelter indicate levels of 100,000-200,000 fibers/m^3 may occur within 5-10 km of the Base Case smelter model. These levels are an order of magnitude (10 times) higher than present ambient levels and are comparable to concentrations measured in Silver Bay near Reserve's taconite processing plant (which is under a compliance agreement to greatly reduce fiber emissions). Fibers from the mine-mill area source model could double concentrations within 1 km of the operation. All these estimates are quite general and represent worst case assumptions, including use of a fiber conversion factor of 10^{10} fibers/gm of dry tailing and concentrate. Further, it is assumed that this conversion is constant for emissions of particulates and for the relationship of TSP to fiber content with increased distance from the source. Actual field data on fiber emission rates and ambient concentrations are required to verify these assumptions or indicate appropriate modifications.

3.2 OVERVIEW OF AIR RESOURCES STUDIES

3.2.1 Georgraphic Areas of Interest

The focal point for this study is the potential for the development of a copper-nickel mining industry in the state of Minnesota. The area most likely to contain any mines, based on available data to date, has been identified in terms of a set of seven resource zones, which are in turn within a larger area termed the development zones which should contain the bulk of facilities needed to serve any mines (see Volume 3-Chapter 2, section 2.1.1). The assumption is made here that initial development is most likely to occur in the most intensely explored areas of the Duluth Complex and not, for example, in the greenstone formations. A major greenstone find could invalidity this assumption. To allow for a

discussion of the potential biological, water, and socio-economic effects which might emanate from operations in any of the development zones, a still larger area, termed the Regional Copper-Nickel Study Area (or simply the Study Area) was defined. This roughly 5,000 km^2 area includes most of the communities adjacent to the areas of potential development. These three areas are shown in Figure 6. Further, for the purposes of discussing the potential air quality impacts of copper-nickel development it is necessary to define a region which is still larger than the Study Area.

Figure 6

By the nature of the global forces which move the atmosphere and any pollutants it contains, it is necessary to investigate air quality over a wide region surrounding the site of potential new atmospheric emission sources in order to properly understand the implications of these emissions. Accordingly, with the development zones as a focal point, an air quality study region was defined as being that area within a radius of 150 kilometers of the center of the development zones (taken here as generally being just southeast of a line between Babbitt and Hoyt Lakes). This more than 70,000 km^2 region is shown on the map in Figure 7.

Figure 7

A few comments concerning the selected air quality study region are in order. The region includes the Voyageurs National Park and the Boundary Waters Canoe Area (BWCA), a designated wilderness area within which the possibility of present or future degradation of air quality is of major concern to many individuals and groups. The region also includes Atikokan, Ontario, which is the proposed site

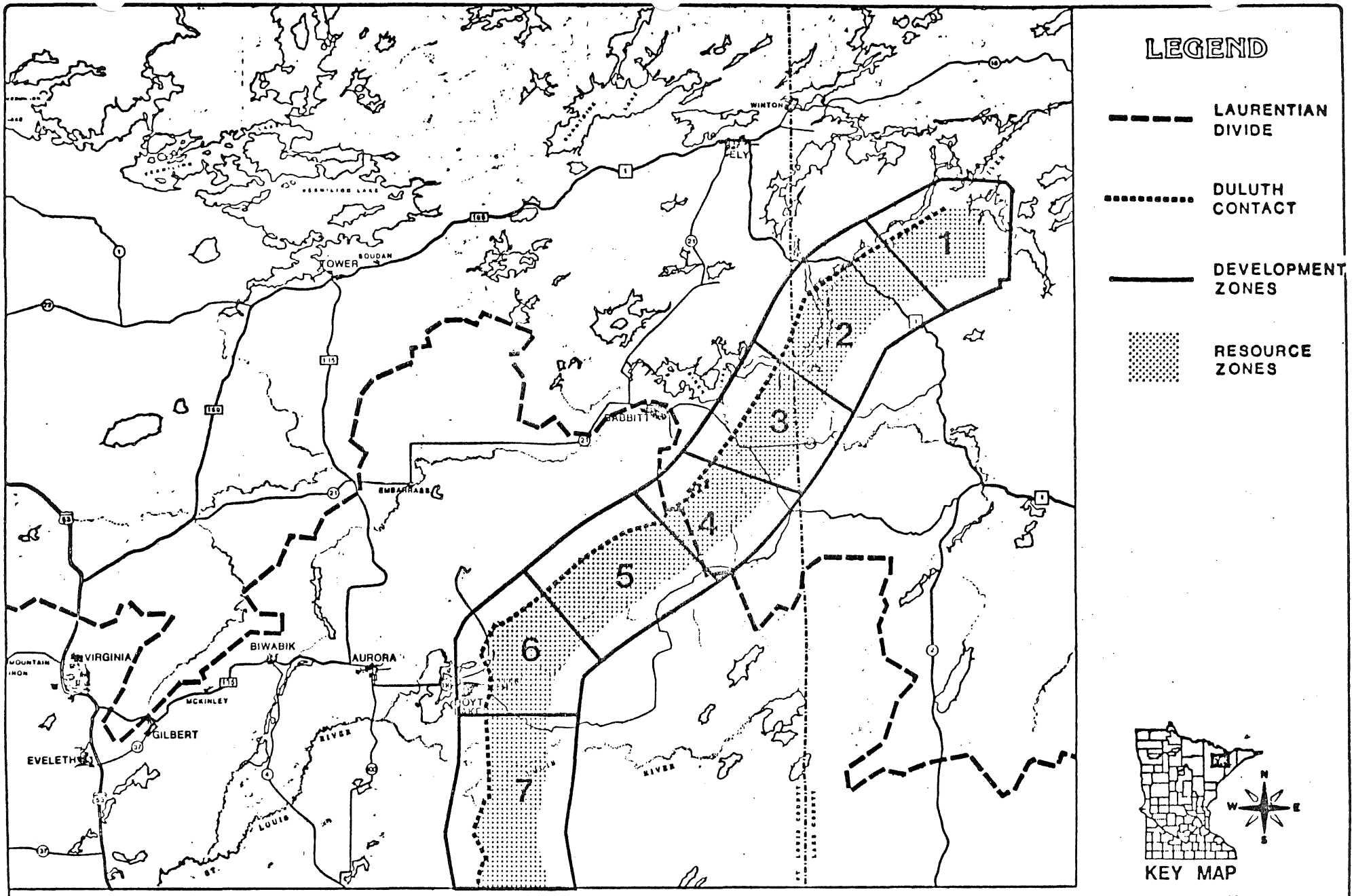

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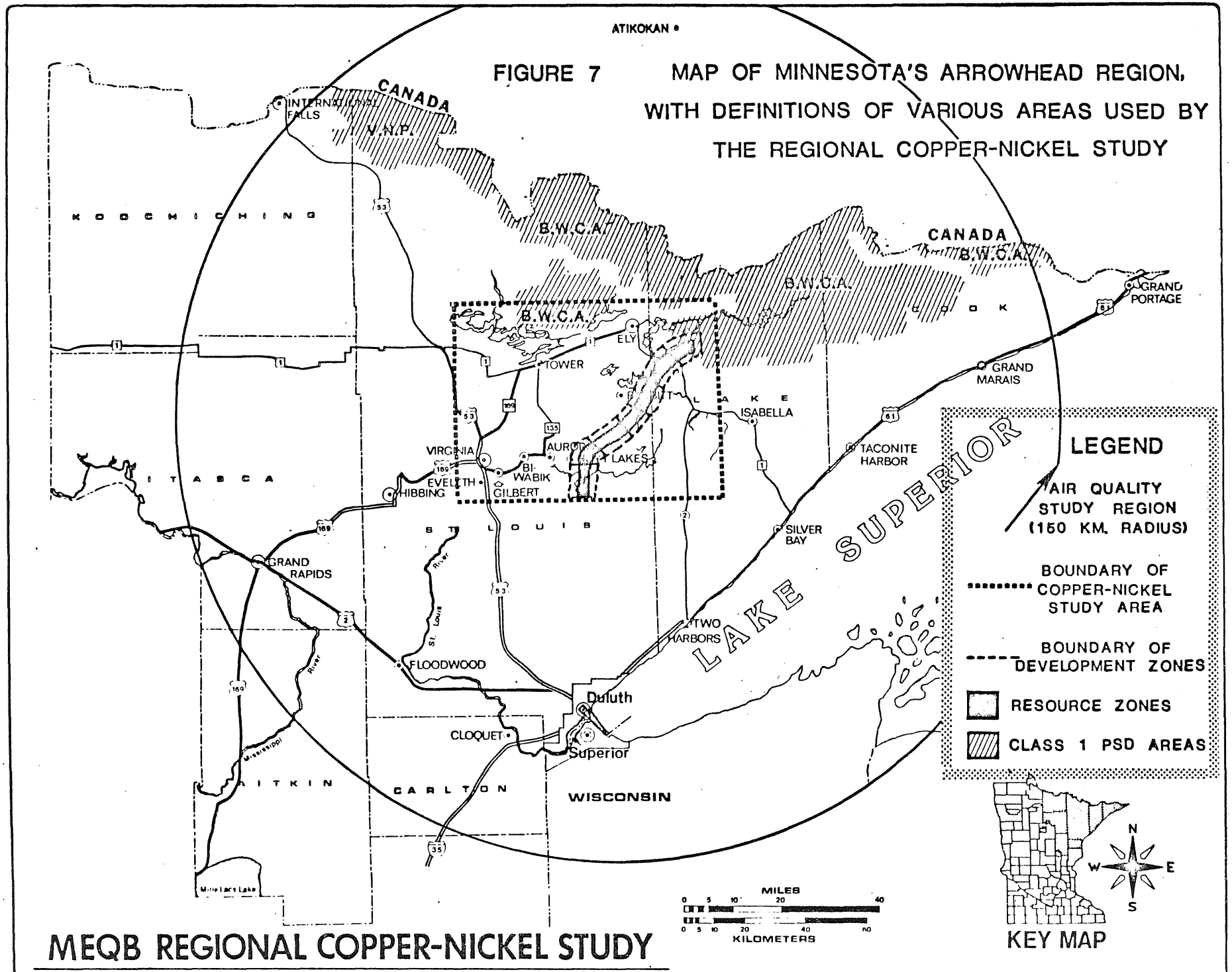
FIGURE 6 MN CU-NI DEVELOPMENT AND RESOURCE ZONES WITHIN THE STUDY AREA

FIGURE 7 MAP OF MINNESOTA'S ARROWHEAD REGION, WITH DEFINITIONS OF VARIOUS AREAS USED BY THE REGIONAL COPPER-NICKEL STUDY



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of a coal-fired power plant which is of concern as a possible source of air pollutants which may affect adjacent wilderness areas such as the BWCA. The region also encompasses the major communities and industrial areas in northeastern Minnesota and northwestern Wisconsin, including all of the Iron Range communities, Duluth, and Superior.

It is recognized that certain copper-nickel facilities, such as a smelter/refinery complex, may be located some distance from the mine site, even out of the state or out of the country. Due to the infinite locational possibilities, it was not considered meaningful to explore other sites in detail. Many of the impact discussions which follow present air quality impacts as a function of degree of source control and distance from the source, and so the implications are generally valid for other sites with reasonably similar meteorology. One exception here is the possibility of a smelter in the vicinity of Duluth. The various attractions Duluth offers as a potential site, coupled with its unique meteorological environment at the tip of Lake Superior, warrant giving the area special consideration. Accordingly, although detailed studies were not carried out there, the nature of the location and possible air quality impacts unique to that lakeshore location will be considered briefly in this report in addition to the discussion of development centered in the Study Area.

3.2.2 Air Resources Study Methodology

The basic task undertaken by the Regional Copper-Nickel Study staff in the disciplines related to air resources was to assess the potential air quality impacts from the development of a copper-nickel mining industry in northeastern Minnesota. To perform this task, several steps were required. First, information was needed to assess the air quality in the region in the absence of

copper-nickel development. Second, reasonably accurate models were needed to simulate the types of sources for various atmospheric pollutants which might be present in a copper-nickel operation. Finally, atmospheric dispersion modeling, both short- and long-range, was required to simulate the potential impacts of the mining sources on air quality in the region. The approaches used in each of these areas are briefly described below.

3.2.2.1 Air Resource Data Collection--Both meteorological and air quality data were needed for the study. Meteorological information is vital to certain other disciplines such as hydrology and water quality. Additionally, data on variables such as wind speed and direction are important parameters in dispersion modeling. Air quality data for parameters which may be affected by copper-nickel development are also vital to establish pre-development levels. Important variables include total atmospheric particulates and SO_2 concentrations, elemental content of ambient and deposited particulates, sulfate deposition, ambient concentrations of mineral fibers, and particle size distribution of atmospheric particulates.

To obtain meteorological data, an exhaustive search was made of historical data available on the region. Meteorologist Bruce Watson assembled this data and prepared a comprehensive climatological report (Watson 1978a), which is summarized here in section 3.3. In addition, meteorological studies were carried out in the region between July, 1976, and August, 1978, while other environmental studies were taking place in the Study Area. These data were invaluable in the interpretation of the findings in several other disciplines. Figure 8 shows the location and elevation of meteorological stations from which data was gathered during the course of this program. Figure 9 shows the type of data collected at each station. The results of these studies are presented in detail in Watson

(1978b), and briefly summarized in section 3.3 of this report.

Figures 8 and 9

A network of air quality monitoring stations was established in the region to record a variety of parameters. The network consisted of existing MPCA stations as well as new sites established specifically for the Regional Study. The map in Figure 10 presents the names and locations of the stations in and near the Study Area, which are of principal interest here. Site numbers are also shown, as well as sites in and near Duluth. Table 6 indicates the instrumentation employed at the various sites. Interested readers are referred to the air quality operations manual (Seltz et al. 1977) for further information on the sites as well as sampling methods and procedures.

Figure 10, Table 6

All data from the monitoring programs was stored in a computer for easy access and evaluation. Data is available from the Minnesota Pollution Control Agency and/or the Land Management Information Center-Minnesota State Planning Agency. Study findings are presented in sections 3.4 and 3.5 of this report.

3.2.2.2 Source Simulation--The principal potential source of air emissions associated with a copper-nickel development is the smelter facility since it is the only potentially major source of SO_2. Further, while it is not the only source of particulates, due to the extremely high metals levels of the concentrate handled by the smelter, there is a great deal more concern about particulates from this source than from other mining sources. Dust from blasting, hauling, etc. is expected to be high in silicate and oxide minerals, which are relatively innocuous compared to sulfides high in heavy metals.

FIGURE 8

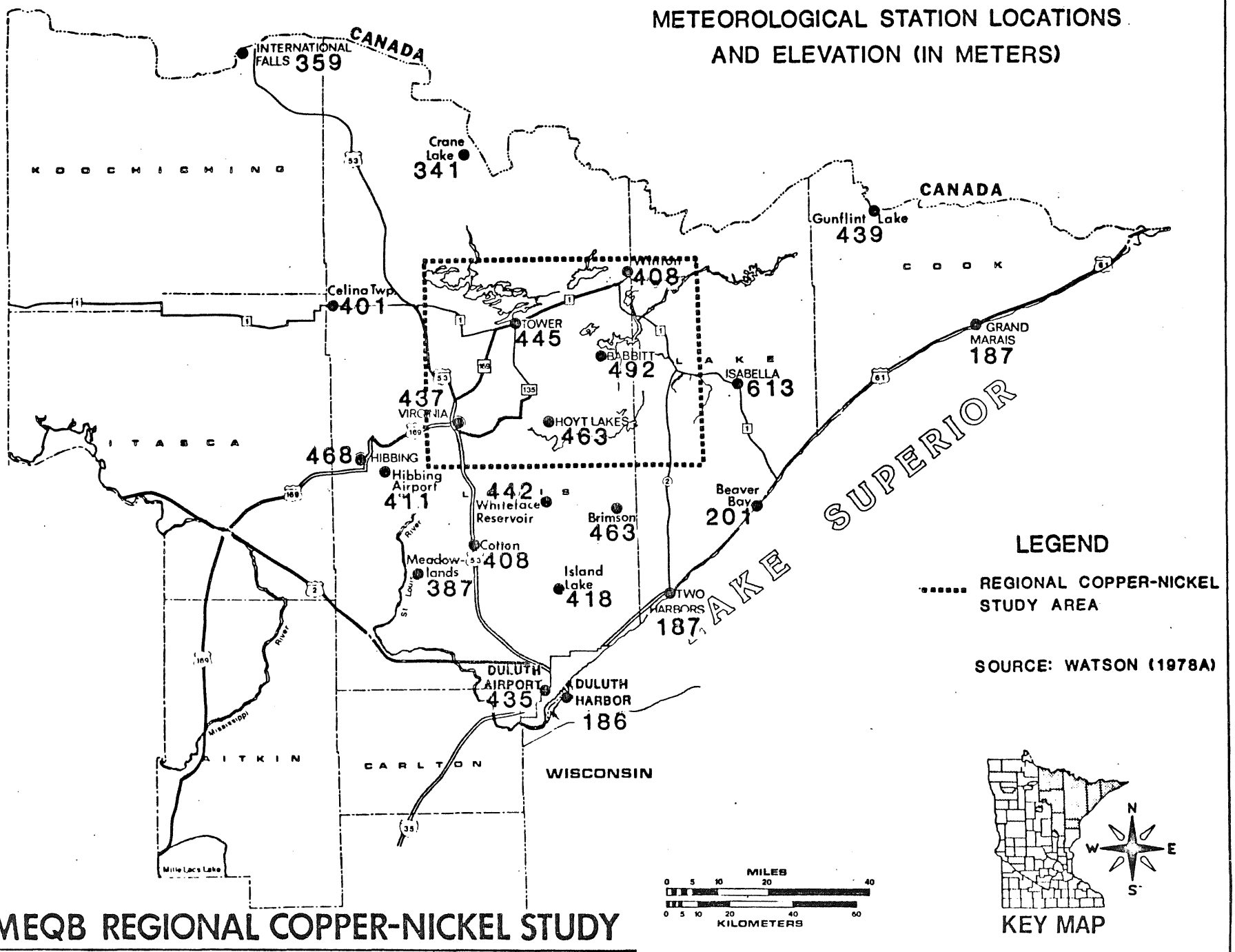

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FIGURE

TYPES OF DATA COLLECTED AT VARIOUS METEORLOGICAL STATIONS

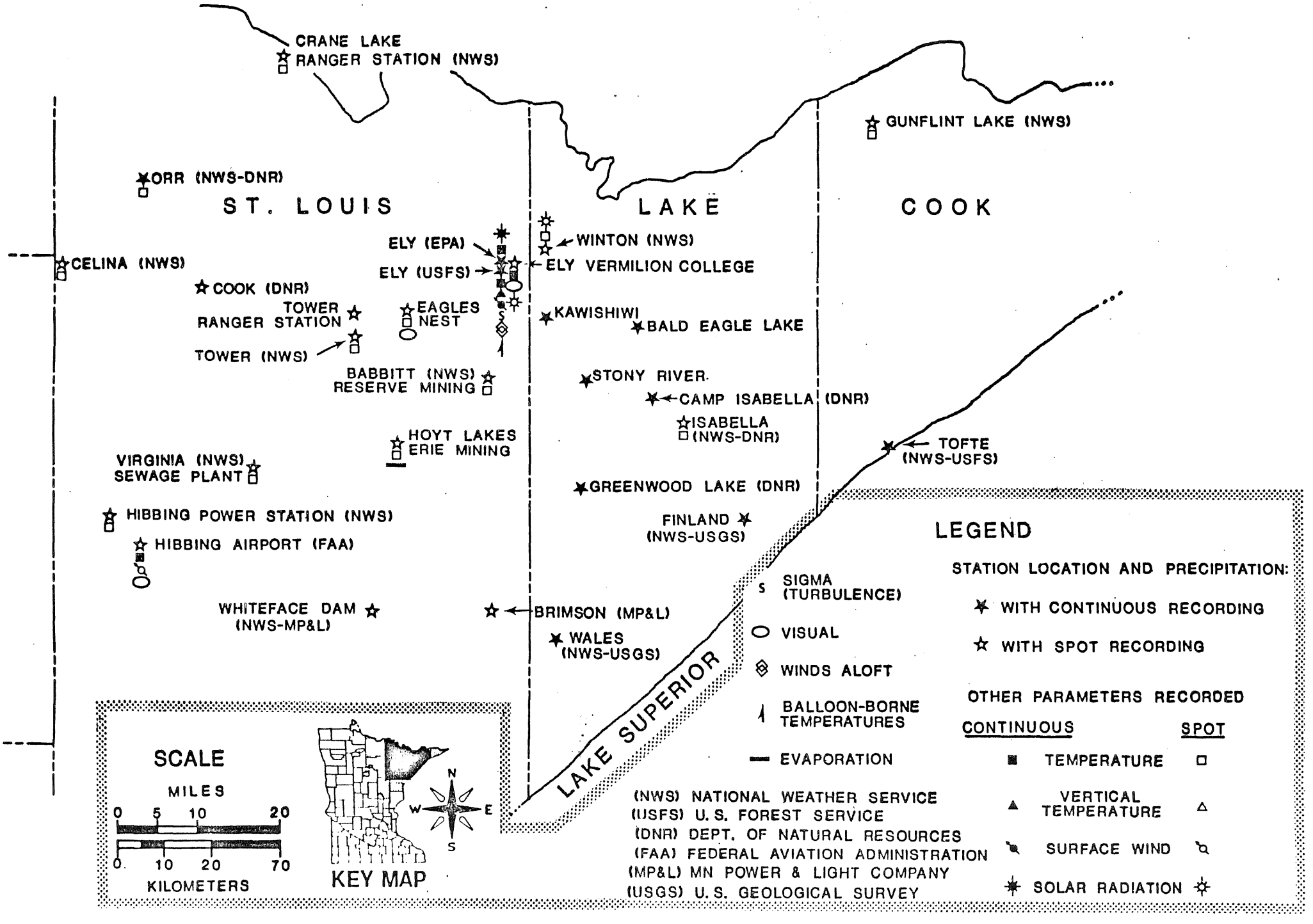
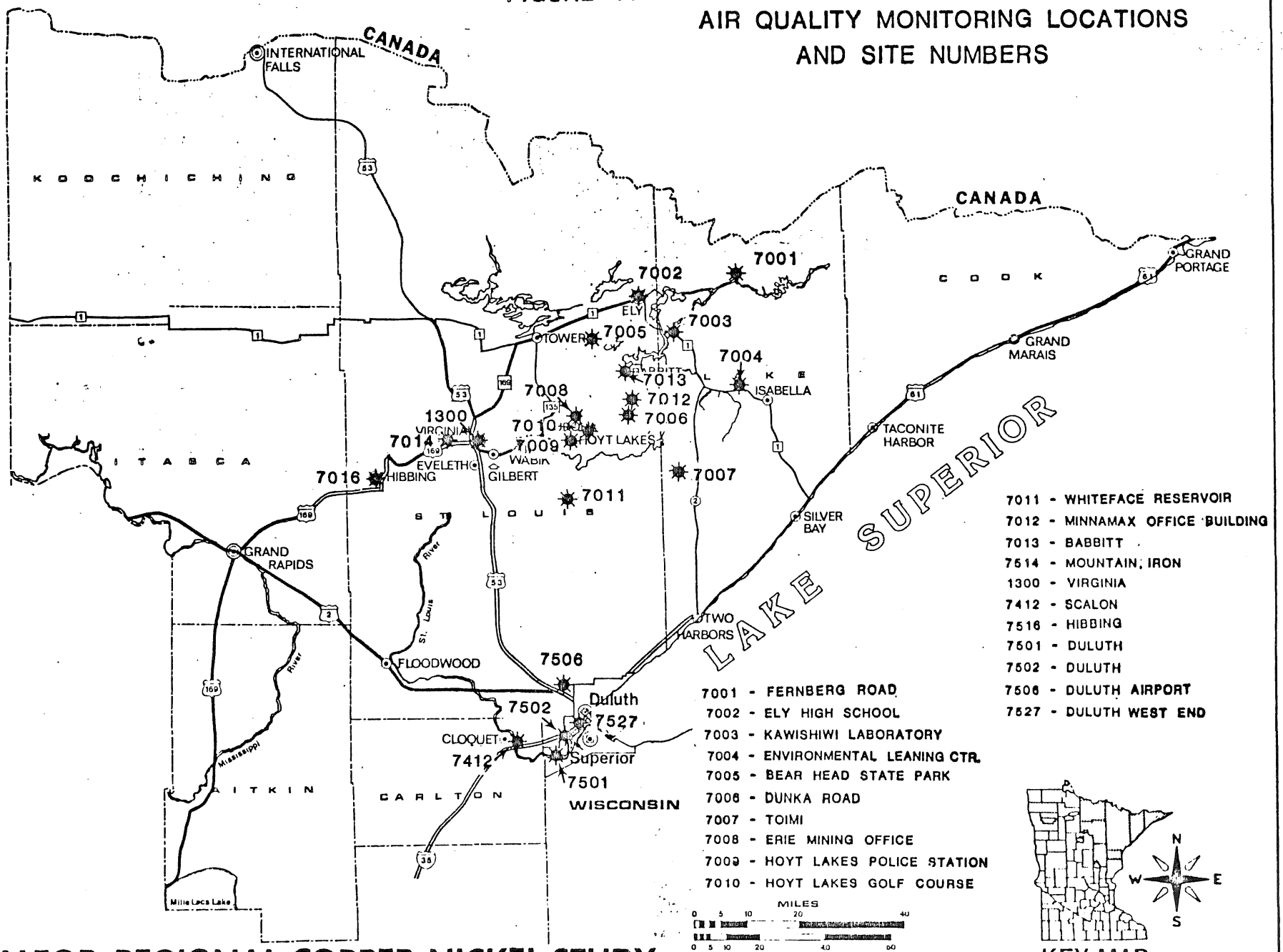


FIGURE 10

AIR QUALITY MONITORING LOCATIONS AND SITE NUMBERS



7001 - FERNBERG ROAD
7002 - ELY HIGH SCHOOL
7003 - KAWISHIWI LABORATORY
7004 - ENVIRONMENTAL LEANING CTR.
7005 - BEAR HEAD STATE PARK
7006 - DUNKA ROAD
7007 - TOIMI
7008 - ERIE MINING OFFICE
7009 - HOYT LAKES POLICE STATION
7010 - HOYT LAKES GOLF COURSE

7011 - WHITEFACE RESERVOIR
7012 - MINNAMAX OFFICE BUILDING
7013 - BABBITT
7514 - MOUNTAIN, IRON
1300 - VIRGINIA
7412 - SCALON
7516 - HIBBING
7501 - DULUTH
7502 - DULUTH
7506 - DULUTH AIRPORT
7527 - DULUTH WEST END

KEY MAP

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Table 6. Air quality sampling site instrumentation.

SITE NO.	NAME	STATUS[a]	HIGH-VOLUME SAMPLER	MEMBRANE SAMPLER	SO_2 & NO_2 (bubbler)	SO_2 (continuous)	EVENT RAIN SAMPLER	BULK DEPOSITION SAMPLER
7001	Fernberg Road	N,C	X	X		X		X
7002	Ely High School	N	X		X			
7003	Kawishiwi Lab	N	X		X		X	X
7004	Environmental Learning Center (ELC)	N		X	X			
7005	Bear Head State Park	N		X	X			
7006	Dunka Road	N	X	X	X			X
7007	Toimi	N	X	X	X			
7008	Erie Mining Office	N	X	X				
7009	Hoyt Lakes Police	P,C	X		X			
7010	Hoyt Lakes Golf Crs.	N	X	X	X		X	X
7011	Whiteface	N		X	X			
7012	Minnamax Office	N				X		
7013	Babbitt City Hall	N,C		X				
7514	Mt. Iron Post Office	P,C	X					
1300	Virginia City Hall	P,C	X					
7516	Hibbing	P,C	X					
7412	Scanlon	P,C	X	X	X			
7501	Duluth; 107th Ave.W.	P,C	X		X			
7502	Duluth; S.88th Ave.W.	P,C	X					
7506	Duluth Airport	P,C	X		X			
7527	Duluth West End	N,C	X	X	X			

[a]P = Site established prior to Regional Study.
N = New site for Regional Study.
C = Site continues to sample some parameters after Study sampling.

A great deal of analysis effort was put into the modeling of sulfur emissions from a range of possible smelter operations. The technology used and modeling assumptions made are discussed in detail in the report on smelting and refining (Volume 2-Chapter 4). All the models represent a smelter/refinery operation producing 100,000 mtpy of copper plus nickel metal. Model parameters are summarized in Volume 2-Chapter 5. These technical models specify gas volumes and SO_2 and particulate emission rates. Section 3.6.1 of this report specifies additional parameters such as stack height, diameter, and exit velocity. These variables are needed to allow dispersion modeling to be done on emissions.

The other topic of importance here is particulate emissions from area sources. Here, the mine, mill, tailing basin, and waste rock storage areas are important. Detailed models for these facilities are discussed in Volume 3-Chapter 2 (Mineral Extraction), Chapter 3 (Mineral Processing), and Chapter 5 (Integrated Development Models). For air quality impact assessment work, the model with the highest potential for particulate emissions was evaluated. This model represents a large open pit mine with associated mill and waste disposal facilities. The mine produces 20×10^6 mtpy of ore and the operation has a total life of 30 years. Impact analysis looks at the worst case, toward the end of the operating life when all facilities have their maximum sizes (e.g. waste rock piles, pit, and tailing basins). Particulate emissions from the various operations are estimated in section 3.6.2.2 of this report.

Models are also presented for particulate emissions from a smelter facility. Though based on more general assumptions than those used for the modeling of SO_2 emissions, these simulations nevertheless provide useful reference points for impact analysis. Technical discussions are presented in the smelting and refining report (Volume 2-Chapter 4), and the source models are outlined in section 3.6.2.1 of this report.

Mineral fibers are also a topic of concern here, since there are indications that cleavage fragments will be present, particularly in the tailing and concentrate from the mill. A discussion of the occurrence of potentially asbestiform minerals is given in the Geology and Mineralogy report (Volume 3-Chapter 1) with the findings of a study on fiber content of mill products given in the Mineral Resources Potential report (Volume 3-Chapter 2). Based on these studies, section 3.6.2.3 presents a simplified fiber source model for use in impact assessment.

3.2.2.3 Short Range Modeling--To assess the impacts of the various emissions discussed in the previous section, atmospheric dispersion analysis was required. With the present analytical methods available, this task was divided into two areas, short range modeling and long range modeling. As used here, short range modeling predicts the concentration of constituents of concern (SO_2 and particulates here) within a distance of 10 km of the source. The models have validity as far as 50 km out, but the reliability of predictions declines rapidly. Long range modeling, on the other hand, begins at 5-10 km from the source and extends out to 250 km or more. This allows a discussion of potential impacts over all of the air quality study region. Short range modeling is discussed here, with long range modeling being treated in the next section.

Three short range modeling situations are addressed:

1) effects from stack emissions for short term periods (3-hour and 24-hour)

2) effects from low level fugitive emissions for short term periods (3-hour and 24-hour)

3) effects from stack and fugitive emissions for long term periods (annual average).

Atmospheric impacts of stack emissions near the source were modeled using the Texas Air Control Board's Texas Episodic Model (TEM) (Christianson 1976) for

short time periods. A building source model developed by the H.E. Cramer Company (Cramer et al. 1975) was used to calculate the dispersion of short-term smelter fugitive emissions. Annual smelter stack and fugitive emissions impacts close to the source were predicted using the Climatological Dispersion Model (CDM) (Busse and Zimmerman 1973; Brubaker et al. 1977).

The Texas Episodic Model (TEM) is a steady state gaussian plume model that computes short-term (10 minutes to 24 hours) ground level concentrations from point and area sources. Features include Brigg's plume rise, exponential pollutant decay, a stability-dependent wind speed adjustment to stack height, and Pasquill-Gifford dispersion coefficients. The model does not treat terrain effects, downwash, or fumigation. Meteorological input consists of user-input 3-hour scenarios of meteorological parameters. Twenty-four hour concentrations are computed from eight 3-hour average scenarios.

The fugitive model used for short-term impacts is a steady state gaussian plume model which computes 1-hour to 24-hour ground level concentrations from a building source. The plume is considered to be emitted at building height (a change, recommended by H.E. Cramer Company, from the ground-level release employed in the published version of the model), and has no buoyancy or plume rise. Building-induced mixing at the source is simulated by giving the plume an initial volume estimated from building dimensions. Pasquill-Gifford dispersion coefficients are used instead of the H.E. Cramer formulation for simplicity and consistency with other models employed. Computed 10-minute concentrations are adjusted to approximate hourly values by the method recommended by Turner (1970). Other features include exponential pollutant decay and a stability-dependent adjustment of wind speed to building height. Terrain effects are not included in the analysis, which is non-site specific. Meteorological input consists of hourly user-input scenarios of meteorological parameters.

The Climatological Dispersion Model (CDM) is a widely-used steady state gaussian plume model that computes long-term (seasonal and annual) ground level concentrations from point and area sources. Features include Brigg's plume rise formulation, exponential pollutant decay, and a stability-dependent exponential wind speed adjustment to the height of emission. The model does not treat terrain effects, downwash, or fumigation. Meteorological input is a joint frequency distribution of 16 wind direction classes, 6 wind speed classes, and 6 stability classes.

Meteorological input data for the 24-hour dispersion model runs for the smelter were generally selected from data collected at the Federal Aviation Agency Flight Service Station at the Hibbing Airport during 1976-1977. Because of the likelihood of a low release height from the smelter due to use of a relatively short stack, worst case dispersion days (that is, those days causing the highest ground level concentrations) were selected on the basis of wind persistence and lack of precipitation. Wind speed and direction, along with temperature data were taken directly from the Hibbing Flight Service Station hourly data record. Hourly mixing depths were estimated from the hourly data. Stability classes were estimated by combining the objective Turner method with insight gained through analysis of the additional data available.

The input meteorological data set for CDM is the 1976 STAR tabulation (joint frequency table of stability, wind direction, and wind speed) for Hibbing. Seasonal tabulations were not available. Average afternoon and nocturnal mixing heights were estimated to be 1,200 m and 460 m, respectively, and a mean annual temperature of 2°C was input.

In terms of modeling error, accuracy within a factor of two (that is, maximum concentrations ranging from 50% to 200% of the computed concentrations) has fre-

quently been claimed for gaussian modeling. A recent position paper by the American Meteorological Society Committee on Atmospheric Turbulence and Dispersion (1978) expressed the opinion that the factor of two error range is probably realistic for practical point source gaussian modeling using good meteorological data and in the absence of certain conditions. Those important conditions under which a significantly larger error could be expected include the following:

1) aerodynamic wake flows, including building and terrain wakes and stack downwash

2) buoyant effluent release

3) flows over surfaces other than flat to gently rolling open fields (such as cities, water, rough terrain, and forests)

4) dispersion in extremely stable or extremely unstable conditions

5) dispersion at downwind distances greater than 10-20 km

With these limitations in mind, the results presented in subsequent discussions will be considered to be accurate within a factor of two.

The interested reader is referred to Endersen (1979) for a further discussion of the models and input values used for various model parameters.

3.2.2.4 Long Range Modeling--The purpose of the Regional Copper-Nickel Study was to assess the potential impacts of copper-nickel mining on northeastern Minnesota. By definition the task was regional in scope and required an impact assessment tool capable of addressing the differential effects of a possible new mining industry on a several thousand square km area which is already experiencing air quality impacts from existing activity within and outside of the area. To address this regional modeling requirement, Study staff developed the mesoscale modified gaussian model.

This model has broad capabilities to predict a variety of parameters of interest including ambient concentrations and deposition rates for SO_2, sulfate, total suspended particulates and metals. The basic model requires the specification of pollutant sources in the area including their location, emission rates, and source characteristics. The model then uses meteorological data from 4 stations spanning the area (Duluth, Hibbing, International Falls and Thunder Bay) to calculate the air quality impact of the various sources on a specified network (or grid) of receptor sites. For the purposes of this analysis, 33 receptors (Figure 11) were located in the Study Region to be representative of regional watersheds (12 receptors), population centers (11 receptors), rural areas (8 receptors) and mining areas (2 receptors). In addition, 8 of the receptors were located in Class I areas to allow regulatory analysis in terms of the PSD regulations. Table 7 lists the receptors and their coordinates, while the map in Figure 11 shows the receptor locations.

Figure 11, Table 7

The model utilizes specific meteorological input data in the form of 24-hour vector averages to compute the corresponding 24-hour air quality impacts of each source at each receptor. The effect of each source is summarized to determine the total effect of all regional sources at each receptor for each 24-hour period. The 24-hour results may then be averaged (or totaled) over a year to determine annual average concentrations (or deposition rates), either geometric means or arithmetic means as appropriate. Further, distributions of the individual 24-hour results during the year may be determined as well. The meteorological data used in the modeling simulations were for the period from November 1, 1976, to October 31, 1977.

FIGURE 11

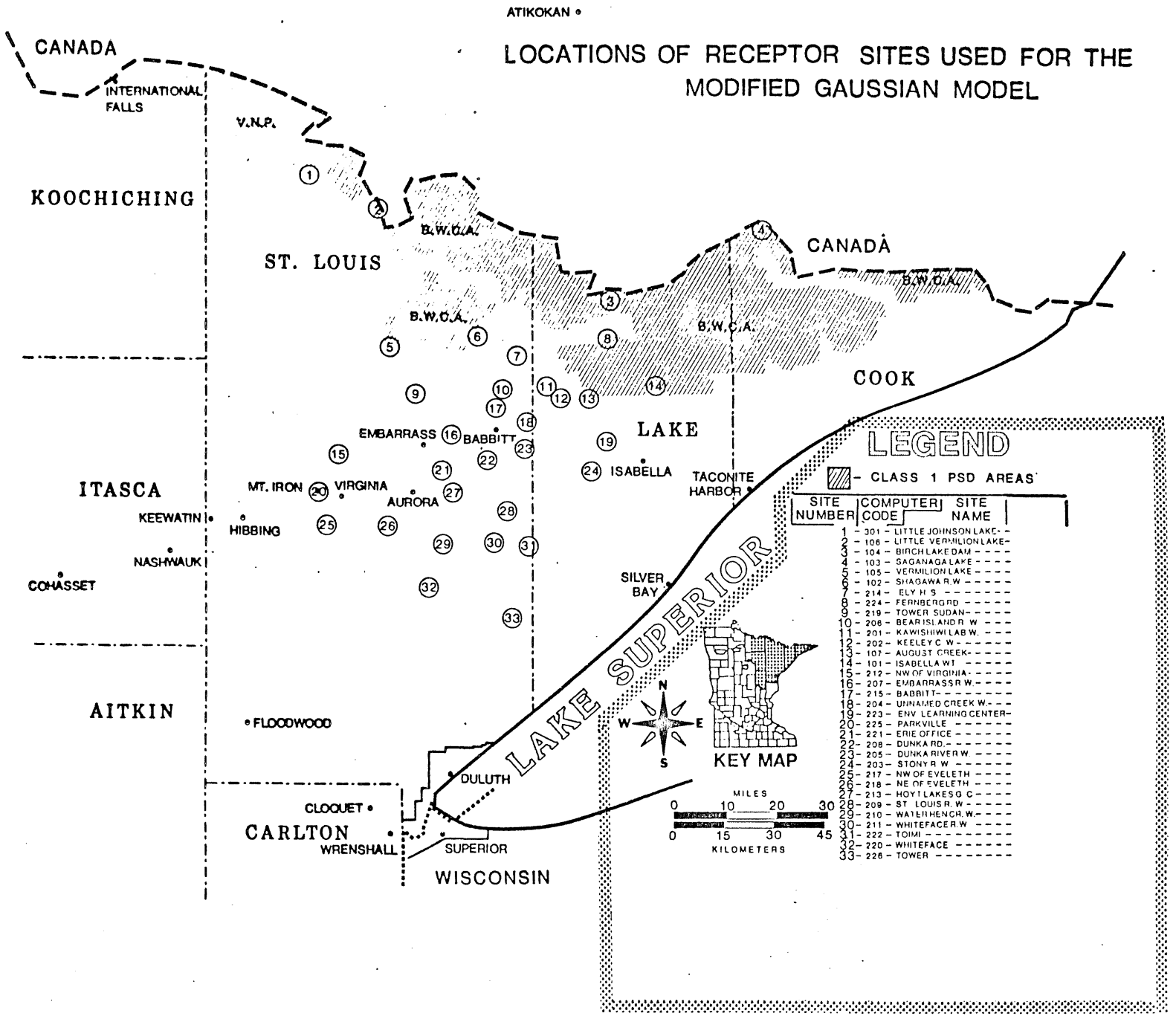

ATIKOKAN
LOCATIONS OF RECEPTOR SITES USED FOR THE MODIFIED GAUSSIAN MODEL
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
B.W.C.A.
ST. LOUIS
CANADA
B.W.C.A.
B.W.C.A.
B.W.C.A.
COOK
LAKE
EMBARRASS
BABBITT
ISABELLA
TACONITE HARBOR
ITASCA
MT. IRON
VIRGINIA
AURORA
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
LEGEND
- CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME
1 - 301 - LITTLE JOHNSON LAKE
2 - 106 - LITTLE VERMILION LAKE
3 - 104 - BIRCH LAKE DAM
4 - 103 - SAGANAGA LAKE
5 - 105 - VERMILION LAKE
6 - 102 - SHAGAWA R.W
7 - 214 - ELY H.S
8 - 224 - FERNBERG RD
9 - 219 - TOWER SUDAN
10 - 206 - BEAR ISLAND R. W
11 - 201 - KAWISHIWI LAB W.
12 - 202 - KEELEY C. W
13 - 107 - AUGUST CREEK
14 - 101 - ISABELLA WT
15 - 212 - NW OF VIRGINIA
16 - 207 - EMBARRASS R.W.
17 - 215 - BABBITT
18 - 204 - UNNAMED CREEK W.
19 - 223 - ENV. LEARNING CENTER
20 - 225 - PARKVILLE
21 - 221 - ERIE OFFICE
22 - 208 - DUNKA RD.
23 - 205 - DUNKA RIVER W.
24 - 203 - STONY R. W
25 - 217 - NW OF EVELETH
26 - 218 - NE OF EVELETH
27 - 213 - HOYT LAKES G. C
28 - 209 - ST. LOUIS R. W
29 - 210 - WATERHENCH R.W.
30 - 211 - WHITEFACE R.W
31 - 222 - TOIMI
32 - 220 - WHITEFACE
33 - 226 - TOWER
N
W
E
S
KEY MAP
MILES
0 10 20 30
0 15 30 45
KILOMETERS

Table 7. Receptor coordinates for the modified gaussian model.

SITE NO.	COMP. CODE	SITE NAME	UTM X	UTM Y	LONGITUDE	LATITUDE
1	301	Little Johnson Lake	522	5358	92.7172	48.3714
2	106	Little Vermillion Lake	542	5349	92.4478	48.2904
3	104	Birch lake Dam	617	5323	91.4410	48.0566
4	103	Saganaga Lake	658	5345	90.8894	48.2544
5	105	Vermillion Lake	547	5307	92.3789	47.9127
6	102	Shagawa River Watershed	573	5311	92.0309	47.9487
7	214	Ely High School	585.7	5305.4	91.8615	47.8979
8	224	Fernberg Road	612.3	5311.2	91.5045	47.9505
9	219	Tower-Sudan	555	5293	92.2715	47.7870
10	206	Bear Island River W.	581	5295	91.9237	47.8048
11	201	Kawishiwi Lab Watershed	594.5	5296.1	91.7438	47.8147
12	202	Keeley Creek Watershed	598	5293	91.6964	47.7868
13	107	August Creek	607	5293	91.5760	47.7868
14	101	Isabella Watershed	626	5297	91.3217	47.8228
15	212	NW of Virginia	532	5274	92.5779	47.6159
16	207	Embarrass River W.	566	5281	92.1241	47.6789
17	215	Babbitt	579.5	5289.5	91.9439	47.7111
18	204	Unnamed Creek-Bob Bay W.	588	5285	91.8302	47.7148
19	223	Env. Learning Center (ELC)	611.6	5279.9	91.5150	47.6690
20	225	Parkville	531.4	5263	92.5853	47.5170
21	221	Erie Office	564	5270.6	92.1513	47.5849
22	208	Dunka Road	577	5273	91.9771	47.6069
23	205	Dunka River Watershed	588	5277	91.8302	47.6429
24	203	Stony River Watershed	608	5271	91.5633	47.5889
25	217	NW of Eveleth	529	5253	92.6167	47.4270
26	218	NE of Eveleth	547	5253	92.3768	47.4270
27	213	Hoyt Lakes G.C.	566.8	5262.9	92.1104	47.5170
28	209	St. Louis River W.	583	5258	91.8970	47.4720
29	210	Waterhen Creek W.	564	5248	92.1502	47.3821
30	211	Whiteface River W.	579	5249	91.9503	47.3911
31	222	Toimi	590	5249	91.8038	47.3911
32	220	Whiteface	559.4	5235.5	92.2111	47.2701
33	226	Tower	585	5227	91.8705	47.1932

The major features of the model include:

1) Atmospheric dispersion: Gaussian dispersion is calculated in the horizontal direction at right angles to the direction of motion of the plume. A box model is used in the vertical direction with concentrations assumed to be constant over the plume thickness, limited by the surface and a specified mixing height.

2) Chemical conversion: The model provides for depletion of SO_2 by conversion to sulfate at a specified rate as the plume is transported downwind.

3) Dry deposition: Atmospheric concentrations of a pollutant are reduced by allowing for dry deposition as a function of the ambient concentration of the pollutant and a specified deposition velocity for the pollutant.

4) Precipitation scavenging: In addition to dry deposition, a pollutant may be depleted as a result of scavenging during precipitation events. The frequency and duration of precipitation are among the input data required by the model. The effectiveness of precipitation scavenging on the removal of a particular pollutant is specified in the form of a scavenging rate coefficient.

Readers interested in the details of the model are referred to Ritchie (1979). Copies of the computer program are on file with the Minnesota Pollution Control Agency and the Land Management Information Center at the Minnesota State Planning Agency.

For a newly developed or modified model such as the mesoscale model developed by the Regional Study, the question of model validation is extremely important. Ideally, the model is validated in the region where it is to be used by comparing predictions with extensive data on actual ambient concentrations and deposition rates recorded in the area. Appropriate meteorological data such as wind speed

and direction, mixing height, and precipitation taken simultaneously with the concentration and deposition data are also needed.

Unfortunately, it was not feasible to obtain this exhaustive data base over the total area of interest to the Regional Study, and other, less ideal validation methods had to be utilized. These included comparisons of the predictions from the mesoscale model to those of the more conventional short range model discussed earlier and comparisons using data from the Sudbury area in Canada. The interested reader is referred to Ritchie (1979) for a detailed discussion of model validation.

In the comparison to the gaussian plume model, runs for selected days were chosen and comparisons made of results for ambient SO_2 concentrations at 5 and 10 km for stack emissions. The 5 days selected were those used for the impact analysis of 24-hour SO_2 concentrations from a smelter when meteorological conditions would maximize concentrations (see section 3.7.1.2). In all of the 10 cases, the predicted concentrations from the two models were within 50% of each other. There was no apparent systematic error. Sometimes the long range predictions were greater than those of the short range model and sometimes lower. Given this randomness of the discrepancy coupled with the factor of 2 accuracy attributed to the short range models used, it is reasonable to conclude that this comparison indicates that long range (mesoscale) model predictions are consistent with those of the short range in their region of mutual validity.

The most extensive validation effort was made in a modeling study of the air quality over a region within a distance of 250 km of Sudbury, Ontario. Air quality data for both ambient concentrations and deposition rates of a variety of atmospheric constituents were obtained for 5 and 10 receptor sites, respectively,

in the area. The source characteristics for the Copper Cliff and Falconbridge smelters in Sudbury were used as input data for the model along with meteorological data from 5 weather stations in the area.

The results of this complex analysis indicate that the modified gaussian model may be considered to have an accuracy of a factor of two for annual average predictions in the 10-250 km distance range (Ritchie 1979). For short term predictions, over a specific 24-hour period, the accuracy decreases considerably to a factor of 5 to 10. The greater variability of the 24-hour values is probably due to problems with wind accuracy on individual days and a limited ambient air concentration data base. The model is limited in its ability to simulate short-term weather based on the few meteorological parameters used as inputs. To deal with this problem in attempting to model worst case 24-hour concentrations from a particular source for PSD review (see the next section) differences were used; that is, the difference between the baseline concentrations without the source and those with the source present were computed, holding the weather constant. This procedure was used for each day in the year and the worst case increases selected, thereby restoring to the PSD review the factor of two accuracy attributed above to annual predictions.

It is important to stress that the regional modeling developed by the Regional Study staff represents a state-of-the-art effort which should prove useful as a mesoscale (approximately 1-100 km) regional planning tool. The modified gaussian model can, of course, be improved and requires further development if it is to become a predictive tool that can be used with confidence in situations requiring engineering precision. As presented here, the results of the modified gaussian model are best state-of-the-art estimates of what may occur on a regional basis in the Copper-Nickel Study Area. The model serves to highlight those areas, both

environmentally and in terms of existing legal standards, which potentially will be most seriously impacted by copper-nickel development. To further refine these results will require a significant effort and must be based on more detailed information relevant to site-specific proposals, as well as regional monitoring data.

3.2.3 Existing Legal Framework

During the course of this report, particularly in the impact analysis sections, comparisons of results to various air quality regulations are made. Thus, it is useful here to briefly summarize the major air quality regulations relevant to the development of a copper-nickel industry in the state. These regulations are grouped into two areas, ambient standards and emission standards.

3.2.3.1 Ambient Standards--Broadly, ambient standards seek to preserve the quality of the atmosphere in an area, independently of the specific nature or location of sources of regulated emissions which tend to degrade that quality. Two important pollutants in terms of copper-nickel development are sulfur oxides (principally SO_2) and total suspended particulate matter. Both the federal and state governments have promulgated ambient air quality standards which are designed to safeguard the health (primary standard) and welfare (secondary standard) of the public. The state standards are more restrictive than the federal standards. Table 8 lists the standards for particulate matter and sulfur oxides. The standards apply throughout Minnesota.

Table 8

Trace elements and other compounds such as copper, nickel, zinc, cadmium, mercury, lead, silica, and mineral fibers may pose environmental health risks, but the ambient air quality standards at present do not encompass these pollutants.

Table 8. Ambient air quality standards applicable throughout Minnesota (values shown in ppm are by volume).

POLLUTANT	WORDING OF STANDARD	PRIMARY STANDARD		SECONDARY STANDARD	
		Federal[a]	State[b]	Federal[a]	State[b]
Suspended Particulate Matter	Annual geometric mean	75 ug/m^3	75 ug/m^3	60 ug/m^3	60 ug/m^3
	Maximum 24-hour concentration not to be exceeded more than once per year	260 ug/m^3	260 ug/m^3	150 ug/m^3	150 ug/m^3
Sulfur Oxides	Annual arithmetic mean	80 ug/m^3 (.03ppm)	60 ug/m^3 (.02ppm)		60 ug/m^3 (.02ppm)
	Maximum 24-hour concentration not to be exceeded more than once per year	365 ug/m^3 (.14ppm)	260 ug/m^3 (.1 ppm)		260 ug/m^3 (.1 ppm)
	Maximum 3-hour concentration not to be exceeded more than once per year		655 ug/m^3 (.25 ppm)	1300 ug/m^3 (.50 ppm)	655 ug/m^3 (.25 ppm)

[a]Code of Federal Regulation Title 40, Part 50 (secs. 50.4-50.7).

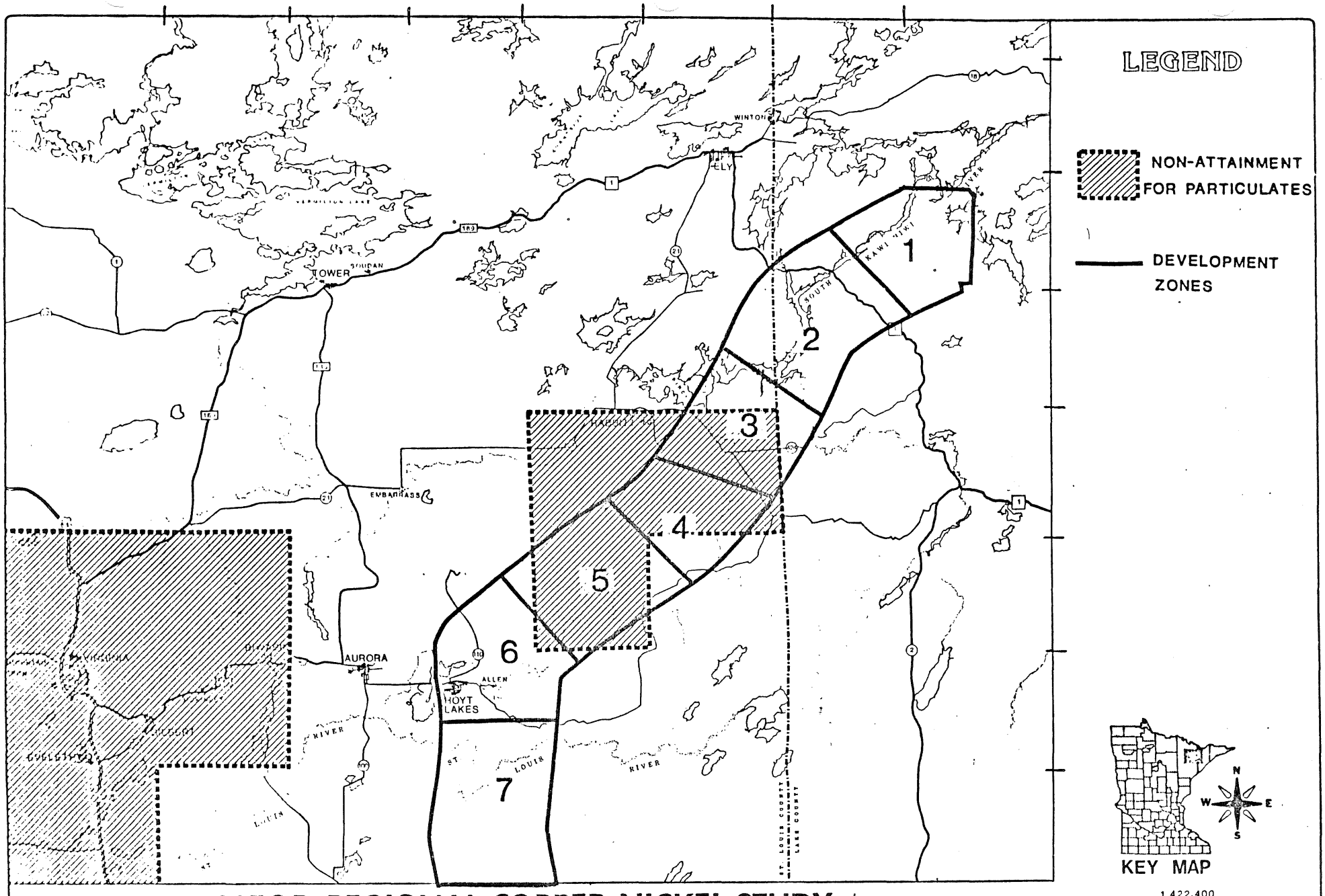
[b]MPCA (1976).

All of the Study Area is currently in compliance with ambient sulfur oxide standards. However, portions of the Study Area along the eastern end of the Iron Range are nonattainment areas for particulates (see map, Figure 12). At the present time any new sources in or near enough to this area to affect particulates in the area are subject to an emissions offset policy. This policy requires that emissions due to the addition of new or expanded sources must be offset by comparable reductions of emissions from existing sources and may affect copper-nickel development in the Area. This same policy applies in Duluth and International Falls which are also nonattainment areas for particulates (as well as other constituents not of concern here). The Minnesota Pollution Control Agency is currently developing a State Implementation Plan (SIP), which will address these nonattainment problems with rules which will supersede the offset policy when the SIP is put into effect (although the SIP may include an offset policy).

Figure 12

In addition to the ambient standards just mentioned, the entire nation is subject to the prevention of significant deterioration provisions of the 1977 amendments to the Clean Air Act of 1970 (USEPA 1978). In Minnesota, the PSD regulations are reviewed and implemented by the MPCA through a delegation of authority from the EPA under 40 CFR 52.21 (USEPA 1978). However, the MPCA is currently preparing a SIP for submittal to the EPA. Following approval of the SIP, the Pollution Control Agency will take over the review and implementation role under the proposed APC-38.

The PSD amendments (40 CFR 52.21) mandate the establishment of baseline reference levels of pollutants present in the atmosphere in 1977 due to existing major



MEQB REGIONAL COPPER-NICKEL STUDY

FIGURE 12

PARTICULATES IN THE STUDY AREA

sources. The amendments then provide for allowable incremental increases above these levels due to new or expanded sources in the area. Additionally, three classes of areas are established, with different allowed increments for each class. All of Minnesota falls into the Class II designation except areas within the borders of the BWCA and Voyageurs National Park which are federally mandated Class I areas [40 CFR 52.21 (e)]. Table 9 gives the allowable PSD increments for Class I and Class II areas. For any period other than an annual period, the applicable increment may be exceeded during one such period per year at any location [40 CFR 52.21 (c)].

Table 9

The amendments provide that a Class I variance may be granted for a federal Class I area if it is demonstrated to the Federal Land Manager that a new source or a source modification would have no adverse impact on the air quality related values of the Class I lands. If a Class I variance is granted, maximum allowable increases over baseline concentrations are limited to the Class II increments, except for the 3-hour SO_2 increment which is reduced to 325 ug/m^3 [40 CFR 52.21 (q)(4)]. Further, a variance of the 24-hour and 3-hour increments may be granted for federal mandatory Class I areas if approved by the Governor with the concurrence of the Federal Land Manager or the President [40 CFR 52.21 (q)(5) and (6)]. In such cases, it must be shown that the variance would not adversely affect the air quality related values of the area.

In order to determine whether a new or expanded source of pollutants in an area would result in exceedances of allowable PSD increments, a PSD review is required for new or modified sources which fall within selected major stationary source categories which have the potential to emit 100 tons per year of any pollutant

Table 9. Allowable PSD increments in Class I and Class II areas [40 CFR 52.21 (c)].

POLLUTANT	MAXIMUM ALLOWABLE INCREASE[a] (ug/m^3)
Class I	
Particulate Matter:	
Annual geometric mean	5
24-hour maximum	10
Sulfur Dioxide:	
Annual arithmetic mean	2
24-hour maximum	5
3-hour maximum	25
Class II	
Particulate Matter:	
Annual geometric mean	19
24-hour maximum	37
Sulfur Dioxide:	
Annual arithmetic mean	20
24-hour maximum	91
3-hour maximum	512

SOURCE: USEPA (1978).

[a]For any period other than an annual period, the applicable maximum allowable increase may be exceeded during one such period per year at any one location.

regulated by the Clean Air Act. Primary copper smelters are included among the source categories subject to this review [40 CFR 52.21 (b)(1) and 52.21 (i)]. In addition, any source which is not included in the selected categories but which emits or has the potential to emit 250 tons per year of pollutants regulated under the act is also required to undergo PSD review [40 CFR 52.21 (b)(1)(ii)].

When a new or modified source is identified as being subject to PSD review, it is further required to apply the best available control technology (as defined in 40 CFR 52.21 (b)(10)) for each applicable pollutant unless the increase in allowable emissions of that pollutant would be less than 50 tons per year, 1000 pounds per day, or 100 pounds per hour, whichever is most restrictive (40 CFR 52.21 (j)(2)).

The regulations require that a baseline concentration be established against which incremental increases can be evaluated. The baseline concentration is defined as the ambient concentration level reflecting actual air quality as of August 7, 1977, minus any contribution from major stationary sources and major modifications on which construction started on or after January 6, 1975. The regulations further define the baseline to include the allowable emissions of major stationary sources and major modifications which started construction before January 6, 1975, but were not in operation by August 7, 1977 (40 CFR 52.21 (b)(11)). In the Air Quality Study Region, this clause has the effect of raising the PSD baseline above the actual concentration present on August 7, 1977 for both SO_2 and particulates. The principal reason is the taconite expansion currently taking place on the Iron Range.

In addition to the increments listed earlier, the PSD regulations also require that pollutant concentrations not exceed the national secondary ambient standard or the national primary ambient standard, whichever concentration is lowest for the pollutant for a given period of exposure (40 CFR 52.21 (d)).

To conduct a PSD review for a new development, three steps must be completed. The first step requires the indentification of all sources that are to be used in determining the PSD baseline as defined by the act. Next, new sources in the area which are not part of the baseline contributors must be identified since they will consume part or all of the allowed increments. Third, the new proposed source under review must be characterized in terms of its location and emissions. Appropriate air quality dispersion modeling for the various periods specified in the regulations (3-hour, 24-hour and annual) can then be used to determine whether the new source, in concert with other new sources in the area, will result in increments being exceeded.

For purposes of the study of potential copper-nickel development impacts, a target date of 1985 was selected for PSD review analysis. This is the earliest date that a major copper-nickel atmospheric pollutant source such as a smelter might reasonably be expected to begin operations. Also, 1985 was the latest year for which emissions projections could be based on expansion plans for industrialization in the region or on possible enforcement actions by the Minnesota Pollution Control Agency.

A regional emissions inventory for use in the PSD review was then assembled (Ritchie, 1978). The inventory includes point sources emitting more than 100 mtpy of SO_2 or particulates within a 150 km radius of the copper-nickel development zones. The inventory includes sources for the base period 1975-76 and the projected period 1985. Point sources in northeastern Minnesota, northwestern Wisconsin and southern Ontario are included. The names and locations of all sources included are given in Table 10. Emission estimates for the periods 1975-76 and 1985 are presented in sections 3.4.1.1 (SO_2) and 3.5.1.1 (particulates). Emissions which were used in the PSD review analysis are also included in these

sections.

Table 10

In terms of the sources located in Canada, it must be noted that their status in the PSD review is not certain. The regulations provide that upon the request of the Governor the increase in pollutant concentrations attributable to new sources outside the United States may be excluded in determining compliance with maximum allowable increases (40 CFR 52.21 (f)(1)(iv)). The major source of relevance here is the new coal-fired power plant at Atikokan, Ontario, which is being constructed by Ontario Hydro.

The base year period 1975-76 was selected for the emissions inventory because it is the most recent year that the state inventory was both nearly complete and available in computerized form, and it corresponds closely to the baseline ambient air quality data which were collected during 1976-77. [Interested readers are referred to Ritchie (1978a) for further discussions of the inventory, as well as a list of specific source parameters.] Using the above information the impact analyses discussed later in this report are used to address the possibility of exceedances of PSD increments in the Study Area.

3.2.3.2 Emission Standards--In addition to the ambient standards discussed in section 3.2.3.1, copper-nickel development would also be subject to a variety of emission standards. The Minnesota Pollution Control Agency has 31 regulations in addition to ambient standards (APC-1) discussed earlier (MPCA, 1976). Many of these will be applicable to various aspects of copper-nickel development in the state. However, the state presently does not have specific emissions regulations governing a primary copper-nickel smelter. Certain existing regulations would

Table 10. Point sources in the air quality study region included in the emissions inventory.

STATE	COUNTY	CITY	FACILITY
Minnesota	Carlton	Cloquet	Potlatch Northwest
			Conwed
		Wrenshall	Continental Oil
	Cook	Taconite Harbor	Erie Mining Company
	Itasca	Cohasset	MP&L Clay Boswell Generating Station
		Keewatin	National Steel Pellet
		Nashwauk	Butler Taconite
	Koochiching	Intl. Falls	Boise Cascade
	Lake	Silver Bay	Reserve Mining
	St. Louis	Aurora	MP&L Sy Laskin Generating Station
		Babbitt	Reserve Mining
		Duluth	Arrowhead Blacktop
			Cargill Elevator B
			Cargill Elevator C
			Duluth Steam
			General Mills A
			International Multifoods
			MP&L Hibbard Generating Station
			Superwood Corp.
			U.S. Steel-Duluth Coke
			U.S. Steel-shipping
		Eveleth	Eveleth Taconite
		Floodwood or Brookston	MP&L Generating Station
		Gilbert	Jones & Laughlin
		Hibbing	Public Utility
			Hibbing Taconite
			Hanna Mining Company
		Hoyt Lakes	Erie Mining Company
		Mt. Iron	Minntac
		Virginia	Public Utilities Dept.
			Inland Steel
		Biwabik	Pickands Mather
Wisconsin	Ashland	Ashland	Lake Superior Power Dist.
			Roffler's Construction

Table 10 continued.

STATE	COUNTY	CITY	FACILITY
Wisconsin	Douglas	Superior	Murphy Oil Corp.
			Farmer's Union Grain
			Globe Elevator
			Superior WL&P
			Orba Corp.
			Burlington Northern
			Univ. of Wisconsin
			CLM Corp.
CANADA			
Ontario		Atikokan	Ontario Hydro Generating Station
			Caland Ore Company
			Steep Rock Mines
		Ft. Frances	Minn. Pulp & Paper

SOURCE: Ritchie ,1978.

apply to such a facility, but since they are not specifically directed at this type of operation, they are not discussed further. The interested reader is referred to the cited MPCA regulations for additional information.

The federal government does have new source performance standards (NSPS) applicable to primary copper smelters (USEPA 1976b). Minnesota enforces these standards under a delegation of authority from the USEPA and may adopt these standards in the future. There is a legal question concerning whether a copper-nickel smelter of the type envisioned to treat concentrates from a Minnesota mining operation is a primary copper smelter as the term is used in existing NSPS as well as in PSD regulations. A ruling by the appropriate legal authorities may be needed to clarify this matter since the presence of nickel in the smelter feed introduces certain complications not present in other domestic primary copper smelters, such as the presence of nickel converters. However, for the purposes of this discussion it is assumed that the regulations are applicable.

The new source performance standards limit emissions from new and modified primary copper smelters. Emissions of particulate matter in the gases discharged to the atmosphere from dryers are limited to 50 mg/m^3 (dry) and an opacity of 20% (40 CFR 60.162 and 60.164, respectively). Also, emissions of SO_2 from roasters, smelting furnaces, and copper converters are limited to 650 ppm (by volume) averaged over a 6-hour period (40 CFR 60.163). Emissions from a sulfuric acid plant used to meet the SO_2 standard may not exhibit an opacity greater than 20% (40 CFR 60.164). The standards also require the continuous monitoring of the opacity of dryer emissions and SO_2 content of emissions from roasters, smelting furnaces, and copper converters (40 CFR 60.165).

3.3 CHARACTERIZATION OF CLIMATOLOGY/METEOROLOGY

3.3.1 Introduction

Information on the climate of an area is of value in an environmental impact study for a wide variety of reasons. Climate is a major factor determining the character of the plant and animal communities, both terrestrial and aquatic which are characteristic of any region. It is similarly important in determining the suitability and desirability of the area as a habitat for man. Although somewhat less important as a factor in determining the nature and extent of industrial development such as mining, it plays an important role in establishing many of the specific technological processes and operating procedures which may be successfully employed in developments.

The science of meteorology allows the climate of an area to be described in terms of recorded values of a series of variables, including wind speed and direction, temperature, and precipitation, which taken together and interpreted over long periods of time paint a picture of the earth's atmosphere as it exists in that area. Included in this picture is an understanding of extreme weather conditions as well as typical conditions. It is against this informational background that discussions of air quality, hydrology and water quality must take place, since meteorological conditions play a major role in all these disciplines.

The following sections focus on a description of the climate of those areas of northeastern Minnesota most likely to be directly affected by the development of a copper-nickel mining industry in the state. Accordingly, the major area of focus centers around the Duluth Gabbro Contact in an area generally south of Ely and east of Hoyt Lakes. For simplicity, this area was designated as the Regional Copper-Nickel Study Area (see the map, Figure 7, section 3.2.3). In essence it

is the "heartland" of the northeastern Minnesota "Arrowhead" region. The "Arrowhead" is that portion of Minnesota that has a western boundary roughly determined by drawing a line from the general vicinity of International Falls to Duluth. The region narrows eastward where Lake Superior approaches the Ontario border, with a sharp tip at Pigeon Point in Lake Superior just east of Grand Portage. The Copper-Nickel Study Area is the "heartland" of this region in that it borders neither on the Ontario line nor on Lake Superior.

In addition to the Study Area noted above, it is also recognized that certain aspects of potential copper-nickel development, particularly smelting and refining processes, may take place some distance from the actual mining sites. In terms of meteorological considerations, the possible locations for these activities which may possess an environment radically different from that found in the Study Area are those laying on and immediately adjacent to the shores of Lake Superior. Certainly, the climate along Lake Superior deserves a study of its own, being highly unique in the world because of the steady year-round temperature of this freshwater inland sea. Such a study could not be undertaken during the course of this project. However, a brief discussion of lakeshore regimes is included later to highlight the unusual types of meteorological situations which may occur in such locations.

Focusing on the vicinity of the Study Area, a description is given of the historical climatological patterns in the area, as well as certain specific meteorological conditions prevailing in the area during the course of work conducted by Regional Study staff, principally in 1976 and 1977. Such specific information is important to a proper interpretation of the results of programs such as the water quality monitoring study (chapter 4), the air quality monitoring program (sections 3.4 and 3.5), as well as air quality impact assessment

work (sections 3.7 and 3.8). This impact work involves utilization of atmospheric dispersion and deposition models which depend in part on accurate meteorological data for their validity. Accordingly, the following section first generally describes major climatological features of the area, and is then followed by specific sections highlighting the important parameters of wind, temperature, and precipitation.

Much of the information given here is taken from the report "The Climate of the Copper-Nickel Study Region of Northeastern Minnesota", prepared for the Copper-Nickel Study by Bruce Watson (1978a, 1978b). Part A of this report discusses the long-term climatological record of the region, while part B discusses the weather in the region during the 1976-1978 project period. Interested readers are referred to this report for more detailed information.

3.3.2 The Copper-Nickel Study Area

3.3.2.1 General Climatological Features--The climate of the Copper-Nickel Study Area (referred to as the Area) is principally a reflection of its mid-continental location, characterized by cold winters and warm summers. However, as the forest vegetation reflects, it is just far enough to the east of the continent center to avoid being a prairie due to atmospheric circulation patterns which bring generous amounts of warm-season rains. This, coupled with low summertime evaporation caused by the absence of hot southwesterly winds penetrating the Area, results in an environment favorable for the climax vegetation to be forest rather than prairie grasses or even savanna. Thus, the Area, is generally forested, even though it is at the extreme western edge of the eastern forest area of North America.

Lake Superior has a weak influence on the climate of the Area. Although the elevation, about 600 meters (which is higher than most surrounding territory), plays a role in modifying the weather, the Lake chills the Area a bit extra when an easterly wind prevails, and precipitation and cloudiness are a bit greater than they would otherwise be without the presence of the Lake. Elevation works in the direction of cooling temperatures and increasing precipitation and cloudiness, and the effect is of about the same magnitude as the Lake effect.

An interesting way to gain an insight into the Area's climate is by understanding the patterns of cloudiness and sunshine which prevail at various times of the year. The sky over the Area displays a great variety of clouds dependent upon time of day and season. Because of the mid-continental location, cloud types vary from the low, grey stratus (reminiscent of the arctic winter) to the enormous, cumulus and thunderclouds of summer.

In January, February and March the sky conditions go through a typical sequence lasting about three days as winter storms pass in succession over the region. As an example, a cold high pressure ridge envelops the area after a storm passage; the sky is brilliant blue by day and deep black at night with thousands of stars visible. As the leading edge of the next storm appears in the west, cirriform clouds (made of ice particles) move in from the southwest. The sun (or moon) grows dimmer as clouds and moisture begin to arrive at successively lower and lower levels. Only the faint outline of the sun or moon remains after a few hours as ice crystals falling from clouds between 10,000 and 20,000 feet fill the sky. Typically, a few hours later the sun or moon is obscured totally when clouds become so low that precipitating ice particles reach the ground as tiny sonwflakes.

Several hours later the low level wind shifts to southeasterly and transports warm moist air under the colder southwesterly flow aloft. The process produces an unstable atmosphere and results in strong overturning of the air, vigorous clouds, and heavy snow. Several bands of overturning air may pass over the region as the storm moves eastward. The climax to the storm comes as cold air sweeps in from the northwest along a broad front. A good portion of the time, especially when Pacific air follows a front, skies will clear almost immediately. At other times, especially when polar air follows the storm front, stratocumulus clouds (grey "blobs" of cloud) located between about 1 to 2 kilometers above the ground, cover the sky for a day or more. This sequence brings some light snow showers ("flurries") lasting generally from 12 to 48 hours. The snow showers generally bring less than an inch of snow and seldom bring more than two inches. A few bands of stratocumulus often pass over after the main part of a storm passes on. These bands often appear in association with short-lived (6 to 18 hours) convergent zones formed by successive impulses of cold air behind the storm. The effects of these zones are stronger by day and weaker by night; hence, skies are clearer at night than by day when such a regime is present. They will be interspersed with areas of clear sky.

Frequently, the first clear sky will be seen with the passage of a front of cold air, behind which there is strong downward movement of air. This zone is called a groove by satellite meteorologists. The leading edge of the first stratocumulus band can often be seen coming from the west while the clouds of the main storm system are still visible in the east. A cold front forming the leading boundary of Pacific air will typically be followed by mild weather, whereas a polar air mass will be followed by cold weather. In either case, small, short-lived cumulus clouds may form briefly in the afternoon following frontal passage.

A day or so after the front is well to the east some patchy cirrus or altocumulus clouds may pass over as moist pockets in weak convergent areas aloft drift over the region.

The sequence to the pattern repeats as the leading edge of the next storm system is seen in the west. Once or twice a winter the sequence may take place in less than a day. At other times, especially during the last two weeks in February, a week or more may elapse between storms.

In April and May storm centers track over or near the Area. When storm centers pass just to the south, the sky becomes overcast with thick clouds delivering heavy snows and/or rains borne on northeast winds. In such a case, Lake Superior moisture gives an extra "kick" to precipitation in the Area. If the storm center passes to the north the sky may be filled with moderate-sized cumulus, which are harbingers of spring.

At this time frontal passages and prefrontal cloud bands are often marked by thunderstorms. The nature of the weather to the rear of the storms is also different from winter. Instead of just stratocumulus bands, large cumulus and small cumulonimbus form to bring passing showers. These showers are composed of snow early in the spring and rain later in the spring. The storm patterns can be frequent and brief as the heavy showers are usually interlaced with periods, on the order of a half-hour, of bright, warm sunshine.

During June, July, August and early September storm centers track most often far to the north. These summer storms also have weaker winds. The diurnal variation shapes the sky much more strongly than in the winter. Here, a typical day has fair skies in the morning, except in a few areas where fracto-stratus from a "lifted fog" may dot the sky. Around the ninth hour of the day the first small

cumulus forms at a height of perhaps 400 meters. Vertical mixing then increases to greater heights as air becomes heated by the warming ground, and the cloud bases increase their height to around one kilometer or more by midday.

If the air aloft is relatively dry, mixing may proceed to the height at which so much dry air is brought into the mixture that all the clouds die out. If the air aloft has a stable layer around two kilometers or so the clouds' tops will spread out below it bringing them longevity and permitting a few light showers to form.

However, if the air has appreciable moisture content and there are no strong stable layers in the first several kilometers, thunderclouds may form, bringing generous rains to the Area (sometimes very scattered rain). These storms generally do not form until late in the day or early evening.

Nighttime brings generally clearing skies. After days without much cloud development the air sinks in connection with density contraction near the surface as the result of diurnal cooling. If thunderstorms rage into the night the sky may be cloudy the next morning with perhaps a few raindrops, in cases where the storms have not had a chance to die out completely. Probably most morning cloudiness in the region is due to left-over thunderstorm parts. However, by noon these remnants usually dissipate.

Occasionally, during the summer, a general storm may pass over the Area bringing an all-day or two-day rain. This is unusual, however, at least during July and August. In such a case, the cloud sequence is similar to that of the winter storm.

In the course of a summer, many varieties of thunderstorm clouds are seen. This variety is created because a thunderstorm causes the generation of various par-

cels of air differing in temperature and moisture content and these parcels are subjected to three-dimensional movement at various stages of their life.

September and October bring a gradual phasing out of summertime convective cloudiness and a phasing in of winter-type storm cloud sequences. Most striking perhaps are the weaker cumulus cloud types by day and the appearance of more vigorous stratocumulus bands following cold front passages. Late September and perhaps the first two-thirds of October, however, have the highest incidence of perfectly clear skies. This period is the end of the summertime cumulus season and the precursor to the general winter storm season. Also, morning fog is especially common in the vicinity of low-lying areas and over lakes at this time. This is due to the mild mixing of air of different temperatures and water vapor contents. The differences of air temperature and humidity are created by long, still, clear nights. When the micro-air masses come into contact, warmer air containing more moisture is chilled by mixing with cooler air which has lost moisture through dew or frost deposit. The result is a super-saturated mixture, and, therefore, fog.

In late October and early November the winter storm season begins. The air is still moist in the upper layers due to water vapor that has been pumped aloft during the warm season. Storm centers track near the Area at this time, causing lots of snow and the well-known gales of Lake Superior.

However, when storms are not present the sky is usually cloudy with dull, low, grey stratus clouds. From late October through early December there is usually a shallow (around 1/2 kilometer) inversion persistent over the Area. The stratus may be present under the inversion for days in a row; at other times, they may break up a bit in the afternoon. Snow in the form of single ice crystals may fall from

these clouds for several days, continuously, and yet not add up to a measurable amount of precipitation. By mid-December these clouds are no longer part of the winter scene except as an occassional happenstance.

When storms pass through in the late fall, the cloud sequence is much the same as in January, February, and March. The sequence, then, repeats each following year until, of course, a major climatic change disrupts the atmospheric pressure systems as they are now known.

Data have been compiled on the percentages of possible sunshine over the general region, as well as average percentages of time of clearness (see Watson, 1978a). Sunshine data indicate that the greatest sunshine occurs in July when the sun is high in the sky, and the least occurs in stratus-enveloped November when the sun is low in the sky. In terms of percentage of clearness of the sky, the greatest clearness occurs around midnight in the summer. This time is undoubtedly the clearest, because daytime convective clouds have usually dissipated by midnight and morning fogs have had little opportunity to form.

Cloudiness is maximum in November in the early afternoon, due mostly to the autumnal stratus. When the stratus are not present the sky is generally plagued at this time either by diurnal stratocumulus or by a November storm. The beauty of the November northland can be appreciated only by those who admire the unusual, peaceful aspect presented by brown vegetation protruding through shallow snow under uniformly leaden skies.

The greater clearness of the February sky is brought by the fine weather occurring during the last two weeks of the month, a statistic correlated with the lack of snowfall at that time. In fact, February is fairer than June. It must also be born in mind that, near low-lying areas, cloudiness will run higher due to higher incidences of fog.

It is worth noting that there is a definite time cycle to summer cloudiness. Historical data from this part of the country show that summers in cycles of 40 years alternated between cloudy and sunny. This is related to the 40-year summer rainfall cycle. In the 1890s, 1930s, and 1970s, summer skies were especially fair, while in the 19-teens and 1950s, summers were cloudy. The cloudform corresponding especially to cloudy summers appears to be stratocumulus and altocumulus formed by the spreading out of cumulus types.

In the context of this discussion of patterns of cloudiness and sunshine in the Area, it is appropriate to discuss two related climatological variables, humidity and evaporation. Humidity expresses the water vapor content of air. There are a number of expressions for humidity because there are a variety of ways in which water vapor content can be viewed and measured. Relative humidity expresses the ratio of the amount of water vapor in the air to the amount of water the air could hold at the ambient temperature of the air.

Humidity is high at sunrise in July and August because of radiational cooling under the frequently fair nighttime skies combined with high amounts of water vapor in the air. Values are low in mid-May, and especially so in the afternoon, because of the downward deep mixing of dry air aloft.

Table 11 gives monthly mean values of relative humidity applicable to the general Copper-Nickel Study Area, derived from climatological studies by Watson (1972) using Babbitt temperatures and water vapor data from surrounding stations. The table also gives the daily relative humidity patterns in terms of mean values at four times during the day, as well as mean values of dew point and vapor pressure. Dew point is the temperature at which water vapor would begin to condense out (in the form of dew, frost, or fog) from air of a given moisture

content. Dew point is highest in July and lowest in January, following the trend of the mean temperature curve quite closely. Vapor pressure is the partial pressure of the air due to water vapor. It is a measure of the absolute water vapor content of the air.

Table 11

Evaporation, which is influenced mainly by sunshine and humidity (as well as other factors), has been measured in Hoyt Lakes since 1958 using a "standard pan". The dimensions of the pan are 48 inches in diameter by 10 inches deep. The water is kept at a level varying between 7 and 8 inches and the pan is exposed to allow water to evaporate freely to the atmosphere.

The noticeable result concerning pan evaporation values for the Area is that mean values are virtually the same as mean values for precipitation. It should be noted that for about 99 percent of the land area of the contiguous United States, evaporation exceeds precipitation. Thus, the Copper-Nickel Study Area is unusual in that the values are virtually identical.

Some of the more subtle aspects of the evaporation/precipitation issue should be considered here because the relationships are not simple. One vital point is that, as a result of complex factors such as water temperature, the evaporation from lakes is only approximately 70 percent of that observed in pans. Thus, clearly, precipitation in the Area exceeds lake evaporation. This feature is important for the maintenance of the water levels of the lakes in the Study Area.

Precipitation and pan evaporation vary in their relative magnitudes in various parts of the Area. In the northeast, where precipitation is higher and pan evaporation is lower than for the Area as a whole, precipitation exceeds pan eva-

Table 11. Monthly mean values of relative humidity applicable to the Copper-Nickel Study Area (period of record, 1921-1976).

HOUR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0600	79	79	80	78	77	84	89	89	91	89	86	81
1200	67	67	65	58	52	58	60	61	65	62	71	74
1800	68	67	64	57	50	56	59	61	67	65	75	76
2400	77	77	76	72	72	80	86	84	86	82	83	79
Mean	73	73	72	66	62	69	74	75	78	75	79	79
Mean Water Vapor Pressure (MB)	2.5	2.8	4.6	6.0	7.9	11.7	11.7	12.9	10.8	7.0	4.9	3.3
Dew Point (°C)	-19	-18	-9	-4	4	8	12	10	7	-1	-8	-15

Watson, 1978a

poration. In the southwest, where precipitation is lower and evaporation is higher than for the Area as a whole, pan evaporation exceeds precipitation. However, it must be borne in mind that over the entire Area, precipitation exceeds lake evaporation.

Evaporation is a function of temperature, humidity, sunshine, and wind speed. Consideration of the microclimate is, therefore, important to an understanding of the variation of evaporation across the Area. Microclimates are highly variable over the Area, with sunshine and wind accounting for the largest variation. In heavily-forested areas, values for sunshine and wind speed are on the order of 20 percent of the values for open areas. Daytime temperatures tend to be slightly lower while daytime humidities tend to be slightly higher as compared to open areas. In such places there is, without a doubt, a great excess of precipitation over evaporation. The heavy growth of mosses, which enhances the beauty of the Minnesota climax forest, is undoubtedly a manifestation of this phenomenon.

The longer period of ice on lakes also influences evaporation. Data on the length of ice cover are normally not recorded in Weather Service observations. Fortunately, this is compensated for by the fact that no natural phenomenon is more closely watched by inhabitants of the Area than ice-in and ice-out times. From interviews, it was found that ice covers the lakes almost half of the year (see Table 12).

Table 12

The mean monthly pan evaporation data from Hoyt Lakes are shown in Table 13. The pan usually is operative from about May 1 to October 20, with existing data showing very little evaporation after the latter date--about 1 millimeter per day

Table 12. Freeze dates and duration of ice on Copper-Nickel Study Area lakes.

	FREEZETIME	DURATION
Ponds, Small Lakes	November 5-April 20	166 days
Medium Lakes	November 15-April 25	161 days
Large Lakes	November 25-April 30	156 days

SOURCE: Watson 1978a.

to the end of October. The values shown are based on data taken daily from 1958 to 1975 by the National Weather Service cooperative station located at the main entrance to the Erie mine. Peak evaporation occurs a bit after mid-July.

Table 13

Evaportion data are not taken in November, but are estimated (Watson, 1978a) to be on the order of 0.5 millimeters per day. Applying all of the above information, evaporation values for the Area as a whole are obtained, as indicated in Table 14.

Table 14

Precipitation in the Area averages from near 700 millimeters in the southwest to 760 millimeters in the northeast, so it is quite evident that actual precipitation exceeds actual lake evaporation by a wide margin--around 200 millimeters. Virtually all of the precipitation that falls on lake surfaces through the year ends up in the lakes, since snow just stays on the ice and most of the rain that falls during freeze-up is simply absorbed in the snow.

3.3.2.2 Wind--The wind patterns characteristic of the Study Area are best understood in the context of the major factors governing the movements of large air masses across the face of the globe. The distribution of air over different parts of the world varies and is never the same from one hour to the next. Under the influences of gravity and pressure, air moves from regions of high pressure to regions of low pressure much like a ball under the influence of gravity rolls down the slope of a roulette wheel. Unlike the roulette wheel situation, however, the end to atmospheric motion is never reached as new regions of low

Table 13. Mean monthly pan evaporation values for Hoyt Lakes

MONTH	PAN EVAPORATION (mm)
April	75
May	112
June	138
July	161
August	127
September	72
October	40
Season	725

SOURCE: Watson 1978a.

Table 14. Mean annual actual evaporation considering the freezing of lake surfaces (in millimeters).

	PAN EQUIVALENT	LAKE EVAPORATION
Ponds, Small Lakes	677	474
Medium Lakes	669	468
Large Lakes	662	463

SOURCE: Watson 1978a.

pressure are born. A parcel of air spiraling toward one low pressure region begins spiraling toward another region as soon as the first-mentioned low pressure region becomes filled.

Many high and low pressure systems migrate around the globe, while others are permanent features of some regions. Certain other areas, such as the lee of the Rocky Mountains, are regions where storms form for dynamic reasons. These pressure systems shape the weather and climate of all places on earth by moving various air masses, and variations in their distribution are responsible for "unusual" weather such as drought, hot spells, dry spells, and cold spells. Any average weather regime, and any unusual weather regime, can be explained by pressure system distribution.

In the cold season, air tends to pile up over the continents; in the warm season, it piles up over the oceans. At the peak of the cold season in January, high pressure systems stretching from the Yukon to Georgia dominate North America, and the ridge to the west of the Study Area accounts for the prevailing northwesterlies at that time of the year. In the warm season, low pressure systems centered over the western portion of North America dominate and account for the abundance of southerlies in the Study Area at that time.

Discussion of pressure and wind in the rest of this section is based principally on 24-hour data taken by the U.S. Federal Aviation Agency at the Hibbing weather station. Hibbing is located 50 kilometers to the west of the Study Area.

Pressures and Winds Aloft--The Study Area is in the tropospheric stream of westerly winds which girdles the entire globe at this latitude. At altitudes from 2 to 8 kilometers, westerly winds prevail aloft. The strongest winds are found in the cold season, and the weakest winds are found in the warm season. At

three kilometers, the upper level tropospheric winds through the winter and spring months are from slightly to the north of west as a high pressure ridge exists over western North America, while a trough lies to the east of the continent. Around June 1, winds aloft are from the south of west as a trough displaces the ridge in the west of the continent.

In early July, the west wind circulation breaks down over most of the United States as the Bermuda high forces its way westward. The return of the western trough comes around August 20 and lasts until late September. The western ridge re-establishes itself by the end of October, the month of transition from the warm season to the cold season.

Annual Surface Wind Patterns--The annual distribution of surface wind speeds and directions at Hibbing is remarkably similar to that of Minneapolis-St. Paul and quite dissimilar to that of Duluth (influenced by Lake Superior) and International Falls (influenced somewhat by the prairie wind regime). Both Hibbing and the Twin Cities have most (about 75%) of their winds from directions between 300° and 360° and from 120° and 190°. Northeasterlies and southwesterlies are infrequent at Hibbing--even less frequent than in the Twin Cities.

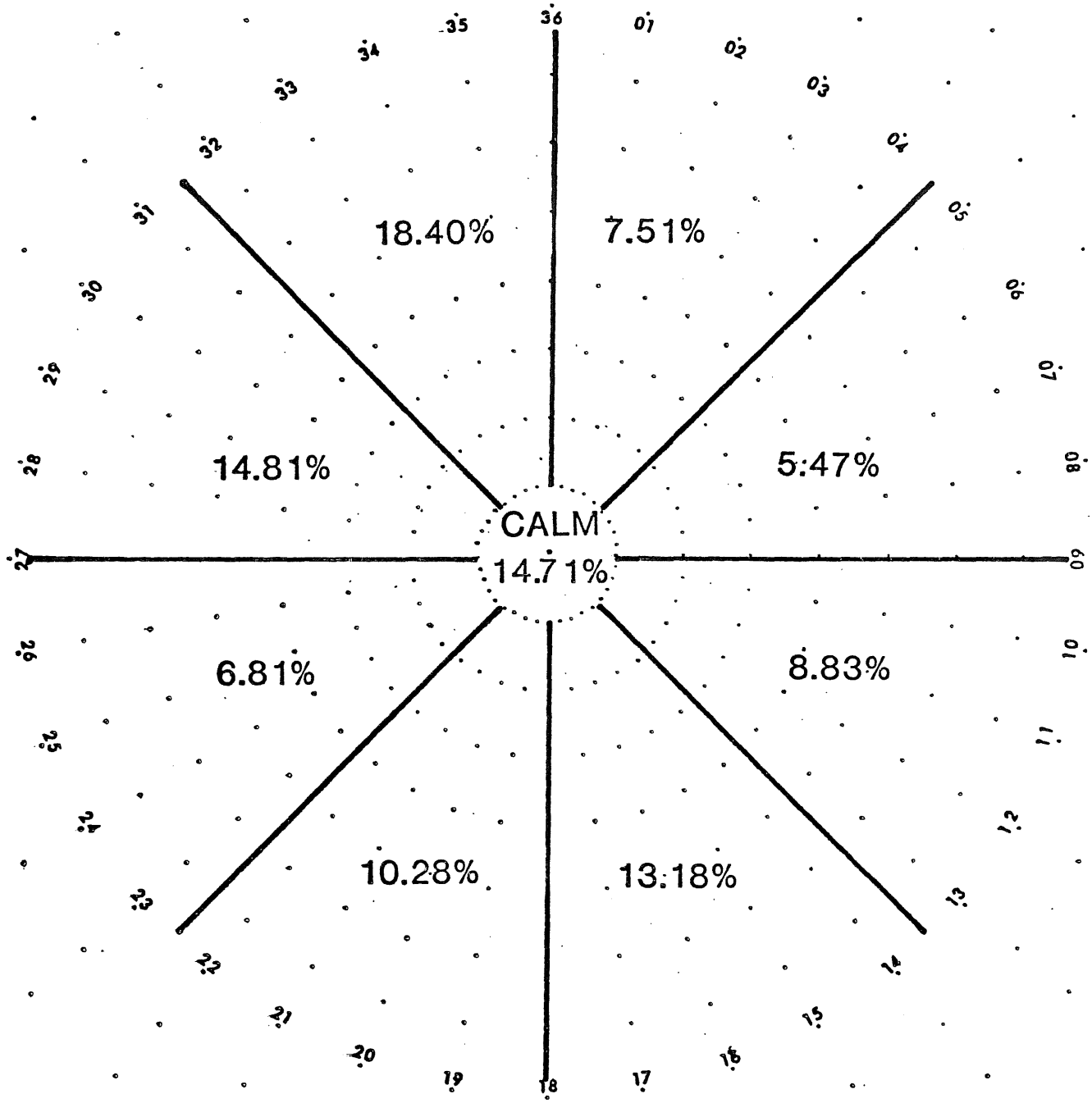
Figure 13 gives the percent of time the surface winds blow from various octants (compass points divided into 8 sections) at Hibbing. Again, note that the majority of the winds blow either from the northwest or from the southeast, and that a good portion of the time the winds are calm (14.7%).

Figure 13

FIGURE 13

WIND DISTRIBUTION % FREQUENCY BY OCTANTS

HIBBING (1964 - 1973 DATA)



SOURCE : WATSON, (1978A).

Figures 13A to 25 are annual and monthly surface wind roses from Hibbing, based on tabulations made by Watson (1978a) of the original data from 1964 to 1973. Wind roses are graphical representations that show the frequency of the direction from which winds blow. The wind roses are plotted on polar coordinate paper where the radials are the directions from which the wind blows and the concentric circles are percent frequency of wind occurrence on each of the 36 radials. On the monthly and annual wind roses, envelopes are drawn for 1½ meter per second (wind speed) intervals (note: 1 meter/second = 3.60 kilometers/hour = 2.24 miles per hour, so 1½ m/sec intervals correspond to 3.36 mph intervals). To make the annual and monthly roses, points were plotted along each radial corresponding to the observed percent of time that the wind came from the corresponding direction. The results are displayed at velocity intervals of 1.5 meters per second. Thus, the distance from the data point to the origin represents the percent of time that a wind from a certain direction blows at a given speed or less. The distance between the points along the radial is the percent of time that the wind blows from the indicated direction in the speed category with endpoints defined by the speeds represented by the two points.

Figures 13A to 25

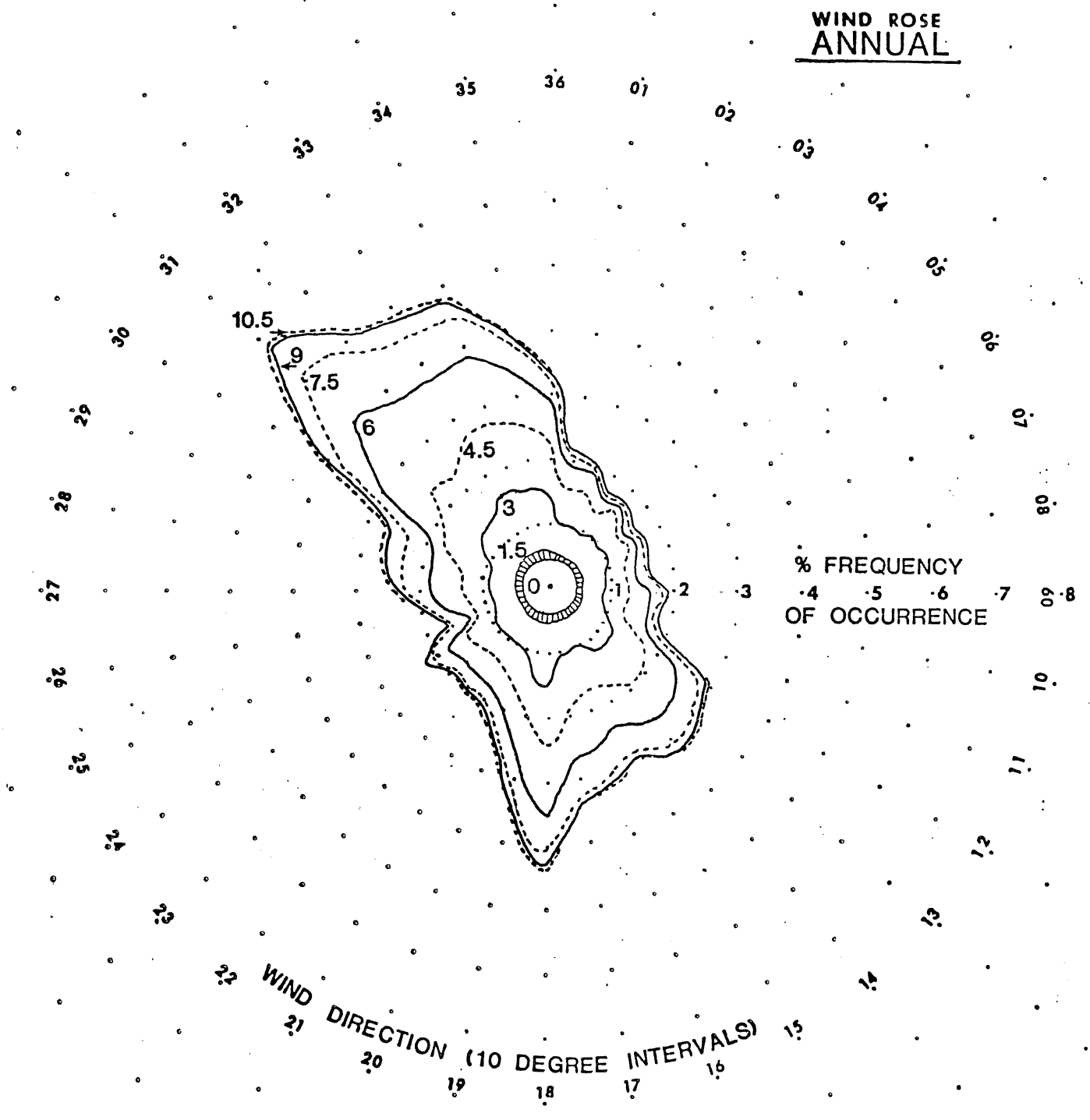
Except for speeds of 1.5 meters per second (which are not shown), lines were drawn connecting points representing equal speeds at 1.5 meters per second speed intervals around the 360° arc. The data points are obscured by the lines drawn over them. The first solid line from the origin represents 3 meters per second; the first dashed line 4.5 meters per second; the second solid line 6 meters per second; the lone hash line 7.5 meters per second; the third solid line 9 meters per second; the second dashed line 10.5 meters per second; the fourth solid line

FIGURE 13A

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



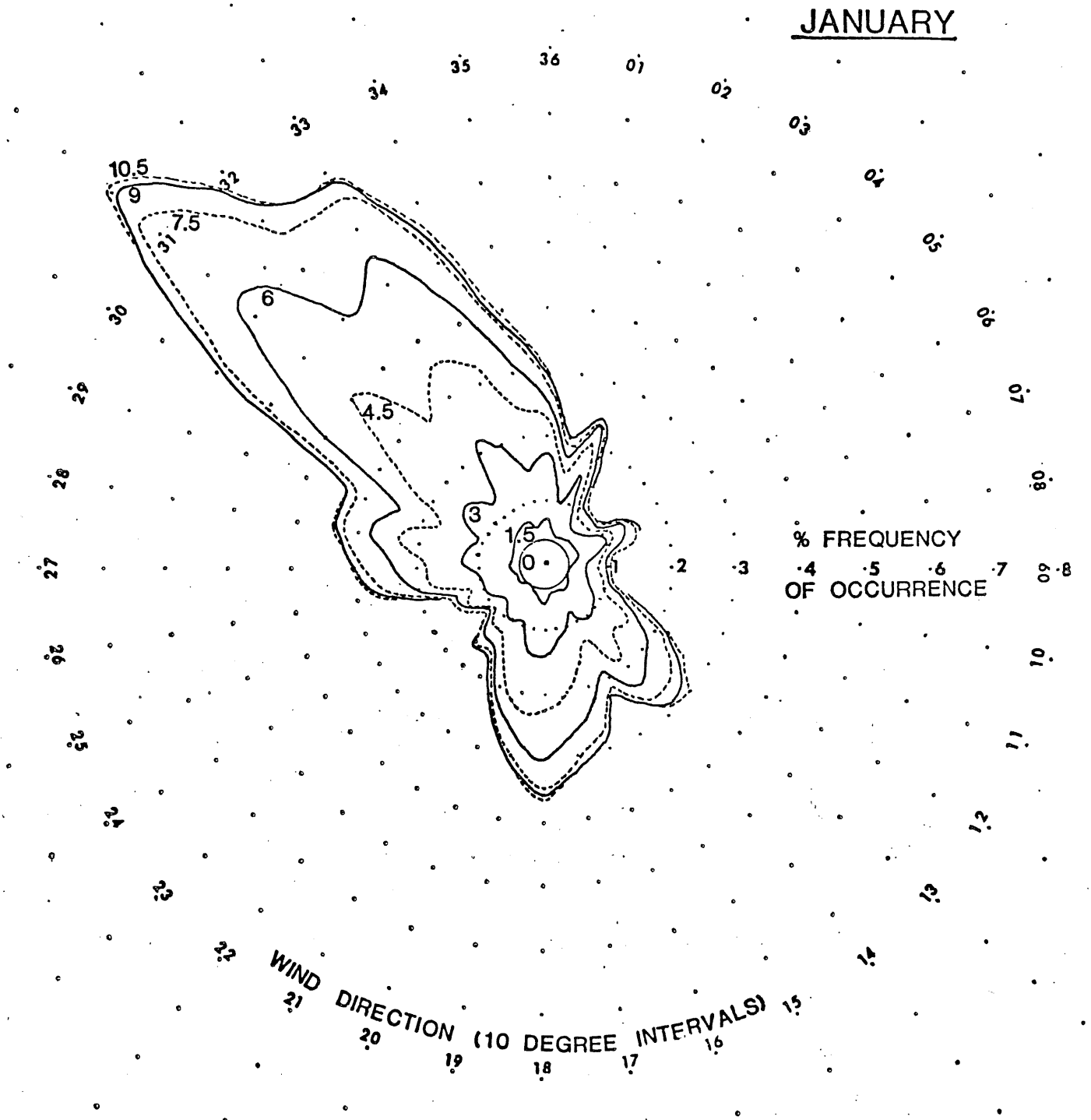
SOURCE : WATSON, (1978A).

FIGURE 14

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



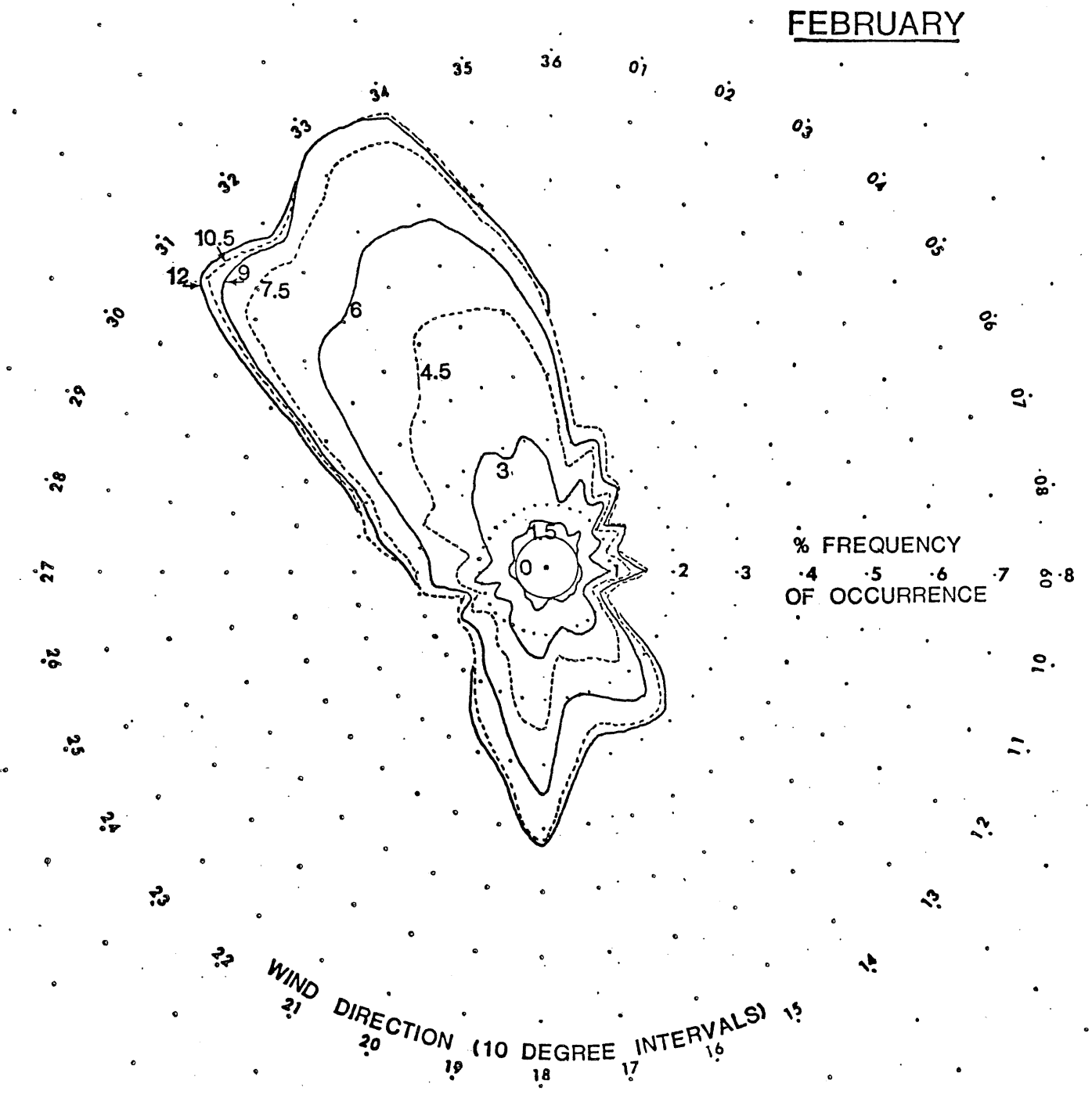
SOURCE : WATSON, (1978A)

FIGURE 15

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



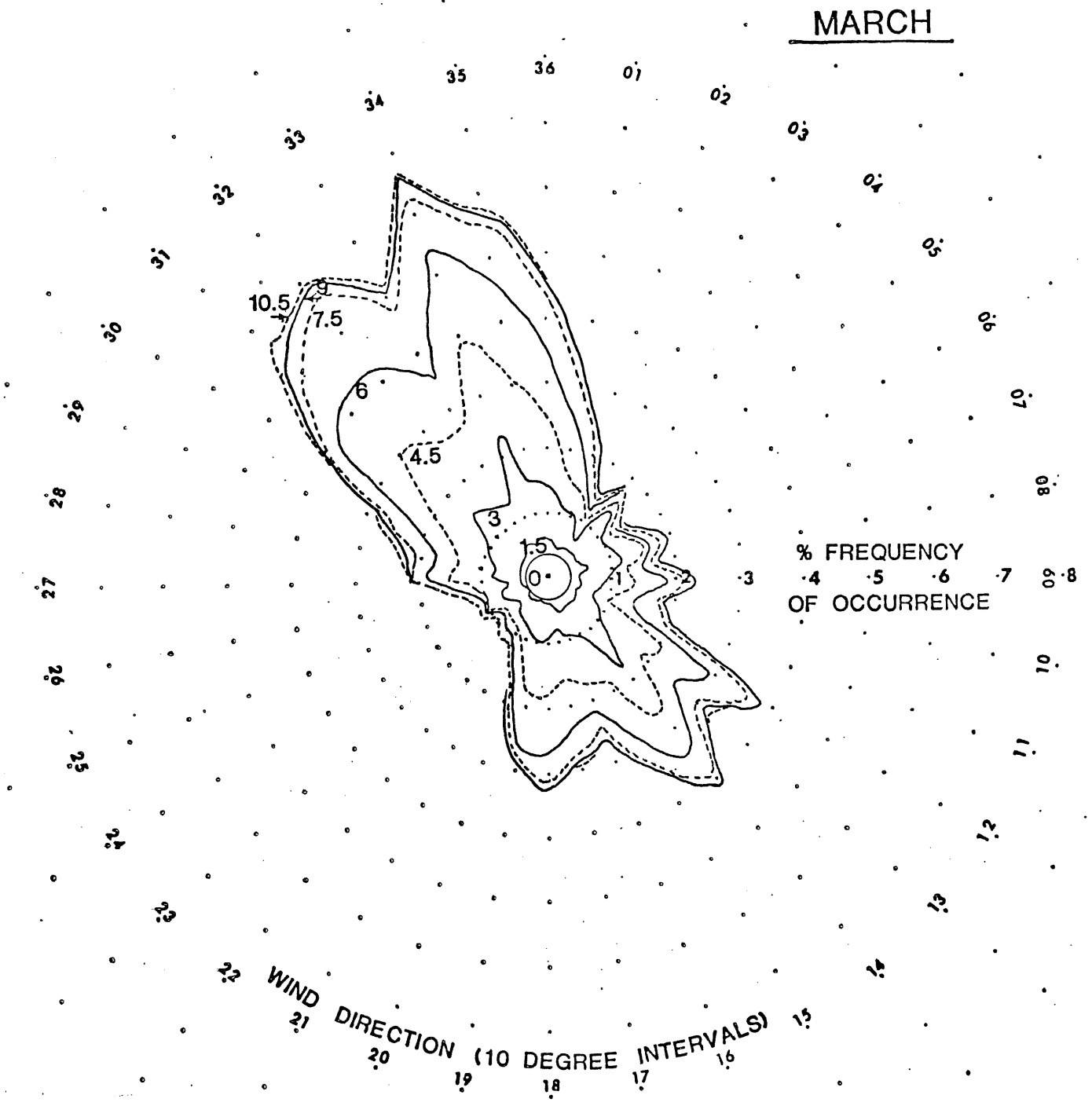
SOURCE : WATSON, (1978A)

FIGURE 16

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



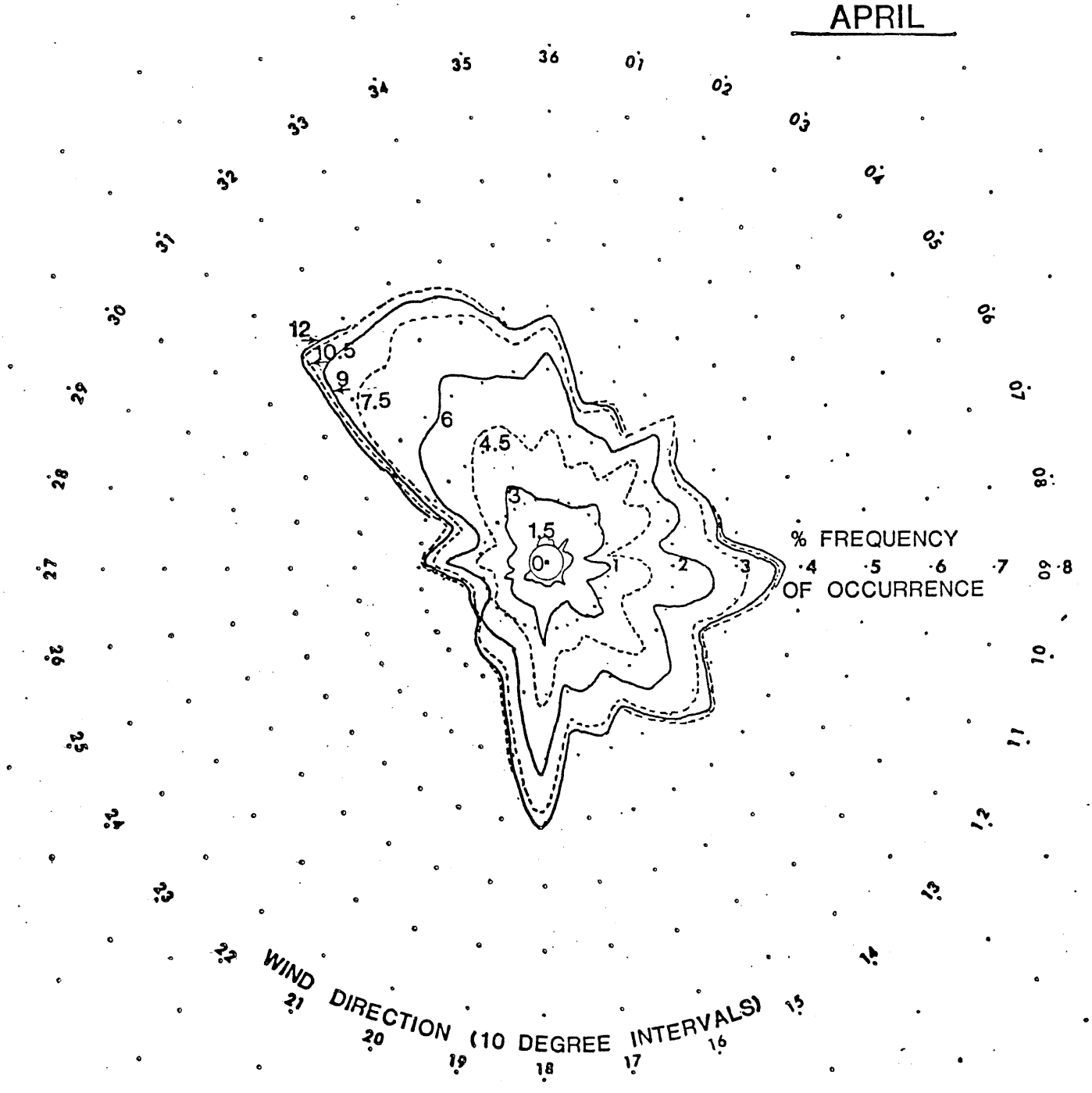
SOURCE : WATSON, (1978A)

FIGURE 17

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



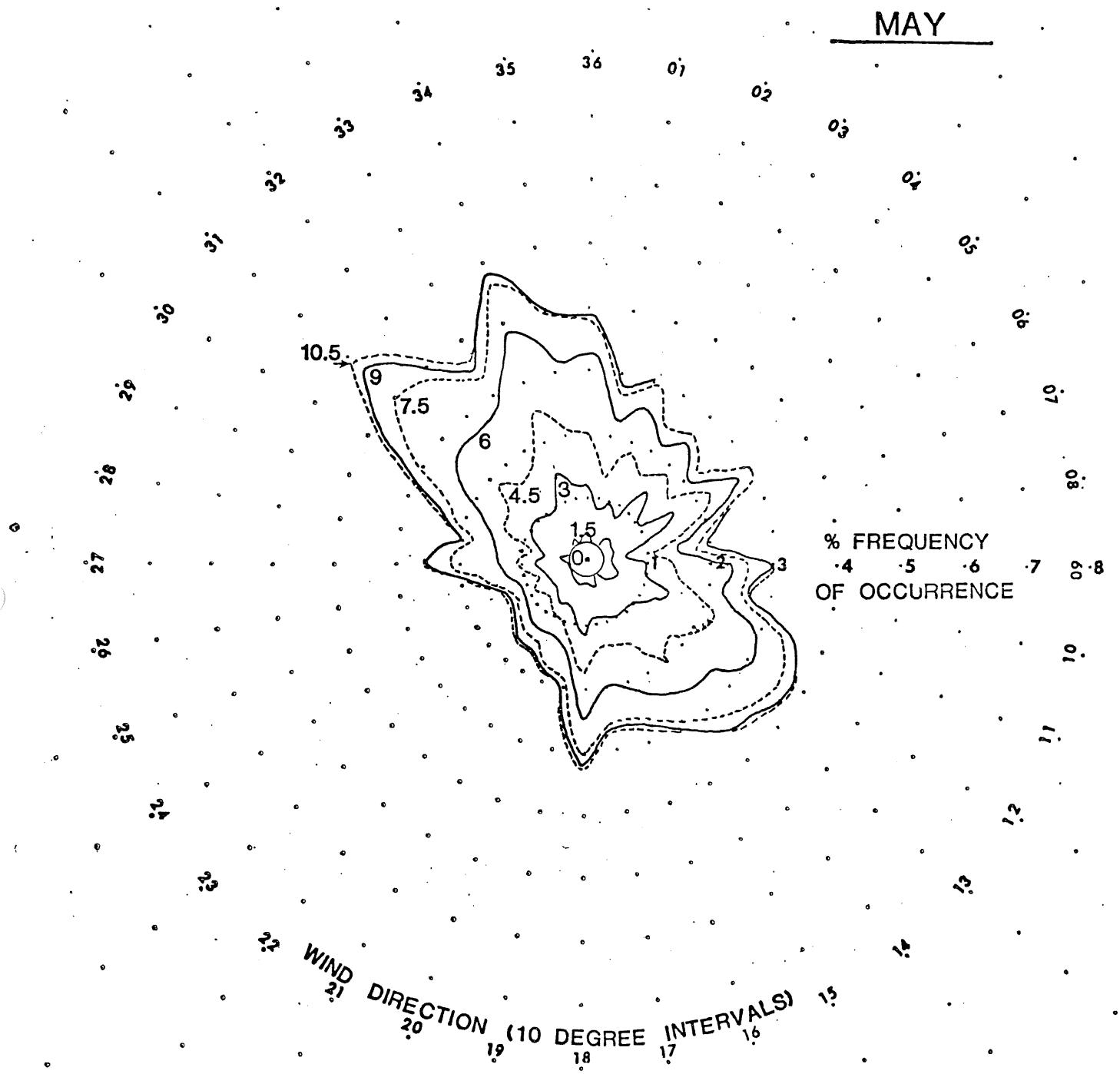
SOURCE : WATSON, (1978A)

FIGURE 18

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



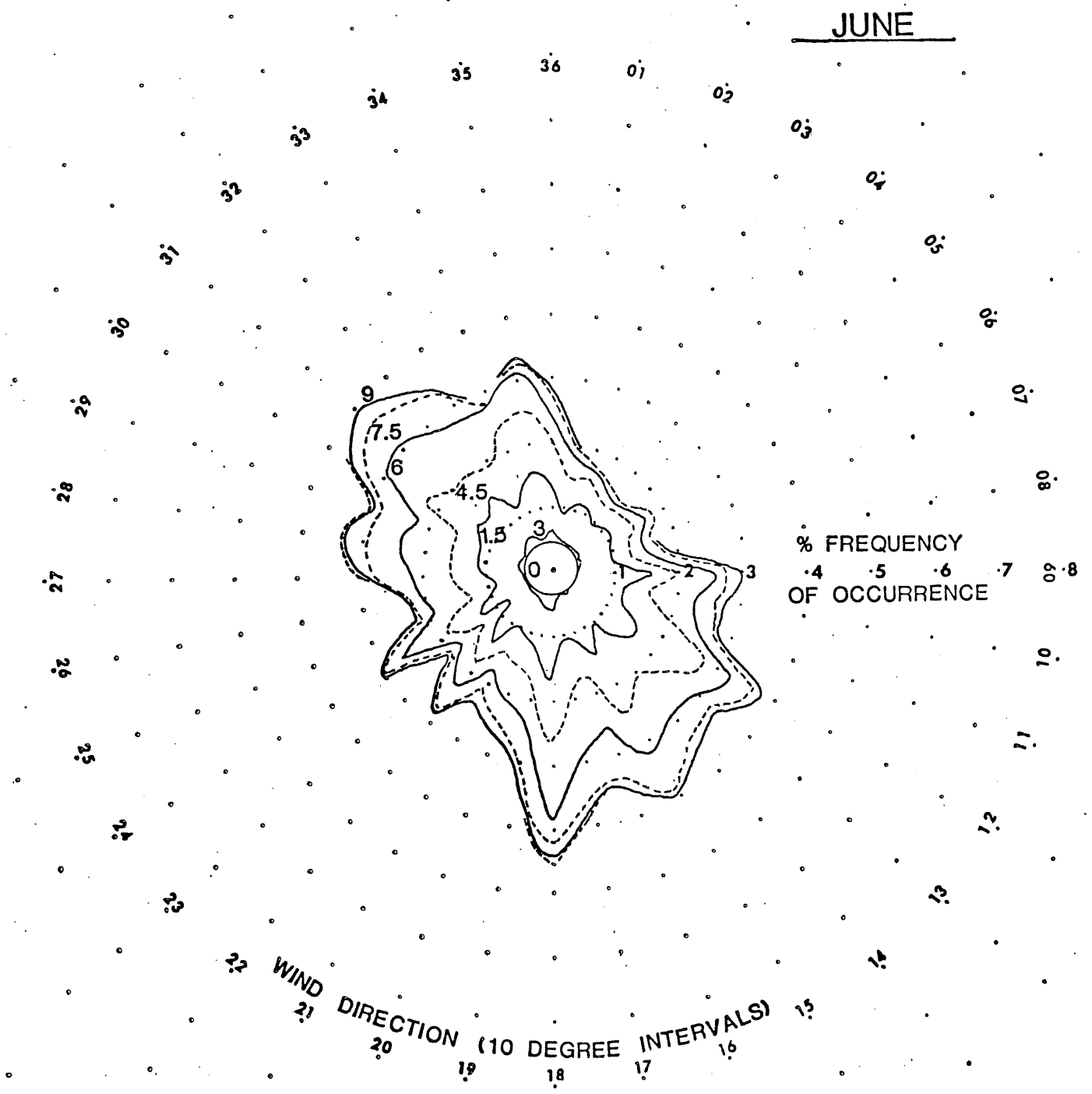
SOURCE : WATSON, (1978A)

FIGURE 19

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



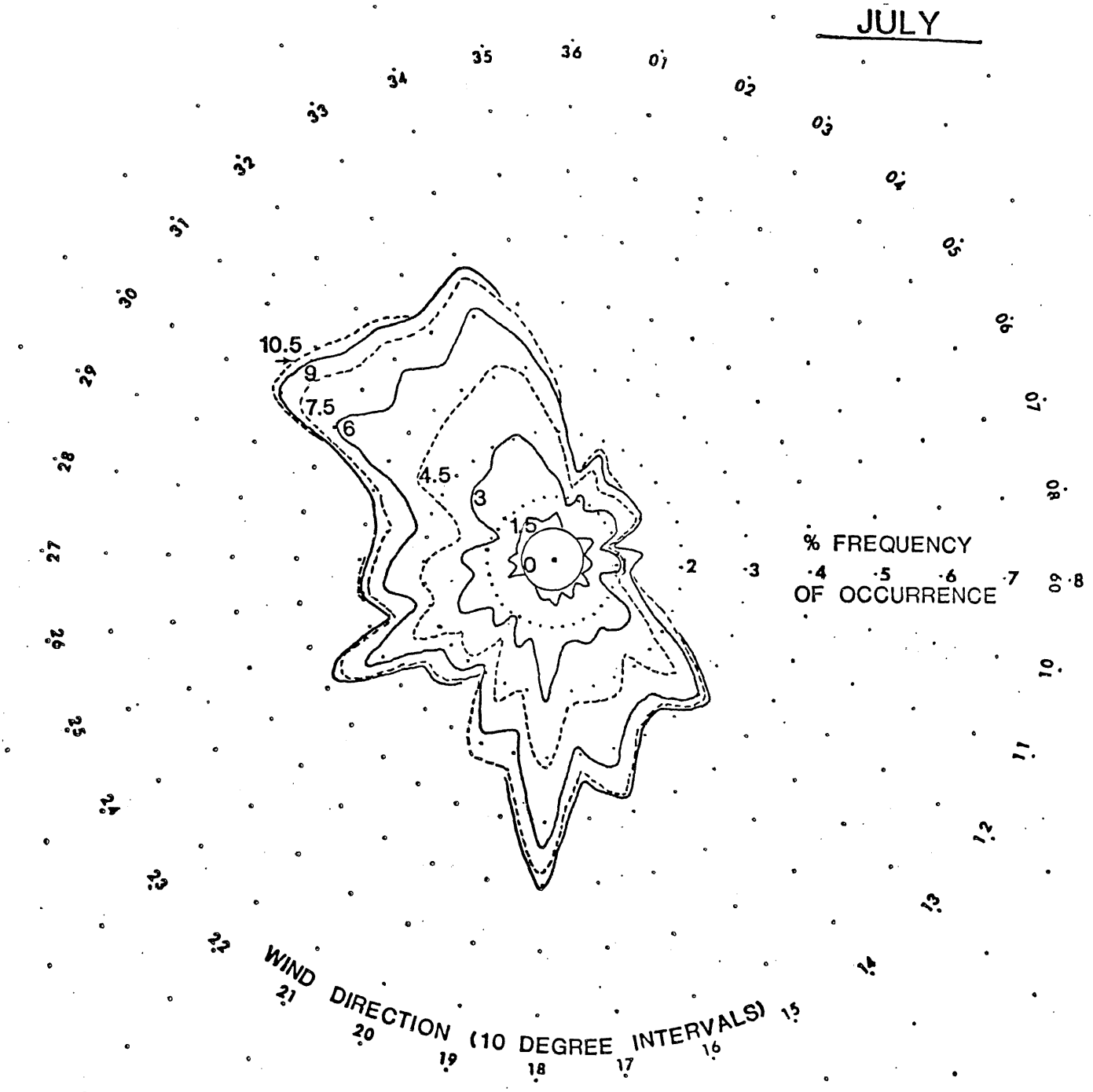
SOURCE : WATSON, (1978A)

FIGURE 20

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



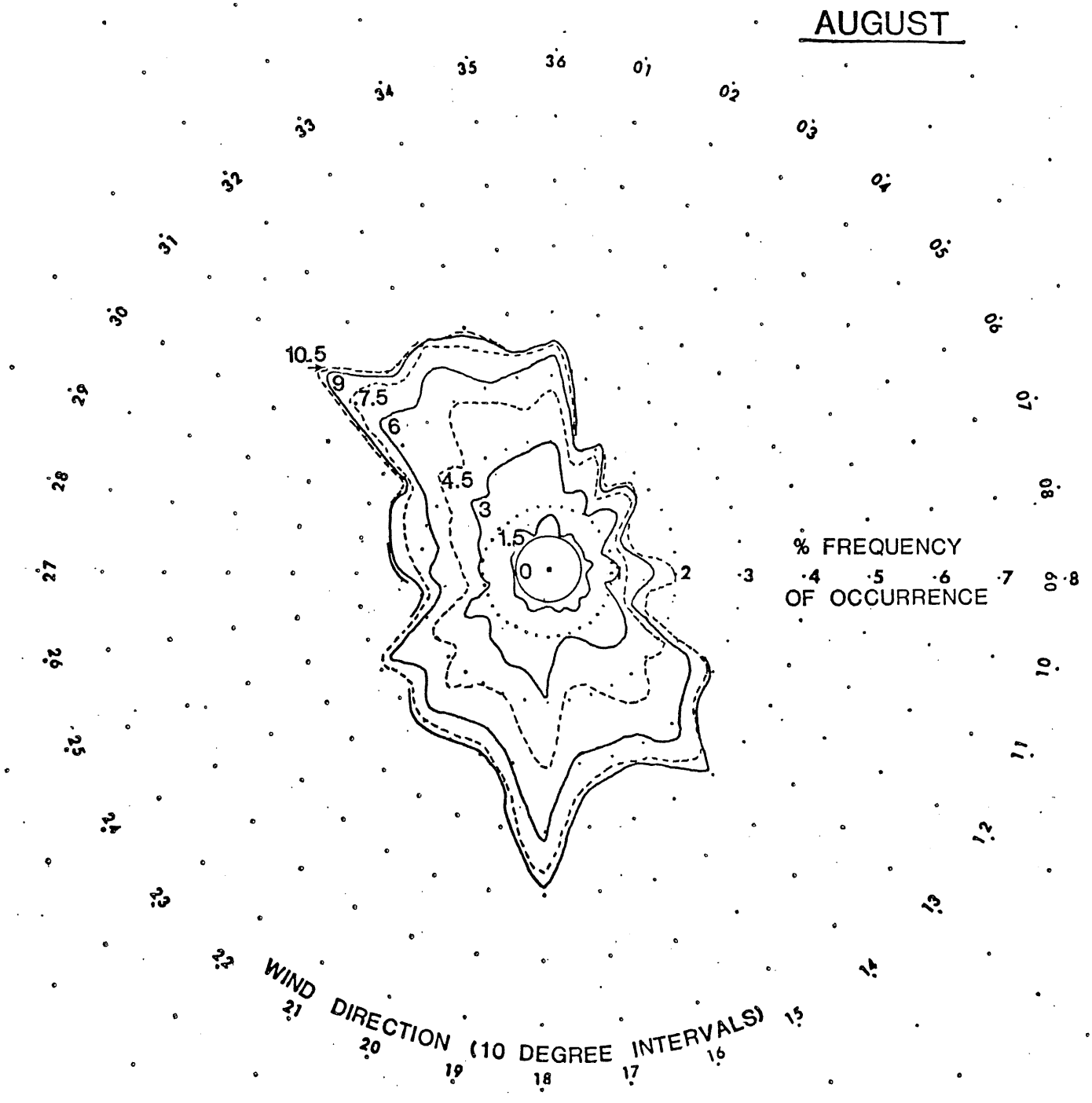
SOURCE : WATSON, (1978A)

FIGURE 21

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



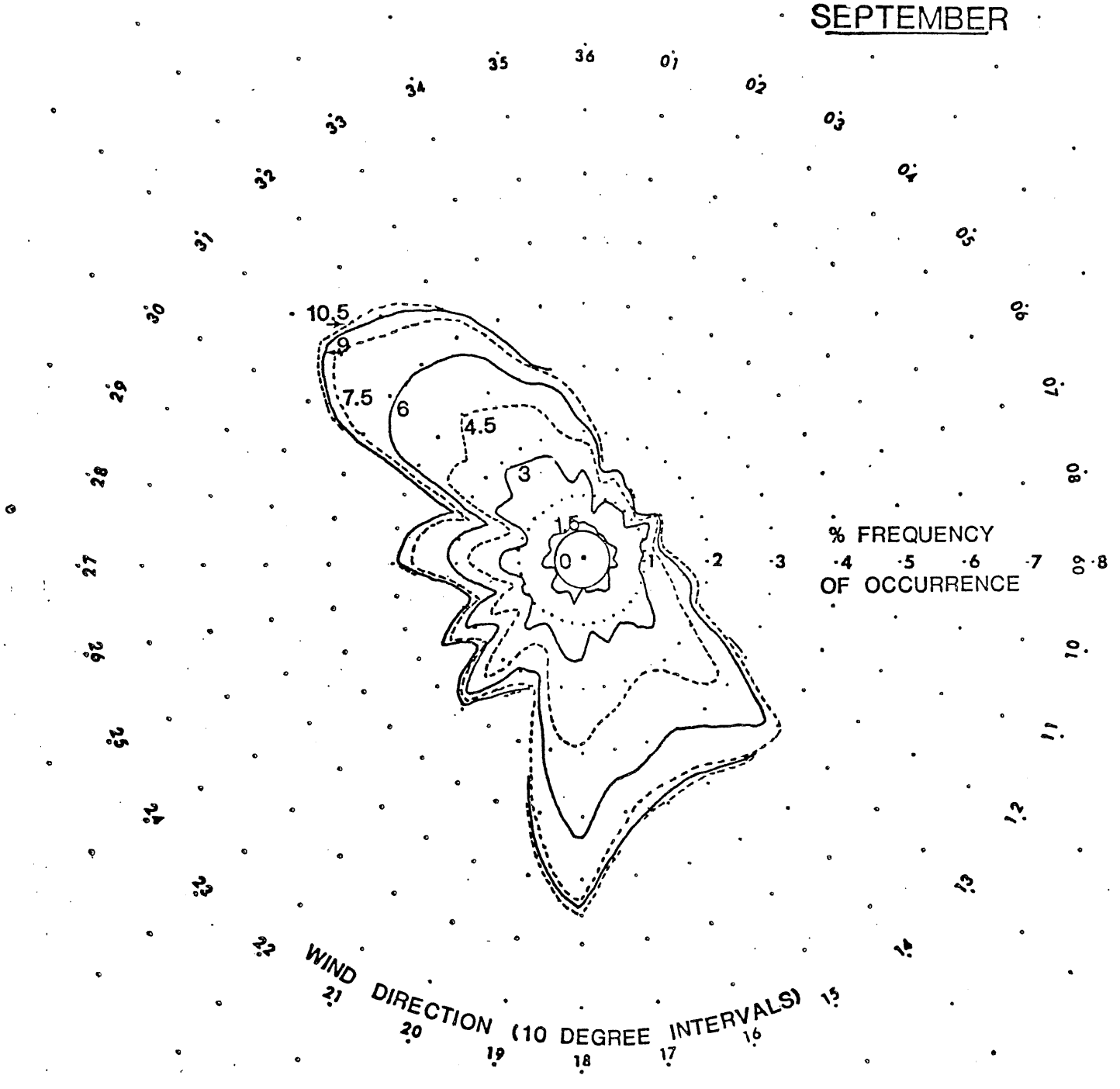
SOURCE : WATSON, (1978A)

FIGURE 22

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



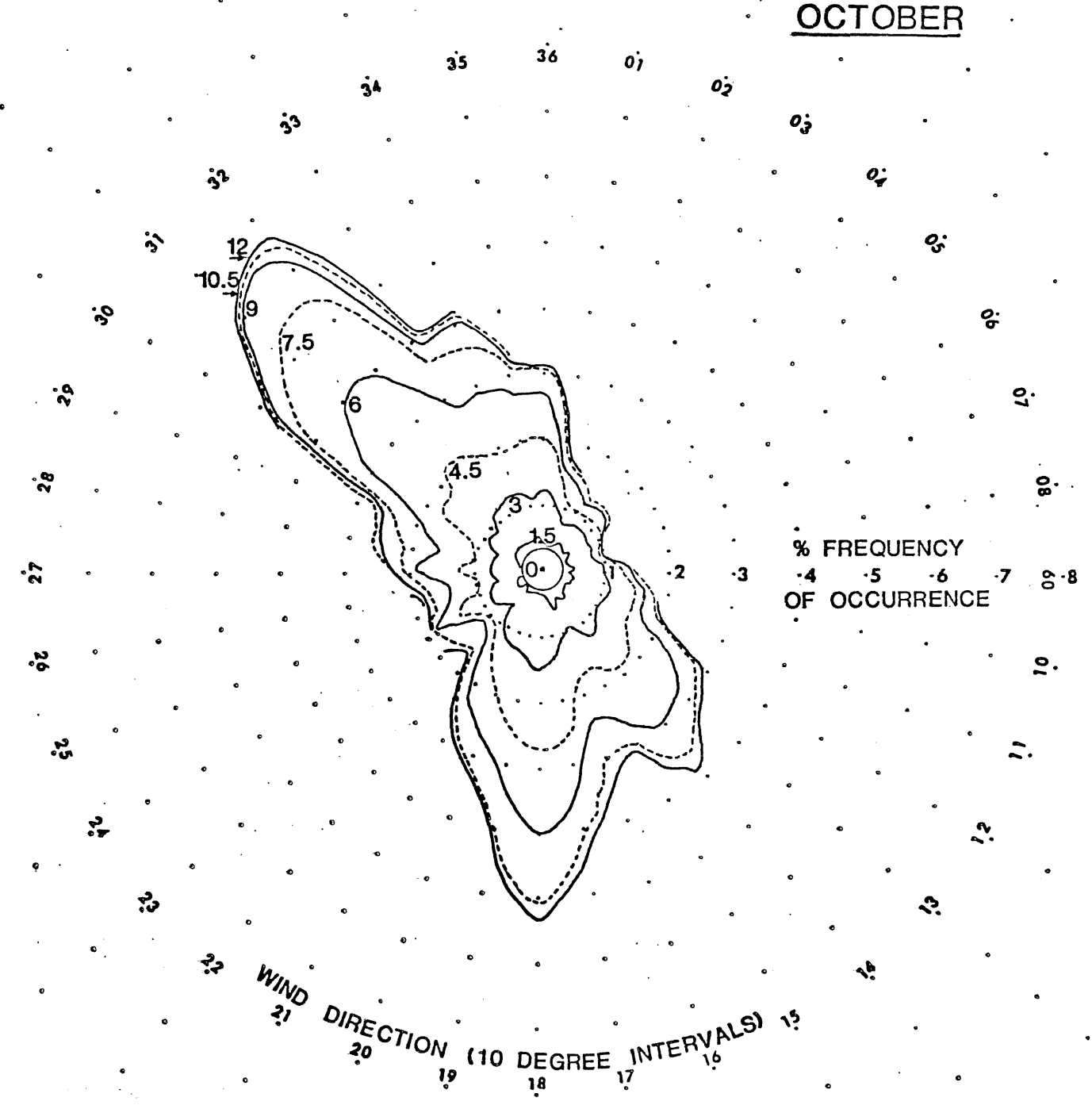
SOURCE : WATSON, (1978A)

FIGURE 23

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



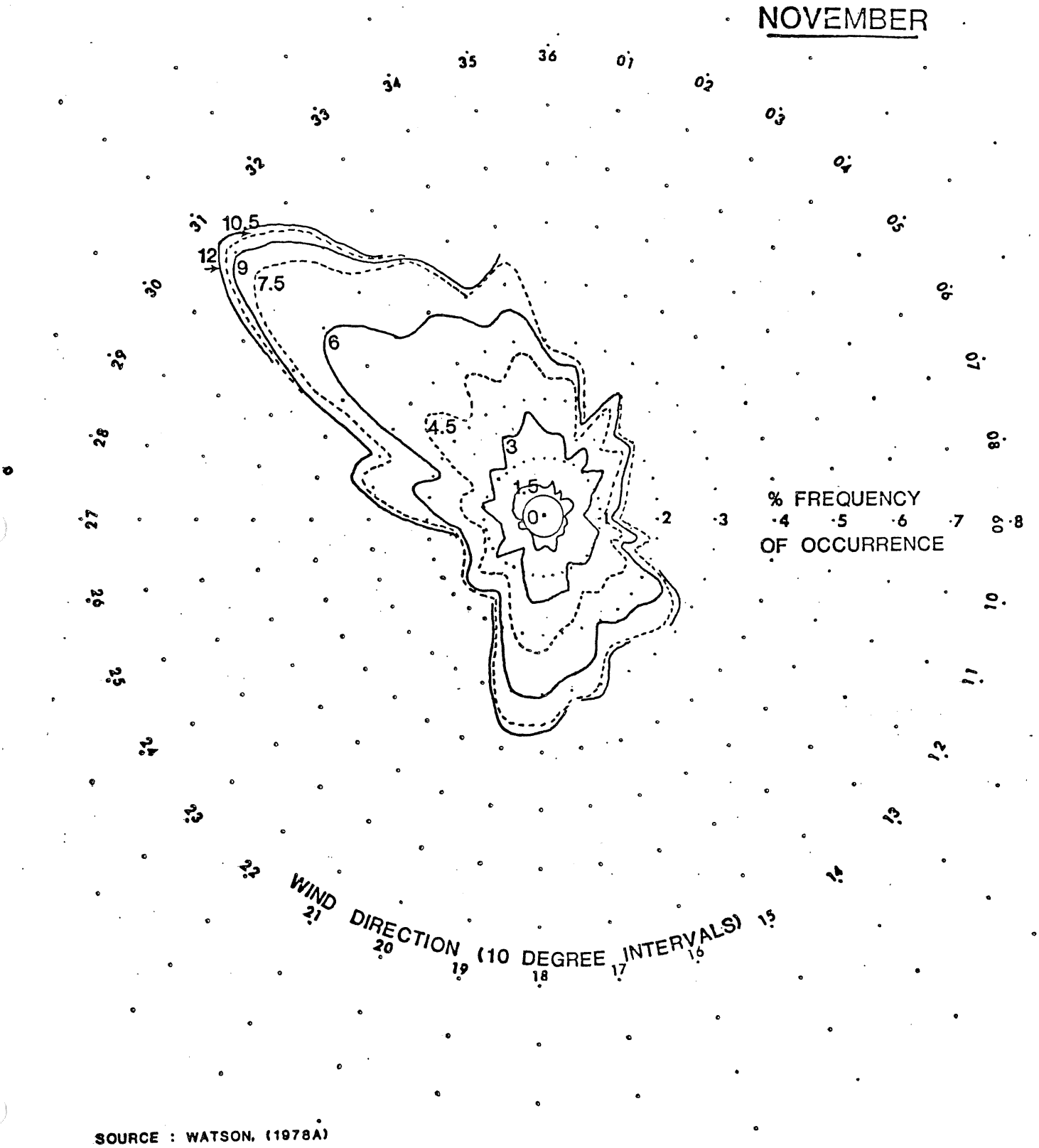
SOURCE : WATSON, (1978A)

FIGURE 24

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



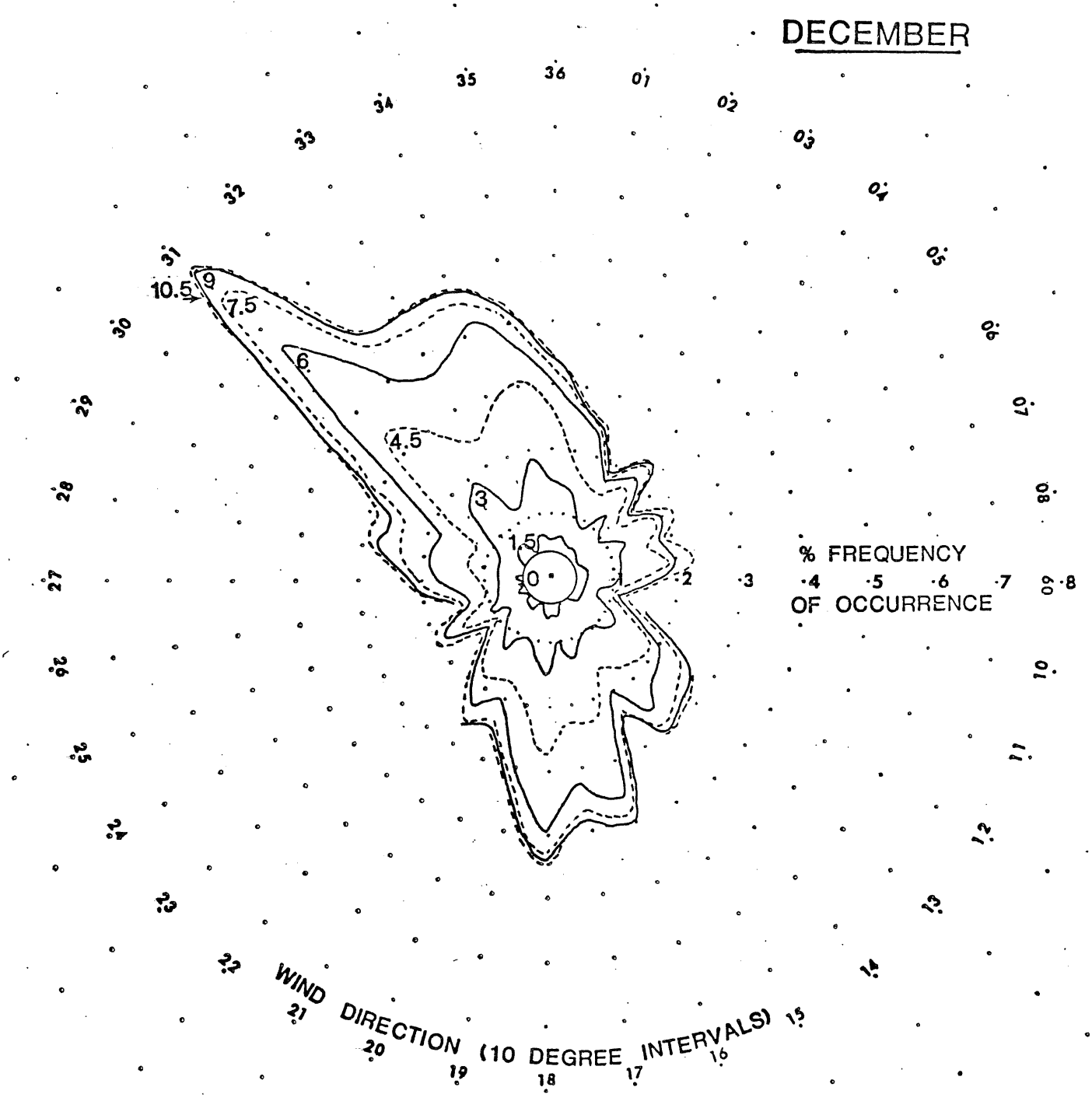
SOURCE : WATSON, (1978A)

FIGURE 25

WIND ROSE

HIBBING (1964-1973 DATA)

(ISOPLETHS SHOW WIND SPEED IN M/SEC.)



SOURCE : WATSON, (1978A)

12 meters per second, etc. In most cases, winds over 10.5 meters per second are so rare that the lines may seem to merge.

It is useful to display some of the data contained in these wind roses. Table 15 indicates the monthly mean wind speeds and prevailing direction at Hibbing, while Table 16 shows the frequency of occurrence of various wind directions as a function of wind speed (Maxwell 1978). Figure 26 is a wind persistence diagram indicating the number of occurances for which the wind persisted from a given direction for various numbers of hours, based on Hibbing data from November, 1976-October, 1977 (Endersen, 1979). The radial axis is in 5-hour increments, and the isopleths represent the number of occurrences as indicated. For example, it is seen that the situation in which the wind blew steadily from the north for 10 hours occurred approximately 13 times for the period of record. The chart indicates that winds from the northwest and south are the most persistent. All of this information is useful in modeling the dispersion of atmospheric pollutants, and interpreting the results.

Tables 15 and 16, Figure 26

In comparing the annual wind rose from Hibbing (based on data from 1964 to 1973, Figure 13A) with roses from individual years, it is found that there is not a great deal of difference from one year to the next (Watson 1978b). Based on roses for 1970 to 1976, it is found that in every case the prevailing wind varies only between 310 and 335°. The southeasterly secondary maximum varies between 130 and 180°. As an example, Figure 27 shows the wind rose for 1976 at Hibbing (Watson 1978b). However, when data on a monthly basis are compared to average monthly data, it is found that the resulting roses may vary radically from the average, even though these variations appear to cancel out when combined to form

Table 15. Monthly wind data at Hibbing.

Month	Mean Speed (mph) (1953-1974)	Prevailing Direction (1953-1974)
January	9.2	NNW
February	9.2	NNW
March	9.4	NNW
April	10.4	NW
May	10.1	NW
June	8.8	NW/S
July	8.2	NW
August	7.8	NW/S
September	8.5	NW/S
October	9.9	NW
November	9.3	NW
December	8.9	NW
Annual	9.1	NW

SOURCE: Maxwell (1978).

Table 16. Annual wind direction distribution--Hibbing (1970-1974 average).

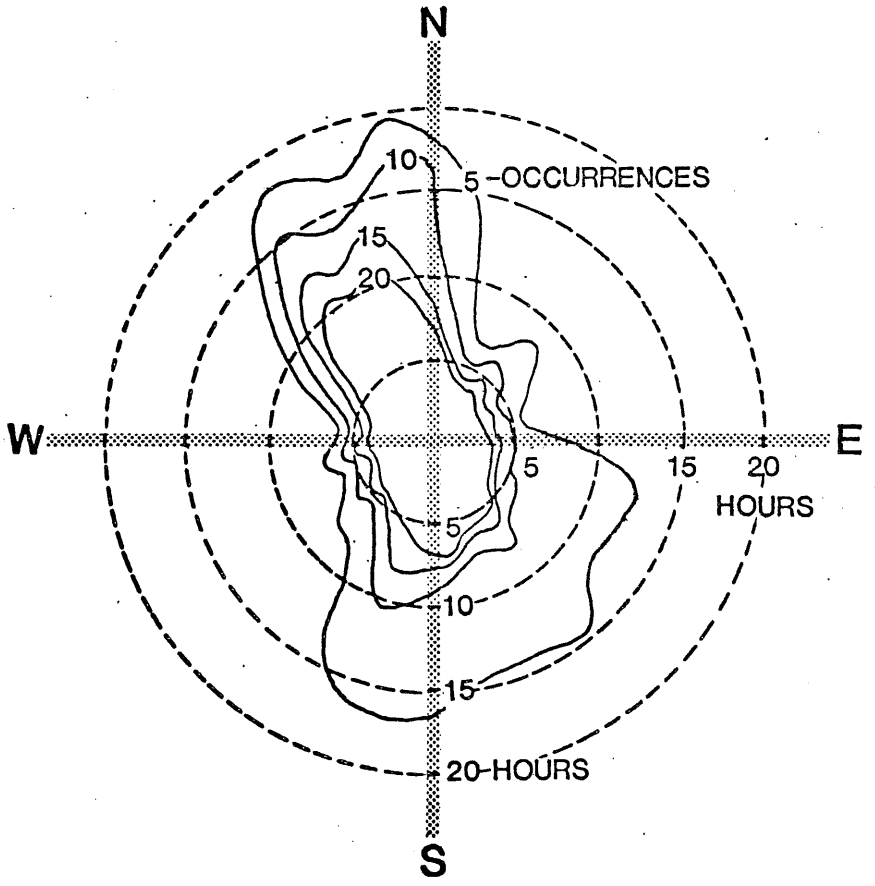
DIRECTION	FRACTION OF TIME WIND IS FROM SPECIFIC DIRECTION Wind Speed (knots)[a] 0-3	4-6	7-10	11-16	17-21	21+	TOTAL
N	0.017038	0.024048	0.036490	0.021866	0.000929	0.000000	0.100371
NNE	0.007312	0.011374	0.017061	0.006801	0.000162	0.000000	0.042710
NE	0.008101	0.012837	0.010864	0.003830	0.000070	0.000000	0.035702
ENE	0.010980	0.010330	0.009401	0.003877	0.000487	0.000000	0.035075
E	0.011049	0.013510	0.014206	0.009099	0.000836	0.000046	0.048746
ESE	0.007010	0.010608	0.014044	0.008890	0.000534	0.000023	0.041109
SE	0.008682	0.013417	0.022981	0.015599	0.000487	0.000000	0.061166
SSE	0.010794	0.012837	0.023538	0.017224	0.000952	0.000000	0.065345
S	0.017688	0.021611	0.041110	0.032266	0.001857	0.000070	0.114602
SSW	0.008217	0.012581	0.022006	0.015390	0.001114	0.000162	0.059470
SW	0.008380	0.011026	0.013231	0.008914	0.000186	0.000046	0.041783
WSW	0.007544	0.009633	0.011676	0.006569	0.000696	0.000116	0.036234
W	0.009076	0.013022	0.019499	0.014740	0.002136	0.000139	0.058612
WNW	0.008473	0.010771	0.024002	0.021379	0.003018	0.000186	0.067829
NW	0.010515	0.014229	0.035980	0.035724	0.003853	0.000395	0.100696
NNW	0.010631	0.019104	0.032985	0.026161	0.001509	0.000162	0.090552
TOTAL	0.161490	0.220938	0.349074	0.248329	0.018826	0.001345	1.000002

SOURCE: Maxwell 1978.

[a]1 knot = 0.5144 m/sec. = 1.151 miles/hr.

FIGURE 26

TOTAL NUMBER OF OCCURRENCES OF PERSISTENCE OF WIND DIRECTION AT THE HIBBING AIRPORT DURING THE PERIOD NOVEMBER 1, 1976 THROUGH OCTOBER 31, 1977



SOURCE : ENDERSEN, 1979

an annual rose. The reader is referred to Watson (1978b) for a discussion of monthly results for the 1976-1977 monitoring period. Only the average behavior is discussed here.

Figure 27

January and February at Hibbing mark the strong domain of northerly winds, while June through August are slightly favored by southerlies. This distribution favors accentuation of the contrast between the cold season and the warm season, for northerlies bring in cold air from Canada while southerlies bring warm air from the southern United States. If the prevailing wind regimes were reversed, the climate of northeastern Minnesota would be much less extreme.

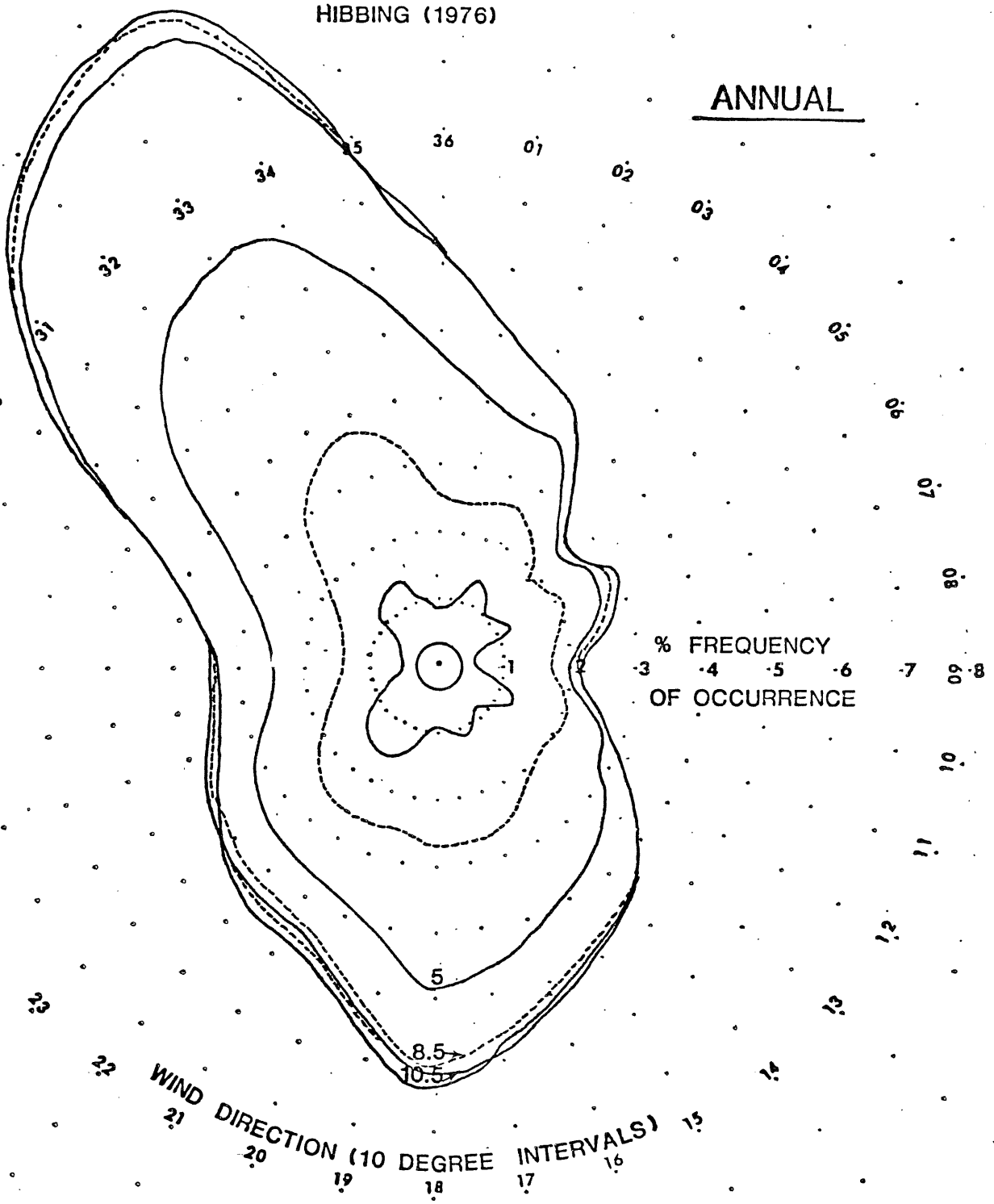
Throughout January and February, the northwest wind prevails at Hibbing with no marked changes during this period. The Hibbing wind roses are remarkably stable in this regard as compared to International Falls and the Twin Cities. The prevailing direction is primarily influenced by the high pressure ridge from the Yukon to Georgia and the low pressure over the northeast of the North American continent. The constancy of the northwesterly direction at Hibbing as compared to points south and west may well be due to the influence of Lake Superior, which has the effect of lowering barometric pressure. The enhanced low pressure over the Lake tends to reinforce, or "lock-in," the winds blowing from the northwest towards the Lake.

In January and February, northwesterlies are vigorous (over 4.5 meters per second half of the time), while the infrequent southerlies and southeasterlies tend to be weak (less than 4.5 meters per second) most of the time. As mentioned earlier, southwesterlies and northeasterlies are especially infrequent during these two cold months.

FIGURE 27

WIND ROSE

HIBBING (1976)



SOURCE: WATSON (1978B)

The arrival of March signals a change in the wind. The high pressure ridge over the North American continent weakens considerably, decreasing the contrast between it and the Lake Superior low. The "locking-in" effect of the Lake loosens its hold, and the isobars become oriented northeast-southwest over the area. Winds blow more from the north-northwest rather than due northwest, and southeasterlies increase in frequency. Daily weather maps at this time show low pressure systems passing closer to the Study Area. Consequently, fewer strong highs are sliding from the Yukon to the southeastern United States.

About April 8, a strong break in the wind pattern takes place. At this time, the mean isobars become oriented east-west along the Canadian border, largely reflecting the passage of storms in a west-to-east direction to the south of the region. The period from April 8 to May 31 marks the reign of the east wind. Even northeasterlies are abundant at this time of the year. Speeds from all directions are vigorous--this is the windy time of the year.

The regime changes suddenly with the arrival of June. A strong, persistent trough forms from the Yukon through Manitoba and the Dakotas to western Kansas and into New Mexico. Southeasterly winds prevail, generally emerging in abundant rainfall from the Gulf of Mexico. Southwest winds peak in frequency during the last part of June. These winds are generally weaker than in the previous weeks.

Air pressure increases in July over the general region from 30° north latitude to 50° north latitude as the high pressure belt ringing the hemisphere makes its seasonal movement northward. This high pressure dominates the region from July through most of October and marks the fine-weather time of the year. Precipitation of short duration is abundant at this time due to convective showers. In contrast with regions just to the west, the Study Area does not "dry

out" in July, August, and September--rainfall is about the same for all three months.

Southwesterlies make their debut about mid-July and are abundant to around August 20. Although they never are the prevailing direction, they blow around one-third of the time during this period. They often blow with appreciable velocities (5 to 10 meters per second), and bring sunny, hot, dry weather. Excess southwesterly winds in some years are associated with low rainfall and high evaporation. These winds bring the scene of white-capped waves on deep-blue lakes surrounded by deep-green evergreens murmuring as the air moves through their needles. Warm air, fed by the heat of the bright sun, envelopes the earth and small, white cumulus clouds dot the afternoon milky-blue sky. When the southwesterly winds overstay their desired time, the result is dusty air in mining areas and low water levels in the thousands of lakes in the region.

Southeasterlies and northwesterlies alternately blow in the summer when the southwesterlies are not active. As southeasterlies give way to northwesterlies during cold front passages, scattered thunderstorms are a common part of the scene. Southeasterlies bring the warm, muggy nights of summer, while the northwesterlies bring brilliant sunshine and cool nights and pleasant days. As the northwesterlies die with the arrival of a high pressure center, temperatures after dark fall to freezing in low-lying areas, even in July.

The summer wind regime begins to yield to the cold season wind regime about September 20, when northwesterlies increase in frequency with the first sharp cold air outbreaks from northwestern Canada. To very near October 25, northwesterlies and southeasterlies alternate, but on that date, the high pressure system over the Great Basin of the western United States begins to form simulta-

neously with the Great Lakes' low pressure system, bringing prevailing northwesterlies for the rest of the year.

3.3.2.3 Temperature--Perhaps the most distinctive feature of the northeastern Minnesota climate is the extreme temperature range. Because the Study Area is located near the center of the continent, there is a minimum of temperature influence by the oceans (Watson, 1978a, gives many temperature statistics for Babbitt, Minnesota, which the reader may wish to examine). Extreme winter-to-summer temperatures in the region do not vary as much as in the prairies of western Minnesota, however. Rather, the significant variation in temperature as compared to the rest of Minnesota is between night and day. Nowhere in the state do temperatures fluctuate as greatly from morning to afternoon as in the flat "meadowlands" areas and in the scattered, isolated depressions of the Study Area. Topographic braking of the nighttime wind and decoupling of the low-level air from air aloft by radiational cooling form cold air pockets and bring occasional freezing temperatures even during the short nights of June and July. Conventional agriculture is largely precluded because of the occasional occurrences of summer frost, and gardens are possible only where the gardeners can cover their plants on cold summer nights.

Although temperatures in the -40s C are commonplace on the long winter nights, southwesterly winds bringing dry air from the Great Plains can raise summer temperatures as high as 40°C on rare occasions. Summer temperatures as high as 39° and 40°C have been recorded at Babbitt and Virginia, respectively.

Yearly Temperature Cycles--At Babbitt, the date of the warmest mean temperature is July 26 (as it is nearly everywhere else in Minnesota) with an average temperature of 19.1°C. The average high on this date is 25.1°C; the average low

is 14.2°C. The coldest daily average is -16.3°C, on January 26, which has an average high of -11.8°C and an average low of -20.9°C. The hottest day of record was July 11, 1936, at 39°C; the coldest was -41°C on January 23, 1935, and again on January 15, 1972.

Since the Babbitt weather station is located high on the hills of the Embarrass Range in the vicinity of the former location of the city, the lowest temperatures of record are higher than those found at stations on lower ground.

A sharp rise in the mean temperature curve begins to take place around February 21, with a leveling off around April 28 when warmer weather generally becomes established. The mean temperature on April 28 is 6.9°C. An initial peak in the curve occurs on July 13 with a cooler period between that date and the second, stronger peak on July 26. This twin-peak is characteristic of the mean temperature curve throughout Minnesota.

There is very little dropping in the daily mean temperature throughout August; a sharper drop begins setting in around September 4 as the longer nights over the continent begin to have a chilling effect on the air.

Typically for Minnesota, there is an autumnal warming peak on October 2, followed by little change in the mean temperature until October 16, when a very sharp drop commences. The strong drop ceases around November 28 when the winter cold regime becomes well established. The decline in mean temperature is then slow to the January 26 minimum with very little change between November 28 and December 23. The difference in the mean temperatures between the two dates is only 2.6°. However, a cold minimum between these dates bottoming out on December 20 occurs in the Area as elsewhere in Minnesota.

Distribution of Monthly Mean Temperatures--Averages of monthly mean temperatures and the mean maximum and mean minimum at various places in northeastern Minnesota provide a convenient way to examine areal variations. Table 17 gives values for 17 meteorological station sites in the northeast, identified earlier with their respective elevations in section 3.2.4.1. The values are derived from National Weather Service observations, except for Brimson and Whiteface where they are derived by an interpolation which considers topographical influence. However, the observations were processed through a model discussed by Watson (1978a) which adjusts the data to long-term (on the order of 150 years) means.

Table 17

Some of the shortcomings of the information include: 1) each station has a different diurnal temperature curve due to the local environment (forest, open plain, "heat island" locality, etc.); 2) length of day varies slightly over the area; and 3) all observers are not equally competent. Nevertheless, the area of the northeastern Minnesota region of interest (depicted in Figure 8) is large enough that the errors are about an order of magnitude less than the real variations.

Armed with these caveats, it is observable that temperature stations along Lake Superior are warmer in the winter and cooler in the summer as compared to inland stations. It is also apparent that Isabella and Babbitt show generally cooler yearly temperatures than stations further to the west. Elevation is a major cause of this coolness. The elevation variation of the Study Area, between roughly 400 meters on the west to some 600 meters on the east, has an effect on temperatures in various ways. Because rising air cools 1°C every 100 meters during times of dry adiabatic lapse rate, the higher elevations tend to be a bit

Table 17. Monthly mean, mean minimum and mean maximum temperatures for the Copper-Nickel Area sites.

(°C)

	January			February			March			April			May			June		
	mean	x-max	x-min	mean	x-max	x-min	mean	x-max	x-min	mean	x-max	x-min	mean	x-max	x-min	mean	x-max	x-min
Duluth Airport	-12.2	-7.1	-17.3	-11.2	-6.3	-16.1	-4.5	0.1	-9.2	2.0	6.4	-2.5	8.1	12.2	3.0	12.2	17.7	6.8
Beaver Bay	-11.9	-6.8	-17.0	-11.3	-6.4	-16.2	-4.8	-0.2	-9.5	2.2	6.7	-2.2	9.0	13.9	4.1	12.8	17.5	6.0
Grand Marais	-11.7	-6.6	-16.8	-11.3	-6.4	-16.2	-5.0	-0.4	-9.7	2.6	7.1	-1.8	9.5	14.3	4.6	11.5	17.4	5.5
Brimson	-15.5	-10.2	-20.8	-13.4	-7.9	-18.8	-6.4	-1.2	-11.6	1.4	7.2	-4.5	8.7	15.1	2.3	13.2	19.4	7.1
Meadowlands	-14.4	-9.1	-19.7	-12.2	-6.8	-17.7	-5.5	-0.3	-10.1	3.4	9.2	-2.5	10.9	17.3	4.5	15.6	21.0	8.7
Cotton	-14.7	-9.7	-20.0	-12.6	-7.2	-18.1	-5.6	-0.4	-10.2	2.8	8.6	-3.1	10.0	16.4	3.6	14.8	21.0	8.7
White Reservoir	-15.1	-9.8	-20.4	-13.0	-7.9	-18.5	-5.8	-0.6	-10.4	2.5	8.3	-3.4	9.7	16.1	3.3	14.4	20.6	8.3
Isabella	-16.2	-10.9	-21.5	-14.6	-9.1	-20.0	-7.0	-1.8	-12.2	0.7	6.5	-5.2	7.6	14.0	1.2	12.0	18.1	5.8
Hoyt Lakes	-15.6	-10.3	-20.9	-13.6	-8.2	-19.1	-5.7	-0.5	-10.3	2.6	8.4	-3.3	11.0	17.4	4.6	15.8	21.9	9.6
Babbitt	-16.0	-10.7	-21.3	-14.0	-8.6	-19.5	-5.5	-0.3	-10.3	1.3	7.1	-4.6	9.7	16.1	3.3	14.0	20.1	8.8
Winton	-15.2	-9.9	-20.5	-13.6	-8.2	-19.1	-5.5	-0.3	-10.1	2.0	7.8	-3.9	10.1	16.5	3.7	15.2	21.4	9.1
Tower	-15.4	-10.1	-20.7	-13.2	-7.8	-18.7	-5.6	-0.4	-10.2	2.6	8.4	-3.3	10.9	17.3	4.5	15.2	21.4	9.1
Virginia	-15.4	-10.1	-20.7	-13.2	-7.8	-18.7	-5.8	-0.6	-10.4	2.4	8.3	-3.4	10.2	16.6	3.8	15.2	21.3	9.0
Hibbing Airport	-15.4	-10.1	-20.7	-13.3	-7.9	-18.8	-5.8	-0.6	-11.0	2.7	8.5	-3.0	10.6	17.0	4.2	15.4	21.6	9.0
Hibbing	-15.4	-10.1	-20.7	-13.2	-7.7	-18.6	-5.8	-0.6	-11.0	2.8	8.6	-3.1	10.6	17.0	4.2	15.2	21.3	9.0
Celina Twp.	-15.1	-9.8	-20.4	-12.8	-7.4	-18.3	-4.3	0.9	-9.5	3.0	8.8	-2.9	10.6	17.0	4.2	15.6	21.7	9.4
Crane Lake	-15.9	-10.6	-21.2	-12.8	-7.4	-18.3	-4.7	0.5	-9.9	2.6	8.5	-3.2	10.7	17.1	4.3	15.6	21.7	9.4

	July			August			September			October			November			December		
	mean	x-max	x-min	mean	x-max	x-min	mean	x-max	x-min	mean	x-max	x-min	mean	x-max	x-min	mean	x-max	x-min
Duluth Airport	16.7	23.1	10.3	15.9	22.2	9.6	14.0	18.2	9.8	7.6	11.7	3.4	-1.3	2.8	-5.4	-8.1	-3.7	-12.3
Beaver Bay	15.8	21.7	10.0	15.6	20.9	10.2	12.4	16.9	8.0	7.1	11.2	3.0	-1.9	2.4	-5.8	-7.7	-3.2	-12.2
Grand Marais	15.5	21.2	9.9	15.4	20.2	10.5	12.1	16.3	7.9	6.9	11.0	2.7	-1.9	2.2	-6.0	-7.4	-3.0	-11.8
Brimson	17.0	23.4	10.6	15.4	21.8	9.0	10.4	16.7	4.1	4.1	10.2	-2.0	-4.8	0.1	-9.9	-12.3	-7.2	-17.4
Meadowlands	18.8	25.2	12.4	16.8	23.2	10.9	12.4	18.7	6.1	5.8	11.9	-0.3	-3.7	1.2	-8.6	-10.4	-5.3	-15.5
Cotton	18.6	25.0	12.2	16.7	23.1	10.8	11.9	18.2	5.6	5.5	11.6	-0.6	-4.1	0.8	-9.0	-10.9	-5.3	-15.5
White Reservoir	18.3	24.5	11.9	16.4	22.8	10.0	11.6	17.9	5.3	5.2	11.3	-0.9	-4.3	0.6	-9.2	-11.3	-6.2	-16.4
Isabella	15.8	22.2	9.4	14.0	20.4	7.6	9.4	15.7	3.1	3.2	9.3	-2.9	-5.3	-0.4	-10.2	-12.8	-7.7	-17.9
Hoyt Lakes	18.3	24.7	11.9	16.2	22.6	9.8	11.6	17.9	5.3	5.0	11.1	-1.1	-4.8	0.1	-9.7	-11.9	-6.8	-17.0
Babbitt	16.8	23.2	10.4	14.5	20.9	8.1	10.6	16.9	4.3	3.6	9.7	-2.3	-5.3	-0.4	-10.2	-12.3	-7.2	-17.4
Winton	18.5	24.9	12.1	16.0	22.4	9.6	11.3	17.6	5.0	4.5	10.6	-1.6	-5.0	-0.1	-9.9	-12.0	-6.9	-17.1
Tower	18.0	24.4	11.6	15.5	21.9	9.1	11.0	17.3	4.7	4.9	11.0	-1.2	-4.3	0.6	-9.2	-12.4	-7.3	-17.5
Virginia	18.1	24.5	11.7	15.7	22.1	9.3	11.3	17.6	5.0	5.0	11.1	-1.1	-4.3	0.6	-9.2	-11.4	-6.6	-16.5
Hibbing Airport	18.7	25.1	12.3	16.5	22.9	10.1	11.8	18.1	5.5	5.0	11.1	-1.1	-4.2	0.6	-9.2	-11.7	-66	-16.8
Hibbing	18.6	25.0	12.2	16.4	22.8	10.0	11.7	18.1	5.5	5.0	11.1	-1.1	-4.3	0.4	-9.4	-11.9	-6.8	-17.0
Celina Twp.	18.3	24.7	11.9	16.3	22.7	9.9	10.7	17.0	4.4	5.0	11.1	-1.1	-4.3	0.6	-9.2	-11.9	-6.8	-17.0
Crane Lake	18.7	25.1	12.3	16.4	22.8	10.0	11.5	17.8	5.2	5.0	11.1	-.1	-4.5	0.4	-9.4	-12.3	-7.2	-17.4

SOURCE: Watson 1978a.

cooler during adiabatic conditions. However, the coolness of these stations is much enhanced in the warm season, especially at Isabella, because of Lake Superior. When easterly winds blow, lake air invades Isabella (and the eastern end of the Study Area) and, to some extent, Babbitt and Brimson. In winter, some slight warming of the Study Area takes place.

Radiation and air drainage at night cause temperatures on locally high ground to run much warmer than over low ground when the air is still or nearly still, especially when skies are clear, partly cloudy, or of just thin, high cloudiness. Atmospheric water vapor content responds to the temperature drop in the radiation-air drainage situation by decreasing via condensation in the cooler areas and by fog formation at vertical and horizontal cold air-warm air boundaries.

All-in-all, the Study Area is not so large that there is a significant latitudinal temperature variation. The elevation variation and Lake effect, although not large, eclipse the latitudinal variation.

Temperatures Aloft--Data on temperature versus pressure from International Falls show the presence of a year-round elevated inversion except in November (Watson 1978a). The inversion is even present in June, despite short nights and the fact that June observations are made about two hours after sunrise and two hours before sunset. (These data differ from radiosonde data from St. Cloud where there is no mean inversion between May and September,) The reason for the inversion's presence at the time of the 6AM observation is that solar heating has not been strong enough during the first two hours after sunrise to overcome the inversion that forms at nighttime.

From December through February, the inversion is about 1 kilometer deep. The data suggest that the inversion is often present throughout the winter day, at least aloft, because the short day and the low-angled sun cannot break up such a deep layer, except when a low pressure system is near the station.

November is a stormy time, and the lack of the elevated inversion suggests that the air is usually moving and the temperatures aloft are usually colder than the surface (bare or snow-covered) temperature, resulting in a prevailing condition of local instability. A common exception to this well-mixed atmosphere occurs, as previously mentioned, when low stratus clouds are trapped beneath a shallow (approximately 1/2 km) inversion.

3.3.2.4 Atmospheric Stability and Mixing--Atmospheric stability (the tendency for the atmosphere to resist vertical displacements) and mixing (the general turbulence of the atmosphere) are determined largely by wind, surface heating, and inversions. Stability and mixing are of particular importance in the modeling of potential air quality impacts which may result from the creation of a new source of air emissions. Thus, their brief discussion in this section is appropriate. A recent report prepared for the Minnesota Pollution Control Agency by Midwest Research Institute (Maxwell, 1978) discusses stability and mixing for the area in and adjacent to the Study Area; and those results are included here.

The air pollution potential of the Study Area is directly related to the capacity of the atmosphere to transport and disperse pollutants. The primary meteorological parameters which determine this capacity are wind speed and atmospheric stability. Stability near ground level is determined primarily by solar heating, wind speed, and surface roughness. The optimum condition for dispersion of emissions from a ground-level source consists of moderately strong

winds combined with a relatively unstable atmosphere. Conversely, atmospheric mixing is minimal in the presence of a ground-based temperature inversion that prevents vertical motion.

Stabilty is commonly characterized by categories, proposed by Pasquill (1961) that indicate the diffusive potential of the lower atmosphere. These stability categories (or classes) are determined by local conditions of time of day, wind speed, and cloud cover. The various categories are indicated in Table 18, with A being the most unstable, D being neutral, and F the most stable. The frequency of occurrence for the various stability classes has been determined for International Falls, and is shown in Table 19 for the period 1970-1976 (Maxwell 1978).

Tables 18 & 19

Another meteorological variable of interest here is the mixing height, a parameter which is strongly dependent on wind and surface heating. As discussed by Hewson (1976), the mixing height may be defined as that height above the earth's surface to which released pollutants will extend, primarily through the action of atmospheric turbulence. A direct determination of this variable may be made using an aircraft mounted turbulence sensor. As the aircraft ascends through the mixing layer, pronounced vertical turbulence is detected. The intensity of this turbulence decreases greatly as the aircraft ascends into the stable or inversion layer aloft. The mixing height is the height at which this pronounced decrease in turbulence occurs. Turbulence sensors carried aloft by captive balloons or on tall towers would serve the same purpose. There are also several indirect methods of estimating mixing height, such as through measurements of the temperature lapse rate, and by observations of cloud heights and types.

Table 18. Key to stability categories.

SURFACE WIND SPEED AT 10m (m/sec)	DAY			NIGHT	
	Incoming Solar Radiation			Thinly Overcast or +4/8	
	Strong	Moderate	Slight	Low Cloud[a]	-3/8 Cloud[b]
less than 2	A	A-B	B	---	---
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
greater than 6	C	D	D	D	D

SOURCE: Turner 1970.

[a]A plus (+) here indicates greater than or equal to 4/8 low cloud.
[b]A minus (-) here indicates less than or equal to 3/8 cloud.

Table 19. Annual stability class occurrences, International Falls.

STABILITY CLASS	FREQUENCY OF TIME STABILITY CLASS OCCURS Year						
	1970	1971	1972	1973	1974	Average 1970-1974	1976
A	0.0049	0.0044	0.0051	0.0042	0.0037	0.0045	0.0042
B	0.0283	0.0307	0.0374	0.0238	0.0119	0.0264	0.0423
C	0.0824	0.0867	0.0909	0.0710	0.0557	0.0828	0.1004
D-Day	0.3136	0.2942	0.2679	0.3514	0.4315	0.3317	0.2840
D-Night	0.2656	0.2849	0.2709	0.3197	0.3179	0.2918	0.2591
E	0.3052	0.2991	0.3277	0.2299	0.1794	0.2683	0.3100

SOURCE: Maxwell 1978.

Estimates of mixing height at International Falls for various seasons and times of the day are presented in Table 20 (Maxwell 1978). This information, along with the information on the occurrence of the various stability classes, is of use in modeling the dispersion of air pollutants, as discussed later in this chapter.

Table 20

3.3.2.5 Precipitation--Precipitation, whether in the form of rain or snow, is a meteorological variable of great importance. It is the link in the hydrologic cycle which makes water available in areas remote from the earth's oceans and large freshwater lakes. For the Study Area, most of the water furnishing precipitation originates in the Gulf of Mexico, although appreciable quantities also come from the Pacific Ocean and Lake Superior. Very minor amounts originate from land surface vegetation, local lakes, Hudson Bay, and perhaps the Arctic Ocean and the Atlantic.

Precipitation Throughout the Year--In the Study Area there is a general wet season and dry season corresponding closely to the warm season and cold season, respectively. From an analysis of composite records, principally from Tower (Watson 1978a) from 1894 to 1976, the wet season can be defined as beginning on April 14, when a sudden increase in average precipitation begins, and ending on October 15, when a sharp drop in average precipitation takes place. Interestingly, the dates are six months apart. Similar data from Babbitt, in the middle of the Study Area, are shown in Figure 28, in terms of average daily precipitation. The wet season noted above is apparent from the graph.

Figure 28

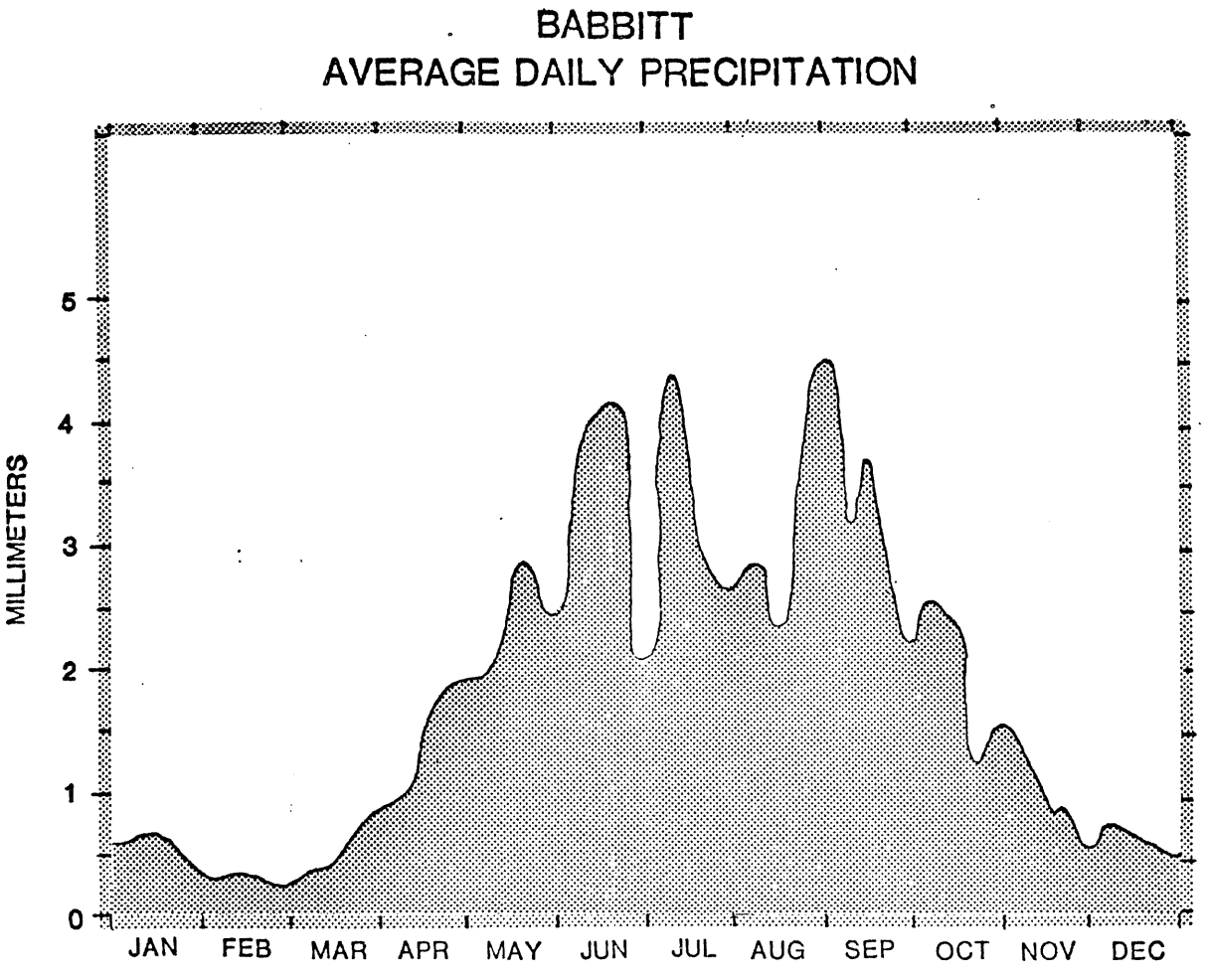
Table 20. Mean seasonal and annual morning and afternoon mixing heights and wind speeds.

	TIME PERIOD	INTERNATIONAL FALLS, MINNESOTA		
		All	NOP*	% NOP
Mean	Winter	347	251	54.0
Morning	Spring	411	319	66.3
Mixing	Summer	337	266	75.2
Height	Autumn	513	406	70.6
(meters)	Annual	402	310	66.4
Mean	Winter	656	584	52.7
Afternoon	Spring	1,646	1,540	68.3
Mixing	Summer	1,747	1,688	78.9
Height	Autumn	1,146	1,054	69.9
(meters)	Annual	1,299	1,216	67.4
Mean	Winter	5.6	4.3	54.0
Morning	Spring	5.6	4.6	66.3
Wind	Summer	4.1	3.3	75.2
Speed	Autumn	6.0	5.1	70.6
(m/sec)	Annual	5.3	4.3	66.5
Mean	Winter	7.0	6.3	52.7
Afternoon	Spring	7.5	7.1	68.3
Wind	Summer	6.9	6.6	78.9
Speed	Autumn	7.4	7.0	69.9
(m/sec)	Annual	7.2	6.8	67.4

SOURCE: Maxwell 1978.

*NOP=Non-precipitation.

FIGURE 28



SOURCE : WATSON (1978A)

In terms of the typical yearly pattern, June and July are the wettest months in the Study Area; February is the driest. The peak of raininess is around June 23, with a secondary peak around September 1. The period from mid-July to August 20 is relatively dry, except for an enhancement around August 8. Late September is also dry, with a wet period in mid-October. There is also a significant dry spell around Memorial Day.

June and July are nearly equal in precipitation, with August being perhaps insignificantly different, especially in the southeastern portion of the Study Area. June and July are so close in average rainfall that it becomes perhaps a moot point as to which is the wettest. To the west of the region, in Virginia, June is slightly wetter than July, according to records since 1894; Babbitt has had slightly wetter Junes than Julys, according to records taken since 1921. However, the evidence indicates that if Babbitt records also had extended back to 1894, July would have averaged out the wettest.

At Virginia, July was the wettest month up through 1960. Since 1960, June has been much wetter than July, with the result that both Virginia and Babbitt, to 1976, have had the wettest month tipped to June for the lengths of record of both places. At other places, such as Winton, July has been the wettest month, even since 1960.

Around August 20, the pressure systems orient themselves similar to the June pattern, and an increase in rainfall takes place which lasts until about September 20. As mentioned previously, from September 20 to October 20 the United States is under the dominance of a high pressure system. Due to the widespread sinking air associated with this high pressure, this is a period of high percentage of cloud-free skies in the Study Area.

Late October brings an end to the high pressure regime over the United States as high pressure systems over Canada become more intense and generate more frequent northwesterly winds. The Upper Great Lakes' low pressure system is reborn and becomes very strong. At this time, low stratus clouds cover the states of these Upper Lakes. The low remains strong through all but the last week of December, and the accompanying cloudiness makes November and December the cloudiest (perhaps dreariest and gloomiest) time of the year.

Spatial Variation--Watson (1978a) describes a method of using available data to estimate the average monthly and annual precipitation at the various weather stations shown on the map in Figure 8 for the period 1894 to 1976. The results are given in Table 21 and Figure 29. In using these values, the reader should keep in mind that total average precipitation will vary from century to century and millenium to millenium, as well as over other time intervals such as decade to decade, as discussed in the next section.

Table 21, Figure 29

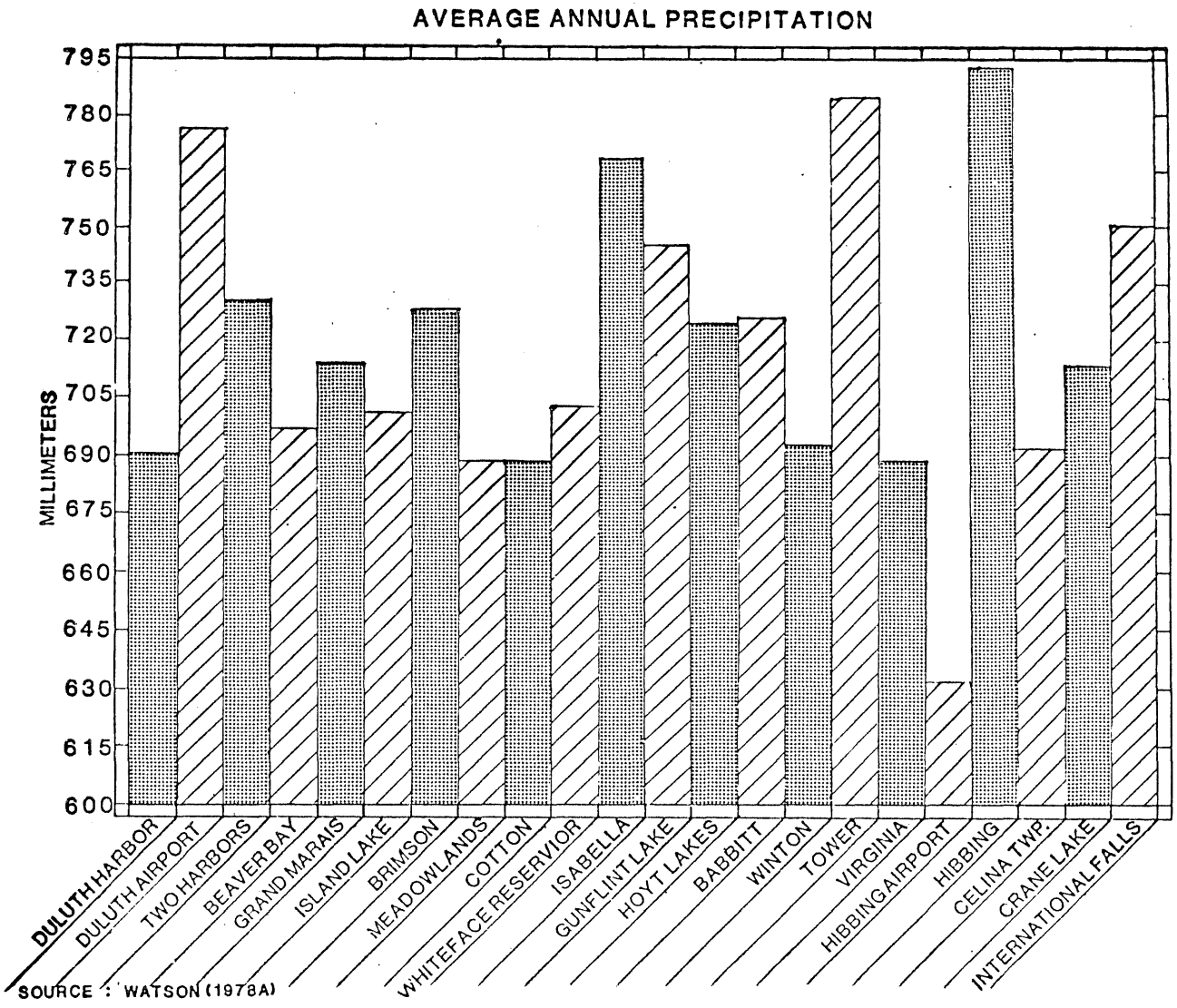
These data cannot show small-scale variations that likely exist because the rain gauges are so far apart. Important average differences can exist over distances as little as several miles. As an example, the difference between the city of Hibbing and the Hibbing airport illustrates the differences that can arise between closely adjacent stations. The differences between the two stations could be due in part to problems caused by differences in rain gauge exposure. The reader should bear in mind that rain gauges chronically suffer from exposure problems. For example, differences may arise from vegetation (i.e. precipitation generally falls at an angle to the ground because of the wind). The trees may intercept the rain or snow, lowering the amount accumulated. This effect is greatest with wind-driven rain or snow.

Table 21. Average monthly and annual precipitation for the sites indicated (millimeter units).

SITE	MONTH												ANNUAL
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	
Duluth Harbor	24.0	21.4	34.8	46.2	76.0	79.9	91.8	108.3	84.2	52.7	48.1	26.4	691.2
Duluth Airport	33.3	31.4	47.2	54.8	77.0	87.1	100.2	115.3	86.7	54.6	56.6	36.3	776.2
Two Harbors	28.6	17.3	42.9	43.4	88.2	81.9	91.2	98.8	92.9	54.6	52.0	34.3	729.5
Beaver Bay	54.8	35.1	51.6	67.6	63.8	69.6	80.8	75.9	82.6	49.3	30.7	36.1	697.7
Grand Marais	26.1	26.3	37.1	52.4	76.0	78.6	95.1	76.5	96.0	52.0	50.5	30.2	714.6
Island Lake	30.6	20.0	32.3	49.3	75.2	88.3	105.0	97.6	90.4	51.8	45.9	29.2	701.6
Brimson	26.5	23.5	42.9	55.7	70.2	90.6	96.0	99.9	87.9	53.9	47.8	32.3	726.9
Meadowlands	19.5	16.2	29.7	55.7	73.5	89.0	107.1	96.1	85.6	50.1	42.5	25.1	689.6
Cotton	20.0	15.9	28.2	52.6	75.0	88.5	104.1	101.4	80.8	52.4	45.0	26.2	689.6
Whiteface Reservoir	26.5	22.5	36.3	54.8	70.7	85.2	103.5	95.6	80.8	52.2	45.3	30.2	703.4
Isabella	26.5	25.9	41.1	58.4	79.7	99.3	103.5	95.6	89.8	63.2	50.2	32.2	768.1
Gunflint Lake	33.6	26.9	26.8	54.2	76.0	76.7	98.7	72.1	132.2	56.5	58.8	34.3	744.1
Hoyt Lakes	24.5	22.8	32.5	50.9	81.0	93.7	106.8	95.3	87.3	62.5	38.0	27.2	724.0
Babbitt	23.4	20.0	29.2	48.7	73.0	98.1	103.8	97.9	94.9	61.7	46.8	28.2	726.4
Winton	23.8	21.1	29.7	41.4	72.5	88.3	114.5	88.3	93.5	56.5	41.0	25.6	693.5
Tower	28.6	26.3	36.8	55.3	88.5	102.1	116.0	93.0	96.6	64.7	45.6	30.2	785.4
Virginia	23.4	17.3	30.7	49.8	75.2	101.9	97.5	91.2	85.6	57.2	35.8	24.4	689.8
Hibbing Airport	16.3	14.8	35.1	41.6	70.2	88.5	101.7	86.3	80.3	48.6	29.7	19.0	632.2
Hibbing	26.1	22.8	36.3	58.8	87.5	106.3	121.7	93.0	96.3	62.7	44.7	34.5	793.7
Celina Twp.	25.6	18.7	28.2	43.8	67.7	91.8	110.9	122.2	83.4	44.9	33.7	29.7	693.2
Crane Lake	22.9	21.8	26.6	50.6	72.5	93.7	130.3	92.1	92.6	50.9	38.6	23.9	714.9
International Falls	27.4	29.7	33.0	50.6	77.5	98.8	130.9	91.5	92.9	58.0	40.1	30.2	751.7

SOURCE: Watson 1978a.

FIGURE 29


AVERAGE ANNUAL PRECIPITATION
MILLIMETERS
795
780
765
750
735
720
705
690
675
660
645
630
615
600
DULUTH HARBOR
DULUTH AIRPORT
TWO HARBORS
BEAVER BAY
GRAND MARAIS
ISLAND LAKE
BRIMSON
MEADOWLANDS
COTTON
WHITEFACE RESERVOIR
ISABELLA
GUNFLINT LAKE
HOYT LAKES
BABBITT
WINTON
TOWER
VIRGINIA
HIBBING AIRPORT
HIBBING
CELINA TWP.
CRANE LAKE
INTERNATIONAL FALLS
SOURCE : WATSON (1978A)

In addition, hilly areas are preferred places for convergence of air and, consequently, precipitation. Areas downstream from hills may also be wetter due to passage of clouds formed or enhanced over hills. The records from Grand Marais, Grand Portage, and Two Harbors clearly show the effects of land, water, and topography. These places are drier than inland in the warm season due to enhanced convergence over the inland ridge about 30 kilometers west of the Lake. In the cold season, they tend to be drier than the high ground around Isabella, but wetter than places to the northwest of the high ground. High winter values at Beaver Bay are likely associated with the very abrupt rise of the land above the lake in that area.

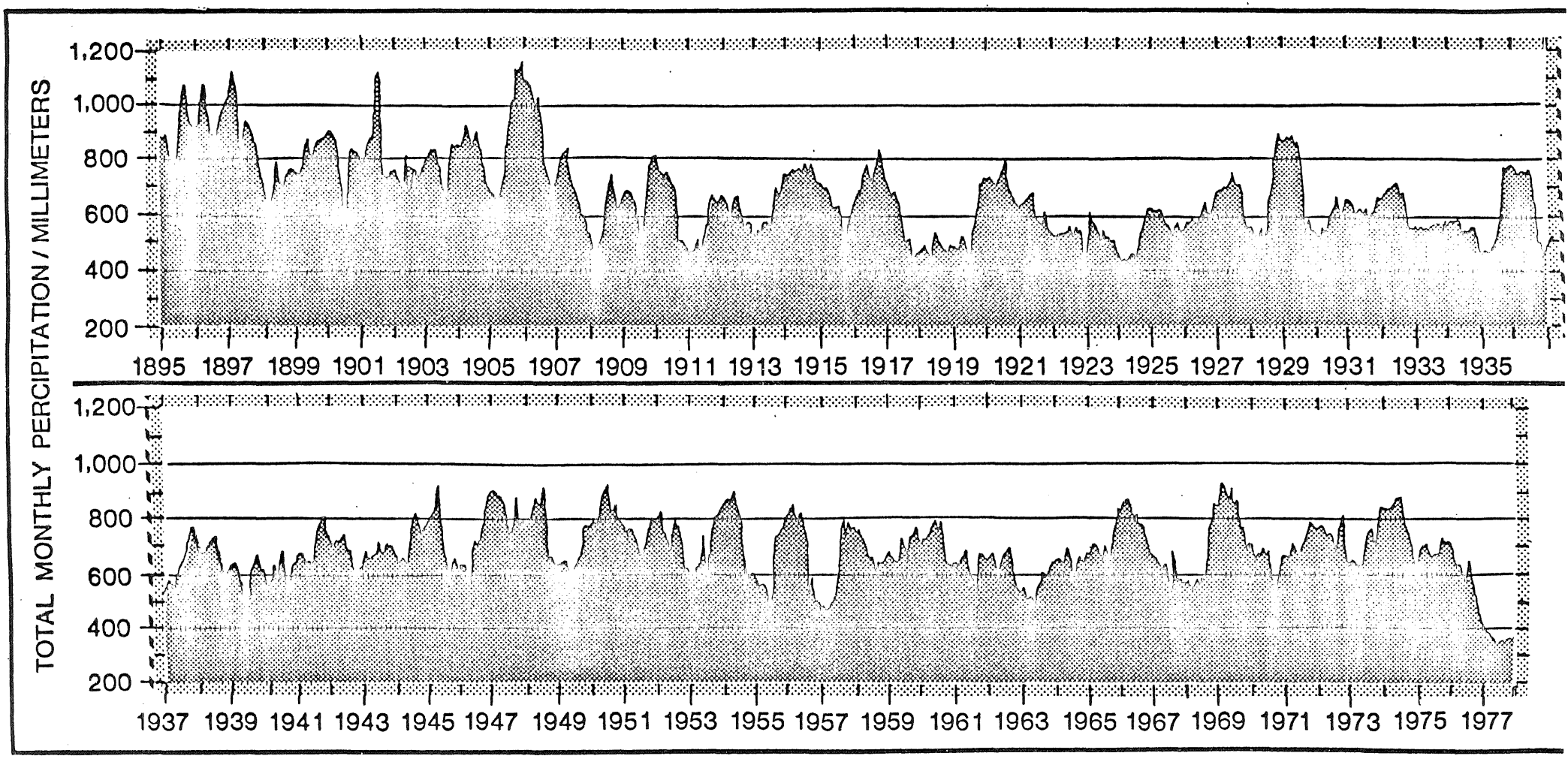
Temporal Variation--To provide an understanding of the long-term temporal variations in the Study Area, Figure 30 gives the total monthly precipitation for 12-month periods at the end of each month at Virginia for the total period of record 1894 to 1977. The curve shows the variations that can be expected, and the cycles of wetness and dryness that can be expected. Values range from 1,160 millimeters in the 12 months ending November 30, 1905, to 365 millimeters in the 12 months ending March 31, 1977. Of this total, it is rather startling to note that over half of the total, 208 millimeters occurred in June, 1976, with only 157 millimeters falling in the other 11 months.

Figure 30

The 1977 drought incident was the only time that the 12-month precipitation total dropped below 400 millimeters. On 12 previous occasions, annual precipitation fell below 500 millimeters, but there were intervening years when annual precipitation was above 500 millimeters. Only once, however, was a dryness situation sustained around the 500-millimeter mark (at least until 1977), which was the long dry period between the spring of 1917 and the summer of 1919.

FIGURE 30

VIRGINIA PRECIPITATION TOTAL FOR TWELVE MONTH PERIODS AT THE END OF EACH MONTH (1895-1977)



SOURCE : WATSON (1978A)

The wet mark for a 12-month period was established in November, 1905, due to a very wet spell in the summer and autumn of that year. Precipitation for that period was 1,160 millimeters. Years from 1895 to 1907 appear to have been unparalleled for wetness, but rains also were most generous from 1944 to 1953, and again from 1964 to 1973.

Evidence of the 20-year drought cycle appears at Virginia, but not as strongly as for the Great Plains. The 1917-1919 drought, however, and those of 1934, 1936, 1954, and 1956 and the one in 1976-1977 appear rather clearly. The inter-cycle dry years of 1910 and 1921-1923 appear in the record, albeit not as sharply as at other locations to the southwest of the Study Area.

Heavy Rains--Heaviest precipitation occurs here, as at most other places, when thunderstorms pass. Large amounts of rainfall may result over time periods of hours or a day if a line of thunderstorms moves in echelon over a point.

In the Study Area, it is possible for a 10-square-mile area to receive nearly 560 millimeters of rain in a 6-hour period. Such an event would be extremely unlikely, but it is important when considering the flood design of structures. Flood design of structures (dams, buildings) are commonly geared to return periods of flood rains which might occur once every 100 years.

Table 22 is a chart showing return periods of heavy rainfalls for a given point in the Area. As an example in reading the chart, a rain of 127 millimeters in 24 hours is to be expected once every 100 years. One caveat to be considered in using this table, a once-in-100-year rain could occur more than once even in a given week, or it may take centuries for it to ever happen. Examination of very long rainfall records reveals that in a given decade rare or unusual rain events tend to be followed closely by one or more subsequent unusual rain events. That

is, rare rain events tend to cluster at times.

Table 22

Table 23 gives some actual observed heavy rainfalls at International Falls which is roughly applicable to the Study Area. The heaviest rains in the area are generally due to thunderstorms occurring in conjunction with sharp outbreaks of cold air. Ordinarily, air mass convective clouds (cumulonimbus) are generally too small to deliver extremely heavy rains. Such is not the case further south in Minnesota, where many of the heaviest rains come with air mass cumulonimbus.

Table 23

The converse to rain events are non-events. For example, no measurable precipitation has occurred at Tower on February 7 since 1960, and precipitation has occurred only once on March 24 since 1953. Every September 21 has had precipitation at Tower since 1969, and it has failed to rain on that date only six times since 1946. None of the heaviest late summer-early fall rains have occurred recently, giving further testimony to the relative dryness of August and September in recent times.

Monthly Variations--Table 24 gives monthly rainfall statistics (other time intervals can be used as well) for Babbitt. The long-term average for the Babbitt data are the adjusted data appearing in the monthly precipitation table (Table 21). All other data in the table are for the period of record as shown. The table thus gives 56-year information for a station in the Study Area.

Table 24

Table 22. Rainfall amounts in inches for various return periods and durations.

DURATION	RETURN PERIOD (years) 2	10	25	50
30 minutes	0.8-0.9	1.2-1.4	1.3-1.6	1.5-1.8
1 hour	0.9-1.2	1.5-1.8	1.7-2.0	1.9-2.2
6 hours	1.6-1.8	2.4-2.7	2.8-3.1	3.1-3.4
12 hours	2.0-2.2	2.9-3.2	3.3-3.8	3.6-4.1
24 hours	2.3-2.5	3.4-3.7	3.9-4.3	4.3-4.6

SOURCE: Watson 1978a.

Table 23. Heaviest rainfalls observed for various time intervals at International Falls, Minnesota.

TIME INTERVAL	YEARS	AMOUNT (mm)	RATE (mm/min)
5 minutes	1953-1961	20.3	4.06
10 minutes	1953-1961	26.2	2.62
15 minutes	1953-1961	29.0	1.93
30 minutes	1953-1961	34.0	1.13
1 hour	1946-1961	36.8	0.61
2 hours	1946-1961	54.6	0.46
3 hours	1946-1961	68.1	0.38
6 hours	1946-1961	68.3	0.19
12 hours	1946-1961	74.7	0.10
24 hours	1946-1961	122.4	0.085

SOURCE: Watson 1978a.

Table 24. Monthly precipitation statistics, Babbitt, Minnesota (1921-1976) (millimeter units).

	MONTH												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	YEAR
Long-term average	23.4	20.0	29.2	48.7	73.0	98.1	103.8	97.9	94.9	61.7	46.8	28.2	726.4
% of annual precipitation in month	3.2	2.8	4.0	6.7	10.0	13.5	14.3	13.5	13.1	8.5	6.4	3.9	--
% of annual total by end of month from Jan 1	3.2	6.0	10.0	16.7	26.7	40.2	54.5	68.0	81.1	89.6	96.1	100.0	--
% of annual total by end of month from May 1	86.4	89.2	93.3	100.0	10.0	23.5	37.8	51.3	64.4	72.9	79.3	83.2	--
Wettest	72.1	49.3	66.8	109.5	149.1	278.9	185.7	212.9	214.4	181.6	83.1	65.0	954.3
Year	1969	1939	1966	1968	1930	1944	1935	1928	1925	1971	1965	1968	1928
Driest	0	1.5	2.3	1.3	7.5	23.9	30.0	15.0	7.4	11.2	5.6	4.1	416.8
Year	1947	1928	1959	1944	1976	1956	1964	1976	1948	1938	1921	1940	1923
Decade Average:													
1921-1930	14.0	14.2	22.9	34.8	58.2	97.5	107.7	88.6	119.4	37.8	30.2	21.3	646.7
1931-1940	21.3	17.0	24.4	43.9	82.8	102.6	86.4	95.3	77.5	51.3	41.9	21.1	665.7
1941-1950	21.8	12.7	23.1	51.3	83.1	137.2	98.3	113.8	86.1	53.3	30.2	20.1	730.8
1951-1960	20.8	18.0	26.2	52.1	76.2	97.3	107.2	107.7	80.8	43.9	42.9	23.9	697.0
1961-1970	22.1	14.2	29.7	66.8	80.3	113.5	85.3	86.1	100.6	67.6	38.9	31.2	736.1
1971-1977	23.1	17.8	32.8	33.3	58.2	105.7	89.9	93.0	72.1	83.8	37.8	22.6	674.9
1921-1976	20.9	15.9	26.1	48.0	74.1	109.2	96.2	97.7	90.6	54.3	36.9	23.4	693.3

SOURCE: Watson 1978a.

The percent of total annual rainfall for each month is listed in the column under the average monthly precipitation. The monthly precipitation is quite evenly distributed over the warm months. From 10 to 15 percent of the annual precipitation occurs each month from May through September. Over the cold months, distribution is also fairly even, with all months from December through March contributing between 2.8 and 4.0 percent. Clearly, however, February is the driest month.

Cumulative percentages are instructive. The third row on the table gives the percent of the annual precipitation occurring at the end of each month starting January 1. For Babbitt, only 40.2 percent of the total annual precipitation has fallen by the end of June. On the average, the half-way mark does not arrive until about mid-July.

The fourth row gives cumulative percentages of precipitation from May 1 onward. From May 1 to the end of August, slightly over half of the annual precipitation occurs; thus, slightly less than half of the annual precipitation occurs in the eight months from September 1 to April 30. Note that September is wetter than May, however, so a few percent less occurs in the eight months from October 1 to May 31. Stated differently, at Babbitt, 64.4 percent of the annual precipitation occurs during the 5-month period from May 1 to September 30. Roughly, then, two-thirds of the precipitation occurs from May through September; one-third from October through April.

The next four rows give the wettest and driest months over the periods of record. The wettest month ever at Babbitt was 278.9 millimeters, occurring in June, 1944. The driest month in Babbitt was April, 1926, when only one-half millimeter of precipitation occurred. At Babbitt, the wettest calendar year ever was 1928,

with a total precipitation of 954.3 millimeters. Driest was 1923, with a 416.8 millimeter total, although 1976 was a close second with 436.1 millimeters.

Further statistics list the longer-period precipitation values for the station. Babbitt data are presented for 10-year intervals plus the 6 odd years of the 1970s. The variations speak for themselves. More than anything, the data illustrate the chronic dryness of February and the switching around of June, July, August, and September as the wettest month of various periods, although September often falters badly. The comparative wetness of more recent Octobers is noteworthy.

Precipitation During Study Period (1976-1978)--It is useful to present specific precipitation data collected in and near the Study Area during the course of the Regional Copper-Nickel Study program. Such data spans the period from April, 1976, through June, 1978, and is needed in order to place the meteorological conditions experienced during this period into perspective by comparison to the historical data just presented. These results are important to the interpretation of the findings of the other studies, such as the water quality and aquatic biological monitoring programs. The needed information is taken from Watson (1978b), to which the reader is referred for further details.

The general precipitation pattern during the Copper-Nickel Study was one of extreme dryness from July 1, 1976, to February 23, 1977, and was followed by very wet and rainy weather for the remainder of 1977. The first half of 1978 was near normal in precipitation. The extreme dryness of the second half of 1976 was preceded by a very wet June. Table 25 lists the precipitation data taken during the study period for stations in and near the Study Area. The data have been adjusted to midnight observation time so that the totals for each month are

comparable between stations. The adjustments were made from the use of weather radar in determining precipitation times (Watson 1978a). These data can be compared to the average monthly data (based on the period 1894 to 1976) for these same stations, as given earlier in Table 21.

Table 25

It is seen that following fairly dry periods in April and May, June of 1976 provided generally twice the normal precipitation for that month at all stations. This was followed by an extremely dry period through February, 1977. During this time, monthly totals at most stations typically varied from one-half to one-tenth average values. November, 1976, for example, was extremely dry, often providing one-tenth the precipitation expected historically at a station. Precipitation was then fairly normal through July, 1977. Rainfall generally exceeded average values for August, September, and November, though October was fairly normal. November values were generally twice the historical average. A fairly normal December, 1977, was then followed by a slightly dryer than average period from January through April, 1978, and a reasonably normal June and July. The 1977 annual averages generally reflect precipitation totals ranging from 13 to 34 percent higher than the averages for these stations, as shown in Table 26.

Table 26

Snowfall--It is important to discuss precipitation which falls as snow, as distinct from rain, since in this form the contained water is immobile and accumulates on the land and ice-covered lakes. Then, during periods of thawing, the accumulated water from previous weeks or months begins to flow into the streams and lakes of the area, making a knowledge of snowfall patterns of major interest

Table 25. Monthly precipitation recorded at stations in and near the Study Area from April, 1976 through June, 1978 (millimeter units).

	Crane Lake	Hibbing	Hibbing Airport	Virginia	Tower	Winton	Babitt	Hoyt Lakes	Gunflint Lake	Isabella (R.S)	Whiteface Reservoir	Cotton	Meadow-lands	Brimson	Island Lake	Grand Marais
1976																
April	44.4	16	203	13.5	10.9	14.2	25.1	27.2	21.8	43.4	10.9			15.5	17.0	23.6
May	13.5	31.0	15.5	10.7	19.6	10.2	7.6	18.5	6.6	25.7	12.2		10.4	9.6	5.8	8.9
June	176	214	158	208	214	183	145	170	183	208	152		195	172.7	149	135
July	62.5	97.8	98.0	34.8	50.3	46.2	36.1	37.3	90.9	45.2	55.1	52.6	60.4	47.0	72.6	35.1
Aug	14.2	32.8	24.9	15.0	12.2	30.5	15.0	11.9	32.0	17.8	28.4	15.5	46.5	36.8	48.0	18.3
Sept	14.5	14	15.7	18.5	35.0	19.3	40.9	25.1	39.2	29.0	19.8		22.1	24.9	21.1	26.7
Oct	25.7	14.5	10.7	9.9	20.6	28.2	33.5	35.8	29.5	29.0	19.8		22.1	24.9	21.1	26.7
Nov	8.1	4.3	4.8	3.3	8.9	6.6	6.1	3.8	7.1		6.1		3.6	7.1	9.4	3.3
Dec	15.5	19.8	8.1	7.6	15.5	16.8	16.8	18.0	15.5		18.5		19.3	18.0	38.9	11.4
1977																
Jan	16.5	13.7	12.2	5.6	7.4	17.3	13.2	13.0	2.67		17.0		18.5	19.0	24.4	13.0
Feb	14.2		18.0	3.6	17.8	16.5	6.1	5.3	23.9		21.6		9.4	7.6	13.7	10.9
Mar	22.6	51.3	22.9	40.4	51.3	35.6	43.2	40.9	47.5		45.7		72.6	58.7	97.5	48.8
April	33.3		30.5	34.5	49.8	24.9	30.5	29.2	30.7	34.5	30.7		28.4	32.0	35.8	15.5
May	131		77.5	102	134	108	140	143	61.5	88.6	98.8		125	99.8	102	57.1
June	137		108	102	124	92.5	140	107	54.6	130	124		77.5	119.6	105	53.1
July	66.3		55.6	82.0	133	73.4	81.5	81.3	80.5	96.8	89.7		81.8	110.7	101	60.5
Aug	121	147	185		200	199	169	202	147	134	137		78.2	124.7	88.9	195
Sept	190	102	125	139	172	144	144	158	244	191	152		119	185.9	142	190
Oct	38.9	59.9	59.7	51.1	56.4	53.1	41.1	52.8	69.9	123	48.5		64.5	66.8	74.2	76.5
Nov		81.3	90.9		71.9	68.6	114	83.3	68.3		73.7		77.7	101	60.7	48.8
Dec		37.3	25.4	27.4	33.3	35.6	28.4	33.8	54.4	56.4	36.6		33.8	37.1	47.8	37.6
1977 TOTAL	--	--	811	--	1051	868	951	950	909	--	875	—	786	963	893	807
1978																
Jan		16.5	10.9			14.2	19.8	13.2	15.0	19.6	17.5		10.2	23.4		21.3
Feb		14.7	13.2	3.8		7.9	7.1	9.9	8.6	6.1	10.2		18.3			4.1
March		18.3	18.3	10.4	21.8	21.3	18.0	17.0	27.4		21.3		18.5	17.3	15.0	
April		39.1	34.0	32.0		28.7	26.9	35.0	26.7		42.7		46.5	37.3		33.5
May		104	99.6	102	112	95.2	115	121	90.7	104	85.8		71.1	102		80.3
June		64.8	49.5		88.4	50.5	59.2	78.2	103	55.1	92.2		91.7			75.7

SOURCE: Watson 1978b.

Table 26. Comparison of 1977 precipitation data to average values at selected stations.

STATION	AVERAGE ANNUAL PRECIPITATION* (mm)	1977 PRECIPITATION** (mm)	INCREASE IN 1977
Grand Marais	714.6	807	13%
Island Lake	701.6	893	27%
Brimson	726.9	963	32%
Meadowlands	689.6	786	14%
Whiteface Reservoir	703.4	875	24%
Gunflint Lake	744.1	909	22%
Hoyt Lakes	724.0	950	31%
Babbitt	726.4	951	31%
Winton	693.5	868	25%
Tower	785.4	1051	34%
Hibbing Airport	632.2	811	28%

*From Table 21 (Watson, 1978a)
**Compiled from Watson (1978b)

to hydrologists. In the Study Area, snowfall is very much a part of the scene most of the year. Snow can probably fall any month of the year, though there have been no verified reports of snow in July.

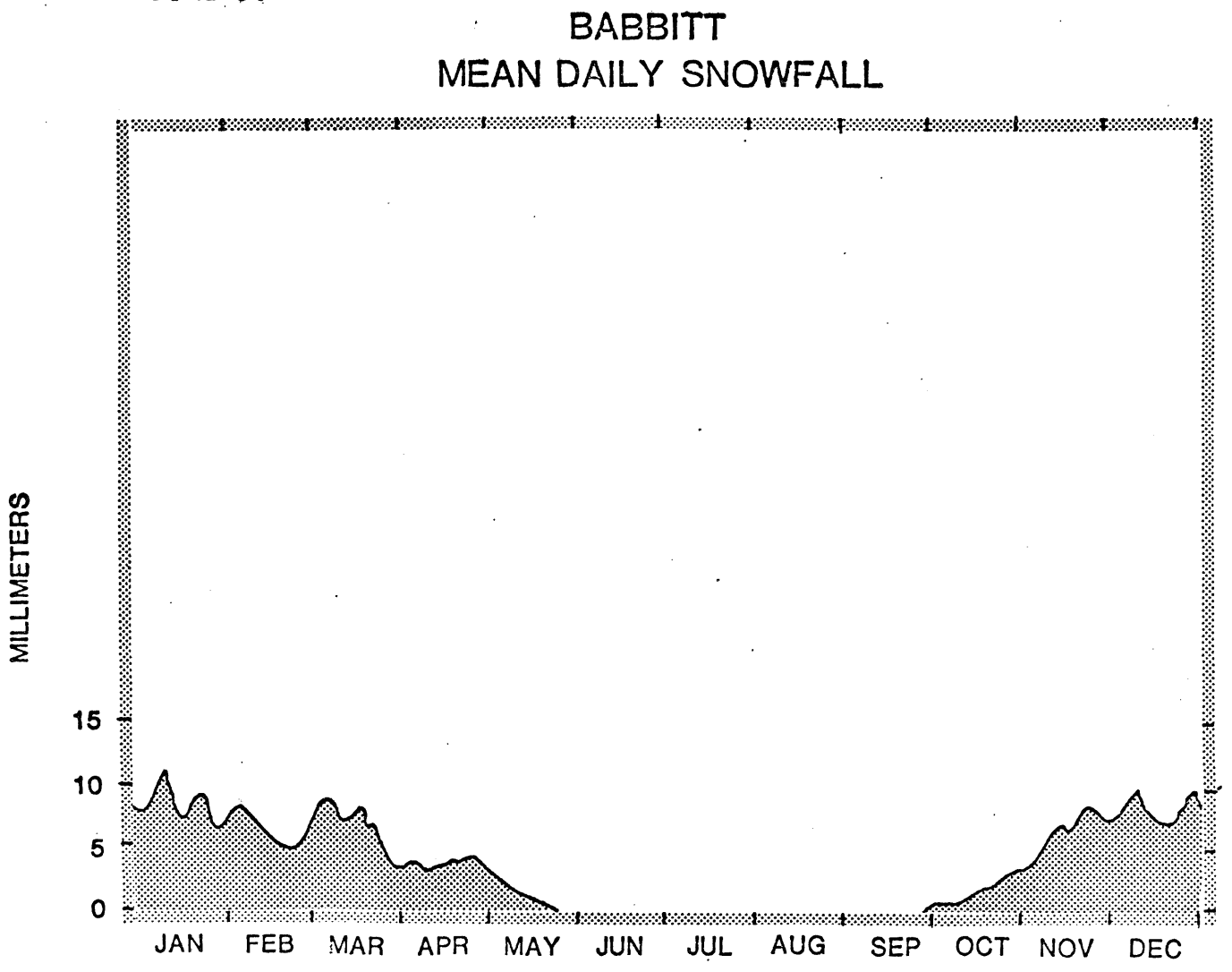
Data in this section are from original records on file in the State Climatology Office. Average annual snowfall in the Tower, Minnesota, area, based on long-term observations from 1894 to 1976, is 1,426 millimeters. January exhibits the greatest monthly average snowfall with 283.5 millimeters. Other months in decreasing order are December, 275.6 millimeters; March, 259.8; November, 255.3; February 215.4; April, 121.9; May, 11.9; and October, 2.3 millimeters.

Seven-day running means of average daily snowfall for Babbitt are shown in Figure 31. When compared with similar data for Winton, Hibbing, and Isabella (Watson 1978a), it is seen that there is substantially higher snowfall at Isabella (just to the east of the Study Area) than at the other locations. This is due to the joint influence of Lake Superior and the high ridge on which Isabella is located. Since there is a general downward slope of the Study Area from east to west (away from the Lake), it is reasonable to expect that average snowfall decreases over the region from east to west. Table 27 gives the average monthly and annual snowfall for the periods of record for the five stations discussed above.

Figure 31, Table 27

In terms of the amount of snowfall during a given time period, in the Babbitt area between 1921 and 1976 there have been 48 days with a snowfall greater than 125 millimeters. This record refers to calendar days only and not to 24-hour totals. The heaviest snowfall ever to occur was March 4-5, 1966, when a total of 546 millimeters fell during these two days; on March 4, the total was 406 milli-

FIGURE 31



SOURCE : WATSON (1978A)

Table 27. Average monthly and annual snowfall (millimeters).

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	TOTAL
Virginia	23	255	276	283	215	260	122	12	1446
Babbitt	40	198	256	251	172	220	107	10	1254
Winton	63	168	252	283	215	228	91	10	1310
Isabella	47	251	315	370	226	256	229	20	1714
Hibbing	16	145	252	236	144	251	145	5	1194

SOURCE: Watson 1978a.

meters. The second greatest one-day total was 302 millimeters on April 7, 1956. A one-day total of 279 millimeters occured twice, once on April 25, 1950, and again on April 1, 1952. Table 28 gives record snowfall data for Babbitt. Note that most of the heavy snows usually occur in March, with April following second. Heavy snows are weaker and less common in January and February than in November, December, March, and April, and the heaviest snows for October and May are greater than for either January or February. Indeed, the heaviest snow in June is not all that far behind the heaviest snows of January or February. The reason for the lack of heavy snow in January and February is the sparse moisture supply in those months--there is simply not enough water vapor in the air to manufacture a really heavy snowfall.

Table 28

Snow accumulated on the ground, as noted earlier, is important for hydrologic reasons. The depth of snow on the ground is a function of snowfall, temperature, sunshine, wind speed, humidity, and the occurrence of other forms of precipitation. Snow depth data were compiled from original records in the State Climatology Office for Winton and Babbitt. Figures 32 and 33 give mean snow depth for two sites (Winton and Babbitt). The deepest snow depth occurs on February 8 at Babbitt and on March 7 at Winton. The Winton snow depth curve is very flat from mid-February to about March 10, while there is a sharp peak up to the Babbitt maximum. This is most likely a reflection of the forest-site of Winton as compared to Babbitt.

Figures 32 and 33

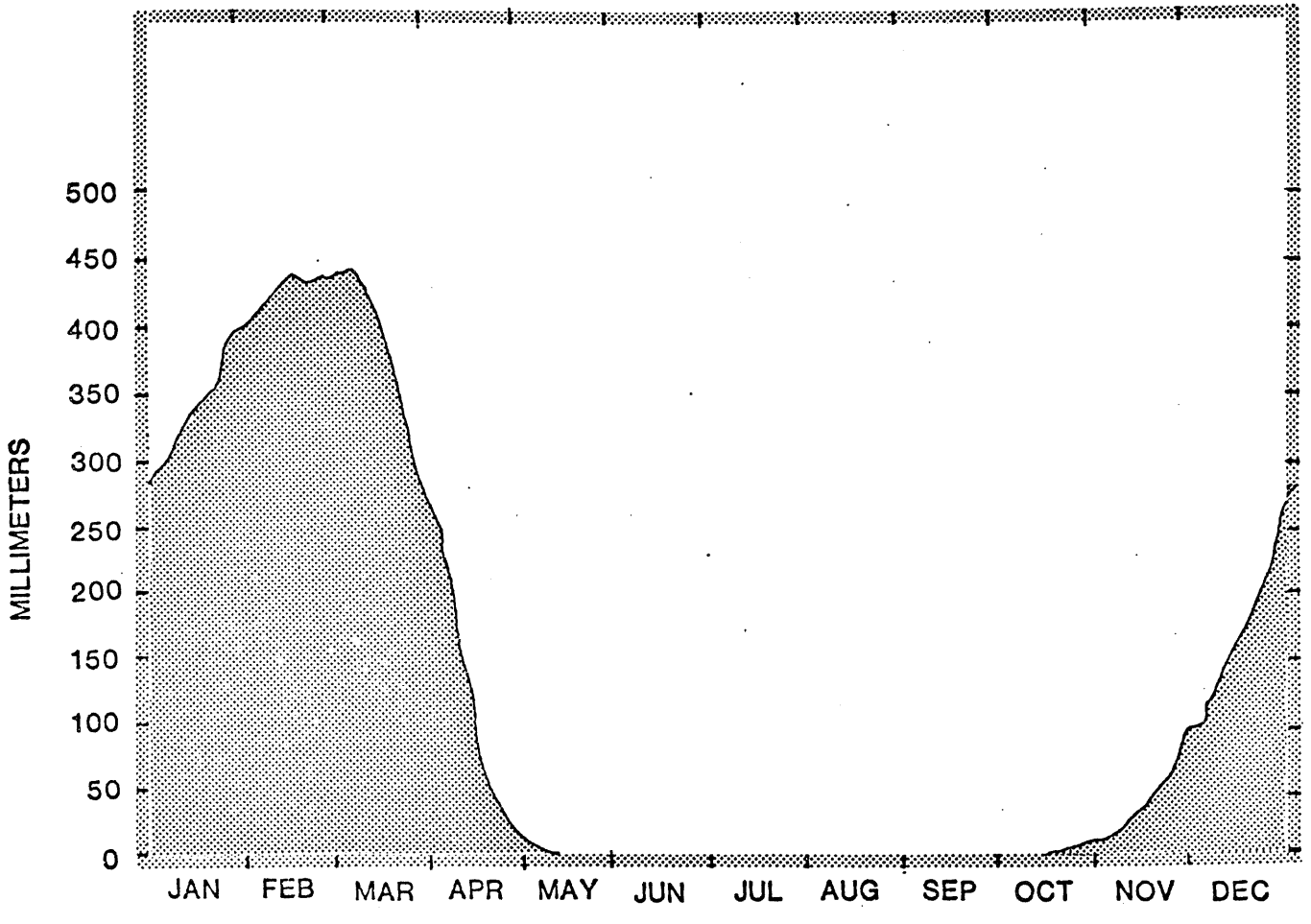
Table 28. Record snowfall data from Babbitt area.

MONTH	NUMBER OF DAYS WITH A FALL OVER 125 mm 1921-1976	HEAVIEST FALL IN MONTH (millimeters)
September	0	25
October	4	203
November	7	254
December	7	178
January	4	178
February	4	254
March	13	406
April	8	302
May	1	191
June	0	102

SOURCE: Watson 1978a.

FIGURE 32

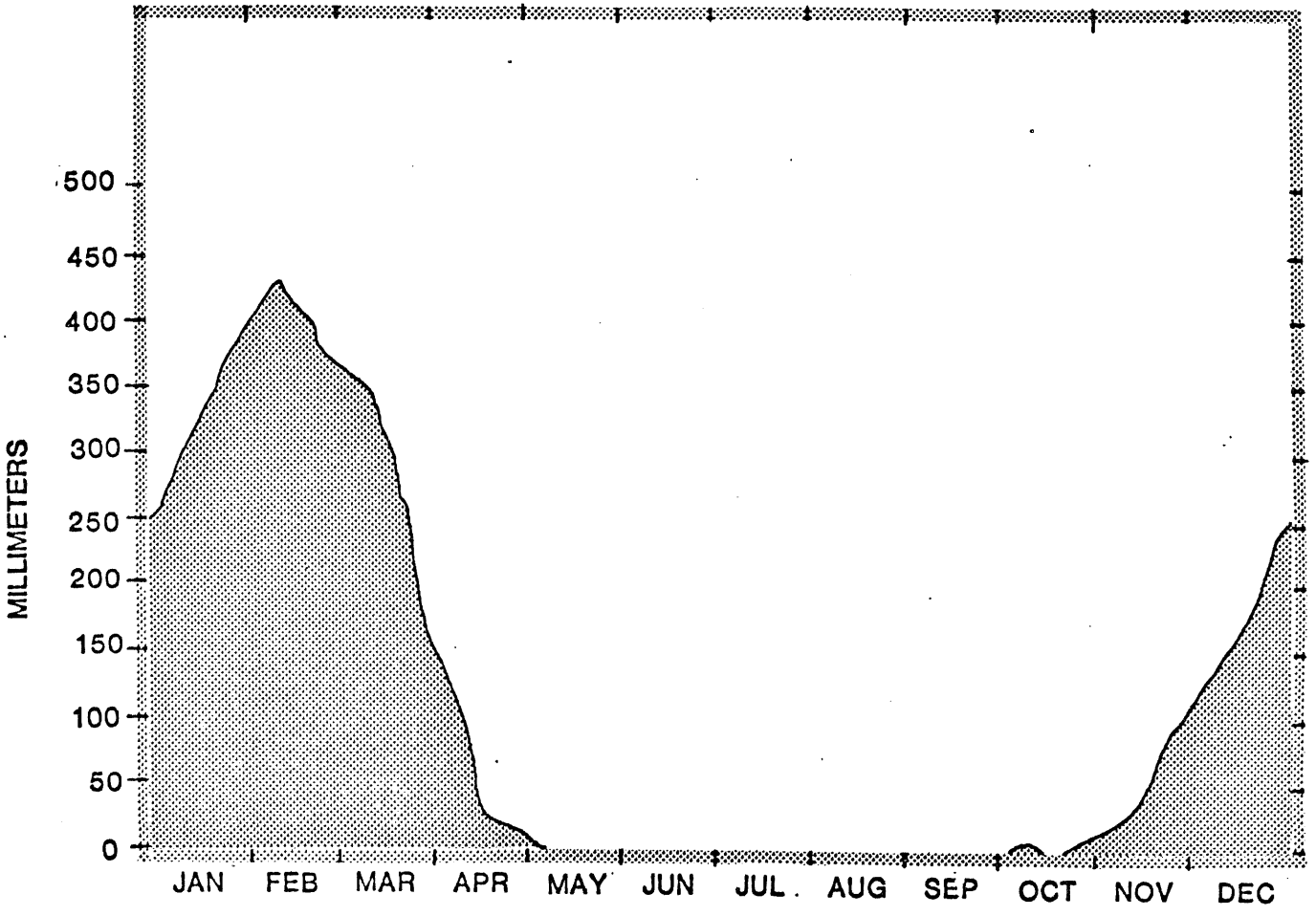
WINTON AVERAGE SNOWDEPTH
1914-20, 1960-74, 1976



SOURCE : WATSON (1978A)

FIGURE 33

BABBITT AVERAGE SNOWDEPTH
1921-1976



SOURCE : WATSON (1978A)

Both locations have an average peak of 450 millimeters snow depth, with Winton being 451 millimeters by March 7 and Babbitt 434 millimeters by February 8. The deepest snow cover ever recorded at Babbitt was 1,270 millimeters from February 1-7, 1969; the deepest at Winton was 1,016 millimeters from February 8-16, 1916. In terms of the least amount of snow on the ground on a monthly basis for these stations, over the periods of record, no January day ever had less than 24 millimeters of snow on the ground at Babbitt; and at Winton no day in January ever had less than 76 millimeters; and no day in February less than 102 millimeters.

The length of time that snow remains on the ground is also of importance. For example, at Babbitt, snow was on the ground continuously from October 24 to April 15 during the winter of 1919-1920. In both instances, this is nearly half the year. In contrast, during the winter of 1930-1931, continuous snow cover at Babbitt lasted only from November 23 to February 23, a time base of 3 months; while at Winton minimum continuous cover lasted only from November 26 in 1913 to April 7 in 1914; and again from December 11, 1914, to March 23, 1915; in both cases about 3½ to 4 months.

3.3.3 Lakeshore Effects

As discussed earlier, the previous climatological discussion adequately characterizes the major meteorological characteristics of the Study Area, which is likely to contain the site of any initial development of copper-nickel mining and processing in Minnesota. However, while a smelter/refinery facility may also be located within the Study Area, these operations could also be performed at a great distance from the Area. Specifically, a site in the vicinity of Duluth appears to be a possibility, and since the climatology of that area is quite

unlike that of the Study Area due to the presence of Lake Superior, it is appropriate to briefly discuss the Duluth area here. Information sources for this section include a discussion on this topic by Watson (1979) and publications of the National Oceanic and Atmospheric Administration (NOAA 1977).

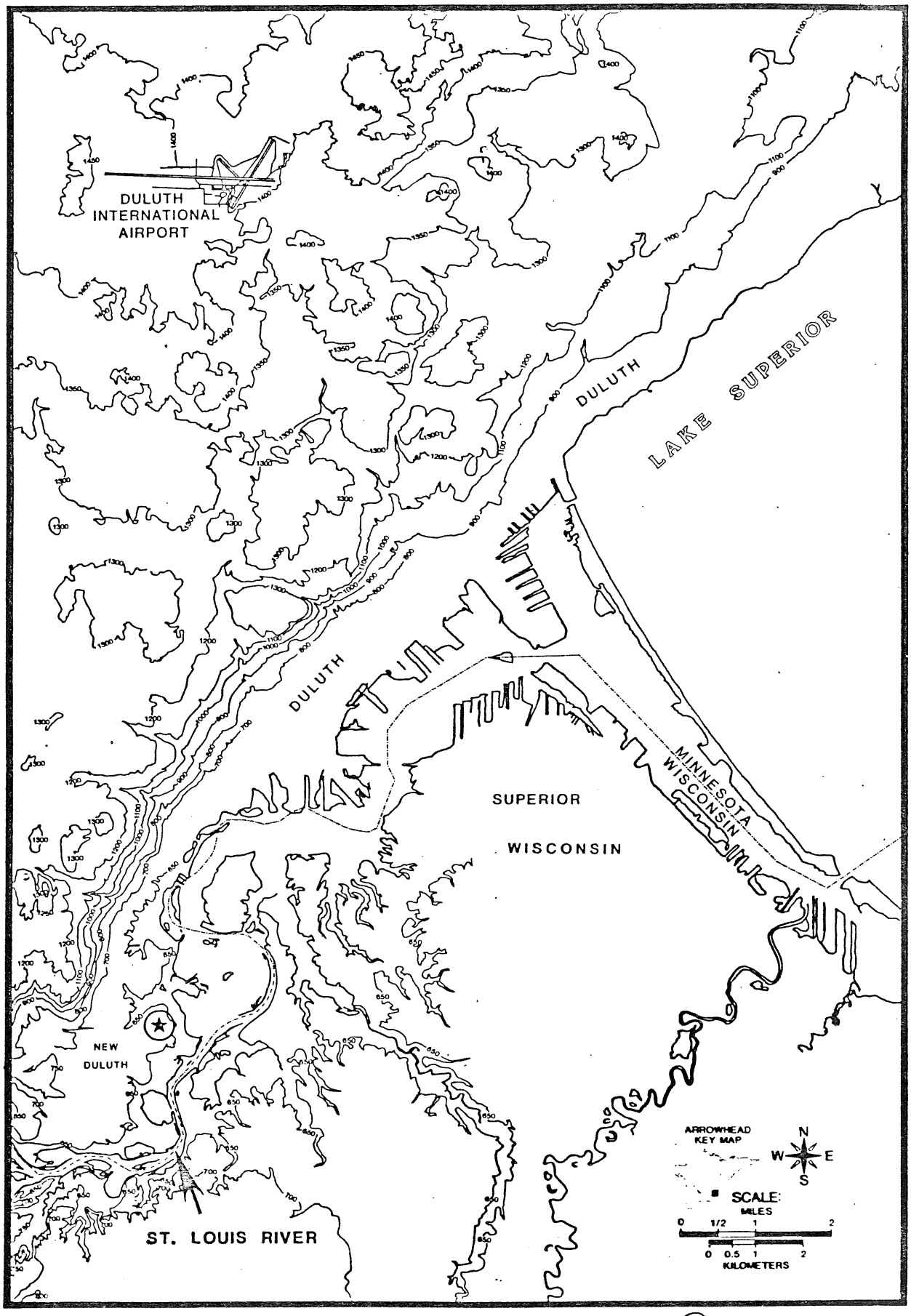
Duluth, Minnesota, is located at the western tip of Lake Superior. The City lies on and at the base of a range of hills that rise abruptly in the highest places from 600 to 800 feet above the level of Lake Superior (Figure 34). The range runs in a northeast and southwest direction. Two or three miles back from the waterfront the country assumes the character of a slightly rolling plateau, not unlike that of the Study Area. Changes in weather are frequent and marked in the area, both summer and winter, making the climate invigorating. An important influence on the climate is the passage of high and low pressure systems that continually move across the United States from west to east.

Figure 34

The proximity of Lake Superior, the largest and coldest of the Great Lakes, materially influences the local climate, especially in the spring and summer and to a lesser degree in the fall and winter. While the winters are cold, the extremely low temperatures that characterize winter in most of northern Minnesota are relatively rare in Duluth area. Occurrences of temperatures of -34°C or lower have averaged less than once per two years. The prevailing winds are from the east and off the lake in May, June, and August, and from the west and northwest from September through April and in July. Summers are cool at the head of the Lakes. Afternoon temperatures of 32°C or higher have occurred on an average of twice a year since the records began. Sometimes, even in midsummer, the local temperature attending the occasional strong easterly winds can be such

FIGURE 34

TOPOGRAPHY OF THE DULUTH-SUPERIOR AREA



SOURCE: USGS QUADRANGLE MAPS

U.S. STEEL SITE

that light overcoats may be necessary in those parts of the City adjacent to the Lake, while one to three miles back of the range of hills the temperature may be moderate and 10 miles farther inland the weather may be swelteringly hot. In Duluth proper the average number of days between the last ocurrence of 0°C in the spring and the first in autumn is 143 days. The average spring date is May 13, and the average fall date is October 3. At the Duluth Airport about six miles away from the Lake, the average number of days between the 0°C occurrences in spring and autumn is 125 days. The average spring date is May 22, and the average fall date is September 24.

Precipitation is well distributed throughout the year and is adequate for vegetation. The heaviest rainfall is observed during the warm summer months, falling from showers and thundershowers. The average snowfall is 55 inches in downtown Duluth and near 75 inches at the airport. After the first general snow cover has fallen, it does not melt until late March or April.

Some general observations affecting the atmospheric dispersion characteristics in the Duluth area can be made in terms of the general effect of Lake Superior (Watson, 1979). The climate of Duluth and the area surrounding Lake Superior is unique in the world, with the sole exception of the area around Lake Baikal in Siberia. The reasons for this are primarily that each of these lakes holds a tremendous amount of water, and that the water in the lakes is contained--not subject to seasonally varying currents as is true with the oceans. Because of the great amount of water in Lake Superior, the bulk of the Lake remains at very near 4°C, the temperature of the maximum density of water. Only about once every 20 years does the Lake freeze over. In most years, the frozen portion of the Lake is small and confined to the shoreline. As a consequence of this, the Lake exerts a very special influence on its environs.

For one, it is an important source of moisture in the winter, bringing heavy amounts of precipitation to the ridge line of Minnesota extending just west of Duluth through Isabella to the Ontario border. The Lake's moisture is fed into the air by evaporation, and then extracted from the air by clouds, produced by uplift, which subsequently precipitate. In summer the Lake is a region of sinking air, so that the immediate margin is appreciably drier than the hinterland.

Temperature and resulting air movement effects are also controlled to an extreme degree. In the warm season, the Lake is nearly always colder than its environs, both by day and night, so that airflow in the absence of an adequately strong pressure gradient is directed away from the Lake to the beaches. The flow, however, is affected by the high ground which impedes outflow. The resulting situation often consists of a band of cold air sitting over the Lake, very often encroaching on the shore regions. Tremendous inversions are created as warmer air, less dense than cold air, flows over the lake air. The commonness of the situation is enhanced by the fact that summer pressure gradients are usually weak, and therefore produce low wind speads. Clear skies rule in the sinking air over the Lake and even mighty thunderstorms are killed as cold air is injected.

Pressures gradients provide the main component of air movement on the earth. Air moves from areas of high pressure to areas of low pressure. However, density differences also cause air to move in the direction from high density to low density. Temperature, in the real atmosphere, is the greatest controller of density. Because of the tremendous temperature differences often present around Lake Superior, density flow often becomes the controlling factor in air movement. Under the influence of gravity, the cold air moves to underlay warm air at the same level. In summer when the lake air is denser the high ground around the

Lake serves as a dam to the cold air. The St. Louis River valley cuts through the dam, so flow in summer must often be directed up the valley. Rising air along the warm high-ground dam, however, will draw in lake air along the slope.

In the cold season, the Lake is nearly always warmer than its environs by day and night alike. The result is an inflow of air to the Lake in the absence of adequately strong pressure gradients. This, along with the rising air currents generated by the relatively warm lake air, results in heavy cloudiness over the Lake. However, in the winter the pressure gradient component of the wind is usually significantly greater than the lake-to-land density component, with the result that onshore winds are found on one side of the Lake, and offshore winds on the opposite side. Thus, the Minnesota high ground running through Isabella receives maximum snow when the general wind direction falls between east and south. In many of the cases, rain falls the first 10 or 20 kilometers inland because of the warmth of the lake air. The area along the Lake is often free of snow when depths at Isabella are one or two meters, or more.

There are two brief periods in the year when the role played by the colder body fluctuates between the land and the water. The periods are found around the two weeks centered on April 10 and October 28. Thus, from late March through late April and from mid-October to around November 12th land and lake density wind systems may operate to some extent. However, the density wind systems are impeded in the spring period since this is the time of year with the strongest pressure gradient winds.

Violent winds may move off the Lake in the Duluth area when low pressure systems with warmer-than-lake air approach from the southwest. In such a situation, the density wind component is added to the pressure gradient component to produce a

strong northeast wind. To add to the velocity, the smooth lake surface, low in roughness and frictional effect on the air, enables the northeast wind to gain great momentum.

In summer, the Lake has a most important effect on air quality both in Duluth and along the north shore. The lake air is then relatively cold and dense and, being in a depression, mixes very poorly with warm air moving in aloft. Rather, the air aloft tends to flow over the lake air, producing extremely strong inversions, often exceeding gradients of 10°C from the lake surface to the top of the ridge. In summer, the inversion is present approximately two-thirds of the time, during which it can trap pollutants near the surface between the lakeshore and the ridge.

In winter, the overriding effects on air quality are principally governed by the large scale pressure systems which create inversions aloft in the Duluth area. The Lake acts to make modifications in some situations, but, since strong northwesterly pressure gradient winds prevail in the cold season, the effects of the Lake in Duluth itself are damped.

In conclusion, it must be noted that because of the complex shape of the topography in the Duluth area, there is a tremendous variation over the region in the frequency of the direction of air flow and also in the speed of flow from the different directions. Because of the intricate pressure-density-wind flow relationships, a solution to understanding the problem by modeling or wind tunnel experiments appears to be impractical. However, if a smelter location is considered there, the air flow in the Duluth area must undergo further study because of the complex relationships that are involved. Extensive meteorological monitoring in the area would be required over a period of several years to

allow the potential air quality impacts of a smelter to be properly understood. Such monitoring should be initiated as soon as possible, if the area is serious candidate for such a facility.

3.4 CHARACTERIZATION OF SULFUR IN THE ATMOSPHERE

The ambient air quality (in terms of SO_2 and sulfate) of the study region is characterized in terms of local emission sources, pollutant concentrations and pollutant depositions for the baseline period, 1975-1977, and for the projected year, 1985 (without copper-nickel development).

Measured ambient air concentrations and deposition data for the baseline period in the Study Region are presented. They are also compared to baseline modeling results to allow general statements to be made about the contributions of local point sources and area sources to ambient air quality. Projections for 1985 are presented to simulate the effects of growth in the region (as discussed in the emissions inventory, section 3.4.1 below).

3.4.1 SO_2 Sources, Present and 1985

Present and future sources of SO_2 emissions in the air quality study region can be divided for simplicity into area and point sources. It is demonstrated later in this section, that the regional ambient SO_2 concentrations can be adequately explained in terms of point sources emitting greater than 100 mtpy of SO_2. Other sources such as small point sources and mobil sources will not be treated in detail here.

3.4.1.1 Point Sources--Table 29 lists the present and projected (1985) SO_2 emissions for the various SO_2 point sources included in the inventory described in section 3.2.4. Sources for baseline and projected emissions data

include the Minnesota Pollution Control Agency, Minnesota Energy Agency, Wisconsin Department of Natural Resources, and the Ontario Ministry of the Environment (Ritchie 1978).

Table 29

The 1985 projected emissions shown are based on proposed source changes in the air quality study region including expansions in the power generation and taconite industries, additions to pollution control systems, fuel conversions such as the change from gas to coal in the taconite industry and the shut-down of some sources. It is important to point out that the data in the emissions inventory do not represent fixed numbers; that is, emission data are continually being refined. The inventory in Table 29 reflects the best available data at the time of the compilation. These data provide the basis for the modeling runs; however the definition of baseline emissions changes with application. For example, a baseline of emissions that reflect the actual pollutants emitted in the region as of July 1977 (termed the regional 1977 baseline) is different from the baseline of emissions prescribed by the legal framework of the prevention of significant deterioration amendments to the Clean Air Act of 1970 (the PSD 1977 baseline, see section 3.2.3.1). Values different from the 1975-76 baseline emissions which have been used for either the regional 1977 or PSD 1977 baseline are indicated in Table 29.

Table 30 provides an overall comparison between baseline (1975-76) and projected (1985) sulfur dioxide emissions. Table 31 and Figure 35 give a breakdown of emissions by source categories (power generation, taconite processing, refineries and commercial-industrial) and by geographic area (Minnesota, Wisconsin and Canada).

Table 29. Regional SO_2 emissions inventory used for sources emitting more than 100 mtpy of SO_2.

SOURCE FACILITY(3)	BASELINE EMISSIONS 1975-76 (mtpy)	1977 BASELINE (if different from 1975-76 values)(mtpy)	PROJECTED EMISSIONS 1985 (mtpy)
Potlach Northwest	1522		5300
Conwed	104	"90"(1,2)	"90"
Continental Oil	1512		1512
Erie Mining (Taconite Harbor)	15310		15310
MP & L Clay Boswell	28400		45720
Butler Taconite	1		"1545"
National Steel	0		1364
Boise Cascade	838		"818"
Reserve Mining (Silver Bay)	3226		"3182"
MP&L (Sy Laskin)	6095		6095
Reserve Mining (Babbitt)	111		111
Duluth Steam	418		"327"
MP & L Hibbard Station	1555		--
Superwood Corp.	139		139
U.S.S.-Duluth Coke	3468		--
U.S.S.-Shipping	326		0
Eveleth Taconite	0	"2273"(1,2)	"3364"
MP&L (Floodwood or Brookston)	--		"28180"
Jones and Laughlin	--		"1455"
Hibbing Public Utility	1009		1009
Hibbing Taconite	0	1382 (1,2)	2073
Hanna Mining	0		1000
Erie Mining (Hoyt Lakes)	707		"5000"
Minntac	238	2036 (2)	"7364"
Virginia PUD	1896	"1818"(1)	"1818"
Inland Steel	0	636 (2)	"1272"
Pickands Mather	--		"1727"
Lake Superior Power District	1440		"4364"
Roffler's Construction	2		2
Murphy Oil Corp.	1824		1824
Superior WL & P	413		413
Univ. of Wisconsin	105		105
CLM Corp.	284		918
Ontario Hydro (Atikokan)	--		53060
Caland Ore Co.	254		--
Steep Rock Mines	13360		--
Minnesota Pulp & Paper	257		257

SOURCE: Ritchie 1978.

NOTE: A missing entry indicates the facility does not exist or will be phased out by the date shown. Tonnages shown in quotation marks indicate estimates by the staff of the Copper-Nickel Study based on available data.

(1) Used in 1977 regional baseline in place of value shown for 1975-76.
(2) Used in 1977 PSD baseline in place of value shown for 1975-76.
(3) Sources are from the list in Table 10, section 3.2.3.1.

Tables 30 and 31, Figure 35

Point source sulfur dioxide emissions (Table 29) are expected to increase 132% over the next ten years. This dramatic rise can be traced directly to proposed growth in the power generation and taconite industries (Table 31 and Figure 35). The taconite companies are planning on a steady expansion which would result in an additional taconite pellet annual processing capacity of 36.3 million metric tons over the 1976-77 capacity of 56.6 million mtpy, requiring 1,300 megawatts of additional electrical power availability in northeastern Minnesota. In addition, taconite companies are converting their operations from natural gas to coal or synthetic gas made from coal. Coal can contain as much as 2,000 times more sulfur than natural gas to supply an equivalent amount of energy, creating increased SO_2 emission possibilities.

If the planned taconite expansions and fuel conversions are implemented in Minnesota, sulfur dioxide emissions from these sources and others in the emission inventory could increase by 111,900 mtpy by 1985 (from 84,820 mtpy to 196,700 mtpy, a 130% increase). This increase is partially offset, however, by the planned closing of two taconite mines near Atikokan, Ontario, which will result in a sulfur dioxide emissions decrease of about 13,620 mtpy. On a regional basis sulfur dioxide emissions from the taconite industry are projected to increase 35% by 1985.

The 99,760 mtpy increase (240%) in SO_2 emissions from the electric power generation industry will be due primarily to 53,060 mtpy (53%) from the proposed Atikokan generating station (although the size of this plant is uncertain at this time and may be reduced below the 800 Mw capacity assumed here), 28,180 mtpy

Table 30. Point source regional emissions inventory summary for sulfur dioxide[a] (mtpy).

	BASELINE 1975-76	PROJECTED 1985	PERCENT[b] CHANGE
Sulfur Dioxide	84,800	196,700	+130

SOURCE: Ritchie 1978.

[a]Regional emissions include those from parts of Minnesota, Wisconsin, and Canada. Values have been rounded.

[b]Percent change is calculated by:

$$\frac{\text{Projected - baseline}}{\text{Baseline}} \times 100$$

Table 31. Sulfur dioxide regional emissions inventory for point sources emitting more than 100 mtpy (emissions in mtpy).[c]

COUNTY/ LOCATION	POWER GENERATION			TACONITE PROCESSING			REFINERIES		
	Baseline[a]	Projected[b]	%Change	Baseline	Projected	%Change	Baseline	Projected	%Change
MINNESOTA									
Carlton	0	0	0	0	0	0	1512	1512	0
Cook	0	0	0	15310	15310	0	0	0	0
Itasca	28400	45720	+61	1	2909	above 1000	0	0	0
Lake	0	0	0	3226	3182	-1	0	0	0
St. Louis	10970	37430	+240	1056	23370	+2100	0	0	0
Koochiching	0	0	0	0	0	0	0	0	0
TOTAL	39370	83150	+111	19600	44770	+130	1512	1512	0
WISCONSIN									
Ashland	1440	4364	+203	0	0	0	0	0	0
Douglas	413	413	0	0	0	0	1824	1824	0
TOTAL	1853	4777	+160	0	0	0	1824	1824	0
CANADA, ONTARIO									
Atikokan	0	53060	--	13620	0	-100	0	0	0
Ft. Francis	0	0	0	0	0	0	0	0	0
TOTAL	0	53060	--	13620	0	-100	0	0	0
REGIONAL TOTAL	41220	141000	+240	33220	44770	+35	3336	3336	0

SOURCE: Ritchie 1978.

[a]Baseline year 1975-76.
[b]Projected year 1985.
[c]Totals are rounded.

Table 31 continued

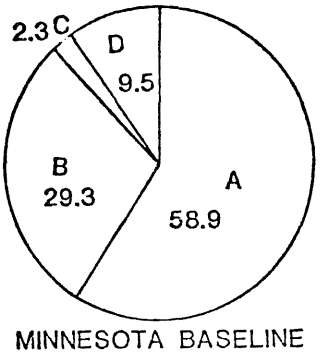
COUNTY/ LOCATION	COMMERCIAL & INDUSTRIAL Baseline	Projected	%Change	COUNTY/LOCATION TOTAL Baseline	Projected	%Change
MINNESOTA						
Carlton	1626	5391	+230	3138	6903	+120
Cook	0	0	0	15310	15310	0
Itasca	0	0	0	28400	48630	+71
Lake	0	0	0	3226	3182	-1
St. Louis	3933	139	-96	15960	60930	+280
Koochiching	838	818	-2	838	818	-2
TOTAL	6397	6348	-1	66880	135800	+103
WISCONSIN						
Ashland	2	2	0	1442	4366	+200
Douglas	389	1023	+160	2626	3260	+24
TOTAL	391	1025	+160	4068	7626	+87
CANADA, ONTARIO						
Atikokan	0	0	0	13620	53060	+290
Ft. Francis	257	257	0	257	257	0
TOTAL	257	257	0	13880	53320	+280
REGIONAL TOTAL	7045	7630	+8	84820	196700	+130

SOURCE: Ritchie 1978.

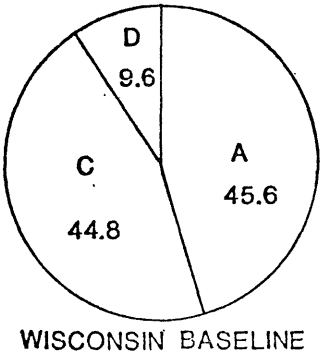
[a]Baseline year 1975-76.
[b]Projected year 1985.
[c]Totals are rounded.

FIGURE 35

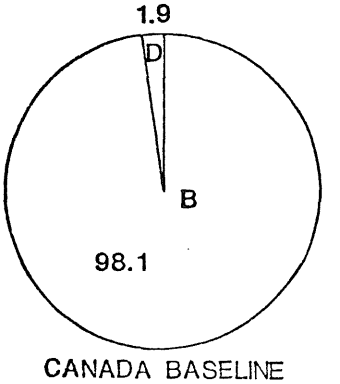
SOURCE CATEGORY CONTRIBUTIONS TO SULFUR DIOXIDE EMISSIONS BY LOCATION



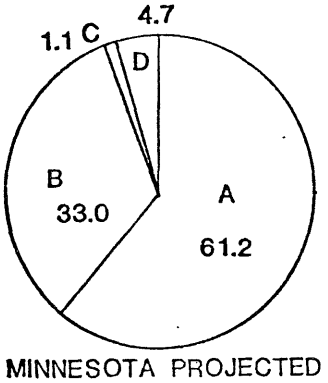
MINNESOTA BASELINE
TOTAL : 68880 MTPY



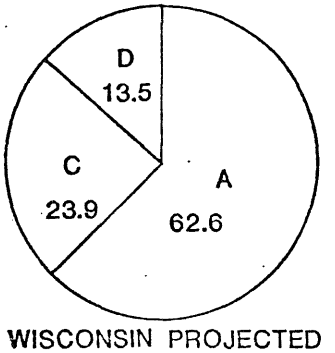
WISCONSIN BASELINE
TOTAL : 4068 MTPY



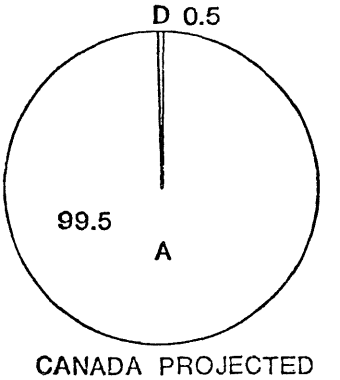
CANADA BASELINE
TOTAL 13880 MTPY



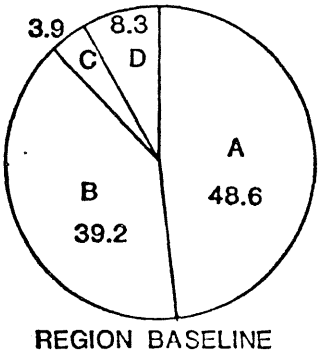
MINNESOTA PROJECTED
TOTAL : 135800 MPTY



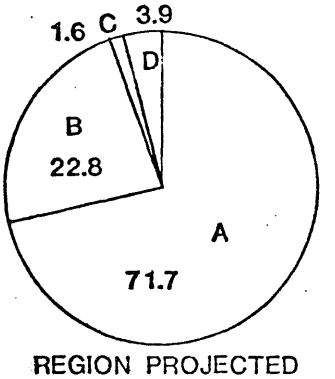
WISCONSIN PROJECTED
TOTAL : 7626 MTPY



CANADA PROJECTED
TOTAL : 53320 MTPY



REGION BASELINE
TOTAL : 84820 MTPY



REGION PROJECTED
TOTAL 196700 MTPY

LEGEND

A - % POWER GENERATION

B - % TACONITE PROCESSING

C - % REFINERIES

D - % COMMERCIAL /INDUSTRIAL

SOURCE : RITCHIE (1978)

(18%) from the proposed generating station at Floodwood, Minnesota and an increase of 17,320 mtpy (17%) at the MP&L Clay Boswell plant, Cohasset, Minnesota. Development plans for the proposed Atikokan plant which will contribute about 27% of the total projected regional SO_2 emissions are being closely monitored because the plant will be located on the edge of the Quetico Provincial Park, a Canadian Wilderness area adjacent to the Boundary Waters Canoe Area.

Refineries and commercial-industrial sources have substantially smaller impacts on regional SO_2 emissions. These categories contribute less than 13% of total baseline SO_2 and less than 6% of total projected emissions (Figure 35). Figure 36 is a map which provides a comparison between present and projected emissions. The SO_2 point source emissions inventory does not include area sources such as residential space heating requirements or line sources such as automobile traffic which could increase regional emissions. These data are being compiled by the Minnesota Pollution Control Agency through a contract with Midwest Research Institute, Kansas City, Missouri. The final report will include a detailed air quality analysis for the Iron Range Region.

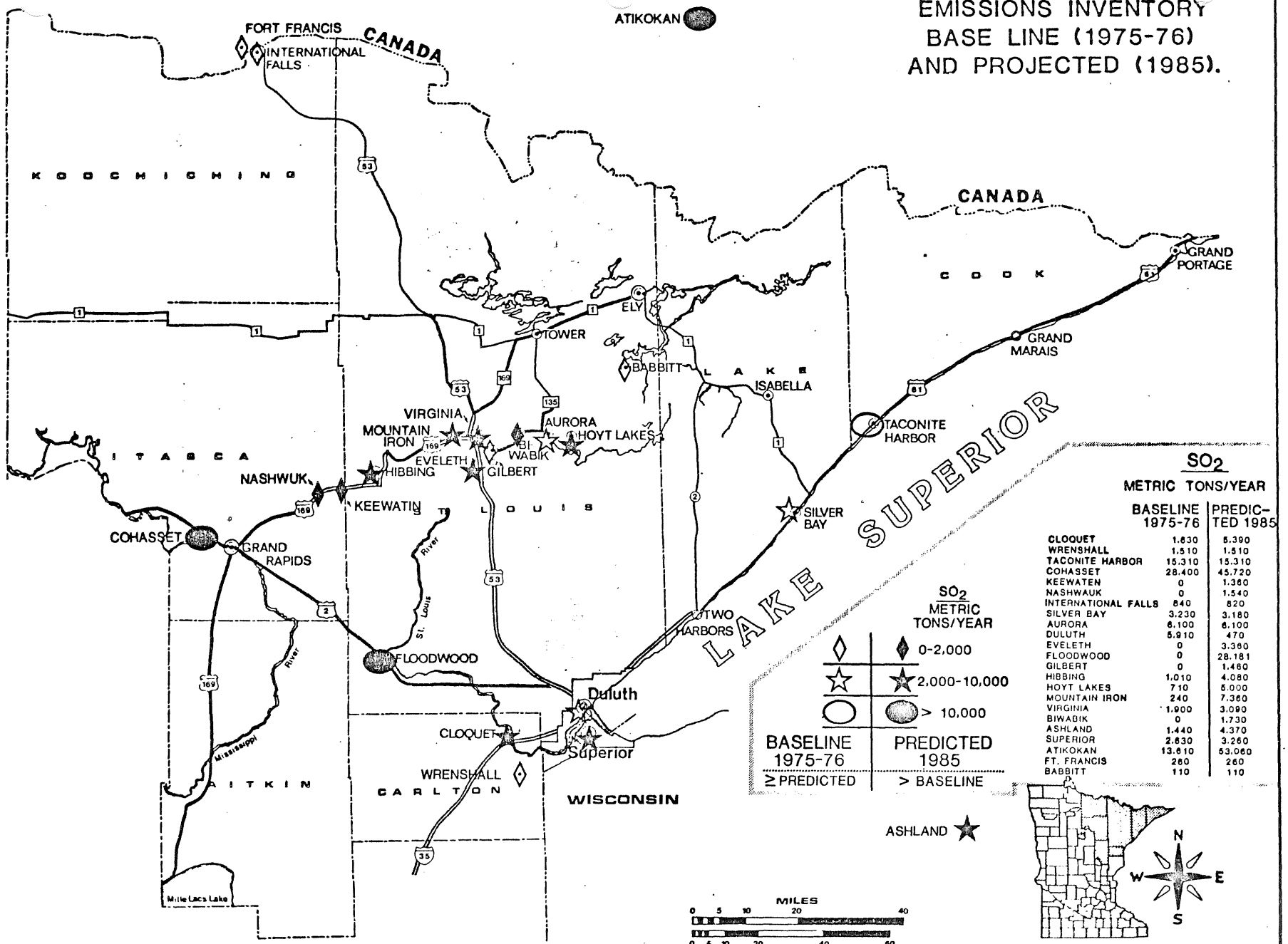
Figure 36

The significance of area source contributions to SO_2 concentrations is discussed in section 3.4.2.1.

3.4.1.2 Geographic Comparsions of SO_2 Source Emissions--SO_2 emissions in the Air Quality Study Region may be put into perspective by comparison to global, national and regional emissions. On a global scale natural sulfur emissions, expressed as SO_2, have been estimated to be 258 million mtpy (Williamson, 1973). Sulfate aerosols produced by sea spray and hydrogen sulfide (H_2S) from volcanic

FIGURE 36

REGIONAL SO_2 POINT SOURCE EMISSIONS INVENTORY BASE LINE (1975-76) AND PROJECTED (1985).



SO_2 METRIC TONS/YEAR

	BASELINE 1975-76	PREDICTED 1985
CLOQUET	1,630	5,390
WRENSHALL	1,510	1,510
TACONITE HARBOR	15,310	15,310
COHASSET	28,400	45,720
KEEWATEN	0	1,360
NASHWAUK	0	1,540
INTERNATIONAL FALLS	840	820
SILVER BAY	3,230	3,180
AURORA	6,100	6,100
DULUTH	5,910	470
EVELETH	0	3,360
FLOODWOOD	0	28,181
GILBERT	0	1,460
HIBBING	1,010	4,080
HOYT LAKES	710	5,000
MOUNTAIN IRON	240	7,360
VIRGINIA	1,900	3,090
BIWABIK	0	1,730
ASHLAND	1,440	4,370
SUPERIOR	2,830	3,260
ATIKOKAN	13,610	53,060
FT. FRANCIS	260	260
BABBITT	110	110

SO_2 METRIC TONS/YEAR

- 0-2,000
- 2,000-10,000
- > 10,000

BASELINE 1975-76 ≥ PREDICTED

PREDICTED 1985 > BASELINE

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activity and organic decomposition are the primary sources (66%) of natural sulfur compounds although anthropogenic sources may dominate on a local basis. Anthropogenic sources have been estimated at 133 million mtpy, expressed as SO_2, and result primarily from the combustion of fossil fuels (Williamson, 1973). About 70% of anthropogenic sulfur emissions are the result of coal combustion (Robinson and Robbins, 1970).

On a national scale sulfur oxide emissions decreased slightly from 1972 to 1975. Anthropogenic emissions in 1972 were calculated to be 33.4 million mtpy compared to 29.9 million mtpy in 1975, a 12% decrease (USEPA, 1976a). The National Air Quality and Emission Trend report for 1975 states that ambient SO_2 levels in urban areas declined markedly probably due to a combination of more stringent pollution control efforts and a significant shift in the use of high sulfur fuels from urban to rural sources (USEPA, 1976a).

In Minnesota available data indicate that sulfur dioxide point source emissions decreased slightly from 1970-71 to 1973-74. The 5% decrease (from 316,900 mtpy compared to 302,700 mtpy) is likely to be reversed in the future due to statewide growth in coal consumption.

In 1976 coal consumption by 71 facilities was reported as 12.0 million mtpy. By 1985, it is projected that 75 facilities will consume 25.8 million mtpy, over a two-fold increase (Minnesota Energy Agency, 1978a). Most of this increase will occur in the power generation industry.

In 1976 the three largest coal consumption development areas were the seven-county metropolitan area (36% of state total), northeastern Minnesota (30.3% of state total) and central Minnesota (19% of state total). By 1985, these three areas will still be the largest users but their ranking will be shifted: central

Minnesota (36% of total), northeastern Minnesota (35% of total), and metropolitan (17% of total)(Minnesota Energy Agency, 1978a). The shift in coal usage from the Metropolitan area is due primarily to the growth in the taconite and power generation industries anticipated in central and northeastern Minnesota.

A summary of point source SO_2 emissions (sources emitting more than 100 mtpy) for both the Air Quality Study Region (Figure 7) and the seven-county metropolitan area is given in Table 32.

Table 32

3.4.2 Ambient SO_2 and Sulfate

3.4.2.1 Ambient SO_2 Concentrations--A regional annual average SO_2 background concentration of less than 5.2 ug/m^3 (lower detectable limit of the analyzer) was measured at the Fernberg Road site during 1976-77. Since concentrations less than 5.24 ug/m^3 could not be detected by the continuous recording monitor, the true value lies somewhere between 0 and 5.2 ug/m^3. Although the recorder trace of this monitor remained on zero during the 1976-77 sampling period, a "less than" value is reported for data handling purposes rather than recording zero values. Figure 37 shows the measured ambient concentration at Fernberg Road in relation to other parts of Minnesota and the U.S.

Figure 37

When the SO_2 concentrations predicted from the regional sources listed in the emissions inventory are calculated using the modified gaussian model and are averaged, a regional annual mean of 1.1 ug/m^3 is obtained. Although this number is consistent with a value of less than or equal to 5.2 ug/m^3, the actual annual

Table 32. 1976 point source SO_2 emissions inventory summary by source category for the Air Quality Study Region and the seven-county Metropolitan area.

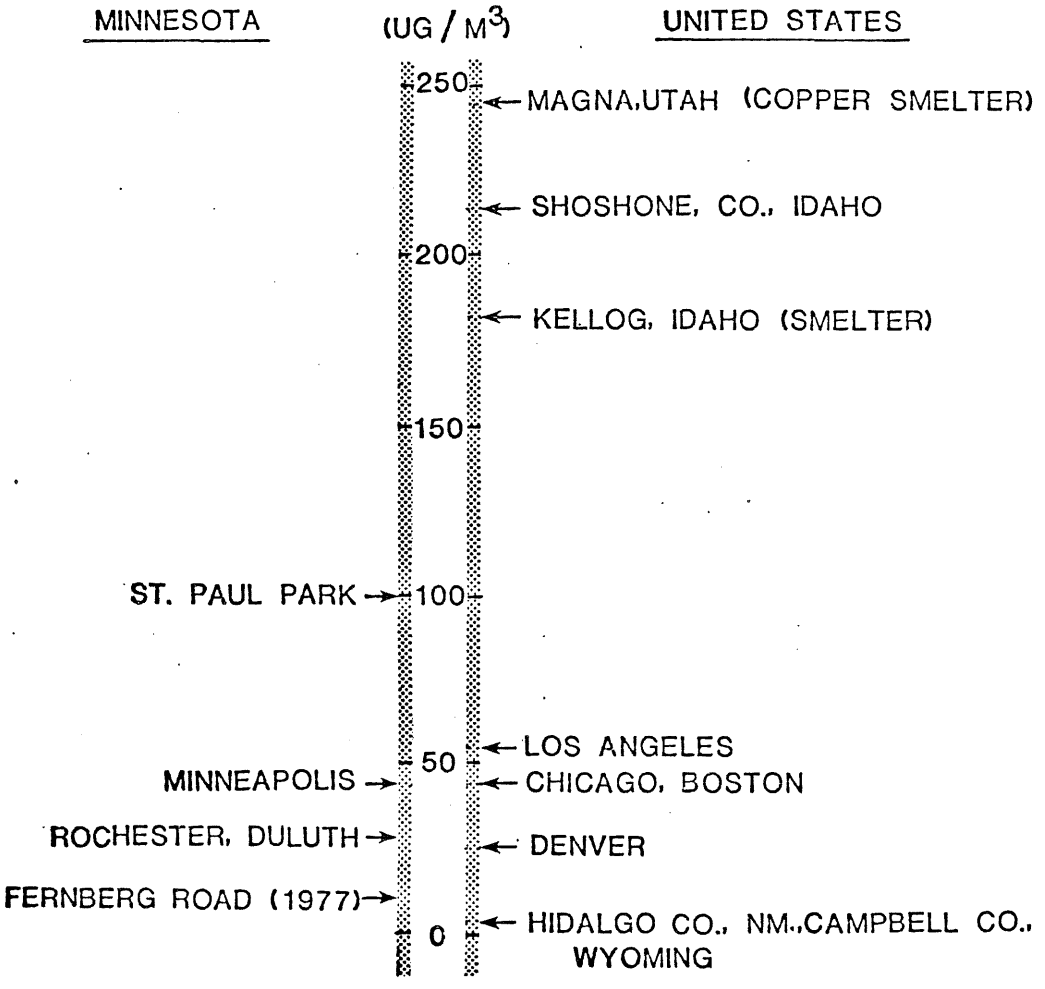
REGION		POWER GENERATION	TACONITE	REFINERY	COMMERCIAL[c] INDUSTRIAL	TOTAL[b]
Seven-county Metro[a]	mtpy	136800	0	22620	23597	183000
	Percent of Total	74.8	0	12.4	12.9	100
Air Quality Study Region	mtpy	41230	33210	3336	7045	84820
	Percent of Total	48.6	39.2	3.9	8.3	100

SOURCE: Ritchie 1978.

[a]Minnesota Pollution Control Agency, 1978.
[b]Total is rounded off.
[c]Includes grain.

FIGURE 37

1975 ANNUAL ARITHMETIC MEAN SO_2 CONCENTRATIONS FOR SELECTED MEASURING STATIONS IN THE UNITED STATES



SOURCE : U.S.E.P.A. (1977C)

average concentration may be underestimated because the modified gaussian model only considers major point sources (greater than 100 mtpy pollutant emission). It is necessary to consider whether or not a significant part of a region's total emissions may be due to area sources, which are defined as a collection of small unidentifiable stationary points of pollutant emissions, all emitting less than the minimum level of 100 mtpy prescribed for point sources (Hammerle, 1976). The major area sources of SO_2 emissions in the study region would result from heating requirements during the colder winter months.

An estimate of the contribution of area sources to SO_2 emissions was obtained from total reported fuel usage. Area fuel usage, as reported by the Minnesota Energy Agency (1978b), was separated by type of use (industrial, residential, commercial institutional, and other uses) and type of fuel (natural gas, coal, fuel oil and liquid propane gas) for the base year 1976. Total emissions by source category and fuel type were then calculated using emission factors from EPA's AP-42 (USEPA 1977a). Table 33 shows the resulting estimated SO_2 area source emissions based on fuel usage.

Table 33

The fuel usage estimates indicate that residential, commercial/institutional and other sectors contribute less than 0.3% of the total SO_2 emissions. The bulk of the emissions come from the industrial sector, and in fact from those industries, including public and private utilities, which utilize coal as a fuel. Some 99.5% of the SO_2 emissions estimated from fuel usage are attributed to industrial use of coal. This use occurs at facilities which are included in the point source emission inventory (Minnesota Energy Agency, 1978c). From this discussion it is concluded that area source contributions to regional SO_2 emissions are minimal

Table 33. Estimated SO_2 area source emissions for 1976, based on fuel usage (metric tons).

SECTOR	NATURAL GAS	COAL	FUEL OIL	LPG	TOTAL
Industry	12.7	4.03×10^4	86.1	---	4.04×10^4
Residential	.778		63.3	.165	84.2
Commercial/ Institutional/ Other	.603		23.9		24.5
TOTAL	14.1	4.03×10^4	173	.165	4.05×10^4

SOURCE: USEPA (1977a) and Minnesota Energy Agency (1978b).

and that emissions can be adequately characterized, for purposes of characterizing ambient SO_2 concentrations, in terms of the sources listed in the inventory. Area sources, as well as small point sources (less than 100 mtpy SO_2)are not considered further.

Regulatory Analysis-Annual Average SO_2 Concentrations

The modified gaussian model predicts that the federal primary annual standard of 80 ug/m^3 will not be exceeded at any of the 33 regional receptors for either the baseline year, 1977, or 1985 within the stated bounds on model accuracy of a factor of two (Ritchie 1979). Figures 38 and 39 show the predicted 1977 baseline and 1985 annual average ambient SO_2 concentrations.

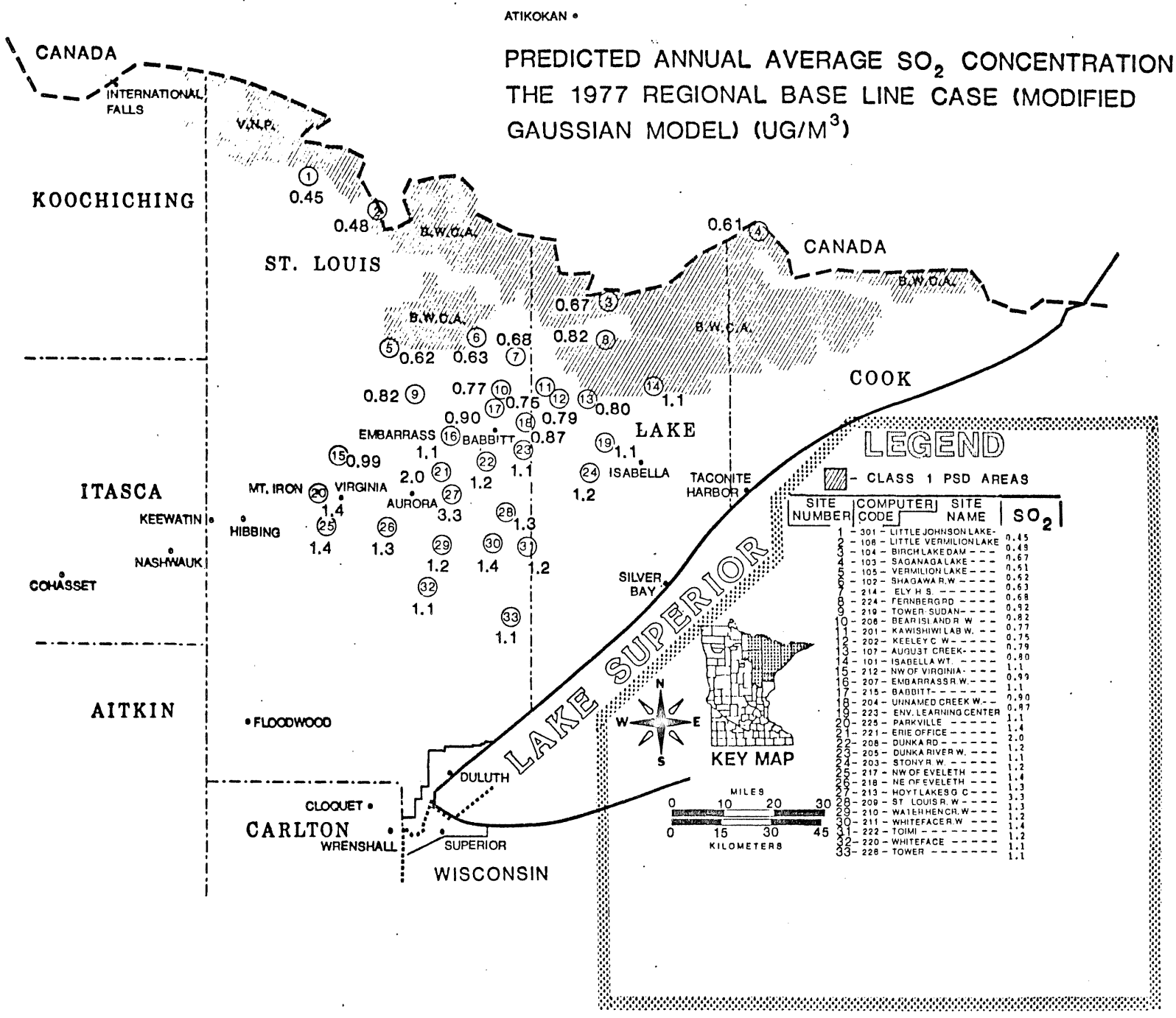
Figures 38 and 39

In 1977 a regional mean (defined as the arithmetic mean of the annual average concentration at the 33 receptors shown in the region) of 1.1 ug/m^3 is calculated. The highest predicted annual SO_2 concentration of 3.3. ug/m^3 (4% of the primary standard) occurred at Hoyt Lakes Golf Course (Figure 38). This value primarily reflects SO_2 emissions from the Aurora power plant which is 4 km to the west-southwest.

In general, by 1985, annual SO_2 concentrations are expected to double over the region. Spatial differences are expected to occur, directly following the increases in SO_2 point source emissions (Table 29, section 3.4.1.1).

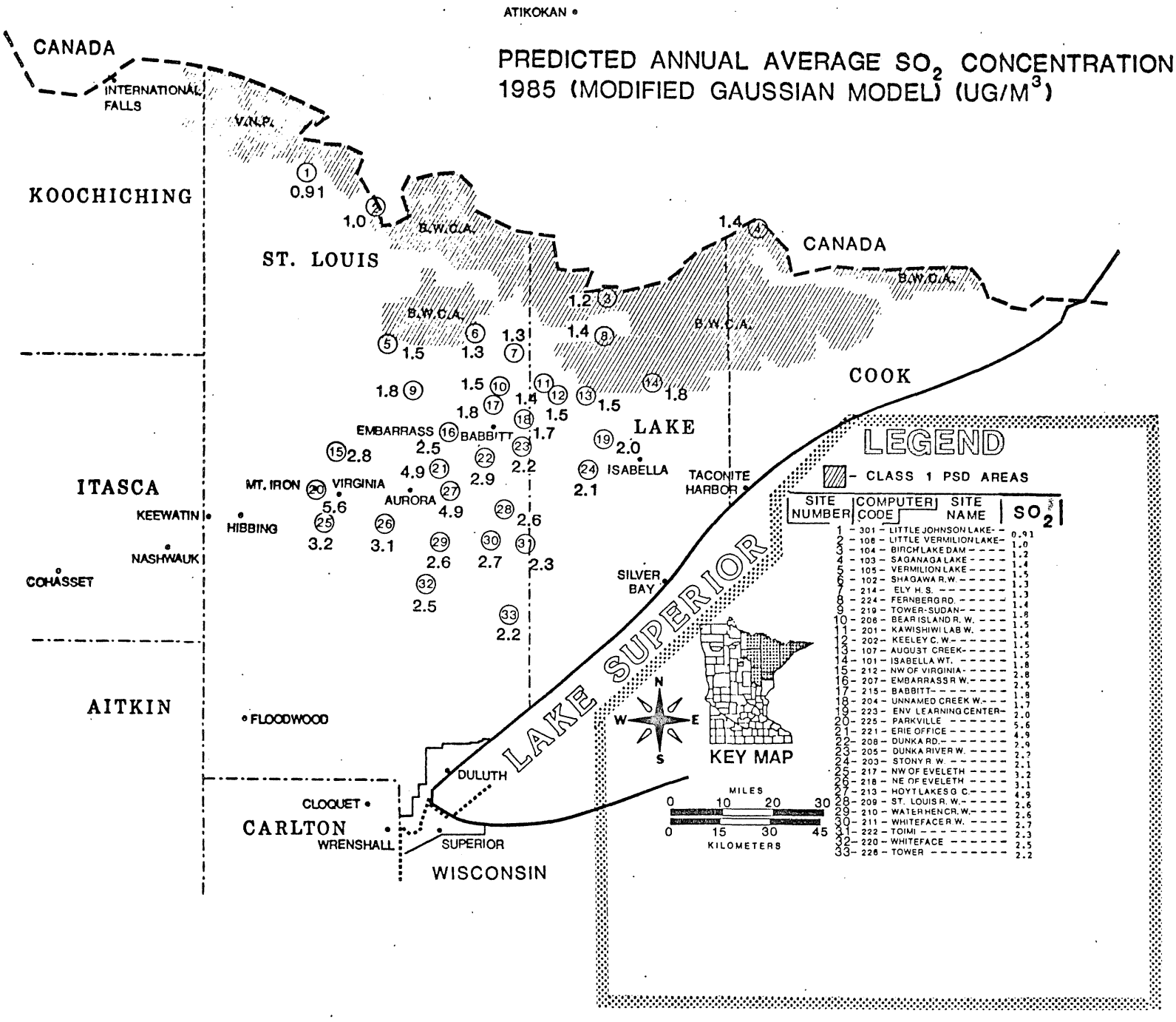
The modified gaussian model predits a 1985 regional SO_2 annual average concentration of 2.3 ug/m^3, an increase of about 110% over the 1977 regional average. The highest annual average in the region, 5.6 ug/m^3 which is 7% of the

FIGURE 38



SITE NUMBER	COMPUTER CODE	SITE NAME	SO_2
1	301	LITTLE JOHNSON LAKE	0.45
2	106	LITTLE VERMILION LAKE	0.48
3	104	BIRCH LAKE DAM	0.67
4	103	SAGANAGA LAKE	0.61
5	105	VERMILION LAKE	0.62
6	102	SHAGAWA R.W	0.63
7	214	ELY H.S.	0.68
8	224	FERNBERG RD	0.82
9	219	TOWER-SUDAN	0.82
10	206	BEAR ISLAND R.W.	0.77
11	201	KAWISHIWI LAB W.	0.75
12	202	KEELEY C.W.	0.79
13	107	AUGUST CREEK	0.80
14	101	ISABELLA WT.	1.1
15	212	NW OF VIRGINIA	0.99
16	207	EMBARRASS R.W.	1.1
17	215	BABBITT	0.90
18	204	UNNAMED CREEK W.	0.87
19	223	ENV. LEARNING CENTER	1.1
20	225	PARKVILLE	1.4
21	221	ERIE OFFICE	2.0
22	208	DUNKA RD	1.2
23	205	DUNKA RIVER W.	1.1
24	203	STONY R.W.	1.2
25	217	NW OF EVELETH	1.4
26	218	NE OF EVELETH	1.3
27	213	HOYT LAKES G.C.	3.3
28	209	ST. LOUIS R.W.	1.3
29	210	WATER HEN CR.W.	1.2
30	211	WHITEFACE R.W.	1.4
31	222	TOIMI	1.2
32	220	WHITEFACE	1.1
33	228	TOWER	1.1

FIGURE 39


PREDICTED ANNUAL AVERAGE SO_2 CONCENTRATIONS FOR 1985 (MODIFIED GAUSSIAN MODEL) (UG/M^3)
ATIKOKAN
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
AITKIN
CARLTON
WISCONSIN
MT. IRON
VIRGINIA
EMBARRASS
BABBITT
AURORA
ISABELLA
TACONITE HARBOR
SILVER BAY
KEEWATIN
HIBBING
NASHWAUK
COHASSET
FLOODWOOD
CLOQUET
WRENSHALL
DULUTH
SUPERIOR
LAKE SUPERIOR
0.91
1.0
1.4
1.2
1.4
1.5
1.3
1.3
1.8
1.5
1.4
1.5
1.8
1.5
1.8
1.7
2.5
2.0
2.8
2.2
4.9
2.9
2.1
5.6
4.9
2.6
3.2
3.1
2.6
2.7
2.3
2.5
2.2
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO_2
1 - 301 - LITTLE JOHNSON LAKE - 0.91
2 - 106 - LITTLE VERMILION LAKE - 1.0
3 - 104 - BIRCH LAKE DAM - 1.2
4 - 103 - SAGANAGA LAKE - 1.4
5 - 105 - VERMILION LAKE - 1.5
6 - 102 - SHAGAWA R.W. - 1.3
7 - 214 - ELY H.S. - 1.3
8 - 224 - FERNBERG RD. - 1.4
9 - 219 - TOWER-SUDAN - 1.8
10 - 206 - BEAR ISLAND R. W. - 1.5
11 - 201 - KAWISHIWI LAB W. - 1.4
12 - 202 - KEELEY C. W. - 1.5
13 - 107 - AUGUST CREEK - 1.5
14 - 101 - ISABELLA WT. - 1.8
15 - 212 - NW OF VIRGINIA - 2.8
16 - 207 - EMBARRASS R W. - 2.5
17 - 215 - BABBITT - 1.8
18 - 204 - UNNAMED CREEK W. - 1.7
19 - 223 - ENV LEARNING CENTER - 2.0
20 - 225 - PARKVILLE - 5.6
21 - 221 - ERIE OFFICE - 4.9
22 - 208 - DUNKA RD. - 2.9
23 - 205 - DUNKA RIVER W. - 2.2
24 - 203 - STONY R. W. - 2.1
25 - 217 - NW OF EVELETH - 3.2
26 - 218 - NE OF EVELETH - 3.1
27 - 213 - HOYT LAKES G. C. - 4.9
28 - 209 - ST. LOUIS R. W. - 2.6
29 - 210 - WATER HEN CR. W. - 2.6
30 - 211 - WHITEFACE R. W. - 2.7
31 - 222 - TOIMI - 2.3
32 - 220 - WHITEFACE - 2.5
33 - 226 - TOWER - 2.2
KEY MAP
N
W
E
S
MILES
0 10 20 30
0 15 30 45
KILOMETERS

primary standard, is predicted at Parkville (Figure 39) which is impacted primarily by the Duluth sources to the south, Mt. Iron, Eveleth and the complex of towns to the southwest.

Neither the Class I (2 ug/m^3) nor Class II (20 ug/m^3) annual PSD increments are expected to be exceeded in 1985 with the regional growth estimated in the emissions inventory. The largest annual SO_2 difference in a Class I area was .81 ug/m^3 (41% of the increment) at Vermillion Lake. In the Class II area the largest difference was 3.4 ug/m^3 at Parkville (16% of the increment).

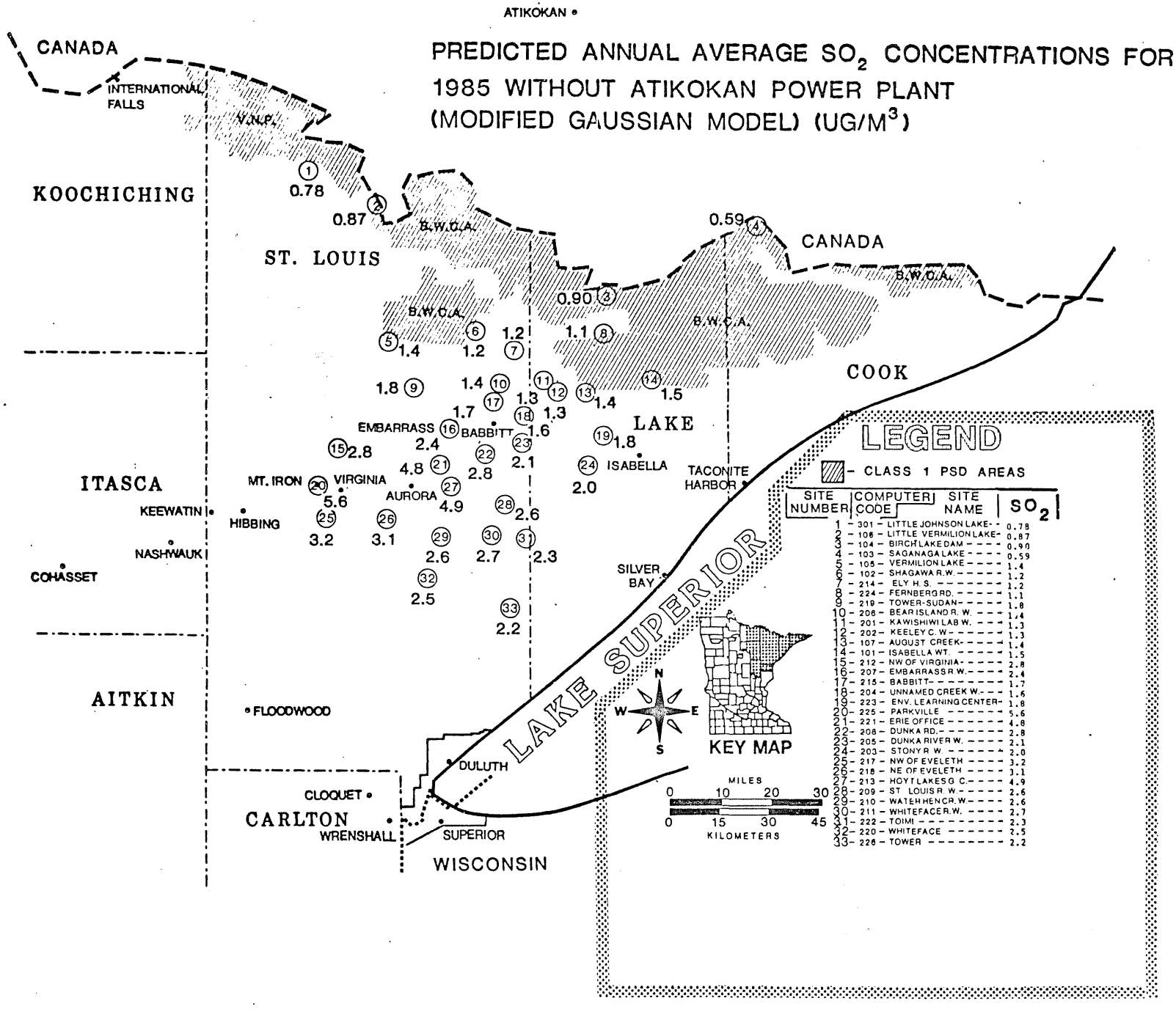
The proposed Atikokan power plant is expected to contribute about 27% of the region's 1985 SO_2 emissions (assuming an 800 MW capacity). This facility could be legally excluded from PSD review under a variance pertaining to sources located outside of the United States [USEPA 1978; 40 CFR 52.21 (f)(1)(iv)]. Therefore, an assessment of the effect of the proposed facility on the regional receptors, particularly the BWCA sites is important.

Figure 40 shows the results of annual SO_2 concentration simulations excluding Atikokan from the 1985 emission inventory. Again, although specific numbers are given they are subject to the limitations of the model's accuracy (a factor of 2).

Figure 40

Removing the proposed Atikokan power plant from the modeling simulations results in about a 9% decrease in the 1985 regional mean annual SO_2 concentration but larger reductions in the Class I area. The 1985 regional mean SO_2 concentration is 2.3 ug/m^3 with Atikokan and 2.1 ug/m^3 without Atikokan. The mean annual SO_2 concentration in the Class I area is 1.3 ug/m^3 with Atikokan compared to 1.1

FIGURE 40


ATIKOKAN
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
AITKIN
CARLTON
WRENSHALL
CLOQUET
DULUTH
SUPERIOR
WISCONSIN
LAKE SUPERIOR
SILVER BAY
TACONITE HARBOR
ISABELLA
BABBITT
EMBARRASS
MT. IRON
VIRGINIA
AURORA
HIBBING
KEEWATIN
NASHWAUK
COHASSET
FLOODWOOD
0.78
0.87
0.59
0.90
1.4
1.2
1.2
1.1
1.8
1.4
1.3
1.7
1.3
1.6
1.4
1.5
2.8
2.4
1.8
4.8
2.8
2.1
2.0
5.6
4.9
2.6
3.2
3.1
2.6
2.7
2.3
2.5
2.2
PREDICTED ANNUAL AVERAGE SO2 CONCENTRATIONS FOR 1985 WITHOUT ATIKOKAN POWER PLANT (MODIFIED GAUSSIAN MODEL) (UG/M3)
LEGEND
- CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO2
1 - 301 - LITTLE JOHNSON LAKE- 0.78
2 - 106 - LITTLE VERMILION LAKE- 0.87
3 - 104 - BIRCH LAKE DAM 0.90
4 - 103 - SAGANAGA LAKE 0.59
5 - 105 - VERMILION LAKE 1.4
6 - 102 - SHAGAWA R.W. 1.2
7 - 214 - ELY H.S. 1.2
8 - 224 - FERNBERG RD. 1.1
9 - 219 - TOWER-SUDAN 1.8
10 - 206 - BEAR ISLAND R. W. 1.4
11 - 201 - KAWISHIWI LAB W. 1.3
12 - 202 - KEELEY C. W 1.3
13 - 107 - AUGUST CREEK 1.4
14 - 101 - ISABELLA WT. 1.5
15 - 212 - NW OF VIRGINIA 2.8
16 - 207 - EMBARRASS R W. 2.4
17 - 215 - BABBITT 1.7
18 - 204 - UNNAMED CREEK W. 1.6
19 - 223 - ENV. LEARNING CENTER 1.8
20 - 225 - PARKVILLE 5.6
21 - 221 - ERIE OFFICE 4.8
22 - 208 - DUNKA RD. 2.8
23 - 205 - DUNKA RIVER W. 2.1
24 - 203 - STONY R W. 2.0
25 - 217 - NW OF EVELETH 3.2
26 - 218 - NE OF EVELETH 3.1
27 - 213 - HOYT LAKES G C. 4.9
28 - 209 - ST LOUIS R. W. 2.6
29 - 210 - WATER HEN CR. W. 2.6
30 - 211 - WHITEFACE R.W. 2.7
31 - 222 - TOIMI 2.3
32 - 220 - WHITEFACE 2.5
33 - 226 - TOWER 2.2
N
W
E
S
KEY MAP
MILES
0 10 20 30
0 15 30 45
KILOMETERS

ug/m^3 without Atikokan, a 15% decrease. In the Class II area, the mean annual SO_2 concentration is 2.5 ug/m^3 with Atikokan compared to 2.4 ug/m^3 without Atikokan, a 4% decrease.

The largest predicted effect of the proposed power plant occurred at Saganaga Lake on the Minnesota-Canadian border. An increase in the annual ambient $SO_2$of about 140% is expected from the power plant, 1.4 ug/m^3 for 1985 with the power plant (at 800 MW) compared to .6 ug/m^3 for 1985 without the power plant.

Regulatory Analysis-Maximum 24-Hour SO_2 Concentrations

The modified gaussian model, using the indicated emissions inventory, predicts that the federal primary 24-hour standard of 365 ug/m^3 will not be exceeded at any of the 33 regional receptors for either the baseline year, 1977, or 1985 within the stated bounds on model accuracy of a factor of two (Ritchie 1979). Figures 41 and 42 show the predicted 1977 baseline and 1985 maximum 24-hour concentrations at each receptor in the region.

Figure 41 and 42

In 1977, the predicted maximum 24-hour SO_2 concentration is 52 ug/m^3 (14% of the standard) at the Hoyt Lakes Golf Course; the second highest 24-hour concentration is 31 ug/m^3 (8.5% of the standard) at the Erie Mining Office. Both sites are impacted primarily by emissions from Hoyt Lakes and Aurora. By 1985, the maximum 24-hour SO_2 concentration is predicted to increase to 78 ug/m^3 (21% of the standard) at the Hoyt Lakes Golf Course, followed by a second high of 77 ug/m^3 at the Erie Mining Office.

The maximum 24-hour SO_2 increment is expected to be exceeded at certain Class I (5 ug/m^3) receptors but not at any Class II (91 ug/m^3) receptors. Table 34 shows

FIGURE 41

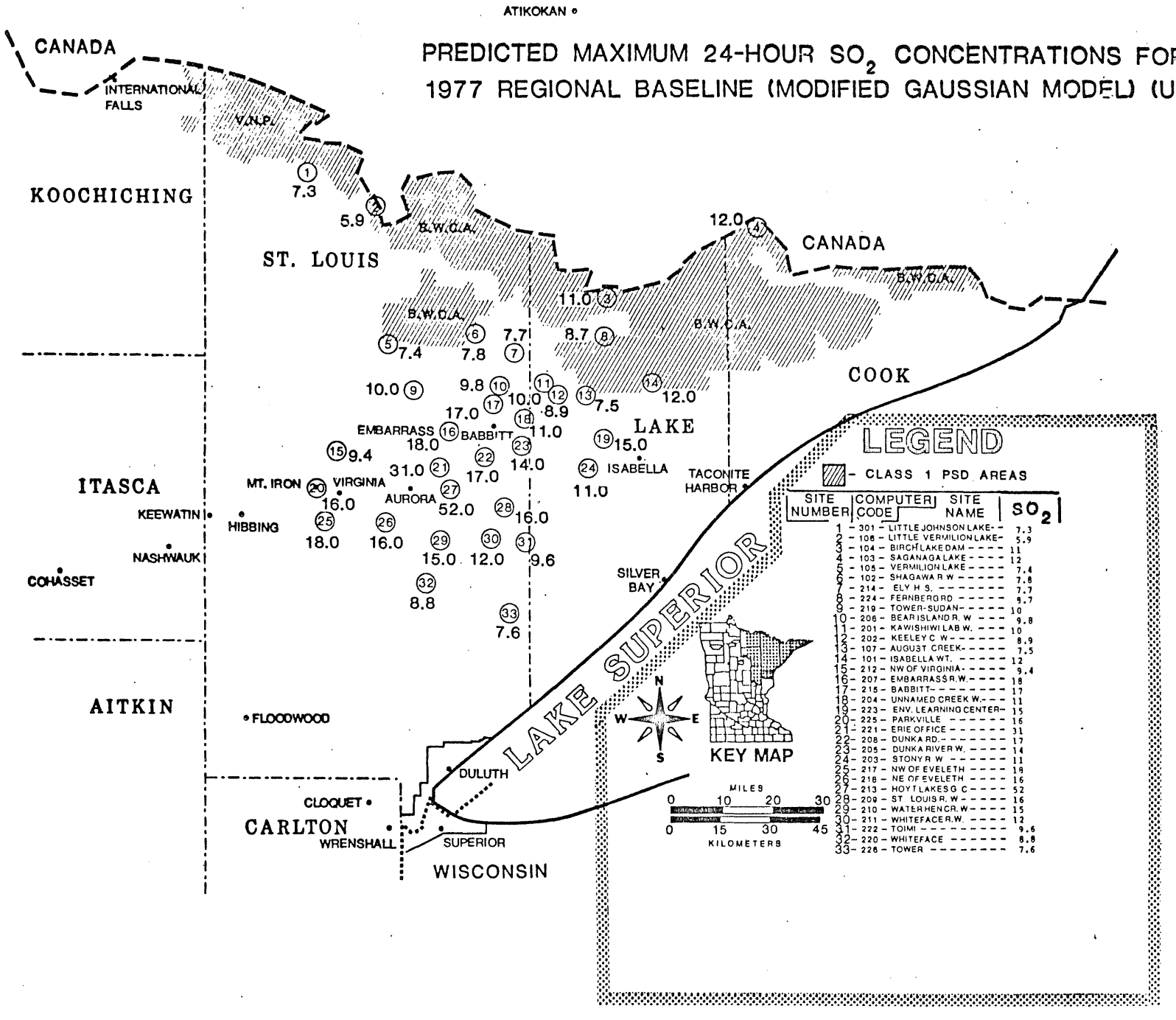
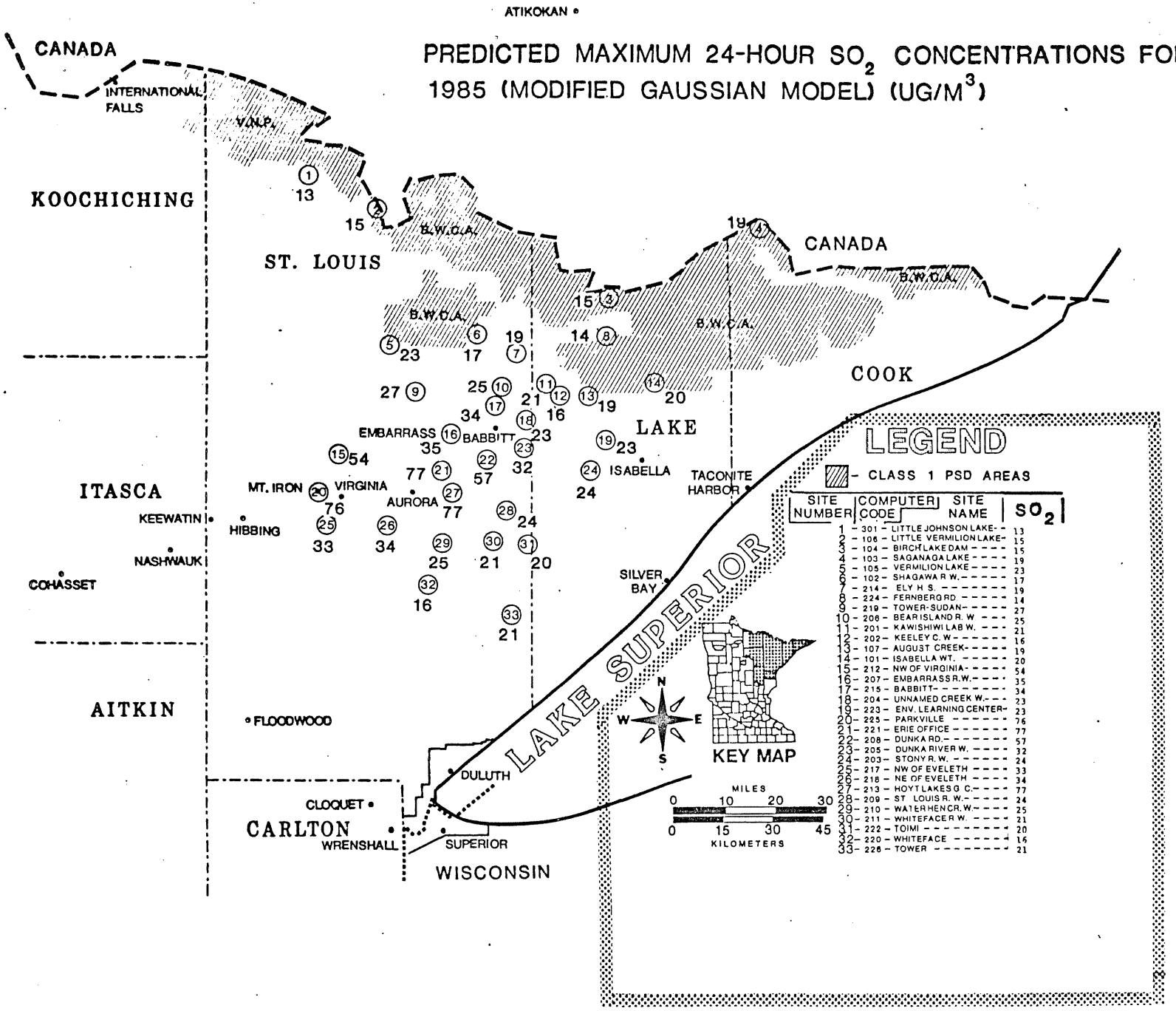

ATIKOKAN
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
AITKIN
CARLTON
WRENSHALL
CLOQUET
FLOODWOOD
HIBBING
MT. IRON
VIRGINIA
AURORA
EMBARRASS
BABBITT
ISABELLA
TACONITE HARBOR
SILVER BAY
KEEWATIN
NASHWAUK
COHASSET
DULUTH
SUPERIOR
WISCONSIN
LAKE SUPERIOR
7.3
5.9
12.0
11.0
7.4
7.8
7.7
8.7
10.0
9.8
10.0
8.9
7.5
12.0
17.0
11.0
18.0
9.4
15.0
31.0
17.0
14.0
11.0
16.0
52.0
16.0
18.0
16.0
15.0
12.0
9.6
8.8
7.6
PREDICTED MAXIMUM 24-HOUR SO2 CONCENTRATIONS FOR
1977 REGIONAL BASELINE (MODIFIED GAUSSIAN MODEL) (UG/M3)
LEGEND
- CLASS 1 PSD AREAS
KEY MAP
MILES
0 10 20 30
0 15 30 45
KILOMETERS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO2
1 - 301 - LITTLE JOHNSON LAKE - 7.3
2 - 106 - LITTLE VERMILION LAKE - 5.9
3 - 104 - BIRCH LAKE DAM - 11
4 - 103 - SAGANAGA LAKE - 12
5 - 105 - VERMILION LAKE - 7.4
6 - 102 - SHAGAWA R W - 7.8
7 - 214 - ELY H S. - 7.7
8 - 224 - FERNBERG RD - 8.7
9 - 219 - TOWER-SUDAN - 10
10 - 206 - BEAR ISLAND R. W - 9.8
11 - 201 - KAWISHIWI LAB W. - 10
12 - 202 - KEELEY C W - 8.9
13 - 107 - AUGUST CREEK - 7.5
14 - 101 - ISABELLA WT. - 12
15 - 212 - NW OF VIRGINIA - 9.4
16 - 207 - EMBARRASS R.W. - 18
17 - 215 - BABBITT - 17
18 - 204 - UNNAMED CREEK W. - 11
19 - 223 - ENV. LEARNING CENTER - 15
20 - 225 - PARKVILLE - 16
21 - 221 - ERIE OFFICE - 31
22 - 208 - DUNKA RD. - 17
23 - 205 - DUNKA RIVER W. - 14
24 - 203 - STONY R W - 11
25 - 217 - NW OF EVELETH - 18
26 - 218 - NE OF EVELETH - 16
27 - 213 - HOYT LAKES G C - 52
28 - 209 - ST. LOUIS R. W - 16
29 - 210 - WATER HEN CR. W - 15
30 - 211 - WHITEFACE R.W. - 12
31 - 222 - TOIMI - 9.6
32 - 220 - WHITEFACE - 8.8
33 - 226 - TOWER - 7.6

FIGURE 42


ATIKOKAN
CANADA
PREDICTED MAXIMUM 24-HOUR SO_2 CONCENTRATIONS FOR 1985 (MODIFIED GAUSSIAN MODEL) (UG/M^3)
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
EMBARRASS
BABBITT
ISABELLA
TACONITE HARBOR
MT. IRON
VIRGINIA
AURORA
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO_2
1 - 301 - LITTLE JOHNSON LAKE - 13
2 - 106 - LITTLE VERMILION LAKE - 15
3 - 104 - BIRCH LAKE DAM - 15
4 - 103 - SAGANAGA LAKE - 19
5 - 105 - VERMILION LAKE - 23
6 - 102 - SHAGAWA R W. - 17
7 - 214 - ELY H S. - 19
8 - 224 - FERNBERG RD - 14
9 - 219 - TOWER-SUDAN - 27
10 - 206 - BEAR ISLAND R. W - 25
11 - 201 - KAWISHIWI LAB W. - 21
12 - 202 - KEELEY C. W - 16
13 - 107 - AUGUST CREEK - 19
14 - 101 - ISABELLA WT. - 20
15 - 212 - NW OF VIRGINIA - 54
16 - 207 - EMBARRASS R.W. - 35
17 - 215 - BABBITT - 34
18 - 204 - UNNAMED CREEK W. - 23
19 - 223 - ENV. LEARNING CENTER - 23
20 - 225 - PARKVILLE - 76
21 - 221 - ERIE OFFICE - 77
22 - 208 - DUNKA RD. - 57
23 - 205 - DUNKA RIVER W. - 32
24 - 203 - STONY R. W. - 24
25 - 217 - NW OF EVELETH - 33
26 - 218 - NE OF EVELETH - 34
27 - 213 - HOYT LAKES G. C. - 77
28 - 209 - ST. LOUIS R. W. - 24
29 - 210 - WATER HEN CR. W. - 25
30 - 211 - WHITEFACE R W. - 21
31 - 222 - TOIMI - 20
32 - 220 - WHITEFACE - 16
33 - 226 - TOWER - 21
KEY MAP
N
W
E
S
MILES
0 10 20 30
0 15 30 45
KILOMETERS

the differences between the baseline and the highest and 2nd highest SO_2 concentrations predicted at Class I receptors.

Table 34

When the highest value at each site is used for the evaluation, the PSD increment is exceeded at 7 of 8 receptors; when the 2nd highest value is used, this number drops to 4 of 8 receptors.

Although from a regulatory standpoint the increment is exceeded in a Class I or Class II area when the 2nd highest value is larger than the allowed increment at any receptor (USEPA 1978), the results of using both the high and second high values are included to provide a perspective of the frequency and size of the increment exceedances. In the Class II area, the largest 24-hour SO_2 difference was 55 ug/m^3 at Parkville (60% of the 91 ug/m^3 increment).

When the proposed (800 MW) Atikokan power plant is removed from the 1985 modeling simulations the maximum 24-hour SO_2 concentrations at each receptor are virtually the same throughout the region except at two sites. Predicted concentrations are 20% lower at the Birch Lake dam (13 ug/m^3 compared to 15ug/m^3) and 32% lower at Saganaga Lake (13 ug/m^3 compared to 19 ug/m^3). In this case, the 24-hour PSD increment would be exceed at 3 of 8 receptors, using the second highest value at each receptor, compared to 4 of 8 receptors if Atikokan is included in the inventory. The wind can be expected to blow from Atikokan to the Study Area (from N-NE to S-SW) only 7.5% of the time. Concentrations in the Class II region would change very little because of distance and the low percentage of time the wind is blowing from the N-NE.

Table 34. Difference between the baseline concentration and the highest and 2nd highest 24-hour SO_2 concentration in a Class I area (ug/m^3).

SITE NO.	COMPUTER CODE	BASELINE	1985		Difference	
			Highest	2nd Highest	High-baseline	2nd Highest
14	101	12	20	14	8	2
6	102	7.8	17	16	9.2	8.2
4	103	12	19	16	7	4
3	104	11	15	12	4	1
5	105	7.4	23	17	15.6	9.6
2	106	5.9	15	11	9.1	5.1
13	107	8.7	19	15	10.3	6.3
1	301	7.3	13	11	5.7	3.7

In summary, neither the ambient air quality standards (annual and 24-hour) nor the annual PSD Class I and Class II increments are expected to be exceeded by regional growth in 1985. However, the 24-hour PSD Class I increment is expected to be exceeded in 1985. Removing the proposed Atikokan power plant (assumed here to be 800 MW) from the 1985 modeling simulation results in an annual ambient air concentration decrease of about 4% at Class II area receptors and 15% at the Class I area receptors; larger decreases are predicted at individual Class I receptors. Maximum 24-hour concentrations remain the same except at two Class I receptors on the Canadian-Minnesota border. The box plots in Figure 43 permit easy comparison of all the modeled receptors for SO_2 concentrations in 1977 and 1985. The box plot illustrates the median, quartile, minimum, maximum and 2nd high values for ONE YEAR OF 24-hour concentrations.

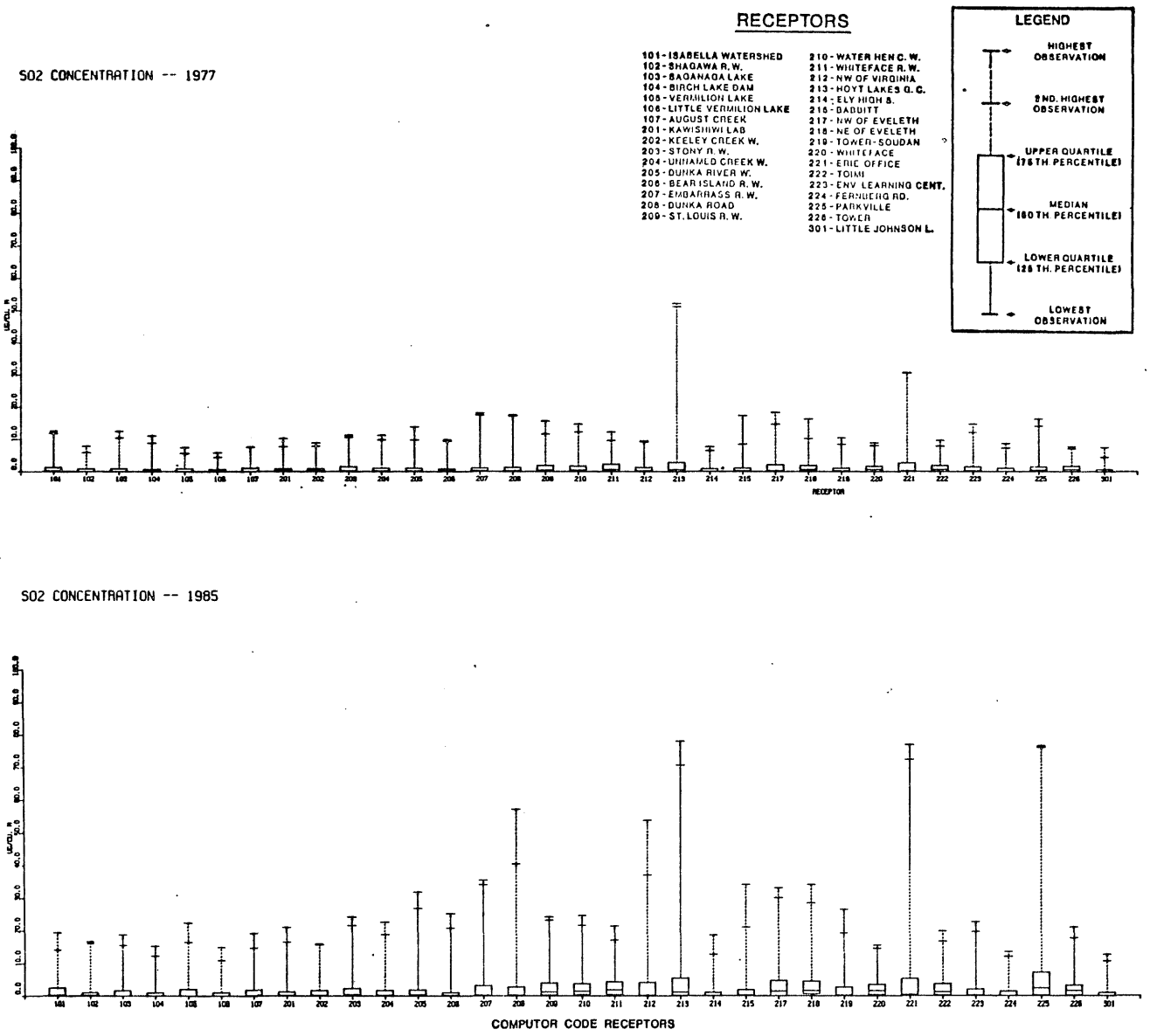
Figure 43

Three sites were selected to show the spatial and temporal variation in concentration levels expected in the study region. The emphasis is on contrasting concentration frequency distributions among a remote site in the eastern corner of the region (Isabella Watershed, site No. 14), an urban site in the center of the region (Hoyt Lakes Golf Course, site No. 27), and an urban site in the western corner of the region (Parkville, site No. 20).

The frequency plots (Figure 44) show the percent of days in the year (with the number of days shown at the top of each bar) each concentration level was predicted. For example, in 1977, a 24-hour SO_2 concentration of less than 5 ug/m^3 is predicted 93% of the time (338 days) at Isabella compared to only 84% of the time (305 days) at Hoyt Lakes Golf Course. The frequency plots also demonstrate the predicted shift to higher concentration levels in 1985. Minimum,

FIGURE 43

BOX PLOTS OF PREDICTED 24-HOUR AMBIENT SO_2 CONCENTRATIONS FOR 1977 AND 1985 FROM LOCAL SOURCES (MODIFIED GAUSSIAN MODEL).



maximum, arithmetic mean and standard deviation are also included in the plots.

Figure 44

3.4.2.2 Ambient Sulfate Concentrations--Ambient sulfate concentrations in the Air Quality Study Region were determined from membrane samples collected by the Copper-Nickel Study which were subsequently analyzed by x-ray fluorescence at EPA laboratories, Research Triangle Park, North Carolina (Eisenreich, Hollod and Langevin 1978). Samples were analyzed for total sulfur and concentrations were expressed as sulfate. Since SO_2 concentrations were low in the study region it seems likely that most of the sulfur present was actually in the sulfate form. The mean sulfur content of air particulates expressed as sulfate at 8 sites (both urban and non-urban) was not significantly different (see Table 35). Eisenreich, Hollod and Langevin (1978) attribute this uniformity in urban and non-urban areas to regional transport and dispersion of sub-micron sized particles into the study region, possibly from distant sources.

Table 35

Weiss et al. (1977) investigated the geographical extent of sulfate aerosal in the midwestern and southern United States and concluded: 1) that haze-producing aerosol in a forested Ozark location was not predominately organic but was dominated by sulfate particles and that the nature of the major sulfate species [$(NH_4)_2SO_4$] was similar to that observed in the midwest; and 2) that sulfate aerosol is distributed over a large geographical region (1000 km from northeast to southwest) in the midwest and south and is not due to local sources. It is generally agreed that the averge residence time of atmospheric sulfur is about 5 days and transport distances may average 1,000 km (Friend 1973).

FIGURE 44

ANNUAL FREQUENCY DISTRIBUTION OF PREDICTED 24-HOUR AMBIENT SO_2 CONCENTRATIONS FOR 1977 AND 1985 AT SELECTED SITES (MODIFIED GAUSSIAN MODEL).

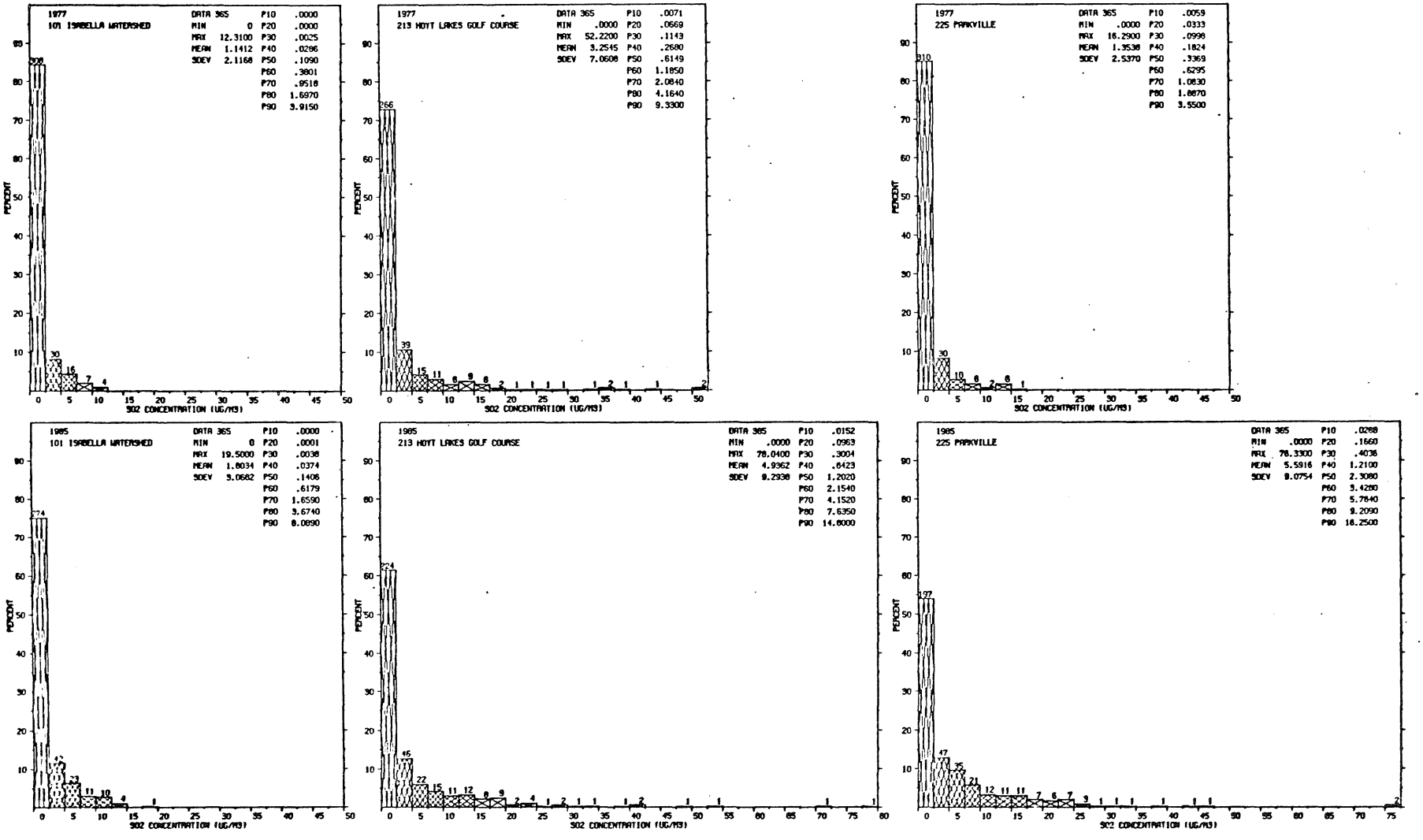


Table 35. Summary of measured sulfur content of atmospheric particulates at eight Study Area sites, expressed as sulfate.[a]

MONITORING SITE	SO_4 CONCENTRATION (ug/m^3) Average	Standard Deviation
Babbitt	2.1	1.8
Whiteface	2.3	1.7
Hoyt Lakes	1.9	1.7
Erie	1.0	1.4
Dunka Road	2.0	1.6
Fernberg	2.1	1.7
Isabella	2.0	1.8
Toimi	1.4	1.4
AVERAGE[b]	1.9	

SOURCE: Eisenreich, Hollod and Langevin 1978.

[a]Data represents sampling from Dec. 1977 through Oct. 1978. Values have been rounded.

[b]Arithmetic average of above eight values.

The measured values in Table 35 compare favorably to sulfate values which have been reported in remote midcontinental areas (Eisenreich, Hollod and Langevin 1978). It is interesting to compare these concentrations to the values derived from the modified gaussian model using the SO_2 point sources from the regional emissions inventory. Data from studies of the Sudbury plume (Lusis and Wiebe, 1976) were used to estimate the rate of conversion of SO_2 to sulfate in the model. The rate varied from 0% to 6% per hour depending on the distances from the sources. The resulting regional arithmetic average modeled for 1977 was 5.4 ng/m^3. This result, when compared to the average of the measured values shown in Table 35 of 1.9 ug/m^3, clearly suggests that major point sources in the region are not primary contributors to ambient sulfate levels in the study region. This is in contrast to the situation with ambient SO_2 . It appears that nearly all of the measured ambient sulfate levels (estimated at more than 99%) are the result of transport from outside the study region.

The modified gaussian model predicts that by 1985 the ambient sulfate concentration due to point sources in the region will increase to 84 ng/m^3, an increase of roughly a factor of 15 over the modeled 1977 value. Maximum 24 hr. concentrations of 1.2 ug/m^3 are predicted at the Hoyt Lakes Golf Course for both 1977 and 1985. The question of possible increases in sulfate transport into the region from remote sources is discussed in the next section (3.4.3).

At the present time there is no national ambient air quality standard for sulfates. It is possible that standards based on total water-soluble sulfates may be established by 1985 (Rowe et al. 1978). A potential 24 hr. standard of 10-25 ug/m^3 and a potential annual standard of 5-15 ug/m^3 have been developed by the Brookhaven National Laboratory Office of Environmental Policy (Rowe et.al. 1978).

Sulfate concentrations for all the modeled receptors are given by the box plots in Figure 45 for 1977 and 1985. Annual frequency distributions for sulfate concentrations are shown for Isabella Watershed, Hoyt Lakes Golf Course and Parkville in Figure 46.

Figures 45 and 46

3.4.3 Regional Sulfate Deposition

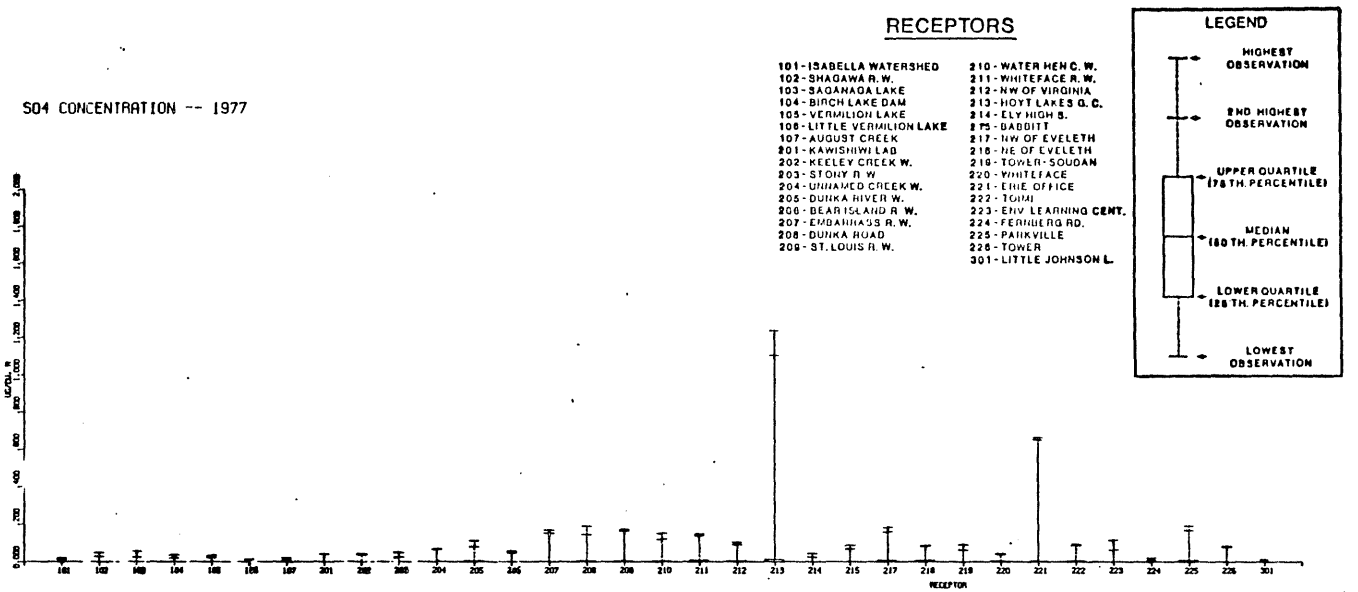
The surface deposition rates for sulfate are of special interest, particularly in the context of potential water quality impacts. In order to properly understand the total deposition of sulfate, it is necessary to consider both wet and dry deposition. This in turn will facilitate an understanding of the importance of the roles played by local and long distance sources.

Sulfate deposition in the Study Area was measured using bulk samples, rain event samplers, canopy through-fall samplers, and membrane samplers. The results of the through-fall samples and the rain-event samples are comparable to the bulk collected samples and are not included in this section to simplify data presentation. A complete discussion of the data can be found in Eisenreich, Hollod and Langevin (1978).

Bulk deposition measurements reflect the combined effects of wet and dry deposition since the collectors are open to the atmosphere during the entire 30-day sampling period. Bulk deposition data in the Study Area was collected at 4 sites: Hoyt Lakes Golf Course, Fernberg Road, Spruce Road/Kawishiwi Lab, and Dunka Road (Figure 10). The samples were each collected for 30 days and then analyzed for a variety of parameters including sulfate from February, 1977 through January, 1978.

FIGURE 45

BOX PLOTS OF 24-HOUR VALUES PREDICTED FOR AMBIENT SULFATE CONCENTRATIONS FROM LOCAL SOURCES, 1977 AND 1985 (MODIFIED GAUSSIAN MODEL).



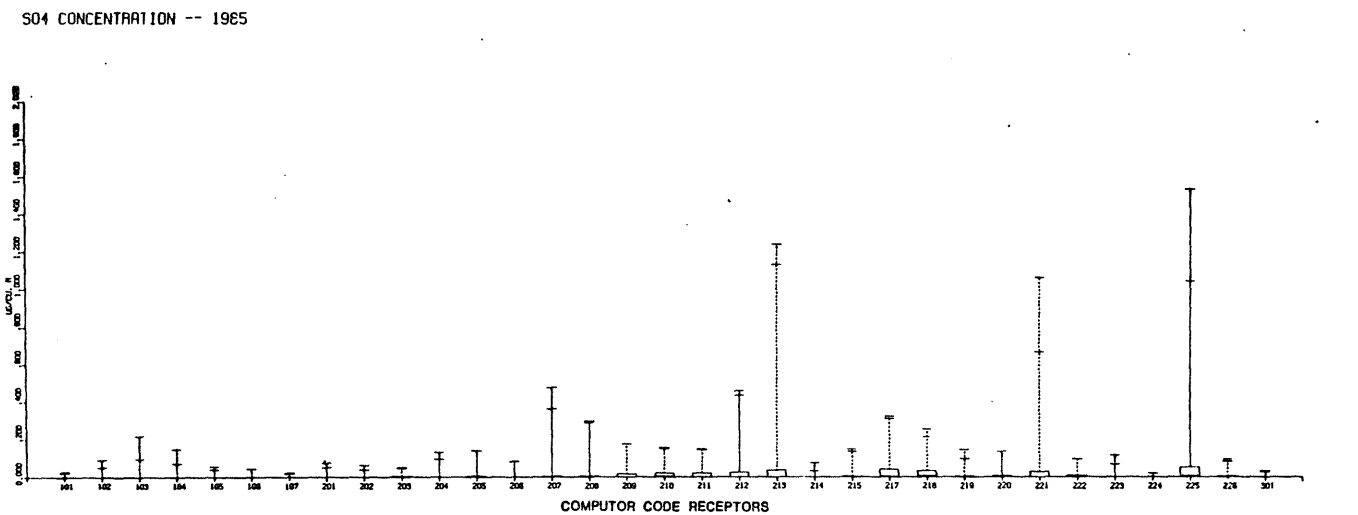


FIGURE 46

ANNUAL FREQUENCY DISTRIBUTION OF PREDICTED 24-HOUR AVERAGE AMBIENT SULFATE CONCENTRATIONS, 1977 AND 1985, AT SELECTED SITES (MODIFIED GAUSSIAN MODEL)

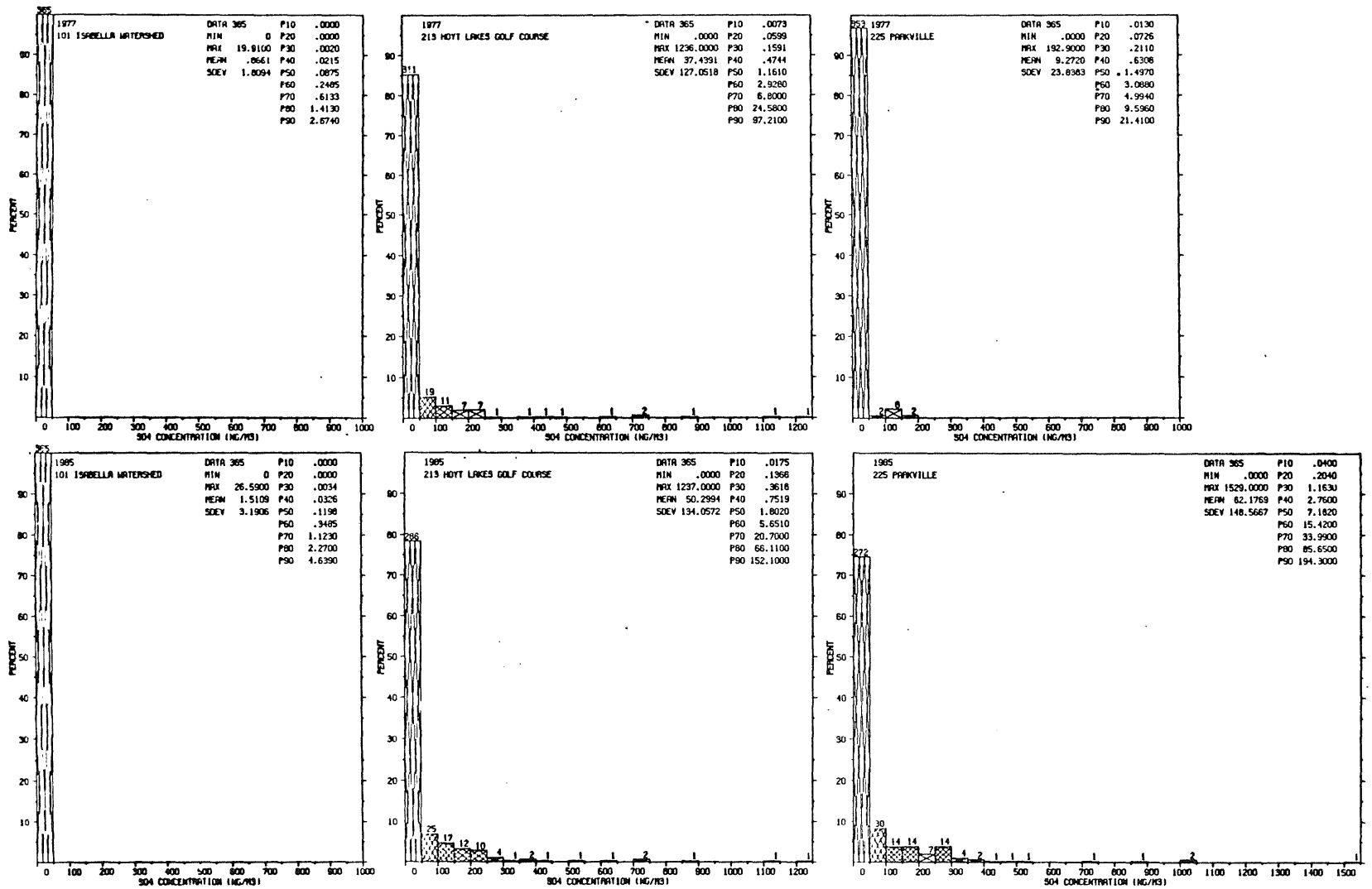


Table 36 shows the resulting data for annual sulfate deposition from the bulk samplers expressed as both geometric and arithmetic means. The concentration of sulfate in the region seems to be uniformly distributed, once again suggesting that locally generated sulfate deposition is minimal.

Table 36

Figure 47 shows the monthly deposition values for each site on a line graph. Precipitation (millimeters) for each month is included on each graph. The highest sulfate loadings occurred around September and the second highest loadings occurred around June. These months were also months of highest precipitation which supports the idea that wet scavenging of sulfate is probably more important than dry deposition (Thingvold et al. 1979).

Figure 47

An estimate of dry deposition of sulfate for the region was also calculated using measured atmospheric concentrations (membrane samplers) and deposition velocity data from Chilton, England (Cawse 1974). It is assumed that the dry deposition value represents sulfate. In actual practice, the analytical technique employed for the membrane samples measures total sulfur, not sulfate.

On an annual basis, the regional dry sulfate deposition was calculated to be 1.78 kg/ha/yr (with a standard deviation of 1.78 kg/ha/yr) (Thingvold et al., 1979). The average wet-dry rate from the bulk samplers is 14.4 kg/ha/yr. Thus, from 0 to 24% of the total deposition is estimated (within 1 standard deviation) to be dry. Because the dry deposition value is low and because very little SO_2 was measured in this region, it is believed that most of the sulfate, as measured by

Table 36. Annual sulfate deposition based on bulk deposition data, kg/ha/yr.

	GEOMETRIC MEAN	ARITHMETIC MEAN
Fernberg Road	14.6	18.3
Spruce Road/Kawishiwi Lab	12.4	15.7
Dunka Road	15.1	19.3
Hoyt Lakes Golf Course	15.4	21.6
AVERAGE	14.4	18.7

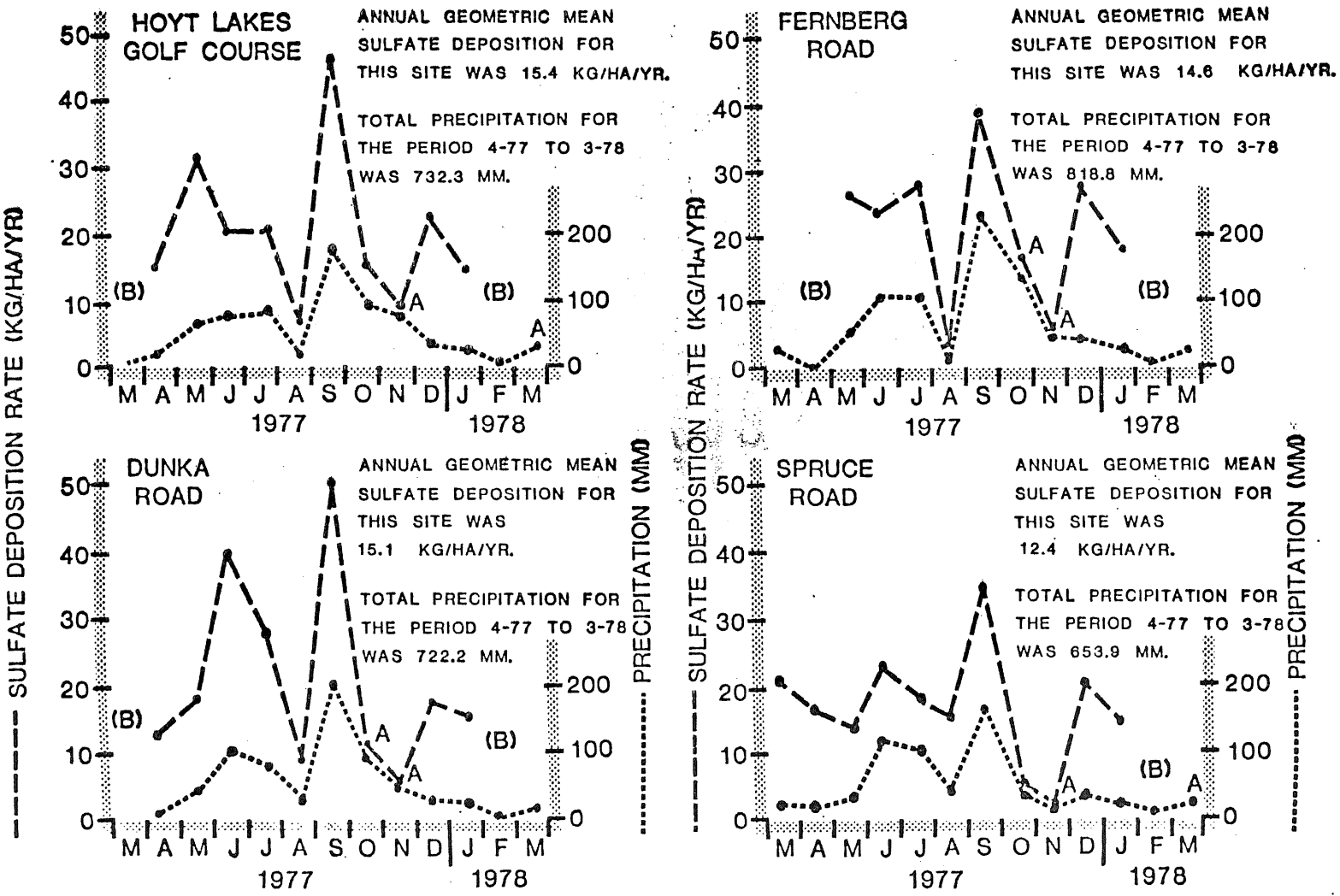
SOURCE: Thingvold et al., 1979.

FIGURE 47

MONTHLY BULK SULFATE DEPOSITION AND PRECIPITATION AT SAMPLING SITES

(A)- INDICATES VALUE WAS LESS THAN THE NUMBER SHOWN

(B)- DATA NOT AVAILABLE



the bulk samples, originates outside of this region, perhaps several hundreds of miles away in areas such as St. Louis, the Ohio valley and the East Coast area (Lyons and Husar 1976; Lyons et al. 1978). Long-range transport of sulfate is quite feasible when large high-pressure systems are centered to the east and south of Minnesota. The large, clock-wise vortex of winds then can move sulfur compounds from the industrialized areas of the East to Minnesota. Under certain conditions, Canadian cold-fronts can collide with this sulfur-laden, warm air mass over northeastern Minnesota causing high levels of sulfate in the precipitation. In this situation, rain scavenging is an important mechanism for deposition.

Deposition values due to local sources were predicted using the modified gaussian model during each 30-day sampling period at selected receptors. This allows a direct comparison of measured sulfate deposition to predicted deposition expected from local sources. Table 37 summarizes the results of both the measured bulk data and predicted data. The ratios of measured to calculated data range from .63 (the only ratio less than 1) to 21. The typically large value of the ratio again supports the thesis that the bulk of the sulfate deposition in the region is due to sources outside of the region.

Table 37

In order to understand the role of local SO_2 sources in regional sulfate deposition, it is useful to consider the data on dry deposition. A comparison of mean annual dry deposition rates (based on Chilton dry deposition velocity and measured ambient sulfate concentrations) and predicted total sulfate deposition from local sources only is given in Table 38. It is important here to emphasize that the predicted average sulfate deposition rates for the 8 sites shown include

Table 37. Measured and predicted local sulfate deposition[a] (kg/ha/yr).

		DUNKA RD.	SPRUCE RD/ KAWISHIWI	FERNBERG RD.	HOYT LAKE GOLF COURSE
March	M[b]	1.1	1.4		1.3
	P[b]	.073	.076		.11
April	M	1.5	1.2	2.2	2.6
	P	.27	.27	.39	.33
May	M	3.3	1.9	2.0	1.7
	P	.28	.33	.36	.21
June	M	2.3	1.5	2.3	1.7
	P	.41	.26	34	.83
July	M	.76	1.3	.31	.59
	P	.14	.13	.13	.93
Aug	M		2.9	3.2	3.9
	P		.14	.21	.75
Sept	M		.47		1.3
	P		.28		.75
RATIO: MEASURED/PREDICTED					
March		15	18		12
April		5.6	4.4	5.6	7.9
May		12	5.6	5.6	8.1
June		5.6	5.8	6.8	2.0
July		5.4	10	2.4	.63
Aug			21	15	5.2
Sept			1.7		1.7

[a]Measured values are based on bulk deposition results, predicted values reflect the effects of local SO_2 sources only, using the modified gaussian model.

[b]M=measured; P=predicted.

both wet and dry deposition in arriving at the arithmetic average rate of 2.85 kg/ha/yr (or 2.2 kg/ha/yr using all 33 receptor sites to arrive at a regional average). This is in contrast to the values calculated from ambient concentrations which include only dry deposition to yield an average of 1.78 kg/ha/yr for the 8 sites.

Table 38

In order to compare these two results, it is first necessary to isolate that portion of the predicted deposition attributable to dry deposition processes. This value can then be properly compared to the calculated result. Accordingly, the predicted wet and dry sulfate deposition components from local sources at 4 sites (Hoyt Lakes Golf Course, Dunka Road, Kawishiwi, and Fernberg Road) are shown in Table 39 (see Ritchie, 1979, for a discussion of the modeling procedures involved here). The resulting dry deposition ranges from 91.4% to 95.9% of the total description.

Table 39

If it is assumed on the basis of these data that at most 10% of the total predicted deposition from local sources is wet, a predicted dry deposition average of 2.56 kg/ha/yr for the 8 sites (or 1.98 kg/ha/yr for the region) is calculated. These values compared favorably to the dry rate of 1.78 kg/ha/yr based on ambient air data and Chilton's dry deposition values.

This result indicates that the bulk of the measured dry deposition in the region is due to local sources since the comparison between predicted (local source) and measured dry sulfate deposition is excellent. However, about 85% of the measured

Table 38. Calculated[a] dry deposition rates and predicted[b] total sulfate deposition (kg/ha/yr).

	CALCULATED	PREDICTED
Fernberg	2.01	2.2
Isabella (ELC)	1.92	2.5
Dunka	1.86	2.5
Toimi	1.32	2.1
Erie	1.01	4.0
Hoyt Lakes	1.79	5.5
Whiteface	2.13	2.1
Babbitt	1.98	1.9
REGION	1.78[c]	2.85[c](2.2[d])

[a]Using Chilton's dry deposition velocity and measured air concentrations.
[b]Based on local (1977) point sources.
[c]Based on 8 sites shown in the table.
[d]Based on all 33 receptor sites in the region.

Table 39. Predicted wet and dry sulfate deposition from local point sources[a] (kg/ha/30 day).

	DUNKA RD.		HOYT LAKES GOLF COURSE		KAWISHIWI		FERNBERG Rd.	
	wet	dry	wet	dry	wet	dry	wet	dry
March	.003	.070	.004	.103	.004	.073		
April	.016	.257	.010	.317	.008	.265	.010	.376
May	.019	.260	.026	.186	.017	.311	.016	.345
June	.016	.392	.021	.807	.006	.255	.010	.328
July	.005	.132	.008	.919	.010	.120	.010	.116
Aug	.017	.377	.066	.683	.018	.119	.028	.182
Sept	.098	.355	.121	.626	.030	.253	____	____
TOTAL	.174	1.843	.256	3.641	.093	1.396	.074	1.723
PERCENT OF TOTAL	8.6%	91.4%	6.6%	93.4%	6.2%	93.8%	4.1%	95.9%

[a]Using the modified gaussian model.

total (wet and dry) sulfate deposition is not accounted for by regional point sources.

The International Joint Commission (IJC 1977) predicts that sulfate loadings in Minnesota could double from 16.4 kg/ha/yr in 1974 to 32.8 kg/ha/yr by the year 2000 with no full-scale SO_2 removal at the sources. However, it could remain at about the 1974 level if additional SO_2 removal is applied to planned and existing sources. Since the specific origins of sulfate deposited in the region from remote sources are not known, it is impossible to predict sulfate deposition increases as a result of SO_2 emission increases at specific locations. However, it is known that sulfate deposition, for example, was high in the region during months such as May, June, and September, when south and southeast winds constitute important components of the wind roses for these periods. Thus, it is reasonable to look at projections for increased SO_2 emissions to the south of the region for general validation of the IJC prediction concerning sulfate loading.

In a report to the Minnesota Legislature, the Minnesota Energy Agency (1978a) estimates that total stack emissions of SO_2 in the state amounted to some 312,000 mtpy in 1976. Of this total, some 226,000 mtpy, or 72%, was due to the combustion of coal. Projections for coal use in the state show an estimated 59% increase in coal-related SO_2 emissions by 1985, with an increase of 104% by 1995. Although the Twin Cities area is forecasted to have a slight decline of coal-derived stack SO_2 emissions, the Duluth-Superior area is estimated to have increases greater than the state as a whole, with 98% and 172% increases projected for 1985 and 1995, respectively. The central Air Quality Control Region just south of Duluth is expected to show increases over 1976 levels of 305% and 455% in coal-related stack SO_2 emissions for 1985 and 1995.

Since these areas may serve as sources of sulfate transported into the Study Area, this information certainly supports the predictions of significant increases in sulfate deposition over the next 20- to 25-year period made by IJC. The energy shortages related to gas and oil with resulting increased use of coal may constitute the determining factor in increasing sulfate deposition. Since this situation is not unique to Minnesota, but affects the entire nation, it is reasonable to expect that wherever the sources of SO_2 emissions responsible for sulfate depositionin the region are located, they will experience emission increases similar to those discussed here for Minnesota. The resulting sulfate deposition in the region can be expected to increase accordingly.

The annual arithmetic mean sulfate deposition due to local point sources is predicted to more than double from 2.2 kg/ha/yr in 1977 to 4.5 kg/ha/yr in 1985. If it is assumed that background sulfate increases correspondingly, then by 1985 the total regional sulfate deposition could be about 29 kg/ha/yr.

Box plots of predicted sulfate deposition from local sources for 1977 and 1985 are shown in Figure 48 for all receptors in the region. Frequency distributions for 1977 and 1985 are given in Figure 49 for three sites (Isabella Watershed, Hoyt Lakes Golf Course, and Parkville).

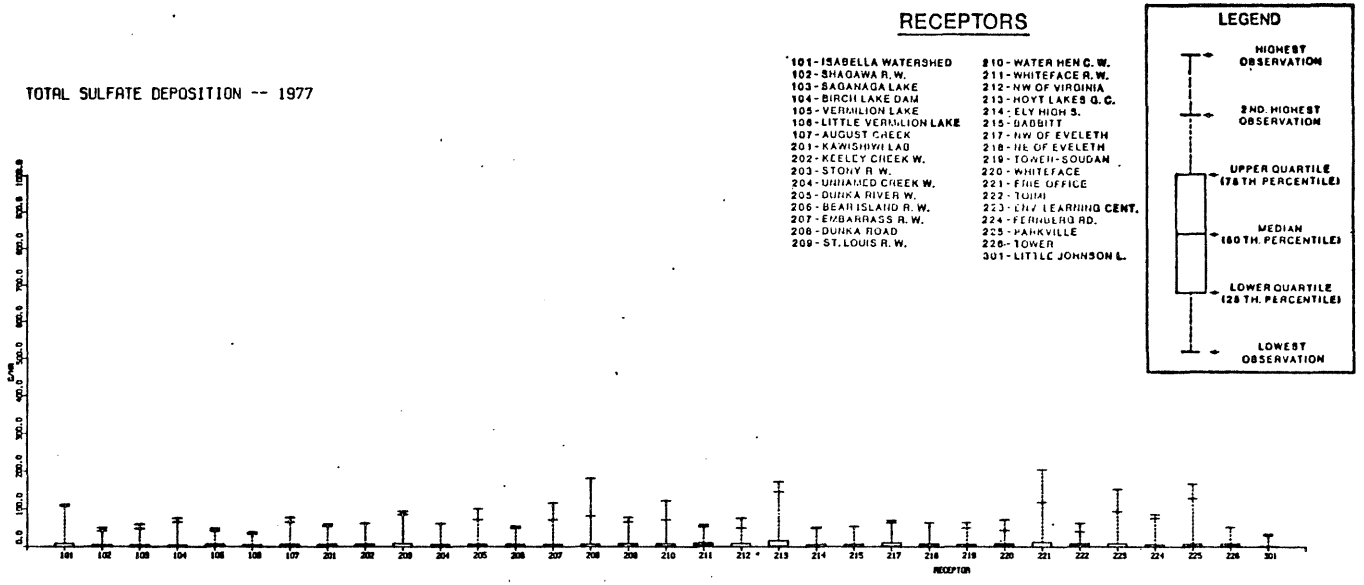
Figures 48 and 49

3.5 CHARACTERIZATION OF ATMOSPHERIC PARTICULATES

The previous discussion focused on a characterization of sulfur in the atmosphere in the absence of copper-nickel development. This section presents a similar characterization of the particulates in the atmosphere. Several questions will be discussed. What are the present major sources of atmospheric particulates in

FIGURE 48

BOX PLOTS OF 24-HOUR VALUES FOR PREDICTED TOTAL SULFATE DEPOSITION FROM LOCAL SOURCES, 1977 AND 1985 (MODIFIED BOX MODEL)



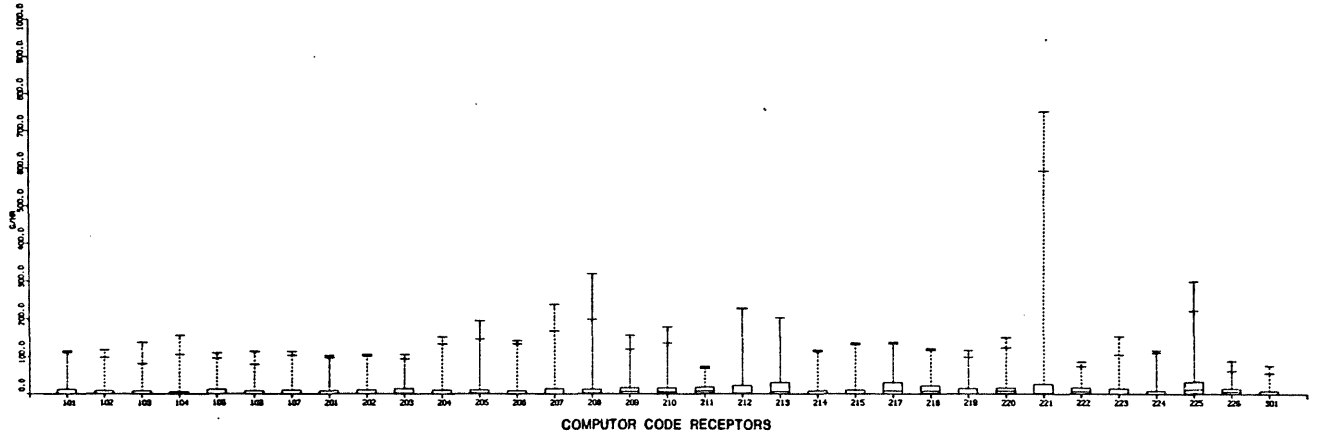
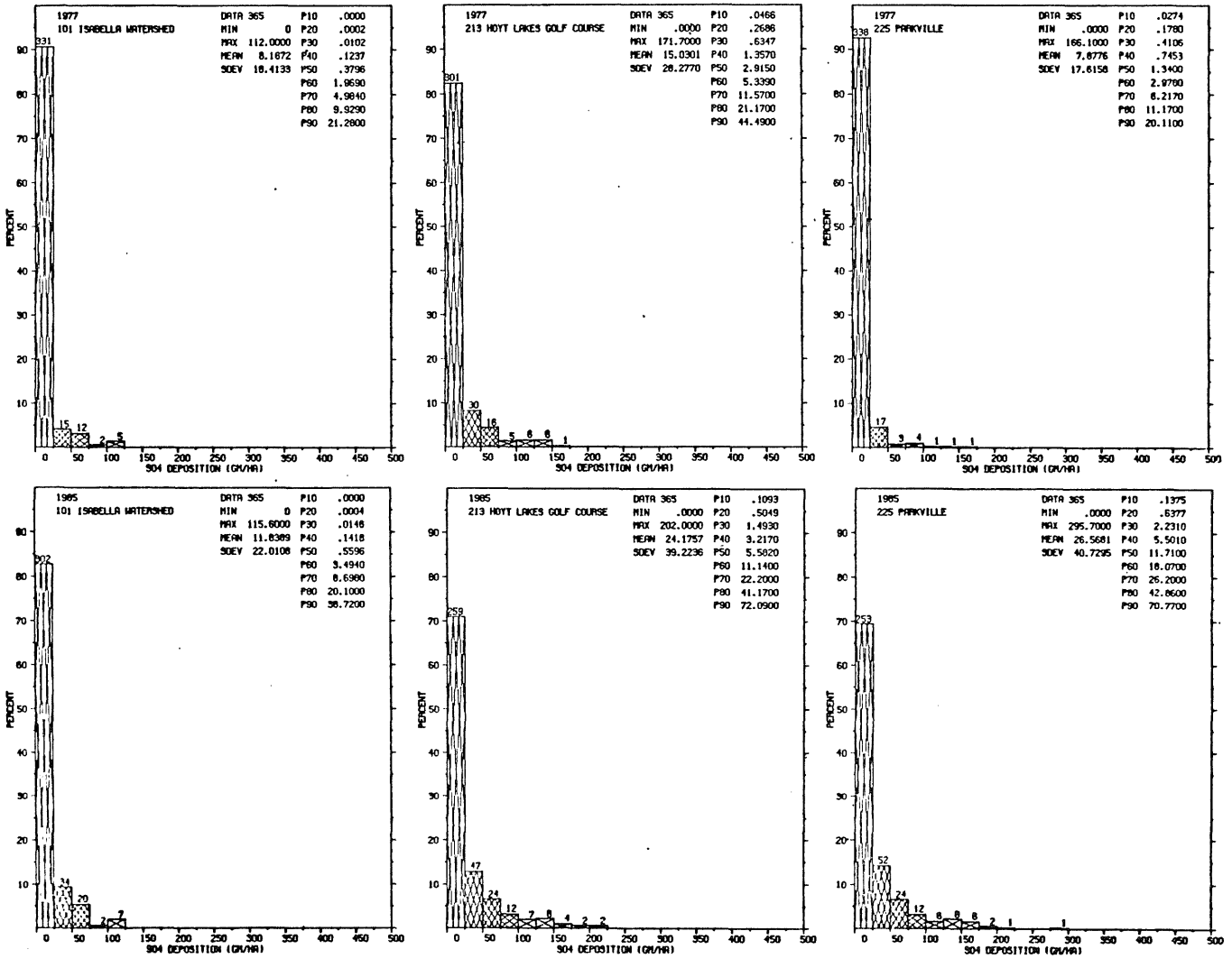


FIGURE 49

ANNUAL FREQUENCY DISTRIBUTION OF PREDICTED 24-HOUR SULFATE DEPOSITION FROM LOCAL SOURCES, 1977 AND 1985, FOR SELECTED SITES (MODIFIED GAUSSIAN MODEL)



the Air Quality Study Region, and what are the resulting ambient TSP levels due to emissions from these sources? How is this picture likely to change in the future (1985 is used as a reference) without copper-nickel development? What is known about the particle size distribution and elemental composition of these particulates? What are the present concentrations of mineral fibers in the atmosphere? In the following discussions, answers to each of these questions will be considered in turn.

3.5.1 Total Particulates

This section discusses particulates without reference to their composition. The focus here is on the amount of solid matter suspended in the atmosphere (referred to as total suspended particulates, TSP) and the deposition of this matter onto the earth's surface. Since the atmosphere merely acts as a dispersing and transport medium in moving particles from one place (or source) to another, it is appropriate to begin with a discussion of particulate sources.

3.5.1.1 Particulate Sources--As was the case with sulfur emissions, the focus is on large point sources in the air quality study region which emit at least 100 mtpy of particulates. Unlike the case for SO_2, however, smaller, more distributed area sources are very important. Their existence explains the general background TSP levels observed in the Study Area. These area sources will be discussed after consideration of the point sources.

As with SO_2 emissions, an inventory of point sources of particulate emissions for the region was assembled from available data (Ritchie 1978). The inventory includes sources present in the baseline period (1975-76) as well as those projected to be in existence in 1985. Table 40 lists the various sources and amounts of particulate emissions. As with the SO_2 inventory, it must be

realized that these figures reflect the best estimates currently available, but the 1985 projections, in particular, will most certainly be refined as plans evolve and new information becomes available.

Table 40

Summarizing the point source inventory data, the inventory yields a rate of 92,480 mtpy of particulate emissions in the region for the 1975-76 baseline period, compared to a total projected rate of 57,740 mtpy for 1985, a 38% decrease over the roughly ten-year interval. Table 41 and Figure 50 give a breakdown of emissions in terms of source categories (power generation, taconite processing, grain elevators, refineries, and commercial-industrial) and geographic area (Minnesota, Wisconsin, and Canada).

Table 41, Figure 50

The 38% decrease (Table 41) in regional particulate emissions between the present and 1985 is primarily due to abatement efforts. Based on emissions data and estimates, these efforts will result in a 68% decrease for point sources in Duluth, a 48% decrease in Carlton County, and nearly a 97% decrease in particulate emissions at the Reserve Mining Company operations at Silver Bay, Minnesota. Particulate emissions in Atikokan, Ontario, are expected to decrease by 85% due to the closing of the Steep Rock Iron Mines, Ltd. and the Caland Ore Company Ltd., two major taconite mining companies.

These decreases, however, are partially offset by projected growth in both the taconite processing industry and the power generation industry. Proposed generating stations near Floodwood, Minnesota and Atikokan, Ontario, and the

Table 40. Regional particulate emissions inventory used for sources emitting more than 100 mtpy.

SOURCE FACILITY[3]	BASELINE EMISSIONS 1975-76 (mtpy)	1977 BASELINE (if different from 1975-76 values)(mtpy)	PROJECTED EMISSIONS 1985 (mtpy)
Potlach Northwest	1312		691
Conwed	444	"227"(1,2)	"227"
Continental Oil	92		92
Erie Mining (Taconite Harbor)	813		813
MP & L Clay Boswell	5504		7649
National Steel Pellet	1766	"1392"(1,2)	2093
Butler Taconite	1575		3182
Boise Cascade	2335		"546"
Reserve Mining (Silver Bay)	31140		"1000"
MP&L Sy Laskin	662		662
Reserve Mining (Babbitt)	none reported		0
Arrowhead Blacktop	100		100
Cargill Elevator B	498		"91"
Cargill Elevator C	205		" 36"
Duluth Steam	150		"150"
General Mills A	306		" 64"
International Multifoods	496		"236"
MP & L Hibbard Station	19		---
Superwood Corp.	279		279
U.S.S.-Duluth Coke	1053		---
U.S.S.-Shipping	193		" 46"
Eveleth Taconite	857	"2545"(1,2)	"3909"
MP&L (Floodwood or Brookston)	---		"2364"
Jones and Laughlin	---		"1909"
Hibbing Public Utility	52		52
Hibbing Taconite	---	1218 (1,2)	1791
Hanna Mining	703		1273
Erie Mining (Hoyt Lakes)	7727		"10460"
Minntac	17440	19160 (2)	"7000"
Virginia PUD	612	"127" (1)	"127"
Inland Steel	---	1227 (2)	2455
Pickands Mather	---		"2273"
Lake Superior Power District	648		"1909"
Roffler's Construction	277		277
Murphy Oil Corp.	56		56
Farmers' Union Grain	354		13
Globe Elevator	321		2
Superior WL&P	5		5
Orba Corp.	---		318
Burlington Northern	---		146
Univ. of Wisconsin	76		76
CLM Corp.	2		8
Ontario Hydro (Atikokan)	---		1900
Caland Ore Co.	1356		---
Steep Rock Mines	11650		---
Minnesota Pulp & Paper	1405		1405

SOURCE: Ritchie 1978.

NOTE: A missing entry (--) indicates the facility does not exist or will be phased out by the date shown. Tonnages shown in quotation marks indicate estimates by the staff of the Copper-Nickel Study based on available data.

1) Used in 1977 regional baseline in place of value shown for 1975-76.
2) Used in 1977 PSD baseline in place of value shown for 1975-76.
3) Sources are from the list in Table 10, section 3.2.3.1.

Table 41. Particulate regional emissions inventory for point sources emitting more than 100 mtpy (emissions in mtpy).[c]

COUNTY/ LOCATION	POWER GENERATION			TACONITE PROCESSING			GRAIN ELEVATORS		
	Baseline[a]	Projected[b]	%Change	Baseline	Projected	%Change	Baseline	Projected	%Change
MINNESOTA									
Carlton	0	0	0	0	0	0	0	0	0
Cook	0	0	0	813	813	0	0	0	0
Itasca	5504	7649	+39	3341	5275	+58	0	0	0
Lake	0	0	0	31140	1000	-97	0	0	0
St. Louis	1494	3414	+129	26730	31070	+16	1505	427	-72
Koochiching	0	0	0	0	0	0	0	0	0
TOTAL	6998	11060	+58	62020	38160	-38	1505	427	-72
WISCONSIN									
Ashland	648	1909	+195	0	0	0	0	0	0
Douglas	5	5	0	0	0	0	675	15	-98
TOTAL	653	1914	+193	0	0	0	675	15	-98
CANADA, ONTARIO									
Atikokan	0	1900	--	13000	0	-100	0	0	0
Ft. Francis	0	0	0	0	0	0	0	0	0
TOTAL	0	1900	--	13000	0	-100	0	0	0
REGIONAL TOTAL	7651	14880	+94	75020	38160	-49	2180	442	-80

SOURCE: Ritchie 1978.

[a]Baseline year 1975-76.
[b]Projected year 1985.
[c]Totals are rounded.

Table 41 continued.

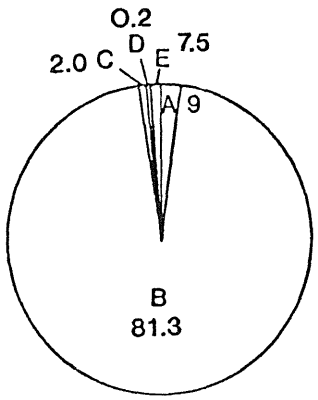
COUNTY/ LOCATION	REFINERIES Baseline	REFINERIES Projected	REFINERIES %Change	COMMERCIAL & INDUSTRIAL Baseline	COMMERCIAL & INDUSTRIAL Projected	COMMERCIAL & INDUSTRIAL %Change	COUNTY/LOCATION TOTAL Baseline	COUNTY/LOCATION TOTAL Projected	COUNTY/LOCATION TOTAL %Change
MINNESOTA									
Carlton	92	92	0	1756	918	-48	1848	1010	-45
Cook	0	0	0	0	0	0	813	813	0
Itasca	0	0	0	0	0	0	8845	12920	+46
Lake	0	0	0	0	0	0	31140	1000	-97
St. Louis	0	0	0	1625	425	-74	31350	35340	+13
Koochiching	0	0	0	2335	546	-77	2335	546	-77
TOTAL	92	92	0	5716	1889	-67	76340	516300	-32
WISCONSIN									
Ashland	0	0	0	277	277	0	925	2186	+136
Douglas	56	56	0	78	548	+603	814	624	-23
TOTAL	56	56	0	355	825	+132	1739	2810	+62
CANADA, ONTARIO									
Atikokan	0	0	0	0	0	0	13000	1900	-85
Ft. Francis	0	0	0	1405	1405	0	1405	1405	0
TOTAL	0	0	0	1405	1405	0	14410	3305	-77
REGIONAL TOTAL	148	148	0	7476	4119	-69	92480	57740	-38

SOURCE: Ritchie 1978.

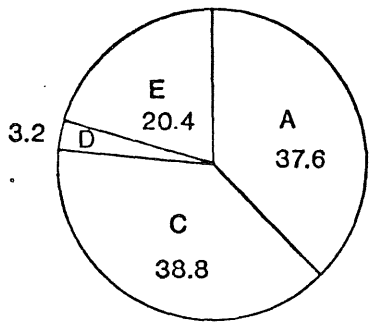
[a]Baseline year 1975-76.
[b]Projected year 1985.
[c]Totals are rounded.

FIGURE 50

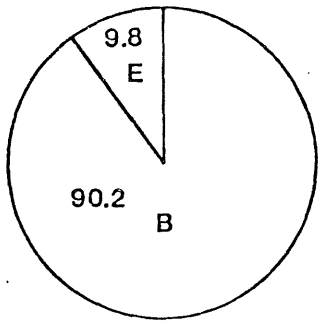
SOURCE CATEGORY CONTRIBUTIONS TO PARTICULATE EMISSIONS



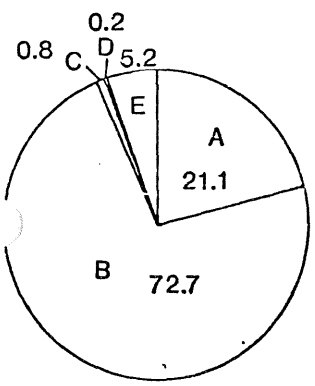
MINNESOTA BASELINE
TOTAL : 76340 MTPY



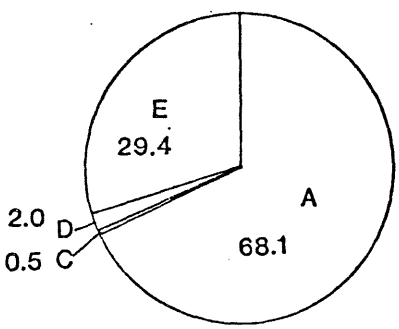
WISCONSIN BASELINE
TOTAL : 1739 MTPY



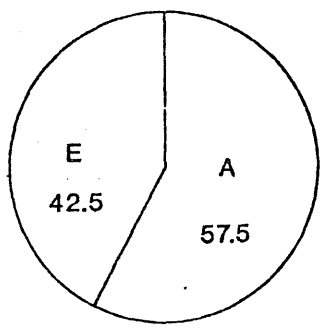
CANADA BASELINE
TOTAL : 14410 MTPY



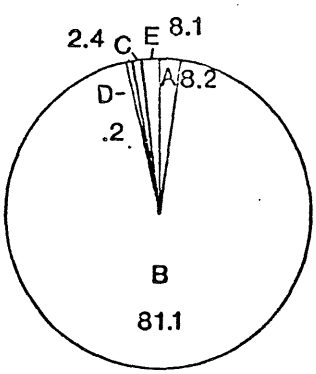
MINNESOTA PROJECTED
TOTAL : 51630 MTPY



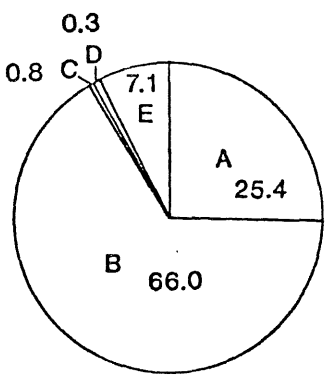
WISCONSIN PROJECTED
TOTAL : 2810 MTPY



CANADA PROJECTED
TOTAL : 3305 MTPY



REGION BASELINE
TOTAL : 92480 MTPY



REGION PROJECTED
TOTAL : 57740 MTPY

LEGEND

A - % POWER GENERATION

B - % TACONITE PROCESSING

C - % GRAIN ELEVATORS

D - % REFINERIES

E - % COMMERCIAL/INDUSTRIAL

SOURCE : RITCHIE (1978)

planned expansion of the MP&L Clay Boswell power plant in Cohassett, Minnesota, will increase regional particulate emissions by 2364, 1900, and 2145 mtpy, respectively. By 1985, taconite processing in Minnesota will contribute an estimated additional 6,274 mtpy particulates over present emissions. The taconite industry is the largest contributor to regional point source particulate emissions for both the baseline (81% of total baseline) and projected (66% of total projected) emissions. Figure 51 provides a comparison between present and projected emissions.

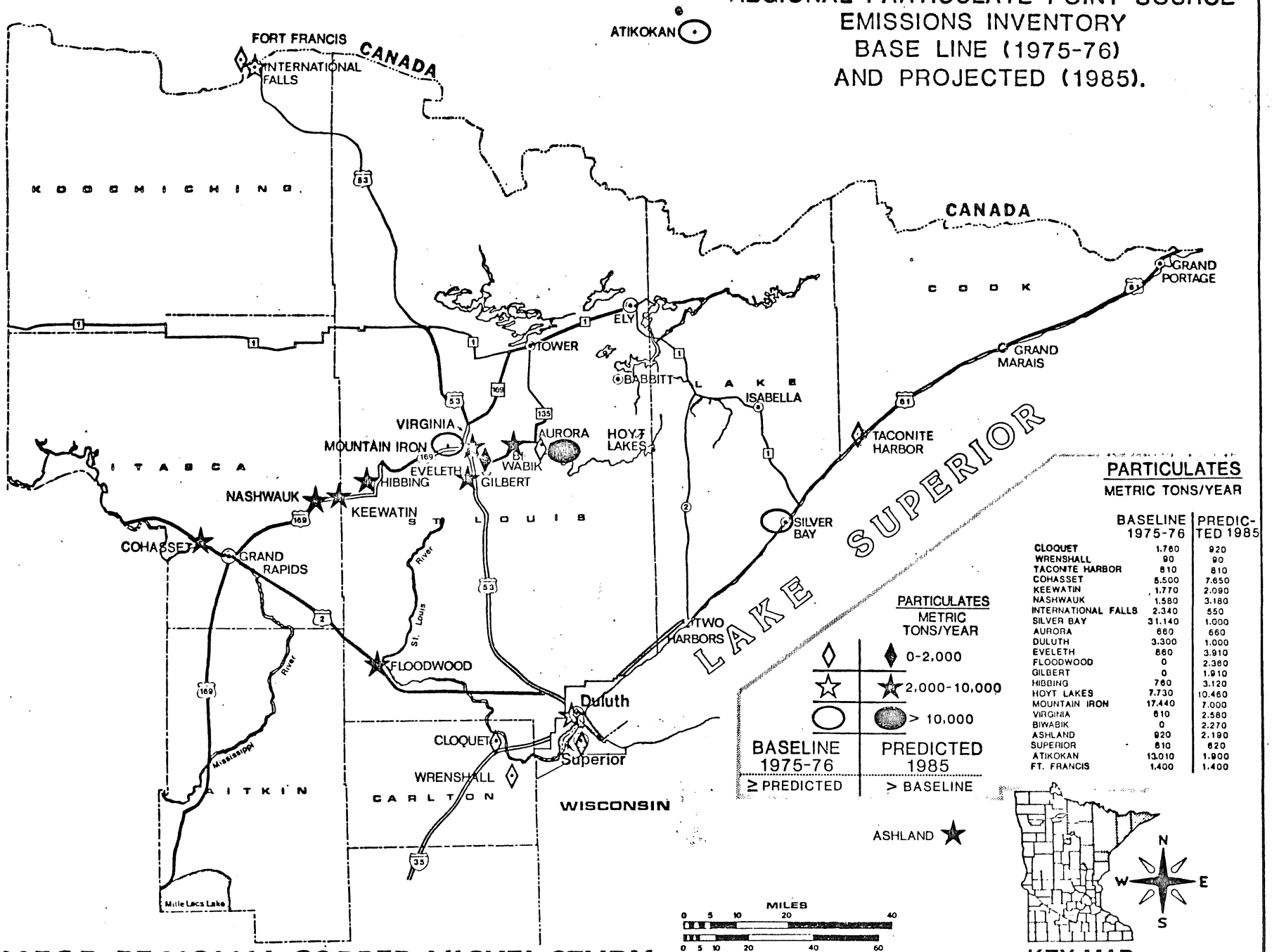
Figure 51

Although particulate point source emissions are expected to decrease, the decline may have little overall effect on the Study Area where fugitive emissions from area sources such as taconite mines and unpaved roads appear to be major sources of particulates. The extent of the fugitive emissions problem is currently being assessed by the Minnesota Pollution Control Agency. The contribution of area source emission to ambient TSP concentrations is discussed in section 3.5.1.2.

Total suspended particulate point source emissions in the Study Area may be placed into perspective by comparison to global, national, and regional emissions. The largest sources of atmospheric particulates are natural, contributing approximately 2,273 million mtpy (Robinson and Robbins 1971). These include both area and point sources. Natural particulate matter is produced by wind erosion of land and sea, forest fires, volcanic eruptions, vegetation, and gas-to-particle reactions. Anthropogenic sources contribute approximately 295 million mtpy which arise from industrial processes, combustion of fossil fuels, and agricultural activities (Robinson and Robbins 1971). Nationally, there has been a 23% decrease in particulate point source emissions from 1972 to 1975 (21.3

F JRE 51

REGIONAL PARTICULATE POINT SOURCE EMISSIONS INVENTORY BASE LINE (1975-76) AND PROJECTED (1985).



PARTICULATES
METRIC TONS/YEAR

	BASELINE 1975-76	PREDICTED 1985
CLOQUET	1,760	920
WRENSHALL	90	90
TACONITE HARBOR	810	810
COHASSET	5,500	7,650
KEEWATIN	1,770	2,090
NASHWAUK	1,580	3,180
INTERNATIONAL FALLS	2,340	550
SILVER BAY	31,140	1,000
AURORA	660	660
DULUTH	3,300	1,000
EVELETH	860	3,910
FLOODWOOD	0	2,360
GILBERT	0	1,910
HIBBING	760	3,120
HOYT LAKES	7,730	10,460
MOUNTAIN IRON	17,440	7,000
VIRGINIA	610	2,580
BIWABIK	0	2,270
ASHLAND	920	2,190
SUPERIOR	610	620
ATIKOKAN	13,010	1,900
FT. FRANCIS	1,400	1,400

MEQB REGIONAL COPPER-NICKEL STUDY

million mtpy compared to 16.4 million mtpy). This has been attributed primarily to the installation of control equipment on industrial processes and utilities, a reduction in coal consumption by non-utility stationary sources and a decrease in the burning of solid wastes (USEPA 1976a).

In Minnesota, point source particulates decreased by a substantial 43% from 1970-71 to 1973-74 (278,200 mtpy compared to 157,700 mtpy) primarily due to greater use of pollution control equipment. A comparison by source category of point source particulate emissions between the seven county metro area and the Study Area is given in Table 42 which clearly shows regional differences in industrial patterns.

Table 42

3.5.1.2 Ambient Particulate Concentrations--In order to understand both present and expected future ambient atmospheric particulate levels in the Study Area, a combination of data from actual field measurements coupled with computer modeling techniques was used. The field data produced a picture of existing particulate levels. Modeling work based on the baseline point source emissions inventory discussed in section 3.5.1.1 provided an understanding of the relative contribution of the anthropogenic sources to particulate levels. Projections for 1985 point source emissions provided the basis for understanding the changes which might be expected in TSP levels in the region in the absence of copper-nickel development. Each of these topics will be discussed in the following sections.

Results of Air Quality Sampling Program--The following discussion of ambient particulate levels is a summary of the analysis described in detail in Endersen

Table 42. 1976 point source particulate emissions inventory summary by source category for the Air Quality Study Region and the seven-county metro area.

REGION	POWER GENERATION	TACONITE	GRAIN	REFINERY	COMMERCIAL-INDUSTRIAL	TOTAL[a]
Seven-County Metro Area						
mtpy	10230	0	6285	2882	21230	40630
% of total	25.2	0	15.5	7.1	52.2	100
Air Quality Study Region						
mtpy	7651	75020	2180	148	7476	92480
% of total	8.2	81.1	2.4	.2	8.1	100

SOURCE: Ritchie 1978.

[a]Totals are rounded.

and Feeney (1979). The air quality sampling program established for the Regional Copper-Nickel Study was described earlier (section 3.2.2.1). Data on suspended particulates in the Study Area were gathered at 16 locations from October, 1976, to March, 1978, using high-volume samplers. A wide range of TSP concentrations was measured over this period; 24-hour concentrations ranged from 1 ug/m^3 (the minimum detectable level) to 367 ug/m^3. Annual geometric mean concentrations ranged from 10 ug/m^3 at Kawishiwi laboratory to 54 ug/m^3 at Virginia. Table 43 gives the adjusted geometric means for TSP concentrations during 1977 at the eleven sampling sites in the region (see map, Figure 10, section 3.2.2.1). A description of the data analysis procedures used is given in Feeney (1978). Note that all of the means are below both the primary (75 ug/m^3) and the secondary (60 ug/m^3) annual standards for TSP concentrations even though several measurements exceeded the 24-hour standards, notably at the community sites.

Table 43

The general character of each of the eleven sites is also identified in Table 43. It is interesting to corrolate the variability of the data from each site with the site's character. The background sites (Fernberg, Kawishiwi lab, and Toimi) tended to be the least variable. For example, a standard deviation of 13.5 ug/m^3 was observed in 1977 at Fernberg Road. Higher standard deviations were seen in industrial areas (24.0 ug/m^3 at the Erie Mining Office), and the greatest variability was seen at Virginia (66.1 ug/m^3). Variability this large is the result of a large number of sources in the immediate area, as well as the effects of events such as the strike against taconite mining operations in the second half of 1977. Histograms illustrating the distribution of TSP readings at each regional site during 1977 along with complete summary statistics are found

Table 43. Adjusted[a] annual geometric means at TSP sample sites (1977).

SITE NUMBER	SITE NAME	MEAN TSP (ug/m^3)	SITE CHARACTERISTICS
7001	Fernberg Road	10	Rural
7003	Kawishiwi Laboratory	10	Rural
7007	Toimi	12	Rural
7010	Hoyt Lakes Golf Course	15	Near town
7008	Erie Mining Office	19	Taconite mining
7006	Dunka Road	20	Taconite mining
7002	Ely High School	22	Community
7009	Hoyt Lakes Police Station	30	Community
7516	Hibbing	37	Community
7514	Mountain Iron	42	Community
1300	Virginia	54	Community

SOURCE: Endersen and Feeney (1978).

[a]Means have been adjusted for missing data (Feeney 1978).

in Figures 52 through 54. A box plot, permitting easy comparison of all Study Area stations, is presented in Figure 55. This plot illustrates the median, quartiles, minimum value, and maximum and second highest values for each site during 1977. Sample size is indicated below each site number.

Figures 52-55

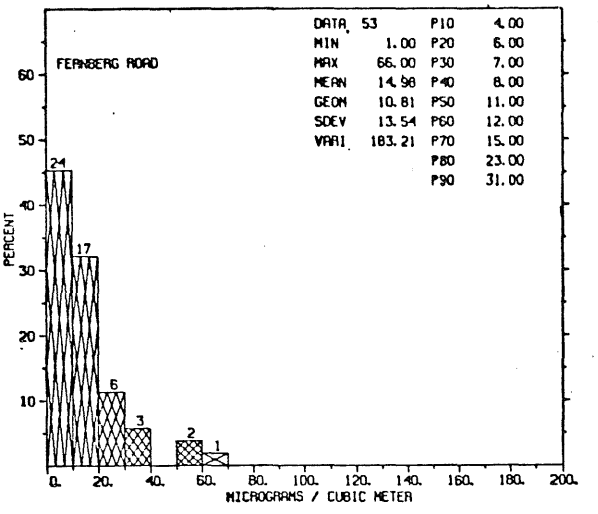
In addition to the variability among sites based on the different character of the various areas, it is apparent from the box plots in Figure 55 that TSP concentrations at a given site vary widely over time. As examples, Figures 56 and 57 present the variations of TSP at the Fernberg Road and Virginia sites, respectively. These graphs show the large fluctuations typically observed from sample to sample at the community sites with the much smaller variability at the background sites, including Toimi and the Kawishiwi Lab as well as the Fernberg Road site.

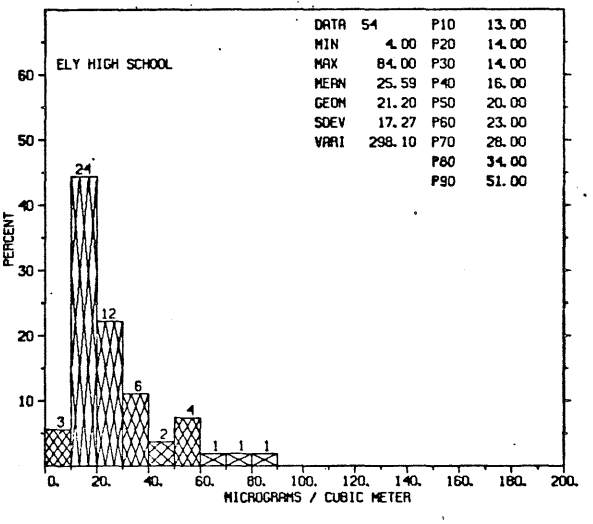
Figures 56 and 57

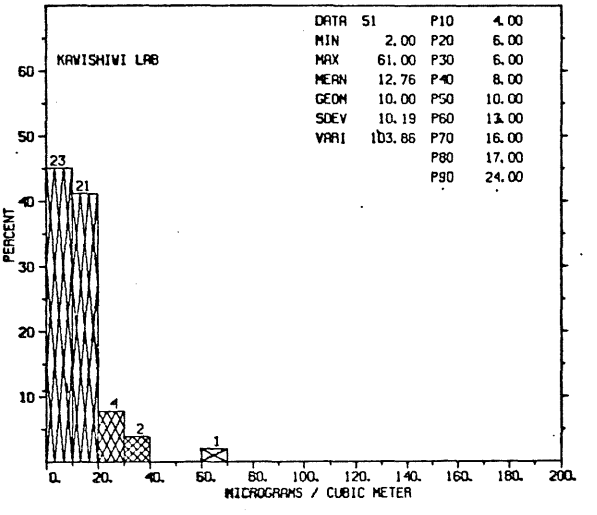
Also shown on these graphs are the 24-hour primary (260 ug/m^3) and secondary (150 ug/m^3) national ambient air quality standards for TSP. These standards are not to be exceeded more than once per year at any site. During the entire 1½-year course of the study, three readings greater than the primary standard and 18 readings greater than the secondary standard were observed in the region. Of the three readings exceeding the primary standard, two occurred in Virginia (see Figure 57) and the third in Hibbing. Of the 18 samples exceeding the secondary standard, 14 occurred at community sites (8 at Virginia, 4 at Mountain Iron, and 2 at Hoyt Lakes), 3 at the taconite mining of Dunka Road, and one at a background site, Kawishiwi Lab. None of the Study Area sites had geometric means in excess

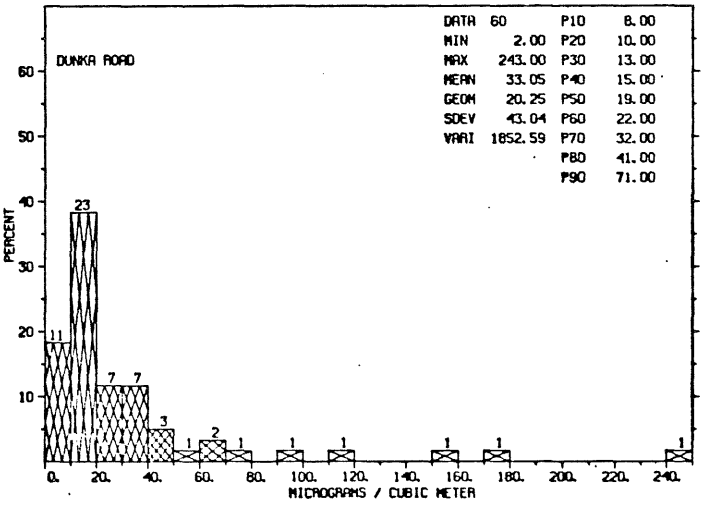
FIGURE 52

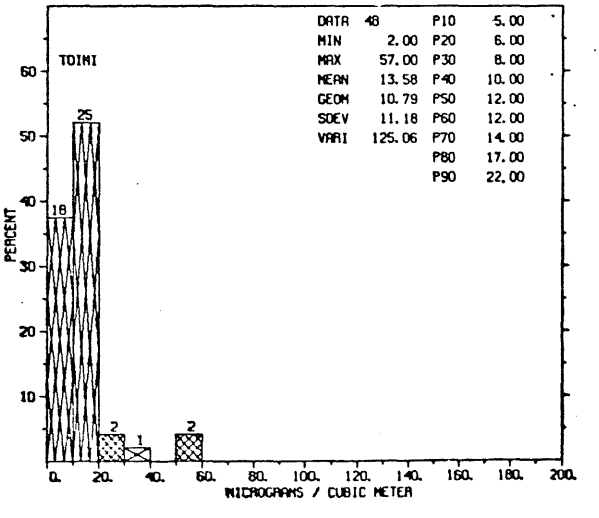
FREQUENCY DISTRIBUTION OF TOTAL SUSPENDED PARTICULATE CONCENTRATIONS FOR SELECTED SITES IN THE CU-NI STUDY REGION JAN-DEC 1977







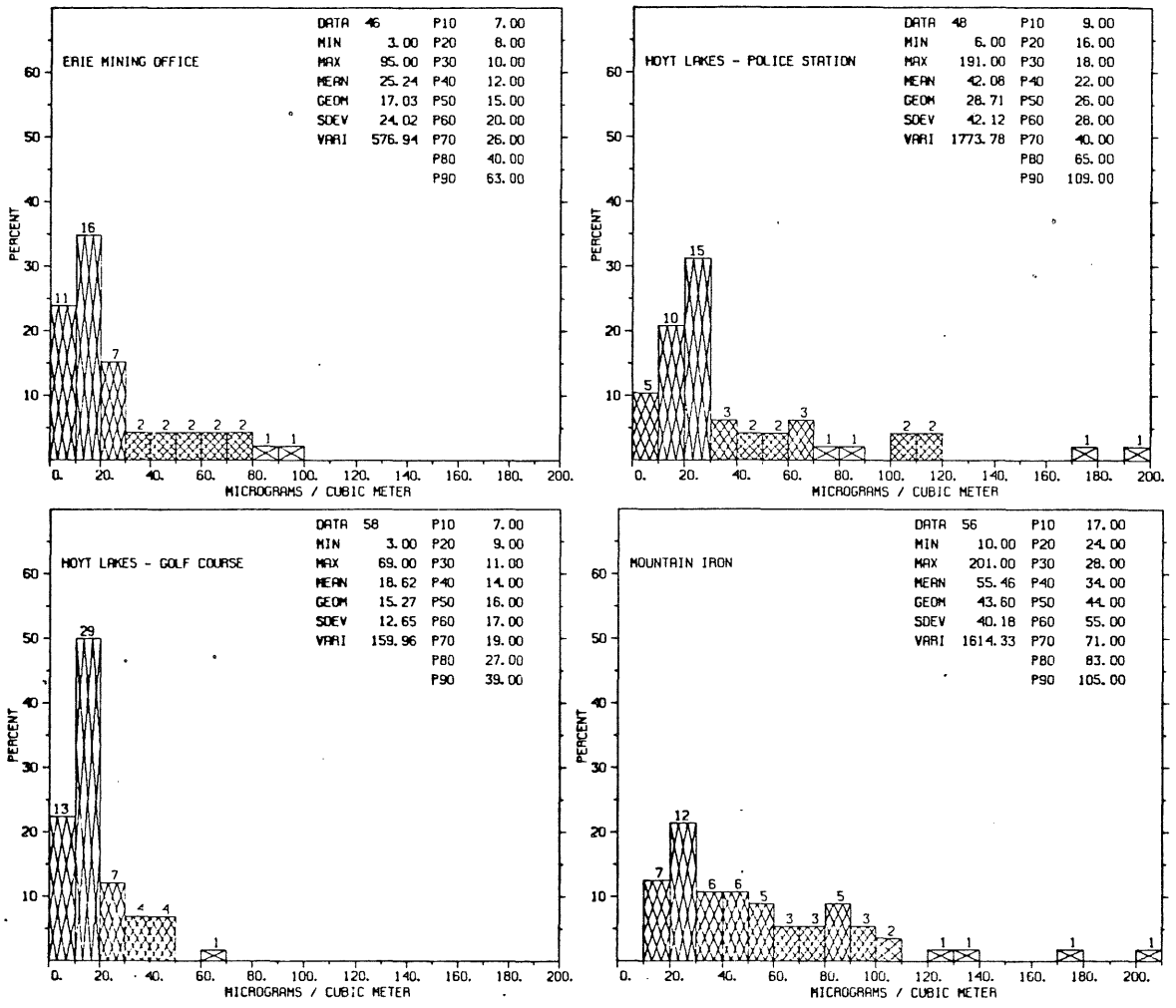




SOURCE : ENDERSEN & FEENEY (1979)

FIGURE 53

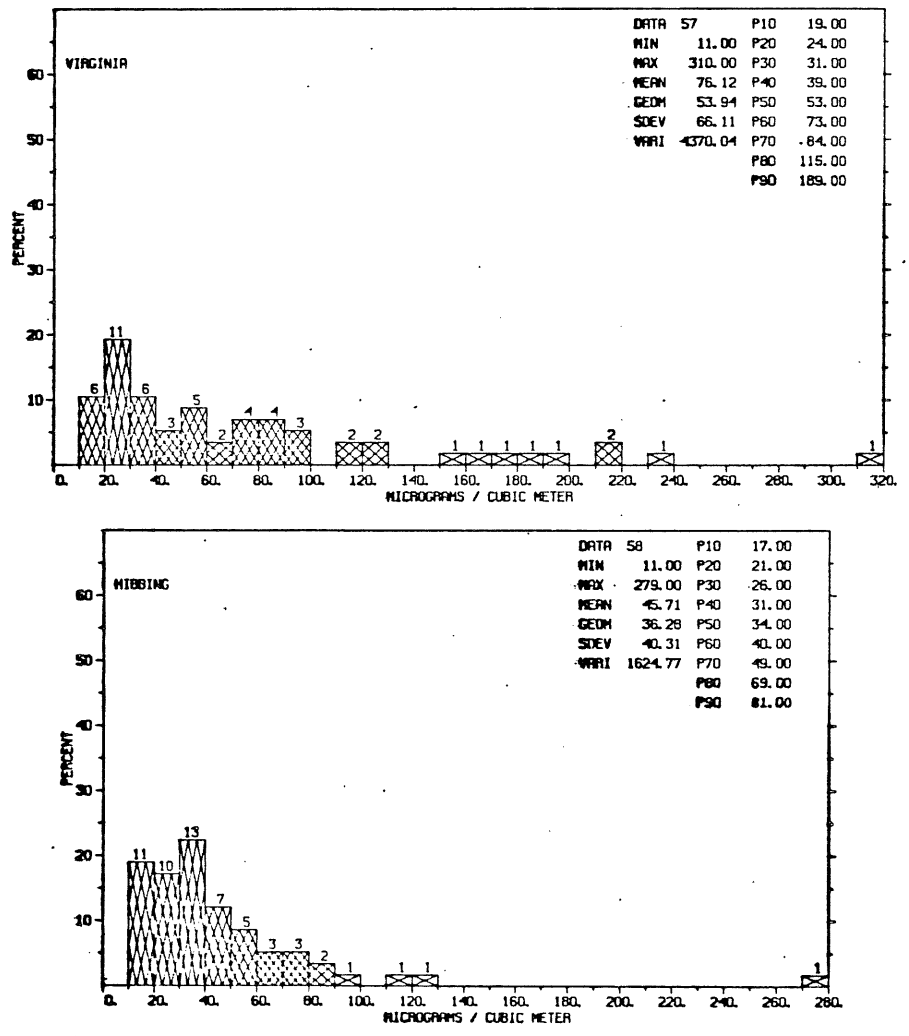
FREQUENCY DISTRIBUTION OF TOTAL SUSPENDED PARTICULATE CONCENTRATIONS FOR SELECTED SITES IN THE CU-NI STUDY REGION JAN-DEC 1977



SOURCE : ENDERSEN AND FEENEY (1979)

FIGURE 54

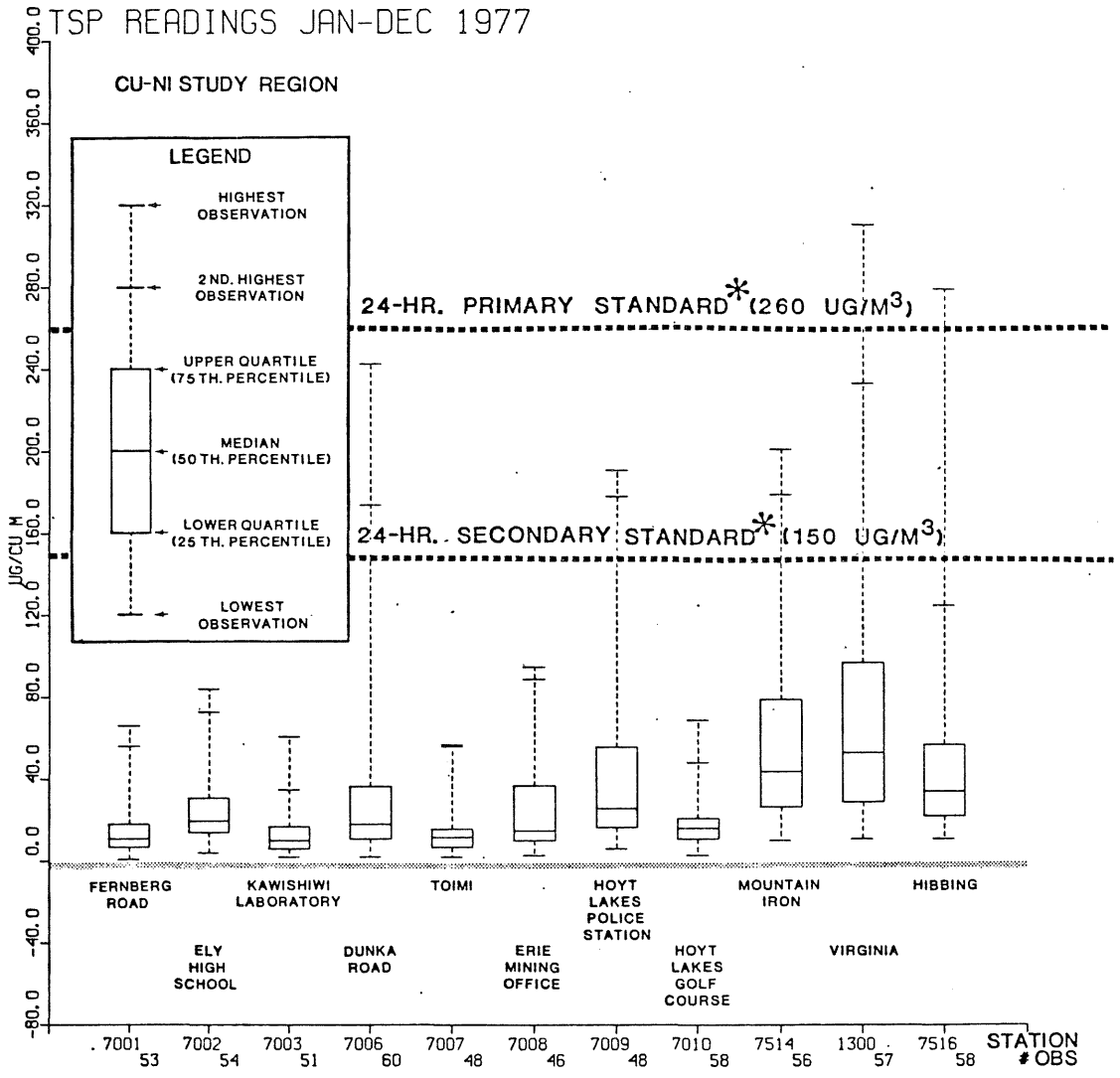
FREQUENCY DISTRIBUTION OF TOTAL SUSPENDED PARTICULATE CONCENTRATIONS FOR SELECTED SITES IN THE CU-NI STUDY REGION JAN-DEC 1977



SOURCE : ENDERSEN & FEENEY (1979)

FIGURE 55

TSP READINGS JAN.- DEC. 1977



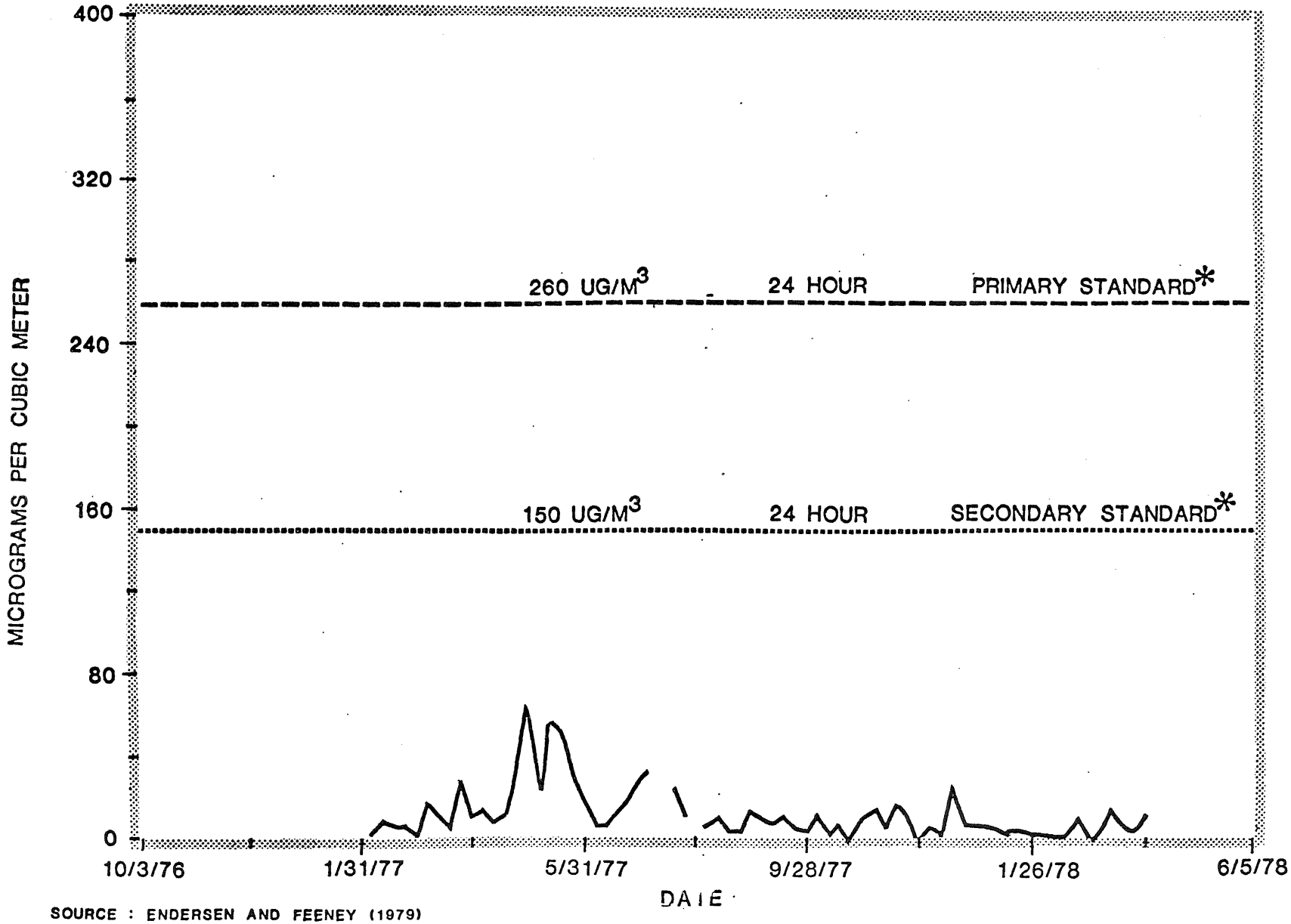
*STANDARDS ARE NOT TO BE EXCEEDED MORE THAN ONCE PER YEAR AT ANY SITE (MPCA, 1976)

SOURCE : ENDERSEN AND FEENEY (1978)

FIGURE 56

TSP AT FERNBERG ROAD

(24 HOUR SAMPLING PERIODS)



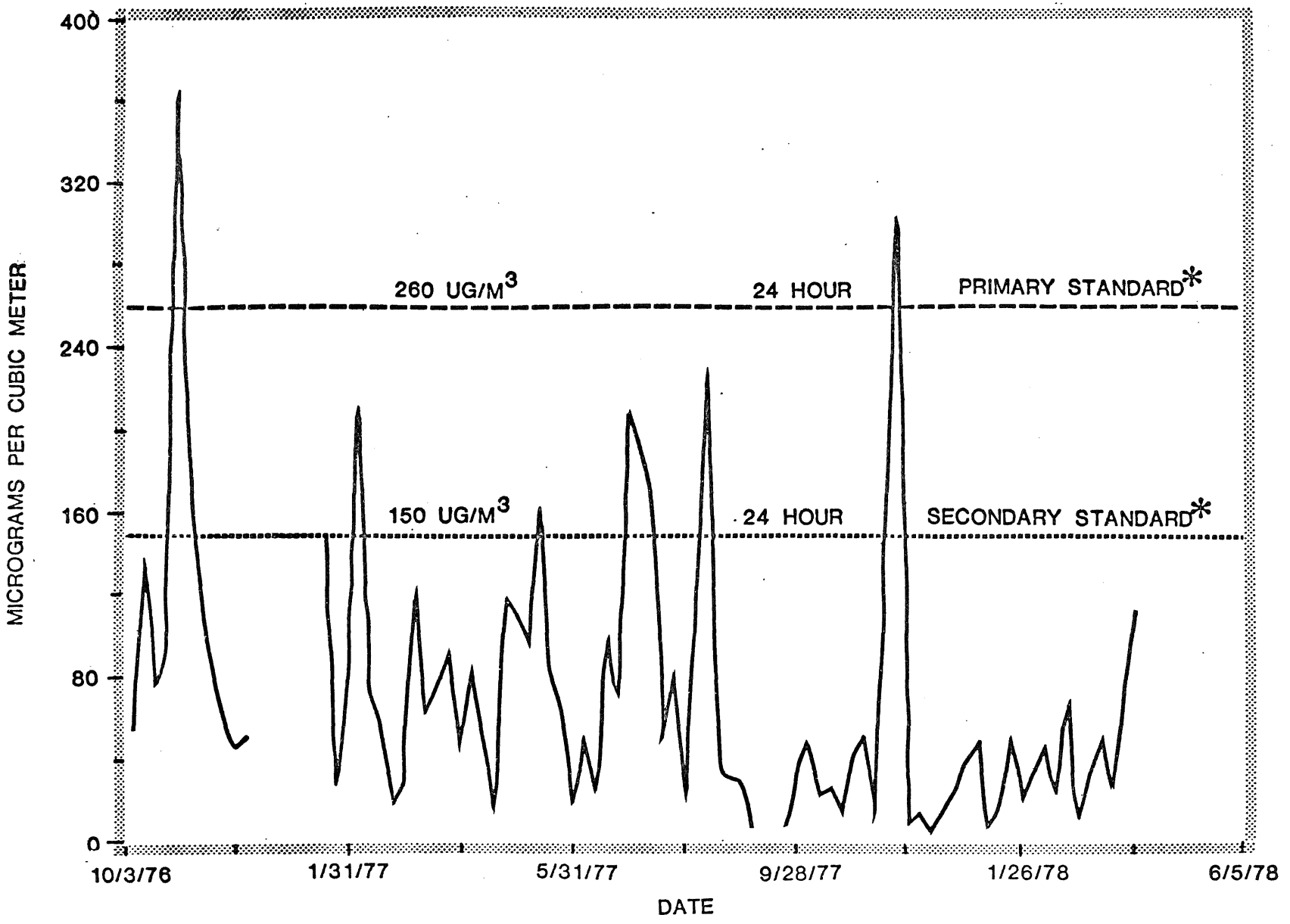
SOURCE : ENDERSEN AND FEENEY (1979)

*STANDARDS ARE NOT TO BE EXCEEDED MORE THAN ONCE PER YEAR AT ANY SITE (MPCA, 1976).

FIGURE 57

TSP AT VIRGINIA

(24 HOUR SAMPLING PERIODS)



SOURCE : ENDERSEN AND FEENEY (1979)

*STANDARDS ARE NOT TO BE EXCEEDED MORE THAN ONCE PER YEAR AT ANY SITE (MPCA, 1976)

of the annual primary standard of 75 ug/m^3 or the annual secondary standard of 60 ug/m^3.

A statistical model was developed to allow analysis of the TSP data in a manner which would reveal major temporal and spatial patterns in TSP concentrations over the course of the study and across the region sampled (see Feeney 1978). As seen in the annual geometric mean concentrations for the various sites (Table 43), there were significant differences among the sites which could be correlated with the type of activity in the site area. Further, there were also significant temporal effects, since conditions in the region were not constant over the sampling period. For example, effects attributed to the presence or absence of snow cover and the effects from a labor strike against the taconite mining operations from August through December, 1977, were evident. These various patterns will be discussed below.

Remote areas generally have quite low particulate concentrations and experience annual geometric mean TSP levels on the order of 10 ug/m^3. During the base year 1977, which included the taconite strike from August until December, the background sites at Fernberg Road, Kawishiwi Lab, and Toimi had adjusted annual geometric means of 10, 10, and 12 ug/m^3, respectively. These levels are far below the annual standard of 75 ug/m^3 and are typical of clean, remote mid-continental areas (Endersen and Feeney 1979). Total suspended particulate concentrations for a 24-hour period in the remote areas were as low as an extremely clean 1 or 2 ug/m^3 and were rarely greater than 20 ug/m^3. The maximum measured 24-hour concentrations at Fernberg Road, Kawishiwi Lab, and Toimi which occurred during the study period October, 1976, through March, 1978 (excluding 2 very high levels at Kawishiwi Lab caused by digging near the sampler) were 66, 61, and 57 ug/m^3, respectively. These levels are far below the 24-hour primary standard of 260 ug/m^3.

The developed areas comprised of communities and industrial facilities have significantly higher particulate levels than do the remote areas. The 1977 TSP geometric means in these areas were approximately 2 to 5 times those measured at the background sites. The highest 1977 geometric mean was the 54 ug/m^3 measured at Virginia. Mean TSP levels in the developed areas of the region are in the range of those measured in non-severely impacted small to medium sized cities, generally larger than those in and near the Study Area. To place these values into perspective, Figure 58 presents the geometric mean TSP levels for selected monitoring sites for 1977. The figure also shows data for other sites around the state and nation for comparison. It is apparent that the cities have levels comparable to other developed areas in the nation, and the undeveloped portions of the region as represented by the Fernberg Road site are as low as other remote wilderness areas nationally.

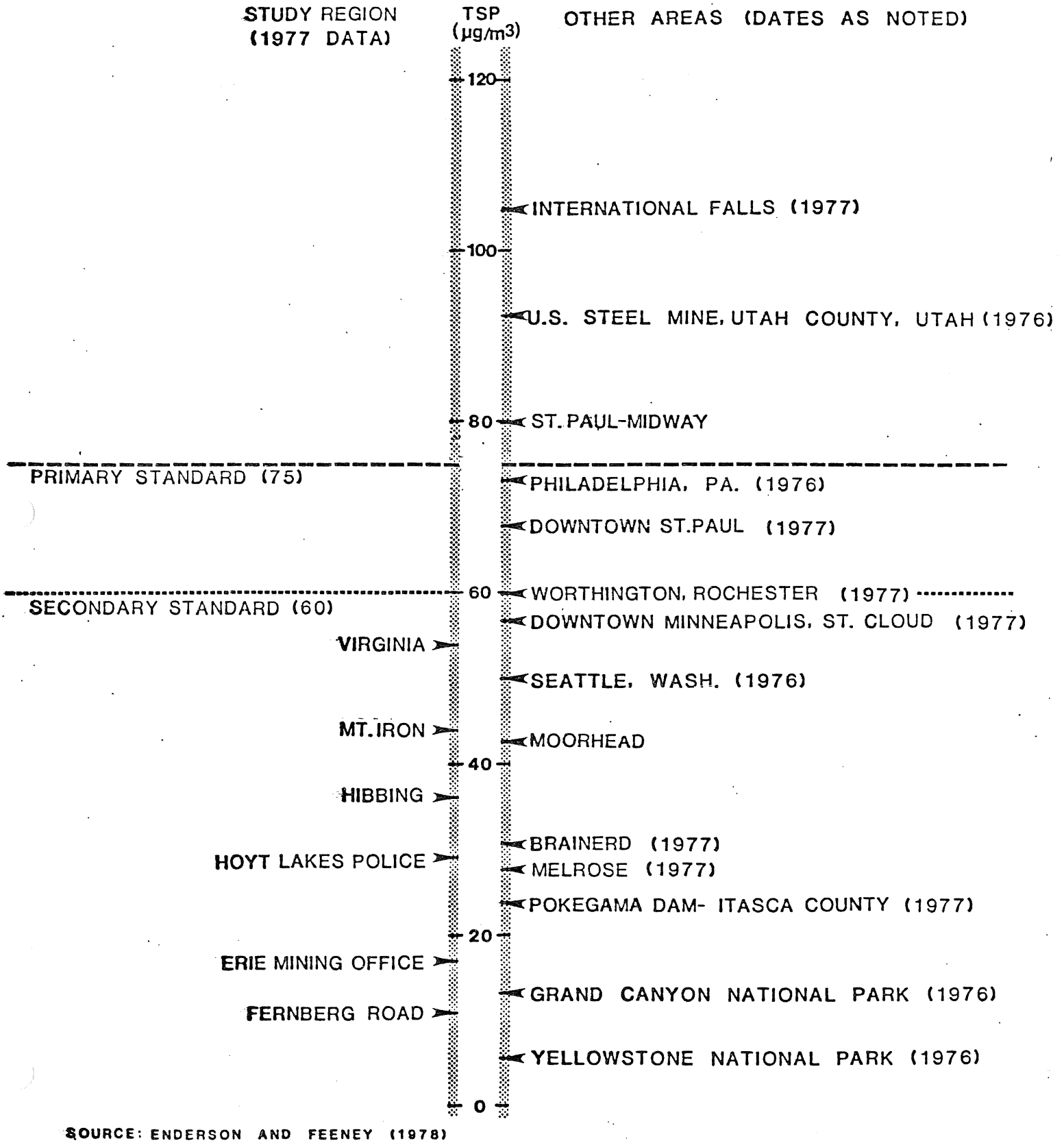
Figure 58

It is apparent that the communities are the most impacted areas of the region. Community TSP levels very rarely fell below 10 ug/m^3 for a 24-hour period. Most of the measured high values and readings which exceeded ambient standards were recorded in the communities. These community levels, varying from near background to well in excess of the 24-hour standards, were caused by varying mixtures of emissions from such sources as industry (including nearby mining), commerce, home heating, automobiles, and resuspension of dust from paved roads.

The mining communities (those communities within a few kilometers of active mines) are generally more impacted than the non-mining communities apparently because of the additional nearby emissions sources. For example, Table 44 presents the adjusted mean annual TSP levels for five communities along with their

FIGURE 58

GEOMETRIC MEAN ANNUAL TSP CONCENTRATIONS



SOURCE: ENDERSON AND FEENEY (1978)

population levels and basic character. The mining influence is apparent. Virginia, a city with substantial nearby mining, had a 1977 annual mean TSP level of 54 ug/m^3, while Hibbing, with 30% greater population but little active local mining, had a mean of 37 ug/m^3. Among the smaller communities, Ely is fairly distant (more than 20 km) and along an uncommon wind direction from the mining area and had a 1977 TSP mean of 22 ug/m^3. By comparison, Mountain Iron, which has about half the population of Ely but is adjacent to a large taconite operation, had a mean level of 42 ug/m^3 which is twice that of Ely. Hoyt Lakes is about the same size as Mountain Iron but had a much lower TSP level of 30 ug/m^3. This difference may be attributed largely to the fact that Hoyt Lakes is roughly 7 km south of the nearest taconite operation while Mountain Iron is only some 2 to 3 km south of an active operation.

Table 44

Community size, in addition to proximity to mining activity, can account for a substantial portion of observed particulate levels. The cumulative effect of the community sources in non-mining communities can be seen by comparing the adjusted TSP level of 22 ug/m^3 at Ely with that of 37 ug/m^3 at the much larger city of Hibbing. The importance of population to TSP levels without significant mining effects was demonstrated for August-October, 1977 (no taconite mining or snow cover) when the correlation of TSP with population was 0.68. During the remainder of the mine strike with snow on the ground, this correlation went up to 0.78. This highly significant winter relationship may indicate the decreased importance of windblown dust and increased importance of home heating emissions during that time of year.

Table 44. TSP data for selected area communities.

COMMUNITY	1976 POPULATION	ADJUSTED MEAN ANNUAL TSP (1977) (ug/m^3)	CHARACTER
Mountain Iron	3756	42	mining (2-3 km)
Hoyt Lakes	3722	30	mining (7-8 km)
Ely	4961	22	non-mining
Virginia	11,730	54	mining (3-4 km)
Hibbing	16,116	37	non-mining

SOURCE: Endersen and Feeney, 1979.

The community size effect is also important for a mining community (but may be less apparent in areas of major mining impact). Virginia, for example, had a high TSP level and more exceedances of the TSP standards than did the much smaller community of Mountain Iron. These higher levels in the larger mining communities seem to result from the larger numbers of general community sources and the greater amount of mining activity usually found nearby.

Total suspended particulate concentrations measured on mining property were about twice the background but were generally much lower than those in the communities during the study period. The Erie Office site, located on a low rooftop about 1 km south-southwest of a taconite processing plant and surrounded by mining operations and roads, had a 1977 adjusted geometric mean TSP level of only 19 ug/m^3. It must be noted that this low value was strongly affected both by the taconite strike that closed Erie Mining Company for five months during that year and by sampling problems that resulted in lost data during the warm season prior to the strike. However, a mean TSP level lower than that found at community sites is consistent with the expectation that the particles emitted in mining areas are primarily large particles (greater than 1 um) generated by physical processes and emitted near the surface or from relatively short stacks. These large particles have high deposition velocities and usually deposit near the source except during periods of very strong winds.

Particulate concentrations within a mine site can be locally very high. The Dunka Road site had a mean TSP level of only 20 ug/m^3 and showed only a small impact from the direction of the Erie Mining Company processing plant 15 km to the west, but did demonstrate the high local concentrations that can be produced by unpaved roads. However, the highest concentrations at Dunka Road, including the maximum level of 243 ug/m^3, occurred on the infrequent days of heavy travel

on an uncontrolled dirt road which intersected the Dunka Road just west of the sampler. Dunka Road itself, about 100 m north of the sampler, had much more traffic and was on a major wind axis to the sampler. Concentrations from this direction were much lower than those from the west, probably as a result of Erie Mining Company's very effective chemical dust control program.

Loading, hauling, and dumping areas within the mines experience by far the highest short-term (on the order of a minute) concentrations in the region. The staff of the Particle Technology Laboratory of the University of Minnesota conducted on-site measurements at a taconite operation as part of the Regional Study (Wilson et al. 1979). A mobile laboratory was employed to measure particle concentrations and characteristics in the dust plumes from a variety of mining operations. The study focused on coarse particles greater than 1 micrometer (um) in diameter which dominate TSP near mechanical sources and may be used to characterize the amount of dust in the air. Assuming a specific gravity of 3 for the particles being measured, concentrations of 1,065, 1,125, and 1,800 ug/m^3 (recorded as 355, 375 and 600 um^3/cm^3) for coarse particles were observed during 3 passes of 85-ton haul trucks at a distance of about 10 m. Although the particle specific gravity involved may range from 2 to 4, thus altering the conversion to ug/m^3, the particulate loadings would still be from several hundred to over a thousand ug/m^3. Clearly, operations such as loading and hauling emit large masses of coarse particles near ground level. However, the large particle sizes and low wind speeds frequently found in the pit areas allow most of the mass of particles to fall out very close to the sources. It should be noted that although blasting injects particles much higher into the atmosphere, it occurs too infrequently to be a significant contributor to long-term particulate levels.

The mobile lab study also found that mining sources such as ore dumping and processing operations and tailing basins produce particles with iron-to-silicon ratios greater than one. Concentrations away from these operations tend to be higher in silicon than iron, however, indicating the importance of local dust sources such as unpaved roads. Unpaved roads can be very significant sources of particulates over short ranges. Particles are lifted from gravel and dirt roads by vehicles and transported downwind. Relatively little road dust is lifted by wind alone. As discussed previously, the Dunka Road site demonstrated a large effect from a nearby uncontrolled dirt road and a much smaller effect from the chemically controlled Dunka Road. The mobile lab study measured average concentrations of from 69 to 2,600 ug/m^3 (using a specific gravity of 3 with volumetric data of 23 to 863 um^3/cm^3) for the plume of a single vehicle passing 110 m upwind on an unpaved road during a light wind, with neutral to stable conditions. Concentrations increased rapidly with vehicle speed and decreased dramatically with distance from the road. As noted above, TSP levels produced by road dust typically had low iron-to-silicon ratios (less than one) compared with ratios greater than one near mining sources (see Wilson et al. 1979).

The Toimi site is located near and west of a lightly traveled unpaved road. Concentrations from the east at that site were generally low, indicating that moderately frequent travel is needed to produce elevated TSP levels.

In addition to chemical control of road dust, nearby vegetation also controls the dispersion of dust. Trees and shrubs can decrease wind speeds and thus the potential transport distance near a road. Trees also act as a filter to remove particles from a passing dust cloud. However, strong winds, of at least 17 km/hr as indicated in the mobile lab study can resuspend this dust and distribute it

over a wider area than would have been possible during the initial suspension. Dense vegetation or the occurrence of precipitation can prevent additional dispersion of the intercepted dust.

Paved roads can also be important local sources of particulates in some communities where particles from nearby sources are deposited on the roads and resuspended by vehicles. Mountain Iron seems to show this effect; particles from Minntac (U.S. Steel's taconite operation) appear to be deposited on the city streets and then are resuspended by heavy automobile traffic. These particles are believed to contribute to the elevated TSP levels from the south at the Mountain Iron sampling site.

The general importance of nearby sources is apparent in the developed areas where measured TSP levels are generally easily explained by sources within a few kilometers of the sampling sites. Mountain Iron and Virginia, for example, were the two most impacted air quality sampling sites in the Study Area. By correlating peak TSP readings at Mountain Iron with wind direction, it is seen that these values can be interpreted as resulting mainly from the Minntac processing plant 2 km to the north-northwest, the Minntac open pit to the north and northwest, local traffic and a tailing basin to the west-southwest, and particulate resuspension from streets to the south (see Endersen and Feeney 1979 for further information in the form of pollution roses for each TSP site).

The effects of plume dispersion, coupled with the rapid fallout of large particles close to the source, act to limit the influences of the mines and communities on the background areas. The three remote sites, Toimi, Fernberg Road, and the Kawishiwi Lab, were at different distances from and orientations to the developed areas. Nontheless, they experienced quite similar TSP concentrations.

These strong similarities among the three sites suggest that particulate levels in the remote areas of northeastern Minnesota are very strongly influenced by region-wide events.

In the context of the region as a whole, it must be noted that although TSP concentrations are consistently high only near significant sources, the developed areas also make a significant contribution to the air quality of the entire Study Area. This influence on the very clean background air is apparent for all three remote sites. Each site received contributions from the directions of the developed areas that, while quite low, are nevertheless much larger than those from the northeast. It is hypothesized that the particles arriving at these remote locations are primarily the smaller particles with lower deposition velocities and, therefore, greater potential for transport.

Further evidence of the effect of local sources in the region was observed as a result of the labor strike against the taconite mining operations during August-December, 1977. This provided a unique opportunity to measure the impact of these operations on regional air quality. Total suspended particulate concentrations in all portions of the Study Area decreased substantially during this period. Late summer concentrations at the eleven sampling locations decreased an average of 59% over the period immediately preceding the strike. Not surprisingly, the impact appeared to be the greatest at the locations on mining property with the sampler at the Erie Mining Office showing a 76% drop. Areas showing less of an effect were the background sites with a decrease of 46% at the Kawishiwi Lab, and the largest communities with decreases of about 45% at Virginia and Hibbing.

Perhaps the stongest indication of the importance of mining-related sources to the air quality of the entire region is that no site decreased by less than 45%

during the strike. The differences in concentrations among sampling locations decreased substantially during the strike, though some significant differences between portions of the Study Area did remain. The TSP decrease was least in the larger communities, suggesting that particulate levels in these areas are strongly controlled by factors other than mining. The general level of activity within the communities, which may have increased while the mines were shut down, seems to be an important factor.

Long distance transport of suspended particulates appears to be a major component of the regional background concentrations measured at the three remote sites. Total suspended particulate levels for all sites were generally elevated when winds were from the south even where there are no known local sources, suggesting transport of particulates from distant sources. Possible source areas in the Upper Midwest include the Duluth area (80 km south of Hoyt Lakes), Minneapolis-St. Paul (300 km south-southwest of Hoyt Lakes), and Chicago (750 km southeast of Hoyt Lakes). Recent research (see Lyons and Husar 1976; Lyons, Dooley and Whitby 1978) has indicated that large masses of pollutants can be transported northward from the Ohio River and lower Mississippi River valley areas. These polluted air masses sometimes are transported to northern Minnesota before being forced eastward across the Great Lakes. Southerly winds are common in northeastern Minnesota in the summer and are responsible for a large portion of the annual background TSP levels, as demonstrated by the strong TSP peaks during periods when the winds are from the south and southeast.

The TSP values also are elevated at Fernberg Road and Kawishiwi Lab under westerly winds. These levels probably represent medium range transport of particulates from the Mesabi Range communities and mines more than 50 km to the west. These particulates, although from regional sources, produce smaller

contributions to annual TSP levels than do those to the north-northwest or south because westerly winds are relatively uncommon.

The possibility also exists for long distance transport of particulates from International Falls, 140 km northwest of Ely. With its paper industry, International Falls has large stack emissions and ambient concentrations of particulates, and it is on the primary wind axis for the entire Study Area. Although concentrations from the northwest are low at most sites, they are generally significantly higher than the extremely low values measured from the northeast. Transport from International Falls would explain the enhanced concentrations associated with northwest winds at background sites (see Endersen and Feeney 1979).

Regional particulate concentrations are highly dependent on meteorological conditions, as demonstrated by the relationships with wind direction which have been discussed. Precipitation is also of major importance in reducing particulate levels. Rain has the immediate effect of removing particles from the atmosphere and wets the surface to decrease lift-off by wind and vehicles. Snow is much less efficient at removing particles from the atmosphere, but is an excellent cover to prevent lift-off. Correlations between TSP and precipitation occurrence were computed for both the day before and day of TSP sample collection. Correlations at each site were negative, indicating that precipitation is associated with periods of low TSP levels. The large effect of snow cover in reducing ambient particulate concentrations is clearly seen in the time lines for Fernberg Road and Virginia (Figures 56 and 57) and the adjusted mean TSP concentrations for each time period as listed in Table 45. In general, TSP concentrations were much lower during snow cover for periods of both normal mining activity and the mine strike. This effect was smaller in the communities

than at other sites, perhaps in response to home heating and commerce in communities during the winter and the importance of unpaved roads and windblown dust in rural areas in summer.

Table 45

The overall effect of a very dry period, such as occurred during 1976, can be seen in the trend plots for Hibbing, Mountain Iron, and Virginia shown in Figure 59. Hibbing, which had shown a gradual decrease in TSP levels during the early 1970s, showed a definite increase in 1976. Mountain Iron and Virginia, sites which revealed no clear trend during the 1970s, also experienced increased levels during 1976. Levels during 1977, a much wetter year that included the 5-month taconite strike, dropped back to the pre-1976 levels at each site. These results suggest the importance of ground sources of particulates.

Figure 59

It must be noted that some high TSP concentrations, sometimes more than 10 times the annual geometric mean, occurred in most areas. Some of these levels occurred under normal conditions and can be expected to recur occasionally. For example, the narrow plumes from the Minntac and Erie Mining taconite processing plants occasionally impinge on the sampling sites at Mountain Iron and the Erie Office, respectively, for sufficient time to produce a large effect on the 24-hour TSP level. A similar effect occurs when an unusual wind direction brings high-TSP air to a normally clean area, such as when southwesterly winds transport particles from the developed areas of the Mesabi Range to Fernberg Road or Kawishiwi Lab. Intermittent sources can also produce these peak values, as when sporadic heavy use of the uncontrolled dirt road near the Dunka Road site produced TSP concentrations as high as 243 ug/m^3.

Table 45. Mean TSP concentrations for all eleven sites in the Copper-Nickel Study Area per time period.

DATES	EVENT	ADJUSTED[a] MEAN TSP (ug/m^3)
11/26/76-3/7/77	Snow cover	18.97
3/14/77-7/24/77	Mining activity No snow cover	35.64
7/30/77-10/4/77	Mine strike No snow cover	14.63[b]
10/10/77	Snow event	7.23
10/16/77-11/9/77	Mining strike No snow cover	16.68
11/16/77-12/15/77	Mine strike Snow cover	13.02
12/21/77-3/27/77	Mining activity resumed Snow cover	15.56

SOURCE: Endersen and Feeney (1979)

[a]Values have been adjusted for missing data.

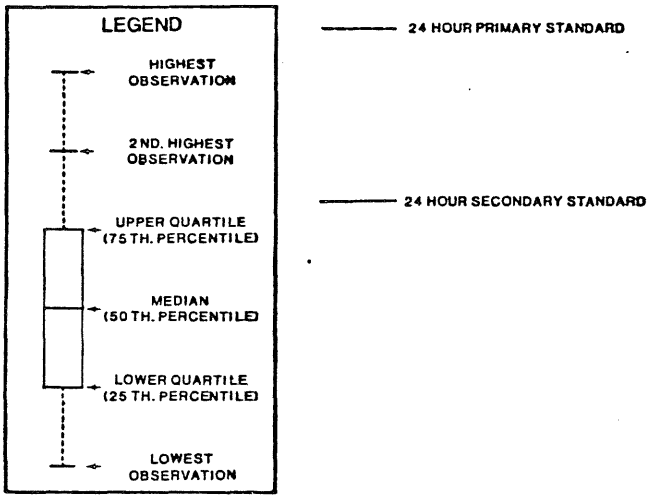
[b]The mining strike began officially on August 1, but the mines were effectively shut down as of July 30. Samples taken on July 30 were included in the strike period.

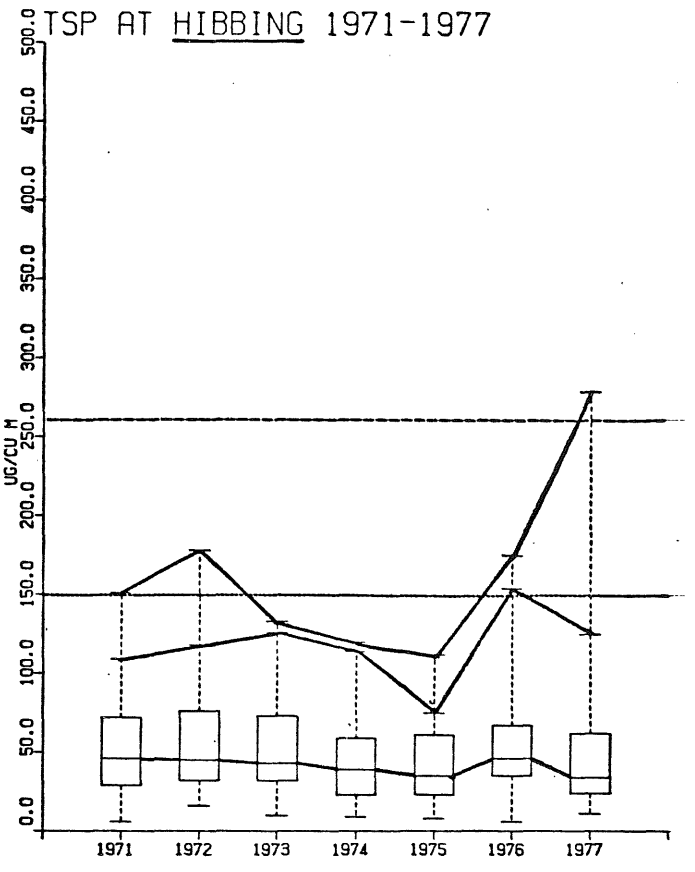
FIGURE 59

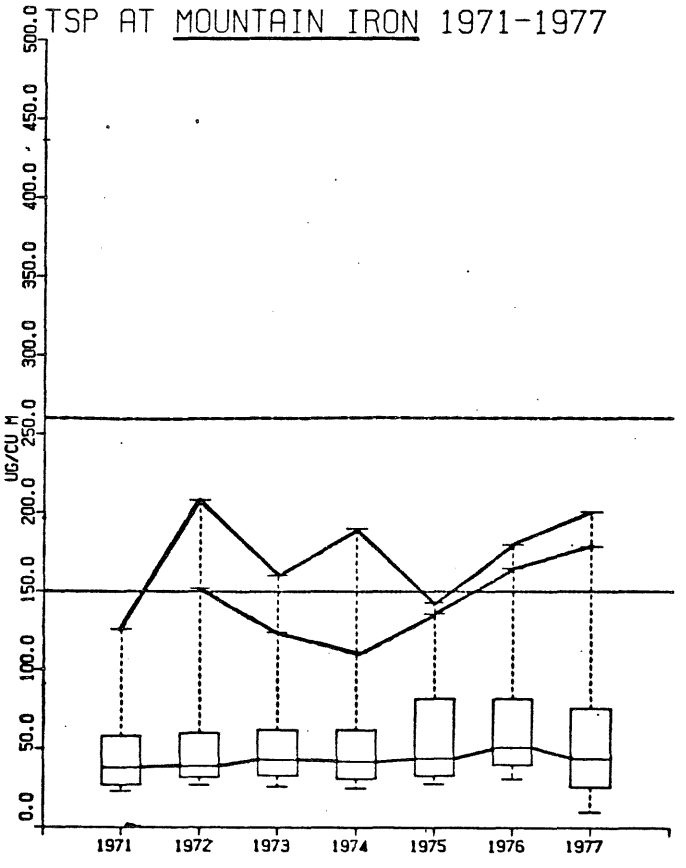
TRENDS IN TOTAL SUSPENDED PARTICULATES

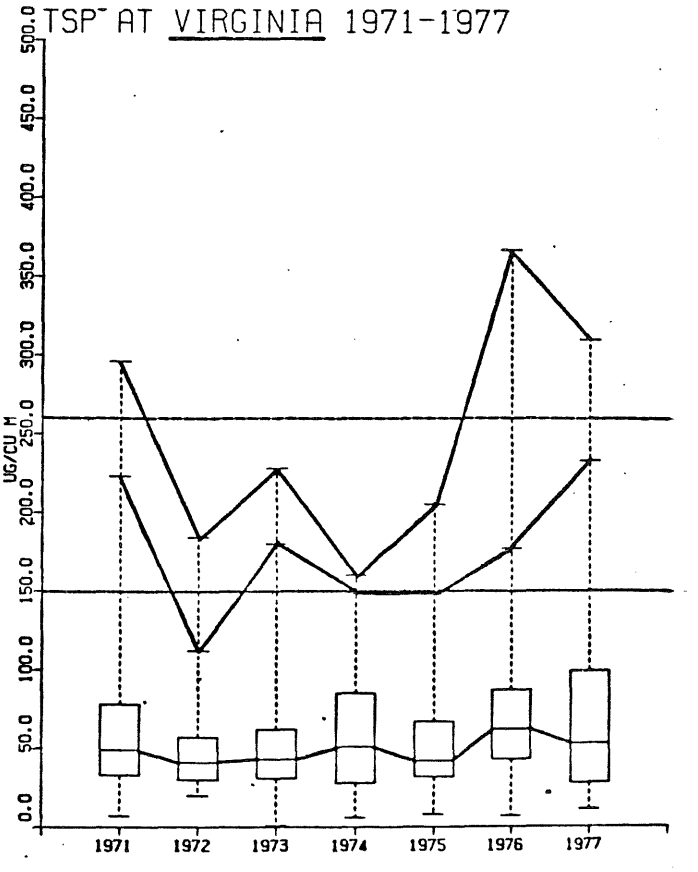
(24-HOUR SAMPLES 1971-1977)

COPPER-NICKEL STUDY AREA









SOURCE: ENDERSEN AND FEENEY (1979)

Combinations of mechanisms can also produce unusually high particulate levels. For example, a plume from a nearby source could impinge on a sampler during a period of elevated regional levels caused by long range transport or windblown dust. Such a combination may have been responsible for the highest TSP measurement at Ely High School (84 ug/m^3) on a day of high regional levels. High TSP concentrations can also be caused by very unusual activity which is not likely to recur. These activities included digging during utility work next to the Kawishiwi Lab and reroofing the Hoyt Lakes Police Station, which produced very high TSP concentrations at those sites. The Hibbing site had one unexpectedly high measurement (279 ug/m^3) of undetermined origin, although local sources and/or forest fires are possibilities.

In summary, the air quality of the Study Area is generally characterized by very low particulate levels. The region is dotted with impacted areas caused by communities, mines, and unpaved roads. These impacted areas tend to be concentrated along the Mesabi Range near the mines and centers of population. Particulate concentrations in plumes from these developed areas decrease rapidly with distance, but have a discernible impact on air quality throughout the region. The TSP background in remote areas is a product of very clean air entering the region from the north (especially the northeast), generally elevated levels from the south as a result of long distance transport, and impacts from distant mining areas and communities. TSP impacts are suppressed considerably during periods of snow cover or rainfall.

The regional nature of most air quality impacts indicates that much of the area northeast of the Mesabi Range, including most of the BWCA, has generally very low particulate levels and probably exhibits patterns very similar to those observed at Fernberg Road. Exceptions undoubtedly occur near local sources such as cabins

with fireplaces, campfires, and communities (especially Ely and Winton). Also, the elevated TSP levels during periods with winds from the southwest, caused by infrequent winds from the developed areas on the Iron Range, would be expected to decrease with distance northeast of the Fernberg Road site. The possibility exists of detecting contributions from such distant sources as Thunder Bay to the northeast and the Atikokan taconite plants to the north, but significant concentrations were not observed from those directions at Fernberg Road during the Study.

The area south of the developed Mesabi Range area and away from the short-range effects of the Duluth/Northshore area is probably impacted very similarly to Toimi. That is, the particulate levels are generally very low with the cleanest air coming from the northeast. A small impact from the direction of the Mesabi Range to the northwest is exceeded in total contribution by a wide angle of impact from the south. As there are few local sources, most of this southerly impact is likely from medium and long distance transport. Areas west of Toimi should experience a greater impact from mining and community activity than areas farther east.

The region northwest of the Mesabi Range is virtually devoid of particulate sources for about 130 km to International Falls and probably has very low TSP levels except near the few small local sources. However, levels may be somewhat higher than those found in similar remote areas northeast and south of the Range. Transport of dust from the mining areas is a much larger contributor to TSP levels when there is no snow cover, and the frequent southeast winds of summer may be responsible for higher remote TSP concentrations than those experienced at Fernberg Road.

The analyses of data and familiarity with each site allow attributing the 1977 adjusted mean TSP level for each Study Area site to five major source categories: background (includes long-range transport, region-wide dust generation, and some minimum level of impact from distant regional sources), communities, mining/processing, unpaved roads, and unusual local sources. The ranges of impacts likely in northeastern Minnesota for these source categories in a year such as 1977 are as follows:

Estimated Contributions to Annual TSP

Source Category	ug/m^3
Background	10
Communities	10-30
Mining/processing	$1-30^+$ (high very close to transfer points)
Unpaved roads	$0-10^+$ (high very close to uncontrolled roads)
Unusual local sources	0-10

The actual level at a site is the sum of contributions from each of the relevant sources listed. It is very important to realize that these estimates are for a generally wet year with a long mine strike and are undoubtedly less than the values to be expected in a more normal year.

The above estimated source category contributions to TSP were derived by apportioning geometric means into arithmetic components, a procedure that is not valid mathematically. The scheme, however, does provide reasonable estimates for various types and degrees of TSP impacts experienced in northeastern Minnesota. These values can be used in combination with the mechanisms discussed in this report (and a great deal of caution) to estimate approximate particulate concentration levels in unsampled areas and for first-cut estimation of approximate levels to be expected near future developments.

Modeling of Ambient TSP Concentrations--The following discussion of mesoscale modeling is a summary of the work performed by Ingrid Ritchie, Joe Bowman, and George Burnett. Ambient TSP concentrations were modeled to estimate the relative contribution of particulate point sources to the overall TSP levels. This provided a basis for extrapolating into the future (1985) to predict TSP levels based on expected changes in point source emissions.

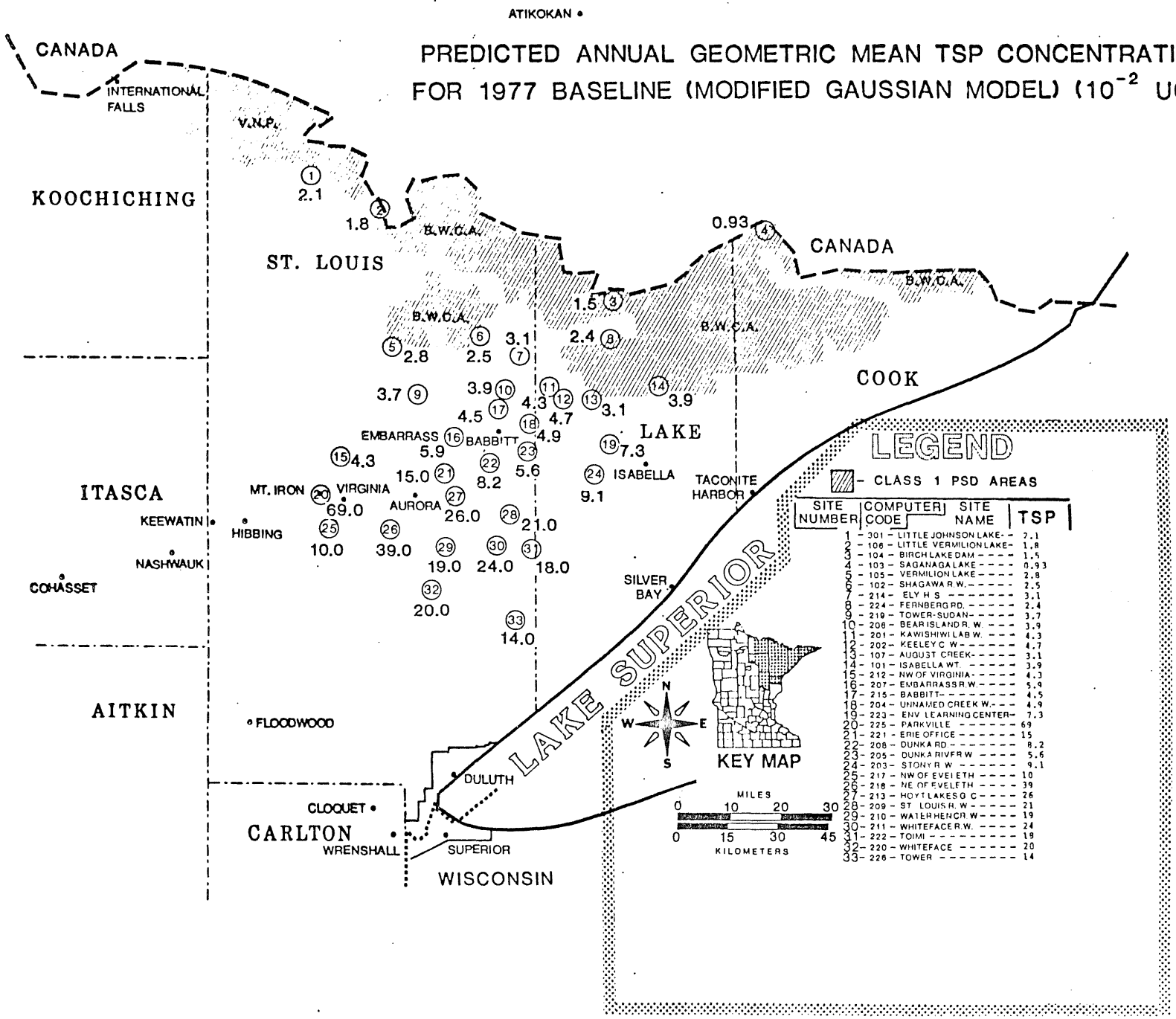
The modified gaussian model was run using the emissions sources existing during the period of measured concentrations (see emissions inventory, Table 40). Figure 60 shows the resulting predicted annual geometric mean concentration at receptor sites in the Study Area. Although the contribution of point sources to annual particulate levels are not revealed by data from the field monitoring equipment, the predicted values are presented and discussed to provide a perspective on regional source contributions.

Figure 60

When the predicted annual means (due to local point sources) at each receptor in the region are averaged for the baseline period, a regional TSP arithmetic mean of .1 ug/m^3 is calculated. The predicted regional mean is negligible (less than 1%) by comparison either to the arithmetic mean of 25 ug/m^3 for the measured values shown in Table 43 (average of 11 sites) or to the regional background concentrations typified by the annual means of 12 ug/m^3 at the Toimi site and 10 ug/m^3 at the Fernberg and Kawishiwi sites.

The low predicted TSP concentrations are to be expected since the modified gaussian model considers only particulate point source emissions and the measured values, of course, include point source and area source (or fugitive)

FIGURE 60


PREDICTED ANNUAL GEOMETRIC MEAN TSP CONCENTRATIONS
FOR 1977 BASELINE (MODIFIED GAUSSIAN MODEL) (10^{-2} UG/M^3)
ATIKOKAN
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
MT. IRON
VIRGINIA
AURORA
EMBARRASS
BABBITT
ISABELLA
TACONITE HARBOR
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
2.1
1.8
0.93
1.5
2.4
2.8
2.5
3.1
3.7
3.9
4.5
4.3
4.7
3.1
3.9
4.9
7.3
4.3
5.9
15.0
8.2
5.6
9.1
69.0
26.0
21.0
10.0
39.0
19.0
24.0
18.0
20.0
14.0
LEGEND
CLASS 1 PSD AREAS
KEY MAP
MILES
KILOMETERS
SITE NUMBER | COMPUTER CODE | SITE NAME | TSP
1 - 301 - LITTLE JOHNSON LAKE - - 2.1
2 - 106 - LITTLE VERMILION LAKE - 1.8
3 - 104 - BIRCH LAKE DAM - - - - 1.5
4 - 103 - SAGANAGA LAKE - - - - 0.93
5 - 105 - VERMILION LAKE - - - - 2.8
6 - 102 - SHAGAWA R.W. - - - - - 2.5
7 - 214 - ELY H S - - - - - - - - 3.1
8 - 224 - FERNBERG RD. - - - - - 2.4
9 - 219 - TOWER-SUDAN - - - - - 3.7
10 - 206 - BEAR ISLAND R. W. - - - 3.9
11 - 201 - KAWISHIWI LAB W. - - - 4.3
12 - 202 - KEELEY C W - - - - - - 4.7
13 - 107 - AUGUST CREEK - - - - - 3.1
14 - 101 - ISABELLA WT. - - - - - 3.9
15 - 212 - NW OF VIRGINIA - - - - 4.3
16 - 207 - EMBARRASS R.W. - - - - 5.9
17 - 215 - BABBITT - - - - - - - - 4.5
18 - 204 - UNNAMED CREEK W. - - - 4.9
19 - 223 - ENV. LEARNING CENTER - 7.3
20 - 225 - PARKVILLE - - - - - - 69
21 - 221 - ERIE OFFICE - - - - - - 15
22 - 208 - DUNKA RD - - - - - - - 8.2
23 - 205 - DUNKA RIVER R.W. - - - - 5.6
24 - 203 - STONY R. W - - - - - - - 9.1
25 - 217 - NW OF EVELETH - - - - 10
26 - 218 - NE OF EVELETH - - - - 39
27 - 213 - HOYT LAKES G. C - - - - 26
28 - 209 - ST. LOUIS R. W - - - - - 21
29 - 210 - WATERHENCR W - - - - 19
30 - 211 - WHITEFACE R.W. - - - - 24
31 - 222 - TOIMI - - - - - - - - - 18
32 - 220 - WHITEFACE - - - - - - 20
33 - 226 - TOWER - - - - - - - - 14

contributions. It appears from the model simulations that over 99% of the regional ambient particulate concentrations on an annual basis are due to regional area source emissions or long distance transport from sources outside of the region.

This result is supported by a dispersion modeling study of the Iron Range from Grand Rapids to Buhl (Shell Engineering and Associates 1978) which concluded that area source emissions had an impact relative to point sources of at least 10 to 1 in most grids inventoried. The emissions inventory in this report showed that unpaved and paved roads were the major contributors to TSP, followed by areas exposed by mining activities and combustion sources. This finding also agrees with the previous discussion of variables affecting TSP levels observed in the region. The effects of the mine strike, snow cover, and community activity all indicate the importance of area sources. The uniform nature of the background levels observed at remote sites supports the conclusion that area sources and regional transport play a key role, rather than specific point sources in the region.

The high variability in TSP levels observed at certain monitoring sites in the region does indicate that since TSP concentrations are not homogeneous, but rather are highly dependent on local factors, the modified gaussian model is a valuable predictor of 24-hour TSP concentrations where point sources in the vicinity of the receptor are the primary contributors.

For example, at Hoyt Lakes Golf Course 27% of the predicted 24-hour TSP concentrations (based on point sources) were within a factor of 10 of the measured values, compared to only 9% at Fernberg Road, which is remote from regional point sources. Table 46 provides a summary of the predicted vs measured 24-hour

concentrations at 7 sites.

Table 46

Although a regional TSP background concentration could be input to the model and a better fit to the measured data could be derived, the point source contribution would obviously be masked. For this reason, the modeling results and subsequent discussions are limited only to the point sources listed in the emissions inventory.

In terms of TSP regulations, it is not surprising that neither the federal primary (75 ug/m^3) nor secondary (60 ug/m^3) annual TSP standards are predicted to be exceeded in the region on the basis of the point source modeling results for 1977 and 1985. The predicted 1985 annual TSP levels from expected point source emissions are shown in Figure 61.

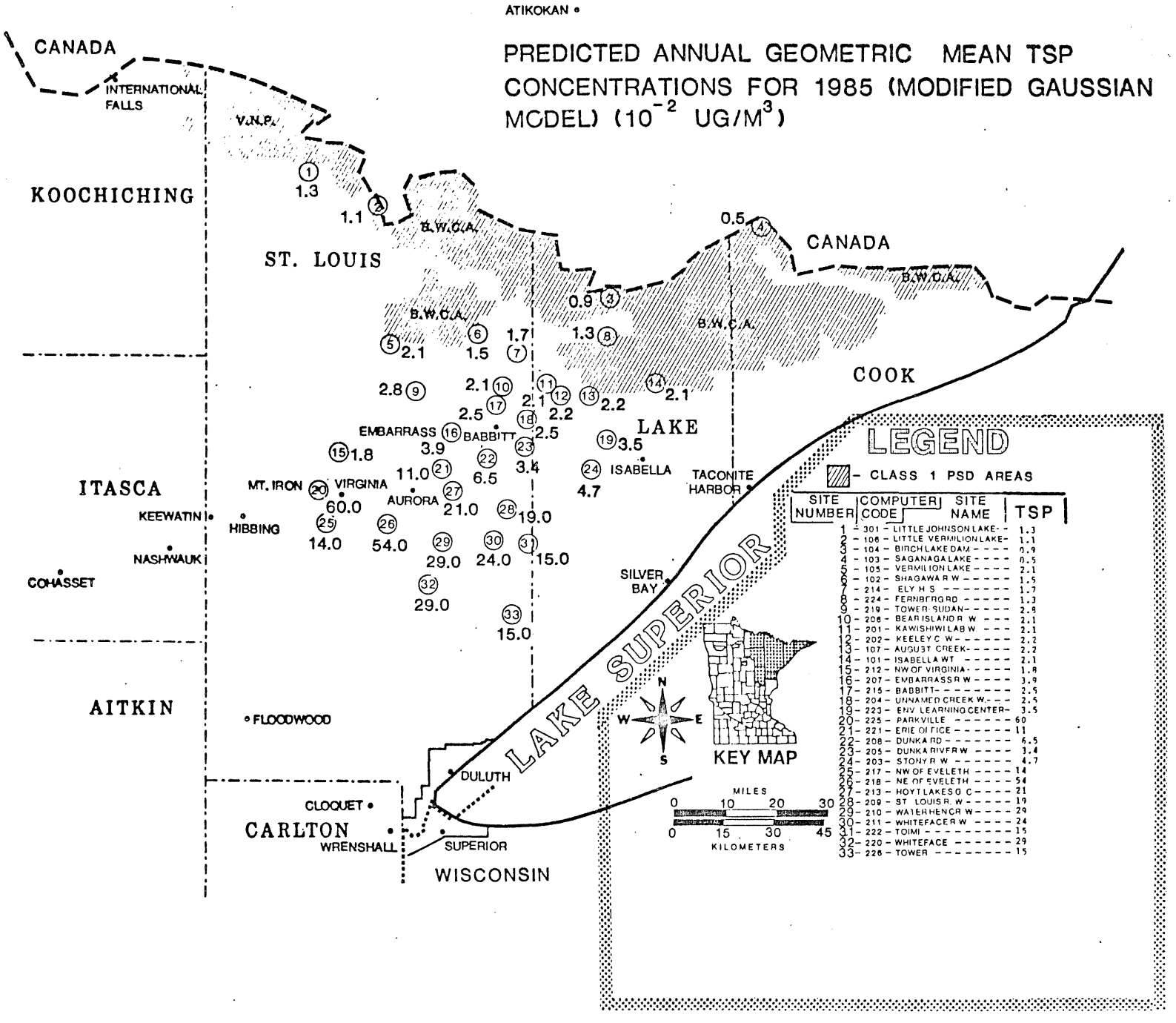
Figure 61

When the predicted annual means at each site in the region are averaged, regional means of about .1 ug/m^3 are calculated for both 1977 and 1985. Although point source particulate emissions in the region are expected to decrease 38% from 1977 to 1985, the regional averages are about the same for the two years because high predicted annual averages at a few sites that are impacted by sources which show substantial increases in emissions from 1977 to 1985. For example, the receptor northeast of Eveleth shows a 50% increase in predicted ambient annual TSP concentrations, from .4 ug/m^3 in 1977 to .6 ug/m^3 in 1985. This receptor is impacted primarily by Eveleth and Gilbert point sources. TSP emissions from these two locations are predicted to increase by about 130% from 2,545 mtpy in 1977 to 5,818 mtpy in 1985.

Table 46. Percent of predicted 24-hour concentrations that are within a factor of 10 of the measured concentrations (modified gaussian model).

SITE	PERCENT	POSSIBLE SOURCE INFLUENCES
Fernberg	9	No local sources
Ely	7	No local sources
Kawishiwi	17	Local dirt parking lot; dirt road
Dunka	18	Local dirt logging road
Toimi	41	Local gravel driveway
Erie Mining Office	35	Open pit mining operation
Hoyt Lakes Golf Course	27	Possibly Erie Mining, or auto traffic to golf course

FIGURE 61


ATIKOKAN
PREDICTED ANNUAL GEOMETRIC MEAN TSP CONCENTRATIONS FOR 1985 (MODIFIED GAUSSIAN MODEL) (10^{-2} UG/M^3)
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
EMBARRASS
BABBITT
MT. IRON
VIRGINIA
AURORA
ISABELLA
TACONITE HARBOR
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
1.3
1.1
0.5
0.9
2.1
1.5
1.7
1.3
2.8
2.1
2.1
2.2
2.1
2.5
2.2
2.5
1.8
3.9
3.5
11.0
6.5
3.4
4.7
60.0
21.0
19.0
14.0
54.0
29.0
24.0
15.0
29.0
15.0
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | TSP
1 - 301 - LITTLE JOHNSON LAKE - 1.3
2 - 106 - LITTLE VERMILION LAKE - 1.1
3 - 104 - BIRCH LAKE DAM - 0.9
4 - 103 - SAGANAGA LAKE - 0.5
5 - 105 - VERMILION LAKE - 2.1
6 - 102 - SHAGAWA R W - 1.5
7 - 214 - ELY H S - 1.7
8 - 224 - FERNBERG RD - 1.3
9 - 219 - TOWER-SUDAN - 2.8
10 - 206 - BEAR ISLAND R W - 2.1
11 - 201 - KAWISHIWI LAB W - 2.1
12 - 202 - KEELEY C W - 2.2
13 - 107 - AUGUST CREEK - 2.2
14 - 101 - ISABELLA WT - 2.1
15 - 212 - NW OF VIRGINIA - 1.8
16 - 207 - EMBARRASS R W - 3.9
17 - 215 - BABBITT - 2.5
18 - 204 - UNNAMED CREEK W - 2.5
19 - 223 - ENV LEARNING CENTER - 3.5
20 - 225 - PARKVILLE - 60
21 - 221 - ERIE OFFICE - 11
22 - 208 - DUNKARD - 6.5
23 - 205 - DUNKA RIVER W - 3.4
24 - 203 - STONY R W - 4.7
25 - 217 - NW OF EVELETH - 14
26 - 218 - NE OF EVELETH - 54
27 - 213 - HOYT LAKES G C - 21
28 - 209 - ST. LOUIS R. W - 19
29 - 210 - WATERHENCR W - 29
30 - 211 - WHITEFACE R W - 24
31 - 222 - TOIMI - 15
32 - 220 - WHITEFACE - 29
33 - 226 - TOWER - 15
KEY MAP
N
W
E
S
MILES
0 10 20 30
0 15 30 45
KILOMETERS

The highest predicted concentrations in the region occurred at Parkville for both 1977 (.7 ug/m^3) and 1985 (.6 ug/m^3). Both values are less than 1% of the annual primary ambient air quality standard, and are 5-7% of background concentrations of 10-12 ug/m^3.

Neither the annual TSP Class I (5 ug/m^3) nor the Class II (19 ug/m^3) PSD increments are expected to be exceeded by point sources in the region. The largest modeled annual difference in a Class I area was .02 ug/m^3 at Dunka River watershed (less than .1% of the increment); the largest difference in the Class II area was .3 ug/m^3 northwest of Eveleth (1.5% of the increment). Although natural area source TSP contributions are important in determining whether or not ambient air quality standards will be exceeded, this contribution is less important in the PSD review because differences are determined rather than absolute values.

On a regional basis, the proposed Atikokan power plant (at 800 MW) contributes about 9% of the TSP concentrations. However, the effect on regional annual TSP concentration is negligible. A regional mean annual concentration of about .10 ug/m^3 is calculated both with and without the power plant. The effect of the proposed plant is most pronounced at the Class I sites where a 30% decrease is calculated (based on 8 Class I receptors) if Atikokan is removed from the 1985 inventory.

The modified gaussian model predicts that the maximum 24-hour TSP primary standard (260 ug/m^3) will not be exceeded by modeled point sources in 1977 or 1985, but that the secondary standard (150 ug/m^3) will be exceeded at one site once during each year. If a modeling error of a factor of two is applied, the possibility is raised that the primary standard will be exceeded at one receptor

site. Recall that one exceedance per year does not constitute a violation of the standard. Figures 62 and 63 show the predicted 1977 regional baseline and 1985 maximum 24-hour concentrations at each receptor in the region.

Figures 62 and 63

In 1977 the predicted maximum 24-hour concentration was 172 ug/m^3 (66% of the primary standard) at Parkville followed by a second high of 162 ug/m^3 (62% of the primary standard) at the same site. By 1985, the predicted maximum 24-hour concentration is expected to drop slightly to 160 ug/m^3 (62% of the primary standard) at the Erie receptor followed by a second high of 150 ug/m^3 (58% of the primary standard) at the same site. For purposes of comparison, Table 47 shows the air quality sampling sites where recorded TSP concentrations exceeded the 24-hour primary and secondary TSP standards during the sampling period 1976-77.

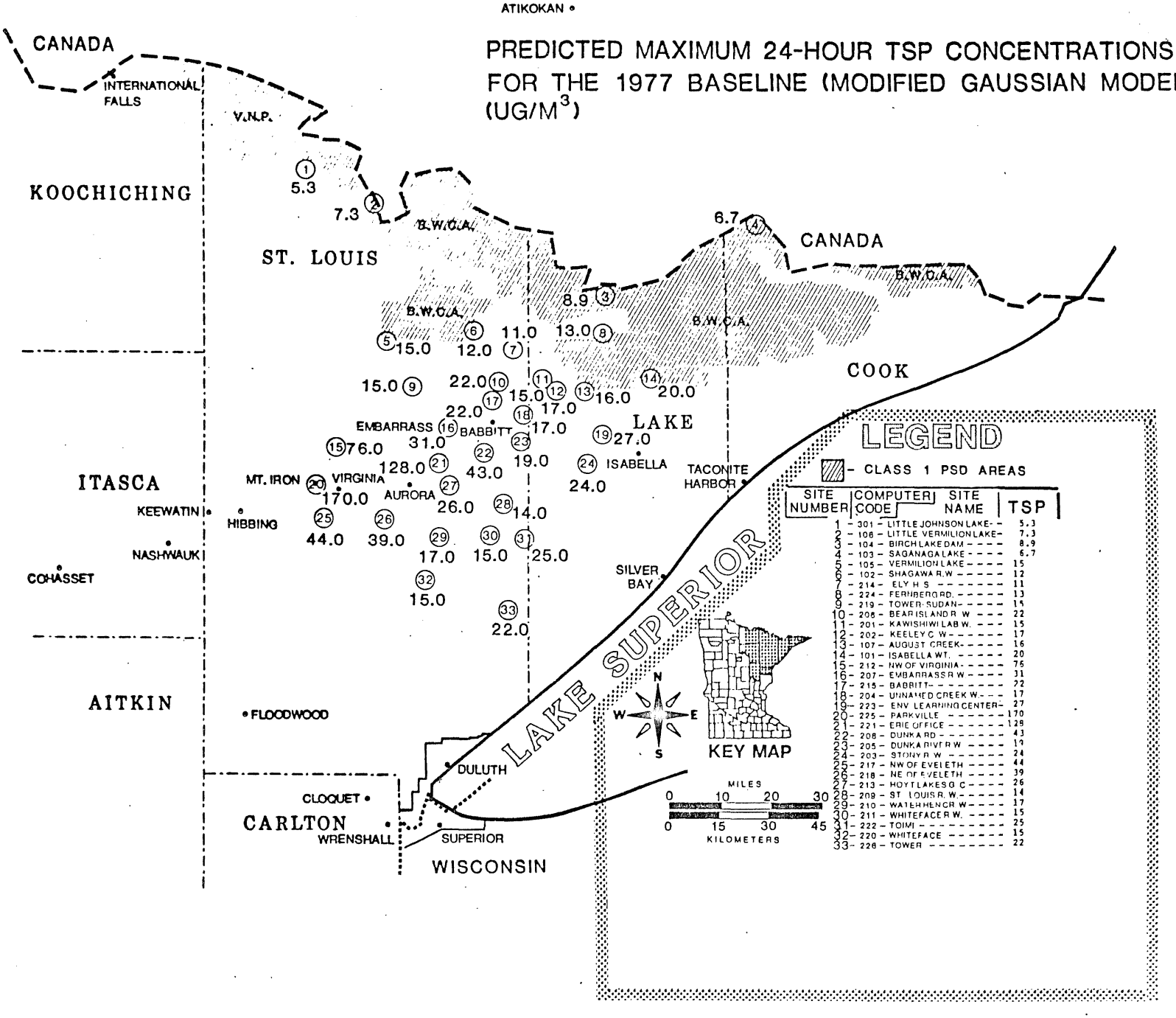
Table 47

The maximum 24-hour TSP PSD increment is predicted to be exceeded in the Class II (37 ug/m^3) area but not in the Class I (10 ug/m^3) area. In the Class I area, the largest difference was 3 ug/m^3 (30% of the increment), which occurred at the receptor site in the Isabella watershed. Table 48 summarizes the predicted values exceeding the 24-hour TSP PSD increment in Class II areas. Removing the proposed Atikokan power plant from the 1985 emissions inventory did not significantly affect the maximum 24-hour TSP concentrations at any receptor.

Table 48

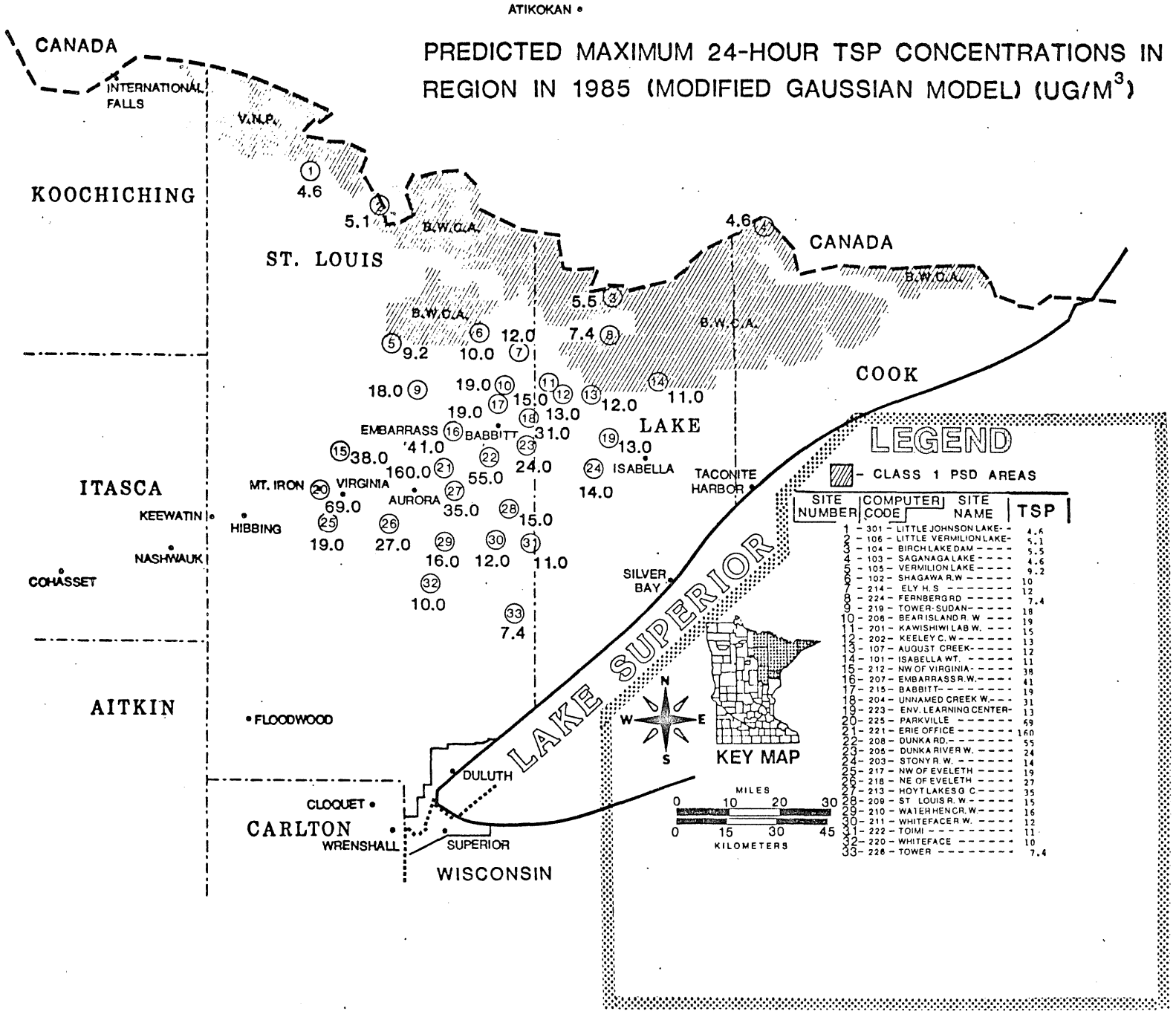
FIGURE 62

PREDICTED MAXIMUM 24-HOUR TSP CONCENTRATIONS FOR THE 1977 BASELINE (MODIFIED GAUSSIAN MODEL) (UG/M^3)



SITE NUMBER	COMPUTER CODE	SITE NAME	TSP
1	301	LITTLE JOHNSON LAKE	5.3
2	106	LITTLE VERMILION LAKE	7.3
3	104	BIRCH LAKE DAM	8.9
4	103	SAGANAGA LAKE	6.7
5	105	VERMILION LAKE	15
6	102	SHAGAWA R.W.	12
7	214	ELY H.S.	11
8	224	FERNBERG RD.	13
9	219	TOWER-SUDAN	15
10	206	BEAR ISLAND R.W.	22
11	201	KAWISHIWI LAB W.	15
12	202	KEELEY C.W.	17
13	107	AUGUST CREEK	16
14	101	ISABELLA WT.	20
15	212	NW OF VIRGINIA	76
16	207	EMBARRASS R.W.	31
17	215	BABBITT	22
18	204	UNNAMED CREEK W.	17
19	223	ENV. LEARNING CENTER	27
20	225	PARKVILLE	170
21	221	ERIE OFFICE	128
22	208	DUNKA RD.	43
23	205	DUNKA RIVER W.	19
24	203	STONY R.W.	24
25	217	NW OF EVELETH	44
26	218	NE OF EVELETH	39
27	213	HOYT LAKES G.C.	26
28	209	ST. LOUIS R.W.	14
29	210	WATER HEN CR.W.	17
30	211	WHITEFACE R.W.	15
31	222	TOIMI	25
32	220	WHITEFACE	15
33	226	TOWER	22

FIGURE 63



PREDICTED MAXIMUM 24-HOUR TSP CONCENTRATIONS IN THE REGION IN 1985 (MODIFIED GAUSSIAN MODEL) (UG/M^3)

Table 47. Summary of 24-hour TSP measurements during the 1976-77 sampling period which exceeded the primary and secondary ambient TSP standards.[a]

SITE	24-HOUR TSP CONCENTRATIONS ug/m^3
Virginia	367, 310, 233, 214, 211, 193, 177, 177, 167, 151
Hibbing	279
Dunka Road	243, 174, 153
Mountain Iron	201, 179, 174, 165
Hoyt Lakes Police Station	191, 178

SOURCE: Endersen and Feeney 1979.

[a]The 24-hour primary standard is 260 ug/m^3, the secondary standard is 150 ug/m^3, both not to be exceeded more than once per year.

Table 48. Predicted values exceeding the 24-hour TSP PSD increment in Class II areas (ug/m^3).

SITE	BASELINE	1985		DIFFERENCE[a]	
		Highest	2nd Highest	High-Baseline	2nd High-Baseline
Erie	118	160	152	42	34[b]
Parkville	19	69	65	50	46

[a]The allowable PSD increment in a Class II area is 37 ug/m^3.
[b]This difference does not exceed the increment.

In summary, neither the annual TSP ambient air quality standards nor the TSP annual PSD Class I and Class II increments are predicted to be exceeded by point source regional growth in 1985. Annual TSP contributions from point sources in the region are low, less than 1% of the primary air quality standard. The maximum 24-hour TSP primary standard is not predicted to be exceeded in 1985, but the secondary standard is predicted to be exceeded.

The maximum 24-hour PSD increment is predicted to be exceeded in the Class II area but not in the Class I area. The proposed Atikokan power plant contributes about 9% of the modeled regional TSP concentration (based on an average of 33 sites); the effect of the plant is most pronounced on the Class I receptors. If it is assumed that the TSP sources shown in the emissions inventory will exist in 1985, further growth in the region could be precluded because both the 24-hour ambient air quality secondary standards and the allowable PSD Class II increments could be exceeded by point source emissions in the region.

In the foregoing discussion, it must be remembered that the conclusions are based on predicted values at a finite set of receptor sites. Further, the model being used is relatively new and would require extensive field validation using actual data gathered over a long period of time in order to place reliable limits of accuracy on the values. Such precision validation was beyond the scope of this study. Therefore, the intent of this presentation was not to quantitatively predict that specific numerical standards will or will not be exceeded at locations in the region. Rather, it was intended to indicate the general TSP levels expected, and in this context, which of many legal standards may be in potential danger of being exceeded.

Figure 64 presents box plots of predicted 24-hour TSP concentrations for 1977 and 1985 at receptors in the region. Figure 65 shows the frequency distribution of

these TSP concentrations for 3 sites in the region, permitting comparison of a rural site, Isabella, with two community sites, Hoyt Lakes Golf Course and Parkville.

Figures 64 and 65

3.5.1.3 Deposition of Total Suspended Particulates--Specific measurements of total particulate deposition in the region were not made, since it is not expected that copper-nickel development in the region will result in a unique problem in terms of dust loading. Rather, concern focuses on the deposition of specific TSP constituents such as sulfate, copper, and nickel. Deposition measurements for specific constituents were made in the region and are discussed in the following section (3.5.2).

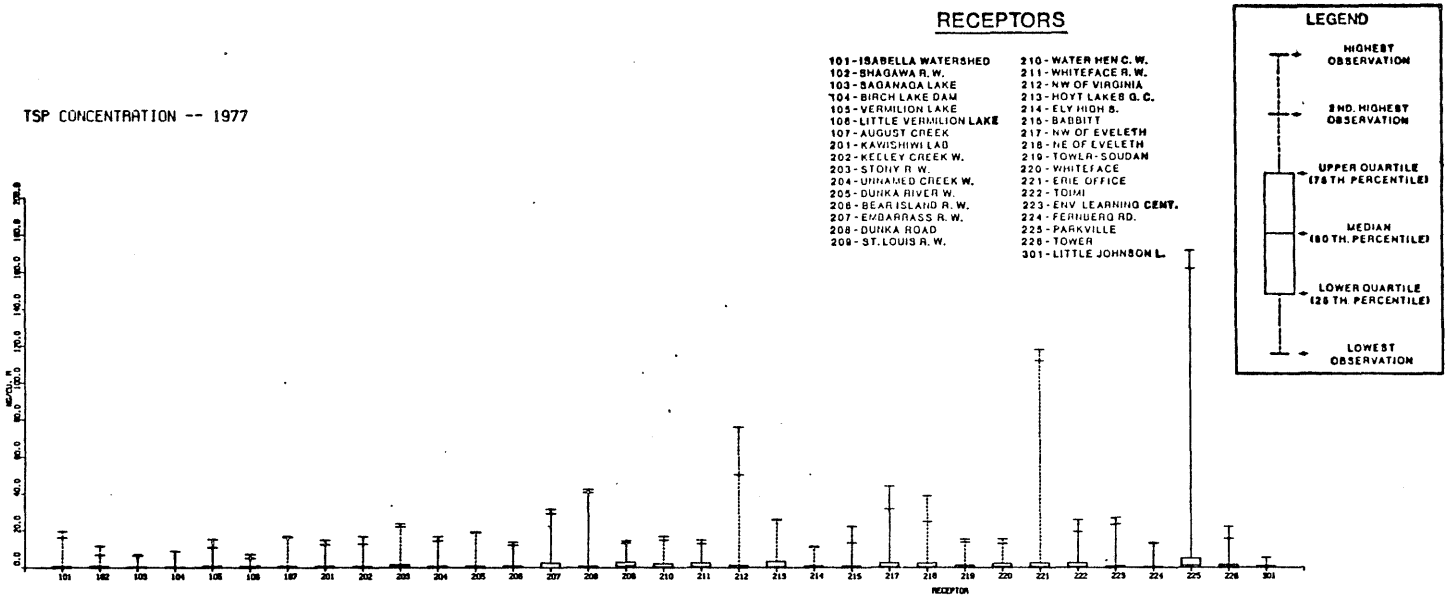
Predictions of total particulate deposition in the region from local point sources were made using the modified gaussian model. Figure 66 provides box plots of predicted 1977 and 1985 24-hour deposition values, and Figure 67 shows predicted annual frequency distributions of 24-hour particulate deposition values at 3 sites in the region. These results are given here to provide a reference for subsequent modeling of potential particulate deposition from a smelter operation. Note that modeled values of local point source contributions to TSP deposition are typically less than 50 gm/ha in a 24-hour period, with infrequent values ranging up to 600 gm/ha or more in several cases.

Figures 66 and 67

Table 49 summarizes the predicted annual deposition of particulates at all receptor sites from local point source emissions. Values for 1977 (regional

FIGURE 64

BOX PLOTS OF PREDICTED 24-HOUR TSP CONCENTRATIONS (MODIFIED GAUSSIAN MODEL).



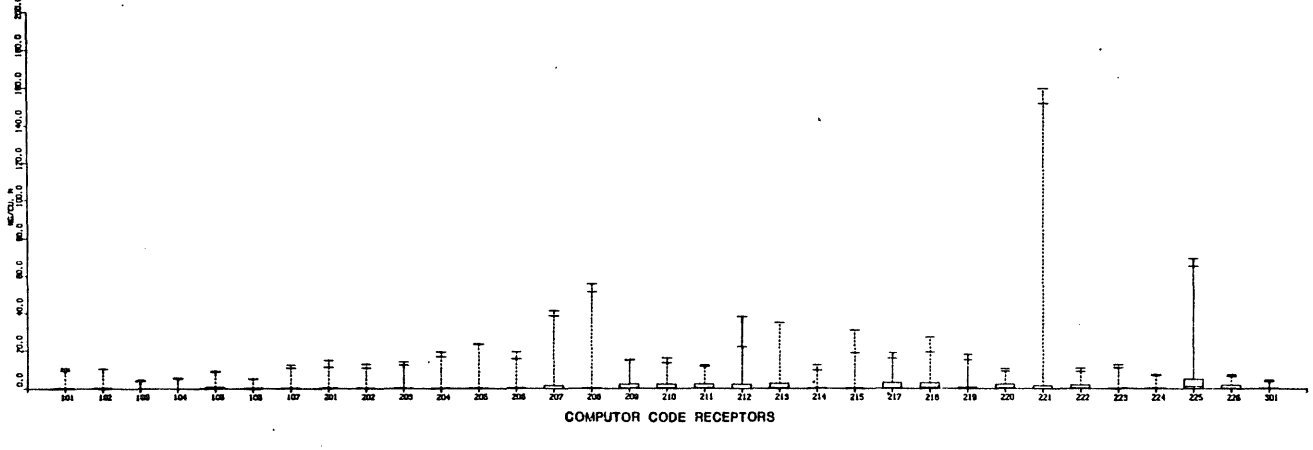


FIGURE 65

ANNUAL FREQUENCY DISTRIBUTION OF PREDICTED 24-HOUR TSP CONCENTRATIONS, 1977 AND 1985, AT SELECTED SITES (MODIFIED GAUSSIAN MODEL).

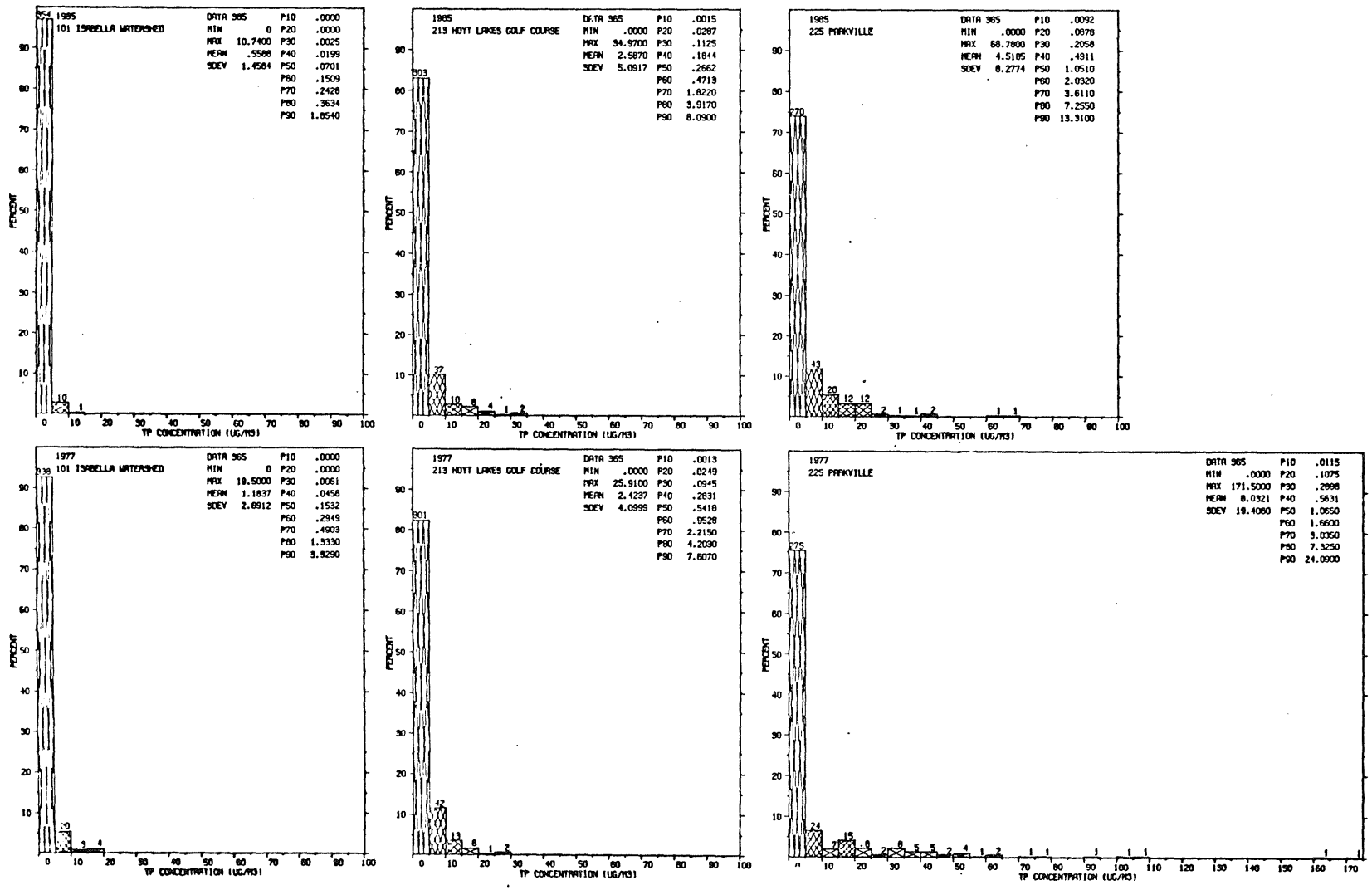
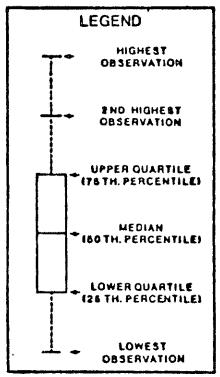


FIGURE 66

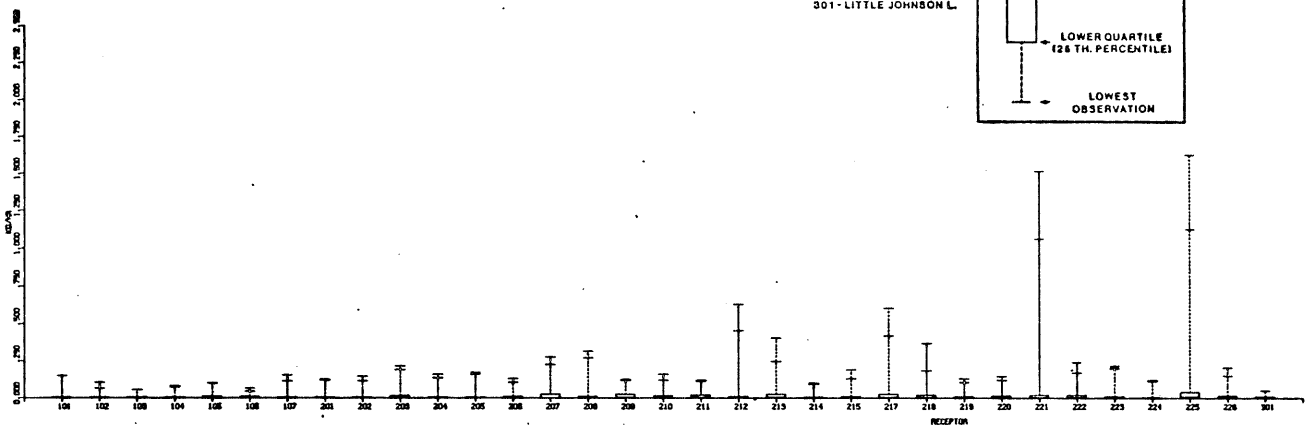
BOX PLOTS OF PREDICTED 24-HOUR TSP DEPOSITION VALUES (MODIFIED GAUSSIAN MODEL).

RECEPTORS

101 - ISABELLA WATERSHED
102 - SHAGAWA R. W.
103 - SAGANAGA LAKE
104 - BIRCH LAKE DAM
105 - VERMILION LAKE
106 - LITTLE VERMILION LAKE
107 - AUGUST CREEK
201 - KAWISHIWI LAB
202 - KEELEY CREEK W.
203 - STONY R. W.
204 - UNNAMED CREEK W.
205 - DUNKA RIVER W.
206 - BEAR ISLAND R. W.
207 - EMBARRASS R. W.
208 - DUNKA ROAD
209 - ST. LOUIS R. W.
210 - WATER HEN C. W.
211 - WHITEFACE R. W.
212 - NW OF VIRGINIA
213 - HOYT LAKES G. C.
214 - ELY HIGH S.
215 - BABBITT
217 - NW OF EVELETH
218 - NE OF EVELETH
219 - TOWER-SOUDAN
220 - WHITEFACE
221 - ERIE OFFICE
222 - TOIMI
223 - ENV. LEARNING CENT.
224 - FERNBERG RD.
225 - PARKVILLE
226 - TOWER
301 - LITTLE JOHNSON L.



TSP DEPOSITION -- 1977



TSP DEPOSITION -- 1985

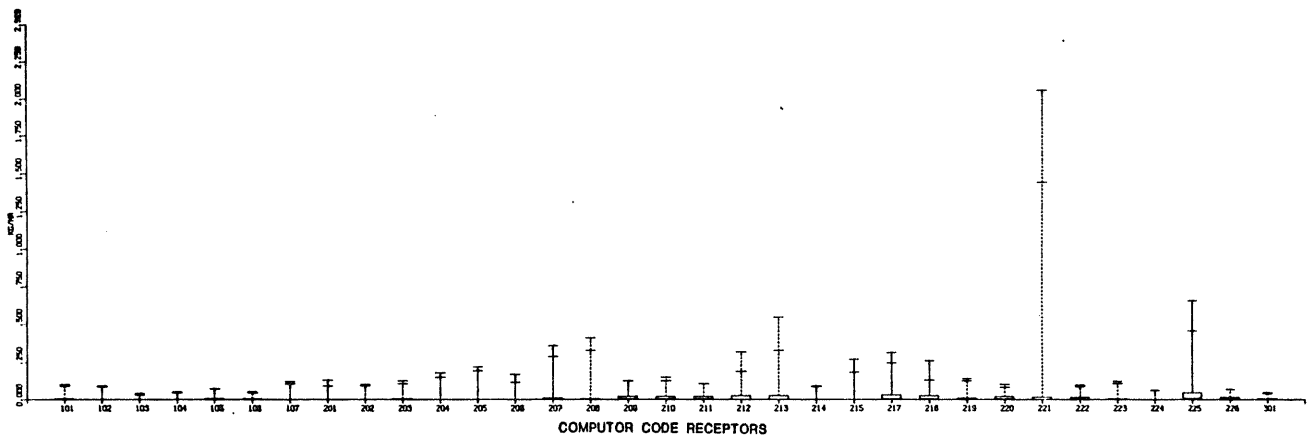
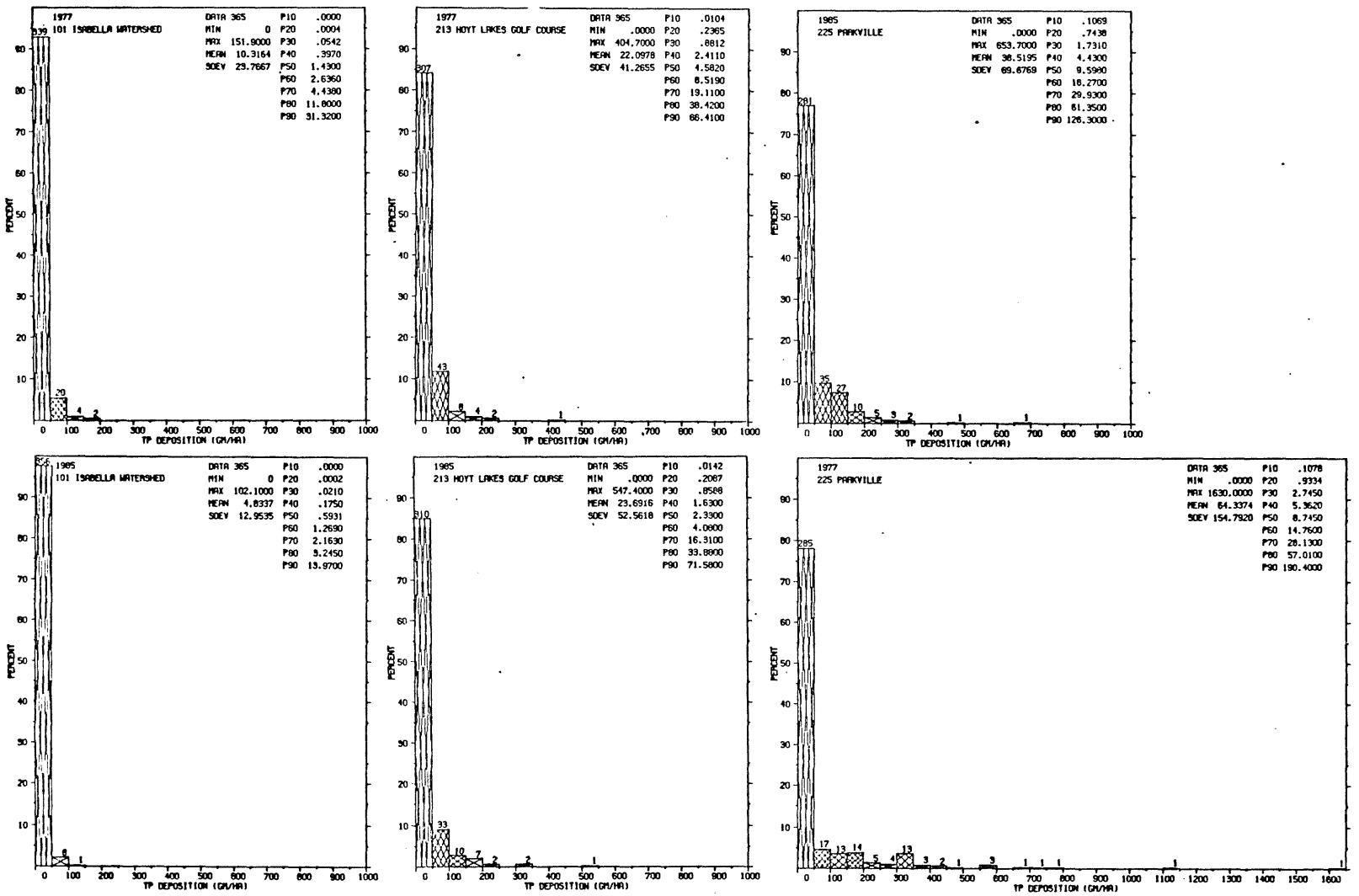


FIGURE 67

ANNUAL FREQUENCY DISTRIBUTIONS OF PREDICTED 24-HOUR TSP DEPOSITION VALUES, 1977 AND 1985, AT SELECTED SITES (MODIFIED GAUSSIAN MODEL).



baseline) and 1985 are shown. Aside from elevated levels near population centers and industrial sources, values tend to range from 1 to 5 kg/ha/yr. Values typically range above 10 kg/ha/yr near major sources.

Table 49

3.5.2 Composition of Particulates

Atmospheric particulate constituents of principal concern for potential copper-nickel development include sulfur (as a sulfide or sulfate) and heavy metals such as copper, nickel, cobalt and zinc. In addition to the amounts of these constituents present in the atmosphere, the size of the particulates is also of interest. Particle sizes are related to the deposition velocity of the particles in the air, and thus to their transport and dispersion characteristics. Size distribution is also an important factor pertaining to the public health significance of particulates (see Volume 5-Chapter 2). This section will discuss the results of studies to determine both elemental compositions and particle size distributions of particulates now present in the region. Both ambient concentration and deposition information is presented.

A large portion of the information presented in this section is based on field data collected during the course of the Regional Copper-Nickel Study. For detailed discussions of these topics, including study data and findings, the interested reader is referred to Eisenreich, Hollod, and Langevin (1978).

3.5.2.1 Composition of Ambient Particulates--Ambient atmospheric particulates were collected at 10 sites in and near the Study Area and at one Duluth site. Sampling was accomplished by drawing air through a 0.45 um membrane filter (pore size of filter is approximately 18 millionths of an inch across). The sample

Table 49. Predicted annual deposition of particulates at various receptor sites due to point source emissions in the Region (kg/ha/yr).

SITE NO.	COMPUTER CODE	NAME	1977 REGIONAL BASELINE	1985 PROJECTION	% CHANGE
1	301	Little Johnson Lake	1.9	1.2	-37
2	106	Little Vermillion Lake	2.2	1.3	-41
3	104	Birch Lake Dam	2.0	1.0	-50
4	103	Saganaga Lake	1.6	.6	-62
5	105	Vermillion Lake	3.3	2.8	-15
6	102	Sh'agawa R. W.	2.9	2.1	-28
7	214	Ely High School	3.2	2.0	-39
8	224	Fernberg Road	2.6	1.2	-54
9	219	Tower-Sudan	4.0	4.0	0
10	206	Bear Island R. W.	3.7	2.7	-27
11	201	Kawishiwi Lab W.	3.6	2.0	-44
12	202	Keeley Creek W.	3.9	2.1	-46
13	107	August Creek	4.0	2.1	-47
14	101	Isabella Watershed	3.8	1.8	-53
15	212	NW of Virginia	9.3	6.9	-26
16	207	Embarrass R. W.	6.7	6.6	-1
17	215	Babbitt	4.3	3.6	-16
18	204	Unnamed Creek W.	4.5	3.2	-29
19	223	Environ. Learning Center	5.3	2.8	-47
20	225	Parkville	23	7.9	-66
21	221	Erie Office	16	20	+25
22	208	Dunka Road	7.9	8.2	+4
23	205	Dunka River W.	5.3	4.7	-11
24	203	Stony River W.	6.2	3.1	-50
25	217	NW of Eveleth	8.9	7.6	15
26	218	NE of Eveleth	7.1	7.0	-1
27	213	Hoyt Lakes Golf Course	8.1	8.6	+6
28	209	St. Louis River W.	6.3	5.7	-10
29	210	Waterhen Creek W.	5.2	5.0	-4
30	211	Whiteface River. W.	5.7	5.2	-9
31	222	Toimi	5.8	4.4	-24
32	220	Whiteface	4.9	4.4	-10
33	226	Tower	4.2	3.4	-19

collection period used was 24-hours, and a sample was collected once every six days from late 1976 through late 1977.

Filters were analyzed using x-ray fluorescence techniques. Elements determined in air particulates were: aluminum (Al); silicon (Si); phosphorus (P); sulfur (S); chlorine (Cl); potassium (K); calcium (Ca); titanium (Ti); vanadium (V); chromium (Cr); magnesium (Mg); iron (Fe); zinc (Zn); cobalt (Co); nickel (Ni); copper (Cu); bromine (Br); tin (Sn); galium (Ga); germanium (Ge); arsenic (As); selenium (Se); rubidium (Rb); strontium (Sr); cadmium (Cd); antimony (Sb); barium (Ba); tungsten (W); mercury (Hg); and lead (Pb). This analytical technique is not capable of detecting elements lighter than magnesium, for example sodium, fluorine and nitrogen.

Elemental concentrations found in air particulates in N.E. Minnesota are given in summary form in Tables 50 and 51. This region-wide summary gives maxium and minimum values, arithmetic means and standard deviations for two data combinations: 1) not-detectable data omitted in calculation of statistical summaries; and 2) not-detectable data included as analytical zero concentration. The true regional or site-specific mean (average) can be assumed to lie between these values.

Tables 50 and 51

In addition to calculating overall averages for the region, it is possible to generally characterize a site as background or urban/industrial, with some sites falling midway between these extremes.

To illustrate the basis for this classification, the concentrations of the elements sulfur, lead, and iron were examined. These three elements can derive from

Table 50. Statistical summary of elemental composition of ambient atmospheric particulates in northeastern Minnesota[a].

	Al	Si	P	S[b]	Cl	K	Ca
				ng/m^3			
Max	3048	8884	249	5623	360	1262	5017
Min	4	3	1	ND[c]	4	1	3
Avg	299	911	51	692	83	163	321
S[d]	413	1336	38	641	75	183	522

	Ti	V	Cr	Mn	Fe	Zn	Co
Max	453	22	40	156	12865	1852	43
Min	1	4	1	ND	5	ND	ND
Avg	56	11	10	19	1050	23	8
S	66	5	6	23	1851	106	8

	Ni	Cu	Br	Sn	Ga	Ge	As
Max	27	109	252	8	11	2	51
Min	ND	ND	ND	ND	ND	ND	ND
Avg	4	12	15	5	2	2	7
S	5	17	26	2	2	1	7

	Se	Rb	Sr	Cd	Sb	Ba	W
Max	5	10	26	132	8	185	132
Min	ND	ND	ND	ND	ND	ND	ND
Avg	1	2	5	9	4	34	7
S	1	1	5	25	2	20	22

	Hg	Pb
Max	11	734
Min	ND	1
Avg	3	59
S	3	92

SOURCE: Eisenreich, Hollod and Langevin 1978.

[a]Not-detectable data omitted. Duluth data is included
[b]ng/m^3 = 10^{-9} grams/m^3
[c]ND = not detected
[d]S = standard deviation

Table 51. Statistical summary of elemental composition of ambient atmospheric particulates in northeastern Minnesota.[a]

	Al	Si	P	S	Cl	K	Ca
				ng/m^3[b]			
Max	3048	8884	249	5623	360	1262	5017
Min	ND[c]	ND	ND	ND	ND	ND	ND
Avg	240	908	49	692	34	163	320
S[d]	389	1335	40	641	63	183	522

	Ti	V	Cr	Mn	Fe	Zn	Co
Max	453	22	40	156	12865	1852	43
Min	ND	ND	ND	ND	ND	ND	ND
Avg	29	0.5	3.7	15	1047	22	2
S	55	2	6	22	1849	105	5

	Ni	Cu	Br	Sn	Ga	Ge	As
Max	27	109	252	8	11	2	51
Min	ND	ND	ND	ND	ND	ND	ND
Avg	2	6	15	1	0.3	0.04	4
S		13	26	2	0.9	0.3	6

	Se	Rb	Sr	Cd	Sb	Ba	W
Max	5	10	26	132	8	185	132
Min	ND	ND	ND	ND	ND	ND	ND
Avg	0.3	0.7	2	0.8	0.6	28	0.7
S	0.6	1	4	8	2	22	7

	Hg	Pb
Max	11	734
Min	ND	ND
Avg	0.2	58
S	1	91

SOURCE: Eisenreich, Hollod and Langevin (1978)

[a]Not-detectable data included as analytical zero. Duluth data is included.

[b]ng/m^3=10^{-9}grams/m^3

[c]ND = not dectected

[d]S = standard deviation

both natural (soil) and anthropogenic sources (mining, fossil fuel combustion, vehicular traffic) and therefore a comparison of air particulate concentrations may be meaningful. Table 52 presents the data on these elements from four sites. Fernberg and Toimi are representative of background sites, while Babbitt and Scanlon represent urban/industrial sites.

Table 52

Lead values at the urban/industrial sites average from 5 to 10 times the levels seen at background sites. The two primary sources of Pb are transport from distant urban/industrial areas and the local combustion of leaded gasoline. It is believed that 80% (100 ng/m^3) of the total lead at urban sites was locally derived (Eisenreich, Hollod and Langevin 1978). Iron is elevated generally by a factor of 2 to 4 at urban/industrial sites on the average. This enhancement is not as large as in the case of lead, probably because the iron sources in the region are relatively less localized than are lead sources. It is likely that the enhanced Fe content of air particulates in N.E. Minnesota is the result of taconite mining, processing and related activities. The average sulfur content of air particulates at the urban and non-urban sites was not significantly different. This behavior can be attributed to the regional transport and dispersion of sub-micron sized particles which contain most of the sulfur. Because SO_2 concentrations were low in the study region (see section 3.4.1.2), the majority of the S was likely in the sulfate form. The source of S to the area is not totally defined, but transport into the region from distant sources is the likely cause for the majority of the S found.

On the basis of the above considerations, the background sites include Fernberg, Isabella, Toimi, and Whiteface. The urban/industrial sites are Babbitt, Scanlon,

Table 52. Sulfur, lead and iron composition of atmospheric particulates at selected Study Area sites.

SITE (NO.)	Fernberg (7001)	Toimi (7007)	Babbitt (7013)	Scanlon (7412)
	(ng/m^3)			
	Sulfur			
Max	1976.0	1603.0	2189.0	5623.0
Min	101.0	23.0	70.0	245.0
Avg	729.1	466.6	695.9	1173.9
SD[a]	559.6	481.3	601.5	1188.2
	Lead			
Max	111.0	48.0	322.0	327.0
Min	ND	ND	6.0	8.0
Avg	18.5	13.3	136.1	177.1
SD	25.3	13.7	80.4	78.2
	Iron			
Max	2448.0	1463.0	9462.0	1998.0
Min	15.0	6.0	49.0	188.0
Avg	376.0	413.0	1483.6	934.2
SD	564.0	442.2	2041.5	540.

SOURCE: Eisenriech, Hollod and Langevin ,1978.

[a]SD = standard deviation.

and Duluth (which is remote from the Study Area and not specifically discussed here). Intermediate sites, which are clearly impacted by human activity but not to the degree of a site such as Babbitt, include the Hoyt Lakes golf course, Bear Head, Erie and Dunka Road. The basis for this grouping is brought out by the box plots for sulfur, lead, and iron for all the sites, shown in Figures 68, 69 and 70.

Figures 68, 69 and 70

A general examination of elemental concentrations in air particulates for the region permits elements to be broadly classified into four main groups:

1) high, with levels generally greater than 1000 ng/m^3 - Fe

2) medium, with levels usually between 100-1000 ng/m^3 - Si, Al, K, S

3) low, with levels usually between 10-100 ng/m^3 - Ti, Mn, P, Ba, Zn, Pb, Br

4) very low, with levels usually less than 10 ng/m^3 - Sr, Rb, Ga, Ni, Ge, V, Cr, Co, Cu, Sn, W, As, Sb, Hg, Cd, Se

Table 53 summarizes elemental concentrations in air particulates at the remote Fernberg Road site along with the regional means, and compares them to typical ranges of concentrations observed at urban and remote areas around the world. In general, elemental concentrations in air particulates at Fernberg Road and in the overall region were typical of remote, mid-continental areas. However, the following elements occurred at concentrations lower than expected at the remote sites: Si, Ni, Cu, Co, V, Cl and S. Elements occurring at higher concentrations than expected were Fe and Cr. In the low concentration category, Cu, Ni, Co, V and S are usually associated with anthropogenic activities (base metal smelting,

FIGURE 68

DISTRIBUTION OF SULFUR IN ATMOSPHERIC PARTICULATES AT STUDY AREA SITES (BASED ON 24-HOUR MEASUREMENTS)

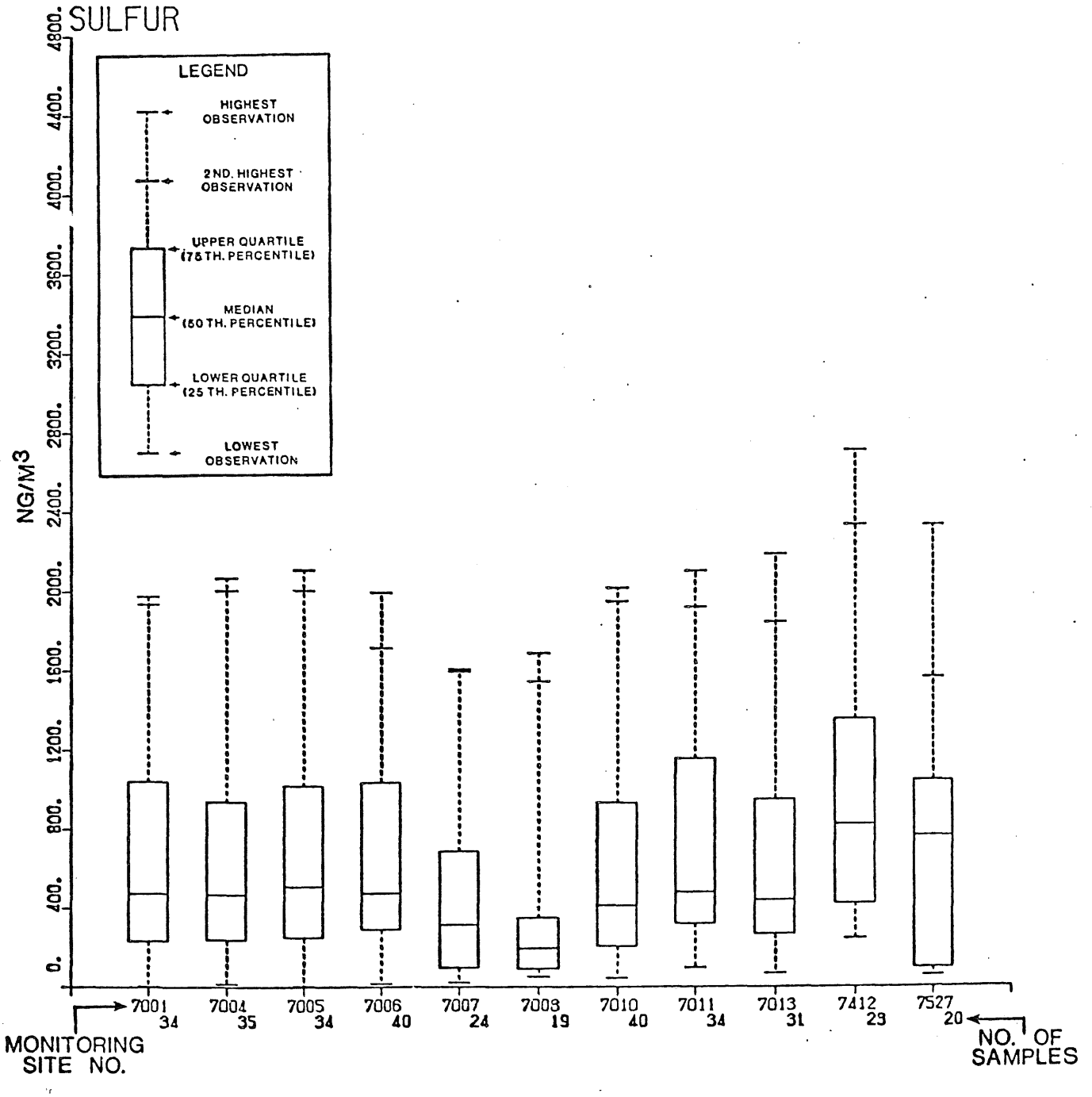


FIGURE 69

DISTRIBUTION OF LEAD IN ATMOSPHERIC PARTICULATES AT STUDY AREA SITES (BASED ON 24-HOUR MEASUREMENTS)

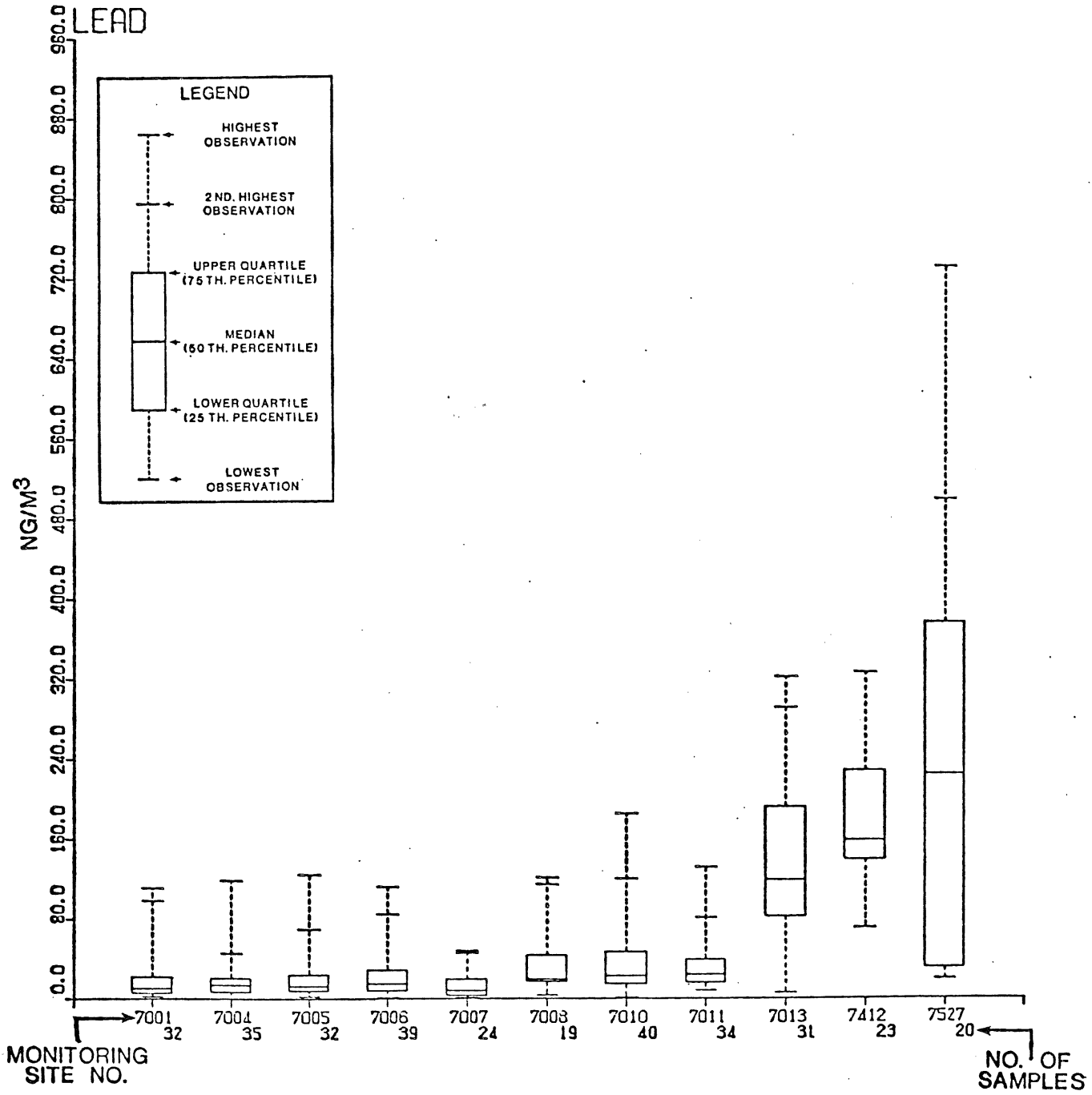
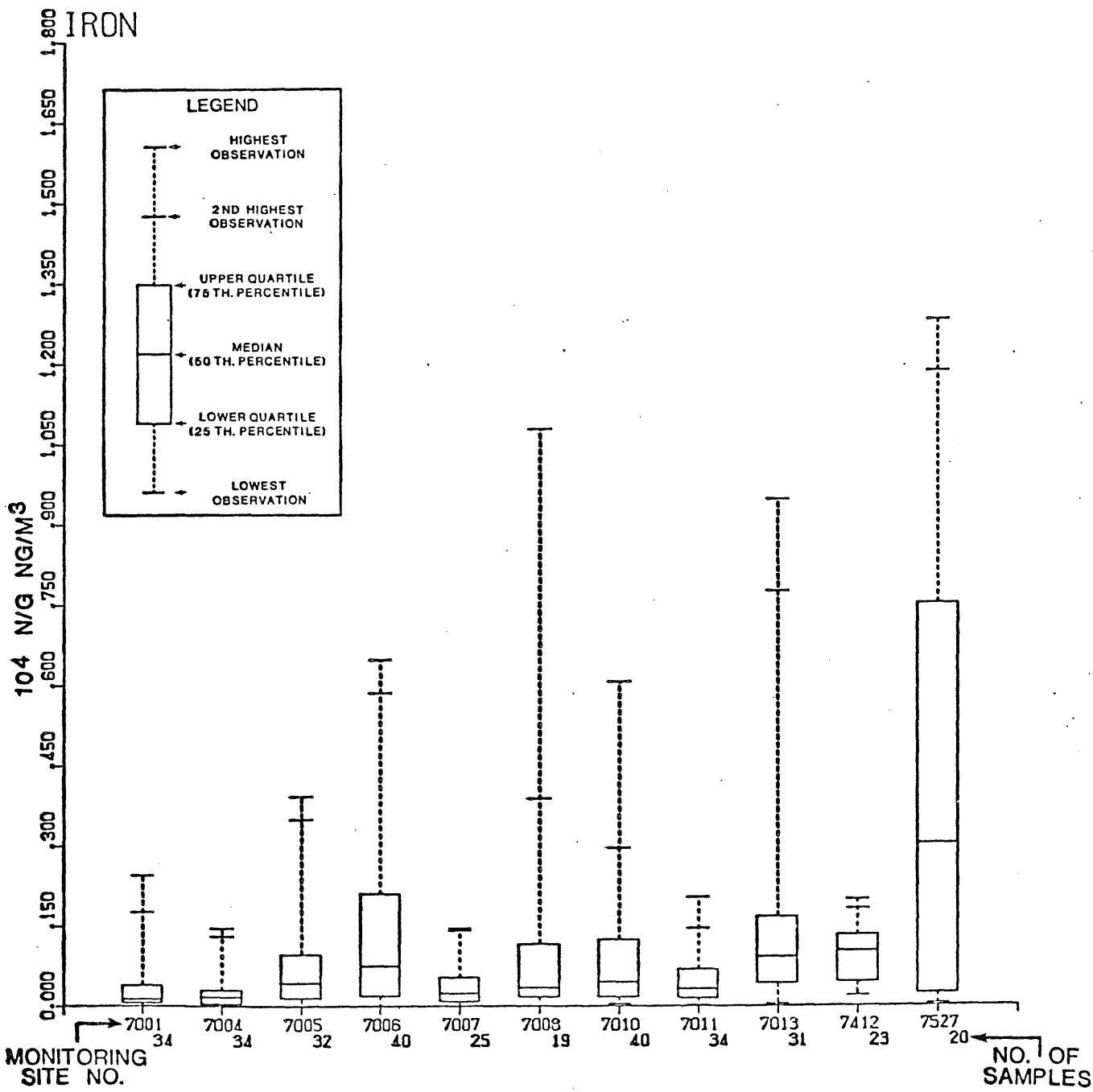


FIGURE 70

DISTRIBUTION OF IRON IN ATMOSPHERIC PARTICULATES AT STUDY AREA SITES (BASED ON 24-HOUR MEASUREMENTS)



fossil-fuel combustion, etc.) while Si and Cl derive from natural sources, soil, and sea-spray, respectively. Vanadium has been used as a tracer of fuel oil combustion, but does not appear to be significant at the remote site. Copper and Ni concentrations were low demonstrating the present lack of man's influence on these two elements in the Study Area. If copper-nickel development occurs, measurements of Cu, Ni, and Co should provide good indicators of particulate air pollution from this industry.

Table 53

The enhanced concentration of Fe in the region may demonstrate the influence of taconite mining and processing on the air quality of the region. The relatively higher values observed for Cr cannot be explained at present; however, possible explanations include natural Cr enhancement in soil, a local unrecognized source, or long distance transport into the region.

Seasonal trends in the concentrations of Al, Fe, Pb and S in air particulates at Fernberg Road, Toimi and Erie are shown in Figures 71, 72, and 73. The patterns observed at these three stations are, in general, typical of those observed at all regional, non-urban sites. The four elements chosen for depiction of seasonal trends were selected because they represent coarse-size (Al, Fe) and fine-size (Pb, S) air particles (Eisenreich, Hollod and Langevin 1978).

Figures 71, 72 and 73

The concentrations of Al and Fe usually peaked in late spring and summer and occurred at lower values in winter. This observation is complicated by the fact that air monitoring was not initiated at the Fernberg Road site until March, 1977, and that the taconite iron industry was shut down after late July, 1977.

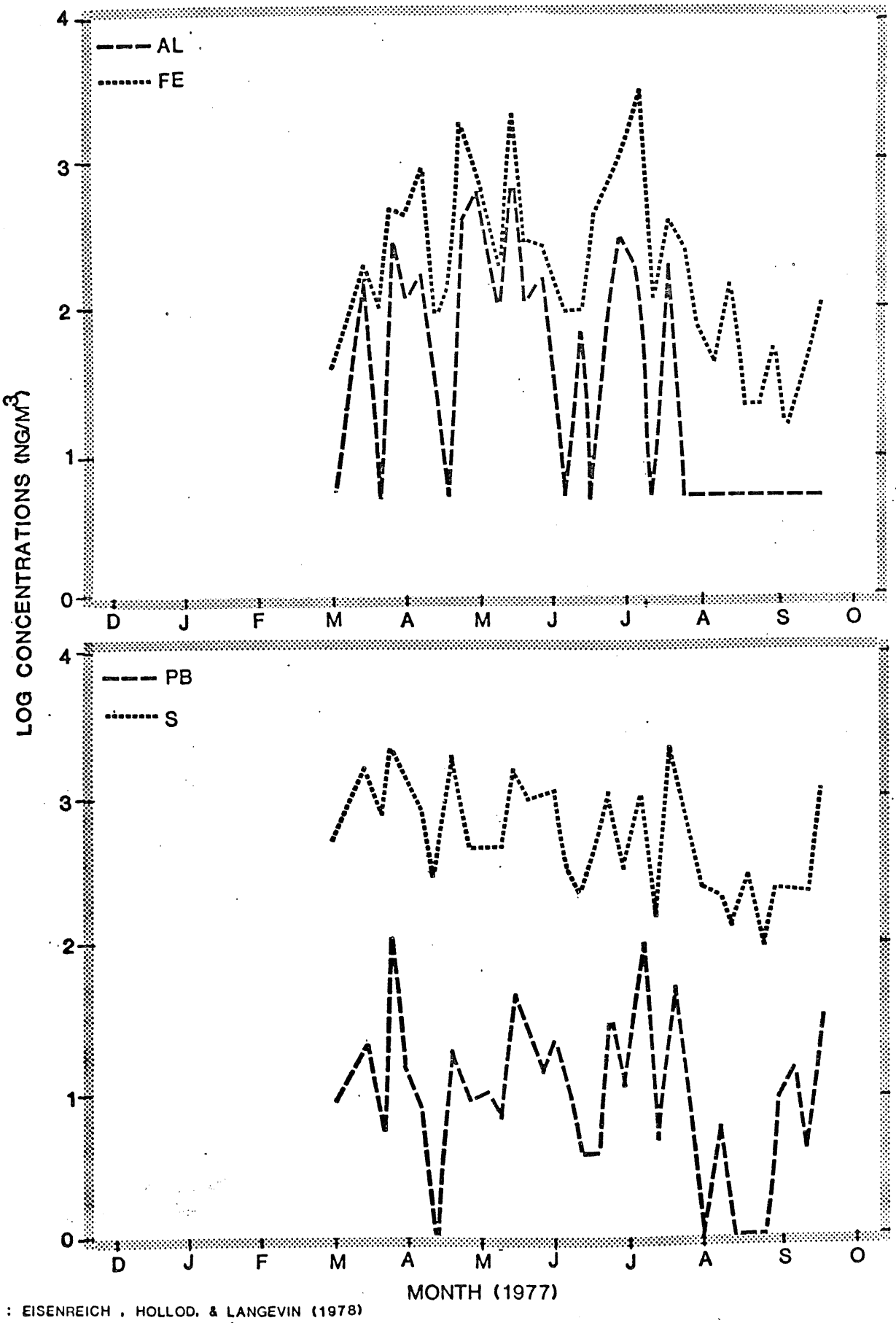
Table 53. Elemental concentrations in air particulates for N.E. Minnesota compared to remote and urban areas worldwide.

ELEMENT	Urban	Remote	N.E. Minnesota Fernberg	N.E. Minnesota Region Average[a]
	---------- ng/m^3 ----------			
Al	190-4,000	2-450	100	240-299
Si	670-60,000	130-7500	455	910
K	200-5,000	10-300	110	163
Ti	18-500	1-50	16	29-56
Sr	----	----	.3	2-5
Rb	----	----	.1	.7-2
Mn	10-200	0.2-20	6	15-19
Ga	----	----	.4	.3-2
Fe	250-10,000	4-800	376	1048
Ni	2-200	0.4-10	1	2-4
Ge	----	----	.2	.04-2
V	20-600	0.5-20	.8	.5-11
P	50-200	5-100	33	50
Cr	2-100	0.1-15	11	4-10
Ba	----	----	15	30
Co	0.2-20	0.1-14	.6	2-8
Cu	10-1,000	0.4-100	5	6-12
Zn	30-3,000	0.03-150	76	22
Cl	70-7063	9-2,000	19	34-83
Sn	----	----	2	1-5
W	----	----	4	.7-7
As	1-40	0.3-5	2	4-7
Ca	150-20,000	10-2,500	201	320
S	2,000-10,000	800-13,000	729	692
Sb	----	----	2	.6-4
Pb	20-3,000	0.3-200	19	58
Br	6-700	.5-8	5	15
Hg	.2-11	.06-4	.2	.2-3
Cd	.3-100	0.01-4	2	.8-9

SOURCE: Eisenreich, Hollod and Langevin (1978)

[a]Where a range is shown, the lower average resulted from including not-detectable data as zero, while the higher average was arrived at by omitting not-detectable data. The data shown here include the Duluth site.

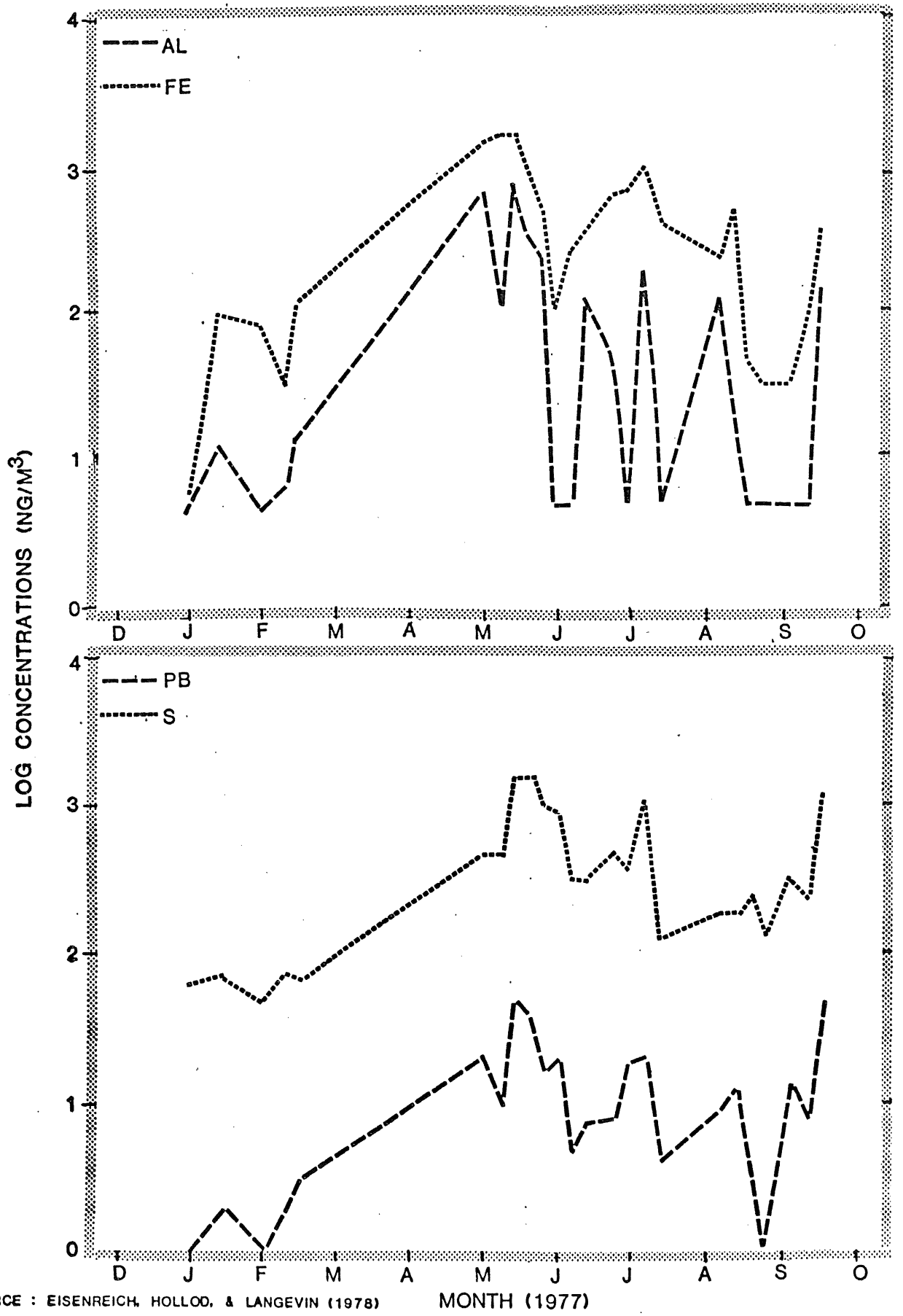
FIGURE 71 SEASONAL VARIATIONS IN ATMOSPHERIC PARTICULATE CONCENTRATIONS (AL, FE, PB, S) - FERNBERG ROAD (REMOTE SITE)



SOURCE : EISENREICH , HOLLOD. & LANGEVIN (1978)

FIGURE 72

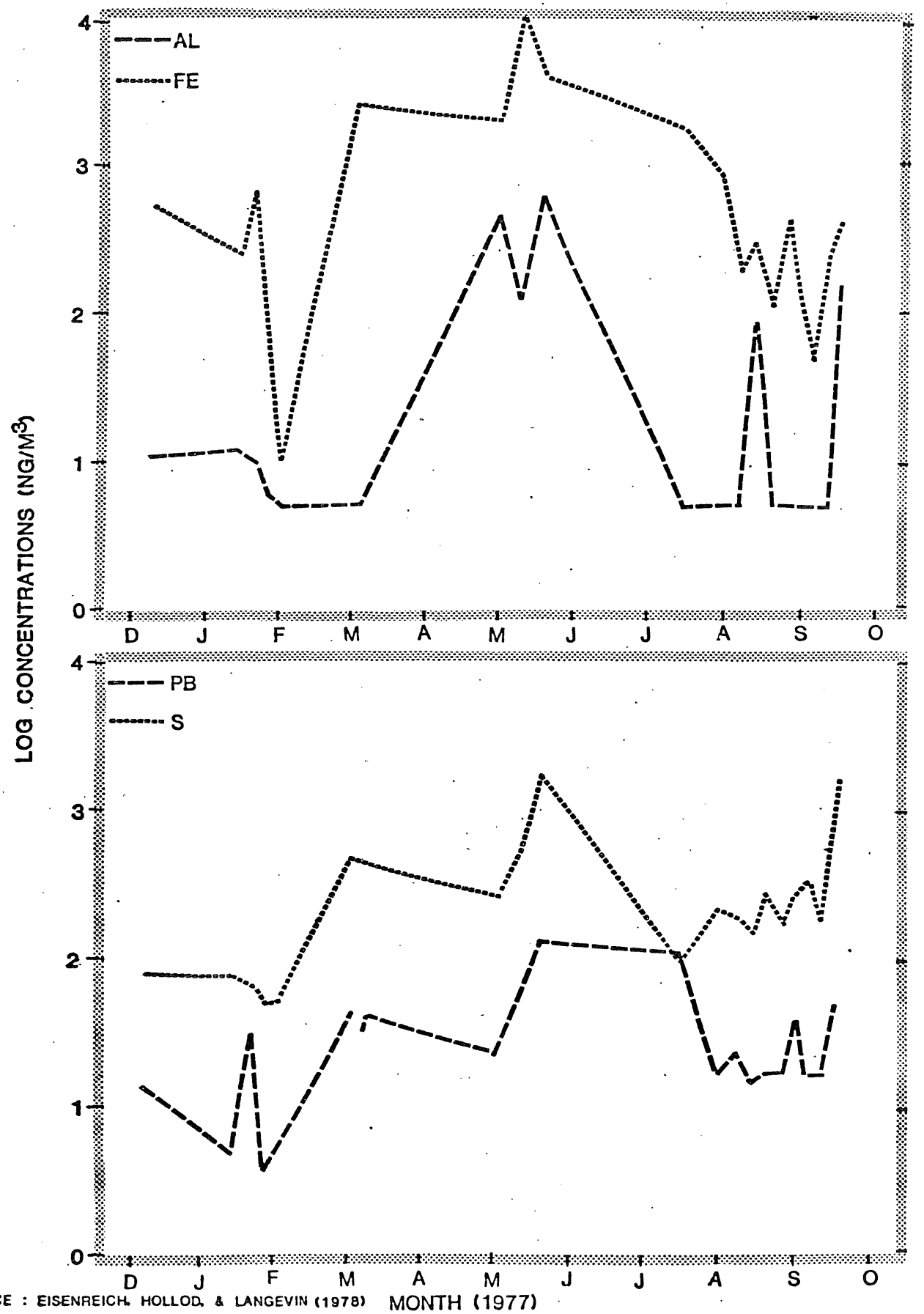
SEASONAL VARIATIONS IN ATMOSPHERIC PARTICULATE CONCENTRATIONS (AL, FE, PB, S) - TOIMI SITE



SOURCE : EISENREICH, HOLLOD, & LANGEVIN (1978)

FIGURE 73

SEASONAL VARIATIONS IN ATMOSPHERIC PARTICULATE CONCENTRATIONS (AL, FE, PB, S) - ERIE SITE



SOURCE : EISENREICH, HOLLOD, & LANGEVIN (1978)

The seasonal trends in Pb and S content of air particulates exhibited two apparently different patterns. At Toimi and Erie, S and Pb content generally increased from winter to summer to fall, although significant variability was evident. However, Pb and S at Fernberg exhibited a slightly decreasing trend over the study period. Due to variability in the data as well as the relatively short period of time for which data is available, it is not possible to clearly identify the source of these trends. This is an area in which the aquisition of further data would be particularly useful.

As noted earlier, the occurrence of the taconite worker's strike during the air sampling program provided a unique opportunity to observe the effect of this industry on the air quality of the region. The effects were apparent not only in terms of the TSP results as discussed earlier, but also in the results for atmospheric loading of elemental constituents as measured by data from the membrane sampling study. Table 54 presents mean ambient concentration data for selected elements at the various sampling sites. The data are divided into results immediately before and during the strike.

Table 54

Several observations may be made concerning these results. First, chlorine, which is not expected to be associated with emissions from mining areas, shows no significant decrease during the strike. If any change is apparent, it is a slight increase at certain sites, indicating no general reduction of atmospheric particulates in the region due to non-mining related factors. Second, constituents which would be expected to be associated with mining emissions, Al, Si, and Fe, show consistent and sizeable decreases during the strike. Concentrations during the strike were typically a factor of 5 to 10 below pre-strike levels.

Table 54. Mean ambient concentration of selected constituents at Study Area monitoring sites before and during the taconite strike[a] (ng/m^3).

SITE	FERNBERG		ELC		BEARHEAD		DUNKA		TOIMI		HOYT LAKES GOLF COURSE		WHITEFACE		BABBITT	
Constituent	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During	Before	During
Al	153	29	214	68	372	106	758	125	226	147	246	82	190	65	406	200
Si	617	100	685	190	1329	305	2273	208	865	329	944	239	738	223	1637	646
Cl	52	69	103	73	65	113	47	90	46	93	34	58	---	67	32	81
Fe	529	49	440	76	1058	137	2118	165	700	170	1539	167	637	113	1962	446

[a]Sampling period before the taconite miner's strike was 3/14/77-7/24/77, with the period during the strike from 7/30/77-10/4/77. The values shown are arithmetic means for the indicated periods.

Third, as might be expected, the declines tend to be greatest close to mining areas (Dunka) and smaller in areas affected by other activities (Babbitt). It is interesting to note that the relative decline at a remote site like Fernberg was as large as that at Dunka. This indicates the importance of relatively long distance transport to the air quality in remote areas.

In order to investigate the size of particles comprising the ambient total suspended particulates in the Study Area, size-differentiated air particulates were collected at the Kawishiwi and Hoyt Lakes golf course sites from September, 1976 through December, 1977 using Delron cascade impactors. Particle-size cutoffs in micrometers (um) were 16,8,4,2,1 and 0.5 equivalent aerodynamic diameter for stages 1 through 6, respectively. The back-up filter collected particles passing the first six stages (of course the above cutoffs are not absolute, but represent nominal size classifications). Air-borne particles were drawn into the instrument under vacuum. The various sized particles impacted onto grease-coated glass slides inserted at the stages. Details of the experimental procedure, results and interpretation can be found in Eisenreich, Langevin and Thornton (1978).

A comparison of size fractionated aerosol samples analyzed for 5 metals at these sites and averaged over the study period is shown in Figure 74. The data are plotted as log (metal) concentration versus impaction stage or cutoff diameter. The results of means for all size fractionated aerosols are given in Tables 55 and 56. Iron, Al, Mn and Ca were nearly always dominated by large particle sizes while Pb occurred primarily in small particles sizes. In general, Fe and Mn concentrations tended to increase in the less than 0.5 um size fraction suggesting a bimodal distribution for these elements, and the presence of more than one source. This pattern was identical at both sites, differing only in

that the metal concentrations were a factor of 2-3 higher at the Hoyt Lakes golf Course than at the Kawishiwi lab.

Figure 74, Tables 55 and 56

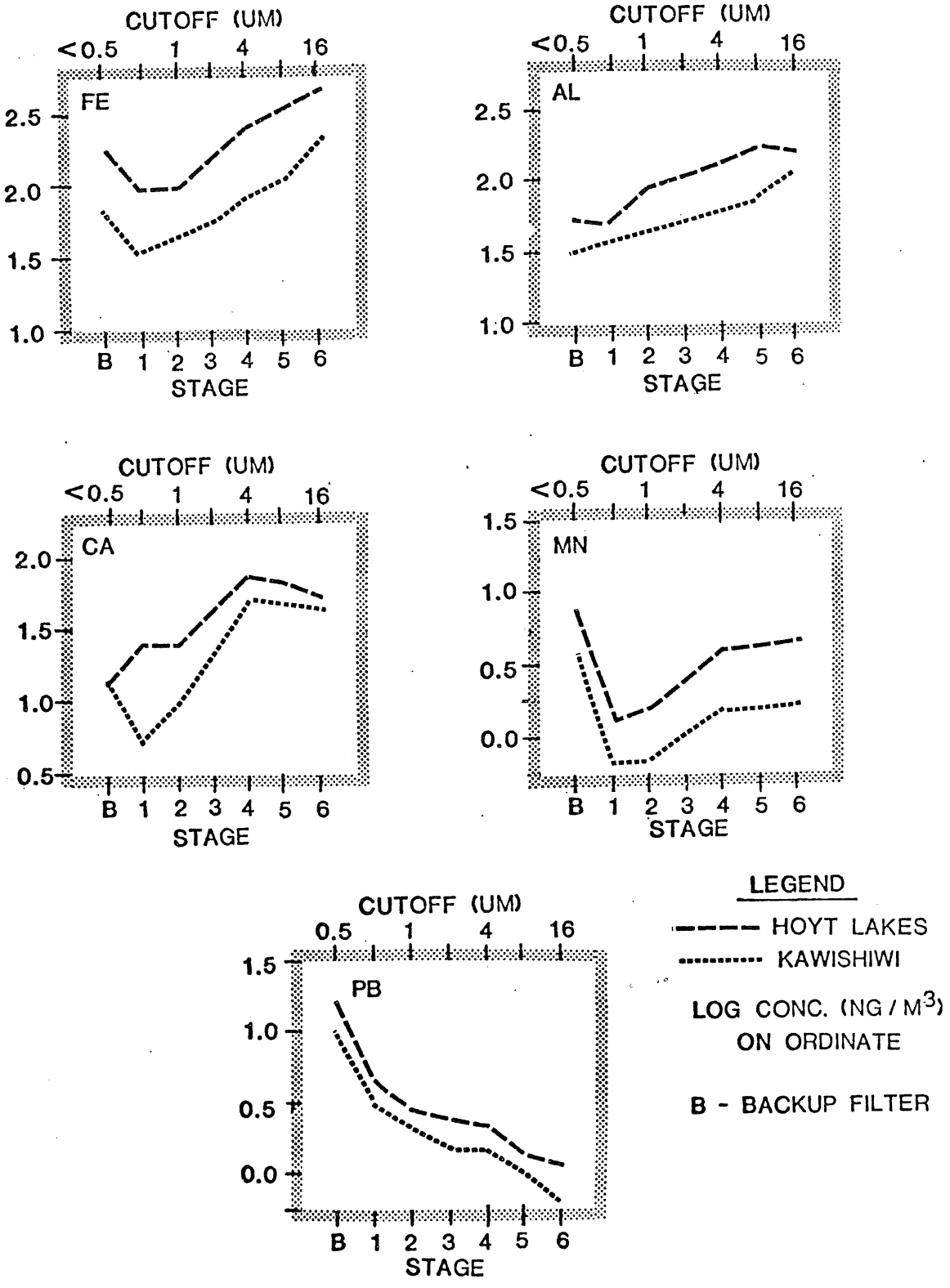
Average mass median diameters (mmd) were calculated for Fe, Al, Ca, Mn and Pb (Table 57). At Kawishiwi, for example, values ranged from 7.8 um for Ca, 6.9 um for Fe, 5.2 um for Mn, and 4.9 um for Al to 1.1 um for Pb. The calculated mmd's were 0.2 to 2.6 um smaller at the Hoyt lakes golf course than at Kawishiwi, but were generally larger than those observed in closer proximity to pollution sources. This is seen from data collected at the University of Minnesota campus in Minneapolis (also shown on Table 57) which are typical of urban values (Eisenreich, Langevin and Thornton 1978).

Table 57

3.5.2.2 Composition of Deposited Particulates--Particulates suspended in air eventually deposit onto land and water surfaces. Deposition occurs both as dry deposition and as rain or snow scavenged deposition. During the course of the Copper-Nickel Study deposition data was gathered in the region using bulk deposition sampling, wet-only sampling, and throughfall sampling. In addition, dry deposition was calculated from the ambient concentrations of various elemental constituents (from the membrane sampling results presented earlier) using deposition velocity data from the literature. This discussion focuses on the results of the bulk deposition sampling. The results of the through-fall and wet-only samples are in general agreement with the bulk results and are not discussed here. The interested reader is referred to Eisenreich, Hollod and Langevin (1978) for a discussion of these programs.

FIGURE 74

SIZE DISTIBUTIONS OF FE, AL, CA, MN, AND PB IN N E. MINNESOTA AEROSOL



SOURCE : EISENREICH, HOLLOD, & LANGEVIN (1978)

Table 55. Mean atmospheric metal concentrations in different size fractions at Kawishiwi Laboratory (ng/m^3).

Size Range (um)	Fe	Al	Ca	Mn	Pb	Cu	Ni
above 16	198	116	46	1.8	0.60	-1.3[b]	-1.1
	(258)[a]	(90)	(35)	(0.97)	(0.61)	(2.5)	(0.49)
8-16	107	74	50	1.5	1.1	-4.5	-0.93
	(153)	(56)	(36)	(0.93)	(1.5)	(6.4)	(0.30)
4- 8	83	59	49	1.5	1.5	-0.79	-0.93
	(121)	(61)	(40)	(0.92)	(1.3)	(0.95)	(0.30)
2- 4	54	50	21	1.1	1.5	-0.53	-1.0
	(57)	(37)	(20)	(0.44)	(1.0)	(0.49)	(0.24)
1- 2	44	47	9.5	0.67	2.1	-1.1	-1.2
	(46)	(28)	(8.9)	(0.38)	(1.6)	(2.1)	(0.90)
.5- 1	34	39	5.5	0.66	3.2	-1.3	-1.1
	(51)	(26)	(6.2)	(0.36)	(2.6)	(2.9)	(0.58)
below .5	61	60	15	3.8	10	ND	-8.4
	(80)	(59)	(11)	(9.0)	(14)		(6.2)

SOURCE: Eisenreich, Hollod and Langevin, 1978.

[a]Numbers in parenthesis represent one standard deviation from the mean.

[b]A minus (-) indicates that the value was less than the number shown.

Table 56. Mean atmospheric metal concentrations in different size fractions at Hoyt Lakes Golf Course (ng/m^3).

Size Range (um)	Fe	Al	Ca	Mn	Pb	Cu	Ni
above 16	443 (591)[a]	162 (249)	53 (39)	4.8 (6.8)	1.2 (0.93)	-1.4[b] (1.5)	-2.2 (2.3)
8-16	304 (345)	168 (207)	69 (80)	4.2 (7.1)	1.4 (1.0)	-2.0 (3.0)	-2.0 (2.3)
4- 8	236 (267)	128 (142)	71 (74)	3.9 (4.9)	2.3 (1.6)	-1.0 (1.1)	-1.5 (0.96)
2- 4	158 (192)	104 (115)	43 (39)	2.6 (3.4)	2.4 (1.8)	-1.0 (1.6)	-1.4 (0.78)
1- 2	90 (115)	82 (85)	26 (39)	1.6 (1.5)	2.9 (1.9)	-2.7 (4.9)	-1.4 (0.78)
.5- 1	98 (157)	52 (43)	26 (24)	1.3 (1.0)	4.8 (3.6)	-1.9 (2.2)	-1.4 (0.78)
below .5	184 (258)	54 (65)	14 (6.5)	7.2 (9.2)	15 (15)	-0.60 ND	-14 (18)

SOURCE: Eisenreich, Hollod and Langevin, 1978.

[a]Numbers in parenthesis represent one standard deviation from the mean.

[b]A minus (-) indicates that the value was less than the number shown.

Table 57. Mass median diameters (um) of particulate metal.

Metal		NORTHEASTERN MINNESOTA Kawishiwi Lab	Hoyt Lakes Golf Course	Univ. of Minn. Minneapolis, MN
Fe	Mean	6.9	7.3	5.2
	Max	+16[a]	10.3	
	Min	approx. 25	3.8	
	Std. Dev	5.8	2.7	
Al	Mean	4.9	4.5	5.3
	Max	9.8	7.8	
	Min	0.69	3.5	
	Std. Dev	3.0	1.5	
Ca	Mean	7.8	5.2	6.9
	Max	14.9	7.7	
	Min	5.5	2.7	
	Std. Dev	3.7	1.9	
Mn	Mean	5.2	5.0	0.47
	Max	17.2	8.1	
	Min	0.08	0.08	
	Std. Dev	5.1	3.3	
Pb	Mean	1.1	0.91	0.38
	Max	3.0	2.6	
	Min	0.04	0.18	
	Std. Dev	1.1	0.88	

SOURCE: Eisenreich, Langevin and Thornton, 1978.

[a]A plus (+) indicates the value was greater than the number shown.

Bulk samples collected both wet and dry deposited materials. For this study, samplers were placed at four sites: Fernberg Road, Spruce Road (near Kawishiwi lab), Dunka Road, and Hoyt Lakes Golf Course. Samples were collected monthly from 3-14-77 to 3-22-78 and each sample represents about 30 days of collection. Detailed sample data is presented in Thingvold et al. (1978). Table 58 summarizes the results by parameter in the form of an average rate using the data from all four sites. When the data set contained readings below detection limits, the resulting regional average is shown as a "less than" value in the table.

Table 58

In addition to a regional average deposition rate from bulk measurements (wet plus dry), Table 58 also shows dry deposition rates for selected elements. These values were calculated from the atmospheric concentrations of each element as measured by the membrane samplers in the region (see the previous section, 3.5.2.1). The deposition rates are arrived at by using the relationship (Chamberlain, 1960): Deposition Rate = (ambient concentration) X (deposition velocity)

Deposition velocities for various elements, as determined at Chilton and reported in Cawse (1974) were used here for calculational purposes. These deposition velocities are shown in Table 59.

Table 59

From the deposition rates shown in Table 58 it is seen that, with the exception of iron, chloride, and sulfate, there is no significant difference between the measured bulk and computed dry deposition rates. This indicates that dry depo-

Table 58. Regional average deposition results.

ELEMENT	MEASURED BULK DEPOSITION RATE REGIONAL AVERAGE (kg/ha/yr)	CALCULATED MEAN ANNUAL DRY DEPOSITION RATE[d] (kg/ha/yr)
Al	.360-1.467 (.846)[b]	.889
As	-.011[a]	.003
Ca	-11.3[a]	--
Cd	.003	.003
Cl	-13.39[a]	.192
Cu	.011	.010
Fe	.345-1.99 (1.08)[b]	6.52
F	-.014[a]	--
K	-3.53[a]	--
Mg	-11.3[a]	--
Na	-3.53[a]	--
Ni	-.014[a]	.007
Pb	.077	.034
Zn	.057	.03
Alkalinity ($CaCO_2$)	-70.51[a]	--
TOC	28.9	--
P-total	.28	--
NO_2, NO_3	2.04	--
TDS	70.5	--
SO_4[c]	14.36	1.78

SOURCE: Thingvold et al. 1978.

[a]Indicates something less than.
[b]Range and (mean), totals.
[c]Geometric mean.
[d]Based on measured ambient concentrations.

Table 59. Dry deposition velocities used to compute dry deposition rates for selected elements.

ELEMENT	DEPOSITION VELOCITY (cm/sec)
Al	1.3
As	0.2
Cd	0.4
Cl	1.0
Cu	0.8
Fe	2.5
Ni	1.4
Pb	0.3
Zn	0.6
SO_4	0.3

SOURCE: Cawse 1974.

sition is the dominant mechanism affecting overall atmospheric input to the surface for these elements in the Study Area.

The high dry deposition rate for iron relative to bulk deposition suggests a possible bias for this constituent as a result of one of the sampling techniques, and/or differences between the set of sample sites used to arrive at the two deposition estimates. Looking only at ambient concentrations at the sites for which bulk data was collected does not resolve this question, since the bulk samples were somewhat removed from the location of the membrane samples, particularly at the Spruce Road bulk site where the Kawishiwi lab was the closest membrane site. In terms of the bias due to sampling methods, recall that most of the iron more than likely originates from area sources such as unpaved roads, tailing basins, and stock piles. A plume from these sources probably does not elevate to any extent, traveling perhaps only several hundred feet off the ground. The membrane samplers are about 8-15 feet farther off the ground than the bulk collectors. Thus, the tree canopies may actually scavenge or screen the iron particles before they reach the bulk collectors. In fact, iron concentrations in bulk collected samples are lower in the summer months during the time when the deciduous trees are foliated.

In contrast to the data for iron, the results for sulfate and chlorine indicate that dry deposition is responsible only for a small portion (roughly 12% for sulfate and 1 or 2% for chlorine) of the total loading of the constituents. For chlorine it is reasonable to hypothesize that road salting may provide a major local source. For example, roughly 10,000 tons of rock salt was applied to roads in the area during the 1975-76 winter season (see section 4.3.2.1 of Volume 3-Chapter 4 on water resources). The chloride used in this application might be susceptible to entrainment in the air by the action of passing vehicles.

Alternatively, it is possible that chlorides are carried into the region by long range transport from remote areas where sources such as sea water create rain events with elevated chloride levels. Further sampling would be required to resolve this question.

For sulfate, the average bulk deposition was 14.4 kg/ha/yr, while the dry rate was 1.78 kg/ha/yr. It must be noted that it is assumed that the sulfur present in dry deposition is in the form of sulfate. Actually, the analytical method used for the membrane samples measures sulfur. This assumption appears valid, however, due to the low predicted calculated values for SO_2 due to local sources, as well as the lack of measurable ambient SO_2 concentrations in the region (see section 3.4). Consequently, it is believed that most of the sulfate, as measured by bulk samples, originates outside of this region, perhaps several hundreds of miles away in areas such as St. Louis, the Ohio valley and the East Coast area. Long-range transport of sulfate is quite feasible when large high-pressure systems are centered to the east and south of Minnesota. The large, clock-wise vortex of winds then can move sulfur compounds from the industrialized areas of the East to Minnesota. Under certain conditions Canadian cold-fronts can collide with this sulfur-laden, warm air mass over northeastern Minnesota causing high levels of sulfate in the precipitation. Thus in this case, rain scavenging would be an important mechanism for deposition, Thingvold et al. (1978). The apparent dominant role of wet deposition of sulfate in the region (see section 3.4.3) supports this explanation.

In conclusion, it is useful to compare the observed deposition rates in the region from bulk deposition data with deposition rates determined elsewhere. Table 60 makes this comparison with data from studies of Lake Superior and Lake Michigan. The data indicate that deposition in the region is generally com-

parable to that found in remote areas, with the possible exception of iron. Recalling that the dry deposition value for iron was some 8 times greater than the observed bulk value, it is reasonable to conclude that this constituent is elevated in the region as a result of local sources, principally taconite mining operations. There also appear to be local sources for lead (internal combustion engines) and chlorides (possibly road salt). Sulfate deposition appears to be dominated by wet deposition, likely from sources outside of the region.

Table 60

3.5.3 Mineral Fibers

Among the potential types of atmospheric particulates of concern are particles classified as minerals fibers. Because of the unique nature of these particles and the concern surrounding them, they are discussed here in a separate section.

Mineral fibers are a potentially serious, but presently poorly understood, environmental health hazard for the occupational and nonoccupational population in both Minnesota, as evidenced by the Reserve Mining controversy, and nationwide. Confusion has resulted from misuse of terminology and the fact that of the mechanism by which fibers affect health is not clearly understood. These topics will be briefly discussed below. Because of the present interest in and difficulties with "state of the art" analysis, this parameter is presented in more detail than other air quality parameters in this section. For further information, see Volume 3-Chapter 2 on mineralogy, and Volume 5-Chapter 2 on human health. Also, refer to the report "Ambient Concentrations of Mineral Fibers in Air and Water in Northeast Minnesota," (Ashbrook, 1978).

Table 60. Summary comparison of atmospheric deposition of trace elements (kg/ha/yr).

ELEMENT	N.E. MINNESOTA A	LAKE SUPERIOR B	LAKE SUPERIOR C	LAKE MICHIGAN D
Al	.85	---	1.6	.86
Fe	1.08	1.18	1.9	.48
Zn	.057	---		.19
Cu	.011	.045	.097	.021
Ni	-.014	---	.024	---
Pb	.077	.079	.17	.11
Cd	.003	.007	.006	.002
As	-.011	---	---	---
Ca	-11.3	4.0	4.2	14
Mg	-11.3	.68	1.0	2.7
Na	-3.5	1.8	---	1.9
K	-3.5	1.6	---	1.1
Cl	-13	---	---	---
SO_4	14.4	27	---	15

A-Bulk deposition data. A minus(-) indicates the average is less than the value shown.
B-Eisenreich, Hollod and Langevin (1978).
C-IJC (1977).
D-Eisenreich (1978).

Asbestos is used as a collective mineralogical term encompassing the asbestiform varieties of various silicate minerals and is applied to a commercial product obtained by mining primarily asbestiform minerals. Five minerals fit this definition: chrysotile (a member of the serpentine group), and the asbestiform varieties of actinolite-tremolite, anthophyllite, cummingtonite-grunerite, and riebeckite (members of the amphibole group). Chrysotile always occurs in the asbestiform habit, while amphiboles usually occur in a non-asbestiform habit as crocidolite. Asbestiform minerals occur as fibers, which display some resemblances to organic fibers in terms of circular cross section, flexibility, silky surface luster, and other characteristics. Cleavage fragments, such as those produced from crushing and processing non-asbestiform minerals, do not satisfy this definition of fibers and should be considered "fiber-like."

When asbestiform and non-asbestiform minerals are subjected to crushing and processing, the resulting fagments have minor differences in morphology and physical properties that are very difficult to distinguish under a transmission electron microscope (TEM). For this reason, when the TEM is used fibers are defined as fragments with an aspect (length to width) ratio of 3:1 or greater, even though many of these fragments may not meet the mineralogic definition of a fiber. In this report, the term "mineral fiber" will be used to denote both asbestos fibers and cleavage fragments of non-asbestiform minerals because ambient levels of mineral fibers were determined by transmission electron microscopy which did not distinguish between these two classifications. Asbestos fibers and non-asbestiform cleavage fragments have different characteristics in terms of tensile strength, flexibility, durability, and surface properties. The extent to which these differences are related to the harmful properties of asbestos is uncertain at this time.

Mineral fibers have a number of possible sources. Fragments can be generated from both asbestiform and non-asbestiform minerals by both human activities, such as construction, drilling, blasting, transporting, and processing ore, and by natural processes such as mechanical effects from wind and water. Asbestos fibers may occur naturally; however, they are uncommon in northeastern Minnesota. Mineral fibers may also be introduced to this region through sources such as insulation materials, foods, and brake linings in motor vehicles.

The Regional Copper-Nickel Study conducted a general survey of ambient atmospheric fiber concentrations in the Study Area to characterize existing levels and to try to correlate these levels with suspected fiber sources near the Duluth Gabbro Contact. The resulting levels found in northeastern Minnesota are comparable to levels reported by other investigators.

Samples were collected throughout 1977 in conjunction with the rest of the air sampling program. Samples consisted of 24-hour membrane air filter samples from six sites and a cascade impactor sample from Hoyt Lakes. Membrane air filters were cut up into pieces and one piece underwent fiber analysis. Five days were chosen as the sample days for fiber analysis based upon varying meteorological conditions and availability of filters for analysis. In addition, a special cascade impactor sample for fiber analysis was collected in Hoyt Lakes, to investigate the aerodynamic size distribution of ambient fibers. Table 61 lists the sites and sampling dates for which fiber analyses were made.

Table 61

All samples were analyzed by the Minnesota Department of Health according to the methodologies appearing in Ashbrook (1978). Fiber concentrations are reported in

Table 61. Site location and dates of sample collection for mineral fibers.

SITE NAME (NUMBER)	MEMBRANE FILTER AIR SAMPLES (1977) 6 February	8 March	1 May	12 June	5 August
Fernberg Road (7001)	X	X	X	X	X
Environmental Learning Center (7004)	X	NA[a]	X	X	X
Bear Head Lake State Park (7005)	X	X	X	X	X
Erie Mining Office Building (7008)	X	NA	X	NA	X
Toimi (7007)	X	X	X	X	X
Babbitt (70013)	NA	NA	X	X	X
	Cascade Impactor Sample				
Hoyt Lakes (7010)	14 October				

SOURCE: Ashbrook 1978.

[a]NA = not available.

four categories. Amphibole fibers were defined as those fibers which gave electron diffraction patterns characteristic of amphibole minerals. A fiber which clearly had a chrysotile diffraction pattern was classified as chrysotile. A mineral with a clearly non-amphibole, non-chrysotile diffraction pattern was classified as non-amphibole, nonchrysotile. Mineral fibers classified as ambiguous had diffraction patterns or elemental ratios which could not be used to place the fiber in one of the three previous categories.

Total fiber levels are given with and without chrysotile because the Minnesota Department of Health was uncertain whether the observed chrysotile fibers were artifacts from the filters or were actually present in the samples. Analyses of blank filters by the Minnesota Department of Health suggested that Millipore filters contain significant levels of chrysotile and Nuclepore filters sometimes contain amphibole fibers.

The aspect ratio of a fiber (length divided by width) is a variable of interest, since it may relate to the potential health hazards involved. (see the health report, Volume 5-Chapter 2, section 2.10.2.2). Mean aspect ratios for each category were calculated by dividing the mean length by the mean width of all the fibers observed in the category.

The results of the membrane air filter sampling are given in detail in Ashbrook (1978). Overall, fiber concentrations varied greatly over the days of sampling at each site. In general, total fiber values averaged between 10,000 and 40,000 fibers/m^3. If chrysotile is excluded from the counts, total fiber levels generally range from 7,500 to 35,000 fibers/m^3. Six blank samples had an average of 1.66 chrysotile fibers per grid square compared to an averge of 1.77 chrysotile fibers per grid squre for the 25 actual air filter samples. Because

fiber levels are calculated directly from fibers per grid square, these data suggest that most, if not all, of the chrysotile found in the air samples can be attributed to contamination of the filters.

The median counts, by fiber type found in all samples collected at each site are given in Table 62. For the sampling period, amphibole fiber counts were highest at the Erie Mining Office; non-amphibole, non-chrysotile fiber levels were highest at the Environmental Learning Center; and ambiguous fiber counts were highest at the Erie Mining Office and Babbitt. The highest individual reading (92,300 fibers/m^3) was at Bear Head Lake State Park on June 12, 1977; the lowest level (5,730 fibers/m^3 -- without chrysotile) was measured at the Fernberg Road site also on June 12. For comparison, the results of earlier work in Silver Bay, Minnesota by the Minnesota Department of Health and others is included in the table for comparison.

Table 62

Silver Bay, Minnesota was studied in 1974 and 1975 because of an industrial source of fibers from a taconite processing plant. The results in Table 62 indicate that at that time there were 1 to 2 orders of magnitude more amphibole fibers, about the same number of chrysotile fibers, and about ten times as many fibers in the other fiber categories in the atmosphere at Silver Bay as compared to the values recorded at six sites in the Copper-Nickel Study Area in 1977.

Results from the cascade impactor analysis are presented in Table 63. In this sample, 60 percent of the amphibole fibers were found in the one micrometer stage. Overall, roughly half the total fibers (with or without chrysotile) were found in the one micrometer stage. Total fibers for all stages added up to

Table 62. Fiber concentration found in ambient air samples (fibers/m).

MONITORING LOCATION (1977)	AMPHIBOLE	CHRYSOTILE	NON-AMPHIBOLE NON-CHRYSOTILE	AMBIGUOUS	TOTAL[a]	TOTAL WITHOUT CHRYSOTILE[a]	COMMENTS
Babbitt	4,750	9,400	8,550	9,400	25,300	18,100	median values
Bearhead Lake State Park	3,640	2,380	7,350	2,120	17,200	16,300	found in membrane
Environmental Learning Center	2,700	5,640	26,500	4,600	42,500	34,600	sampling program
Erie Mining Office	14,200	6,780	4,360	10,400	36,000	35,000	
Fernberg Road	1,520	7,670	9,120	1,820	20,400	12,500	
Toimi	3,590	3,580	6,800	2,390	25,700	19,700	
Hoyt Lakes	21,000	48,200	39,200	17,500	126,000	78,000	Total-all stages of cascade impactor sample
Silver Bay (1974-75)							
Compton School	264,000	4,000	90,000	207,000	474,000	--	Median values of four samples
Kelley School	198,000	6,000	92,000	75,000	361,000	--	
McDonald School	145,000	3,000	40,000	35,000	236,000	--	

SOURCE: Ashbrook 1978.

[a]Median values were computed for each category and the totals, so that the median totals shown are not necessarily equal to the sums of the median values of each category shown. These discrepancies are not important compared to counting errors alone which were typically ±30% or more (see Ashbrook, 1978).

126,000/m^3 with chrysotile, and 78,000/m^3 without chrysotile. Particles in the respirable range (1-2um) are of the most concern from the public health perspective. Based on this one sample, sixty percent of the amphibole fibers and approximately half of all fibers observed were in the respirable range. Although they may not be directly comparable, total fiber levels for all of the cascade impactor stages combined were higher than almost all of those found in the membrane air samples.

Table 63

Amphibole fiber levels were found to vary with wind direction consistent with a source of amphiboles coming from the general area of the eastern end of the Mesabi Iron Range. Other types of fibers and total fibers did not appear to be related to wind direction. Wind direction on the dates of the highest and lowest amphibole fiber levels are illustrated in Figure 75.

Figure 75

Highest amphibole levels at Bear Head Lake State Park, Babbitt, and Fernberg Road occurred when winds were from the south or south-southeast, while the lowest levels were found when the winds were from the northwest or north-northwest. At the other three sites, the lowest amphibole levels were found during the taconite workers' strike (August-December, 1977) when there was no mining activity. The highest amphibole fiber levels at the Erie Mining Office were found when the wind was from the north-northwest. It is interesting to note that this site is due south of the Erie processing plant. Unfortunately, no samples were available for the Erie site on the two days when the wind was from the south. At Toimi, the highest amphibole fiber levels were found when the wind was from the north-

Table 63. Cascade impactor data from Hoyt Lakes (October 14, 1977) fibers/m^3 (aspect ratio).

	AMPHIBOLE	CHRYSOTILE	NON-AMPHIBOLE NON-CHRYSOTILE	AMBIGUOUS	TOTAL FIBERS	TOTAL WITHOUT CHRYSOTILE
Stage 3 (4 um)[c]	670[a] (9.4)	10,000 (28.3)	9,380 (6.1)	4,690 (8.3)	24,800	14,700
Stage 4 (2 um)	-536[b] (--)	4,820 (32.2)	2,140 (8.4)	538[a] (36.6)	7,500	2,680
Stage 5 (1 um)	15,000 (6.2)	8,740 (12.0)	21,200 (5.0)	6,240 (8.5)	51,200	42,500
Stage 6 (0.5 um)	-1,790[b]	16,100 (8.8)	-1,790[b] (---)	1,790[a] (7.4)	17,900	1,790[a]
Stage BL (less than 0.5 um)	5,360 (3.6)	8,570 (20.2)	6,430 (7.2)	4,290 (6.6)	24,600	16,100
Total-All Stages	21,000	48,200	39,200	17,500	126,000	78,000

SOURCE: Ashbrook 1978.

[a]Detection limit, based on one fiber observed.
[b]No fibers observed. A minus (-) indicates the value was less than the number shown.
[c]50% cut-off for aerodynamic diameter.

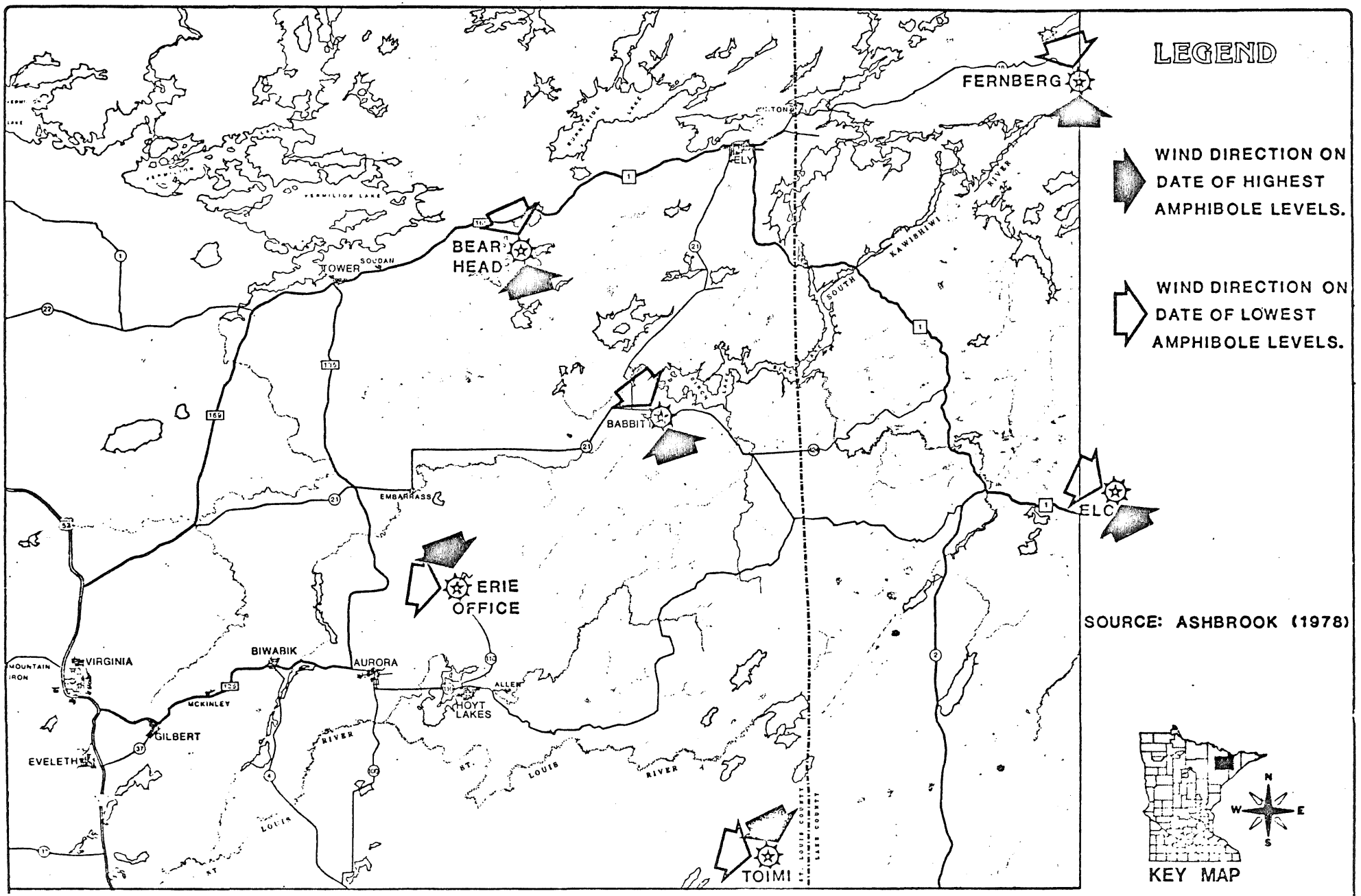


FIGURE 75 MEQB REGIONAL COPPER-NICKEL STUDY

WIND DIRECTION ON DAYS OF HIGHEST AND LOWEST FIBER LEVELS

northwest. Highest amphibole levels at the Environmental Learning Center occurred when the wind was from the south-southeast. This observation initially appears inconsistent with a source of amphibole fibers coming from the eastern end of the Iron Range. However, the wind was never from the direction of the eastern end of the Iron Range, except during the strike. The south-southeast wind direction on the day of the highest levels suggests the possibility that the fibers came from Reserve's Silver Bay processing plant, which processes ore from the eastern end of the Iron Range (Ashbrook 1978). More extensive sampling clearly would be required to verify or disprove this possibility.

In summary, ambient atmospheric concentrations of fibers in northeast Minnesota near the Duluth Gabbro Contact were found to be 1 to 2 orders of magnitude below those found in Silver Bay. Typical concentrations ranged from 10,000-40,000 total fibers/m^3. Amphibole fiber levels appeared to be related to wind direction and to come from a source in the eastern end of the Mesabi Iron Range. Other types of fiber categories showed no such correlation. A single cascade impactor sample in Hoyt Lakes found 60 percent of the amphibole fibers and half of all fibers in the stage with 1-2 um aerodynamic diameter (the respirable range).

3.6 COPPER-NICKEL SOURCE SIMULATION MODELS

In order to assess the potential air quality impacts from copper-nickel devlopment in northeastern Minnesota it was necessary to identify the types and general quantities of air emissions likely to result from copper-nickel development. The principal constituents of concern from an air quality standpoint are sulfur and solid particulates. The sulfur will be of most concern when emitted in the form of gaseous sulfur dioxide from a smelting operation. Significant particulates emissions may occur both from the smelter, as a point source, and from blasting, haul roads, waste piles, and tailing basin surfaces as major potential area sources. In consideration of the potential impacts from particulates, the elemental composition of the particulates from the various possible sources in question is of particular concern. In order to provide a systematic framework for a discussion of all of these topics, a series of source simulation models were developed and are discussed below. See Volume 2-Chapters 2, 3, 4, and 5; and Volume 3-Chapter 2 for further information supporting these models.

Before discussing the various source simulation models a few words about the various emissions not modeled are in order. Certainly various gases such as the oxides of nitrogen carbon monoxide, ozone, and hydrocarbons will be created and emitted by various operations involved in copper-nickel development. For example, vehicles burning gasoline and diesel fuel will be used, and will create and emit these gases. However, when such emissions are placed in the context of other sources of such constituents, such as coal-fired power plants and metropolitan areas containing high densities of automobiles, they appear to be negligible. Even in the context of the possible wilderness locations for mining development, these constituents do not appear likely to be present in significant quantities, and thus are not discussed further.

3.6.1 SO_2

As noted, sulfur is a constituent of major concern, as expected in a sulfide mining development. The two major sulfur species of concern environmentally are sulfur dioxide (SO_2) and sulfate (which typically occurs in aqueous solution in ionic form, $SO_4^=$). Sulfate is generated via two principal pathways, directly by oxidation and dissolution from the sulfide minerals, or from the oxidation of SO_2 generated by high temperature pyrometallurgical processes in a smelter. In terms of air emission models, all significant sulfur emissions are considered to take place either in the unaltered sulfide form (in gross particulates) or as SO_2.

The consideration of sulfates follows from an understanding of the oxidation of SO_2 to sulfate, with subsequent deposition on the surface. The question of sulfur as sulfides in gross particulates is discussed in the last section. The following discussions focus on models for SO_2 sources.

As noted in the discussion of the regional emissions inventory, the principal interest here is in mining point sources likely to emit more than 100 mtpy of SO_2. This consideration rules out any significant sources associated with mining and milling operations (for reference, Figure 76 summarizes the various operations involved in a copper-nickel development operation). Significant point sources of concern in the remainder of the operation include the smelter, copper refinery, and nickel refinery. The smelter is a possible SO_2 source due to the sulfur content in the concentrate it treats. The refineries are potential sources as a result of their need to consume fuel principally to provide heat for a variety of precesses. For example, the model copper and nickel refineries described in Volume 2-Chapter 4 require some $1,631 \times 10^9$ BTU per year of

thermal energy which can be provided by any available type of fuel. Of this, some 80% is needed in the nickel refinery, with the balance going to the copper refinery. If this energy is assumed to be provided by fuels of known sulfur content, the expected annual SO_2 emissions from these sources may be estimated. Table 64 summarizes these possibilities as a function of fuel type, using typical sulfur contents for the various fuels.

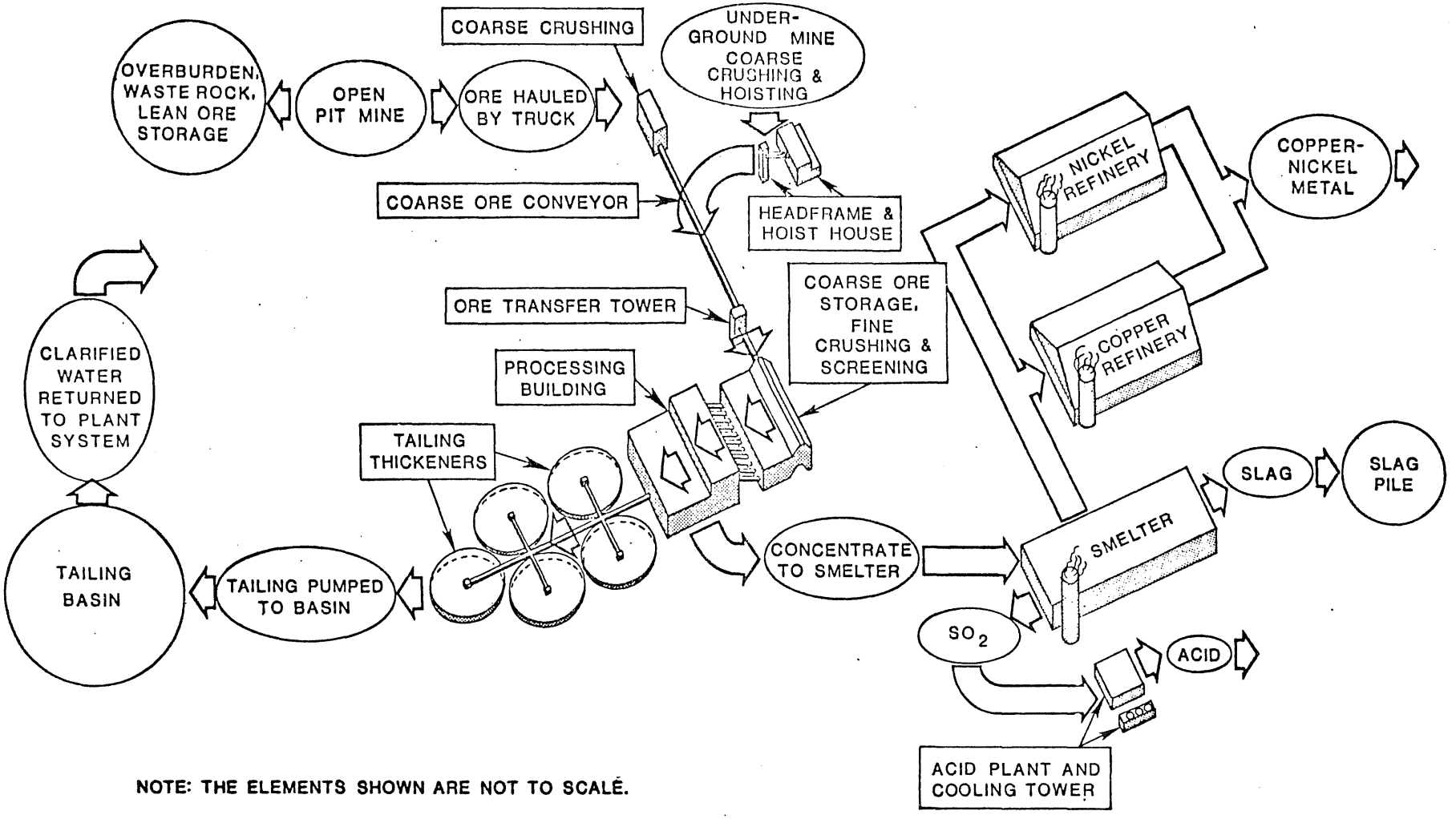
Figure 76, Table 64

The figures in Table 64 indicate that if coal or high sulfur residual oil are used as fuels, these facilities could constitute major new point sources of SO_2 emissions. However, if a relatively sulfur-free fuel such as natural gas is used the resulting emissions would be insignificant. Thus, clearly the choice of fuel here is a major factor in determinig the resulting emissions. Another major factor relates to the locations of the two refineries. The model just discussed is based on adding the individual energy requirements from the smelter, copper refinery and nickel refinery. In reality, if one or both of the refineries are located at the site of the smelter, a significant portion, if not all, of the thermal needs of the refineries may be met by waste heat from the smelter. The actual extent to which waste heat can meet such needs depends, of course, on the technologies which are chosen for both the smelter and the refineries.

From the above discussion it is clear that though there is the potential for one or both of the refineries to act as a significant source of SO_2 there is also the real possibility that through appropriate selections of technology, choice of fuels, and energy conservation by use of waste heat, no such significant emissions will exist. Consequently, no specific source models for refinery SO_2 emissions are given.

FIGURE 76

PRINCIPAL MINING COMPONENT RELATIONSHIPS IN THE PRODUCTION OF COPPER AND NICKEL METAL



NOTE: THE ELEMENTS SHOWN ARE NOT TO SCALE.

Table 64. Sulfur dioxide emission possibilities from a point source producing 1631×10^9 BTU of thermal energy per year.[a]

FUEL TYPE	ANNUAL AMOUNT NEEDED[b]	TYPICAL SULFUR CONTENT ASSUMED	ANNUAL SO_2 EMISSIONS[c]
Natural Gas	1.63×10^9 CF	0.6 lb/10^6 CF	.89 mtpy
Coal (low sulfur)	92.7×10^3 mt	0.5 wt.%	927 mtpy
Coal (high sulfur)	61.5×10^3 mt	3.0 wt.%	3690 mtpy
Fuel Oil (residual)	10.9×10^6 gal	0.17 lb/gal (2.0 wt.%)	1600 mtpy

[a]This energy requirement is based on a model of the heat requirements of a copper refinery and nickel refinery producing 100,000 mtpy of metal (see Volume 2-Chapter 4).

[b]Conversion factors used are:

Natural gas: 1000 BTU/CF
Coal (low sulfur): 17.6×10^6 BTU/mt
Coal (high sulfur): 26.5×10^6 BTU/mt
Fuel Oil (residual): 149,690 BTU/gal

[c]Assumes all contained sulfur is emitted as SO_2.

The fact that an integrated copper-nickel development will require a major amount of electrial power raises another SO_2 emission possibility which must be mentioned here. The fully integrated development models for operations producing 100,000 mtpy of copper and nickel metal require roughly one billion kilowatt-hours of electrical energy per year, with a peak load requirement of some 150 megawatts. To place this into perspective, if this power is generated in a large central station power plant requiring 10,500 BTU to produce one kilowatt-hour of energy, and if the plant burns coal with a fuel value of 8,000 BT/lb, it would require some 600,000 mtpy of coal to produce the required energy. If this coal is assumed to have the low sulfur content of 0.5%, and all of this sulfur is converted to SO_2 and emitted, the result is a point source emission of 6000 mtpy of sulfur dioxide. Clearly, this constitutes a significant point source of SO_2.

In the context of copper-nickel development in northeastern Minnesota, it is reasonable to assume that the electrical energy needs discussed above will in fact be met by large central station power plants. Though some of the energy may be provided from nuclear power plants, it is not unreasonable to assume that the bulk of the requirements will be met by coal-fired generation, and thus will result in SO_2 emissions on the order of that indicated above. However, it is quite unlikely, given the present status of the power industry in Minnesota and North Dakota, that this added electrical demand will require the construction of a coal-fired power plant in the Study Area. In fact, it does not appear that a plant will be built anywhere expressely to provide power for copper-nickel, since the total demand for a single large development requires only a fraction of the output of a large, modern power plant. In reality, copper-nickel development is viewed by the power industry simply as a factor in their future demand growth

projections. The net effect is to move up the dates at which system capacity increases are required. Thus, to some extent, the potential of copper-nickel development can be thought of as already being represented in the emissions inventory projections for power plants in 1985 (Table 29 given in section 3.4.1.1).

In fact, additional electrical energy requirements may be met, via the power network, by new or existing plants located far from the Air Quality Study Region, such as by mine-mouth plants in North Dakota. Because of these factors, there is no firm basis for modeling SO_2 emissions from such sources in the region. Consequently, this topic is not pursued further here.

Having eliminated the potential point sources of SO_2 which will not be modeled, the time has come to introduce the source which is modeled here, the smelter. This facility is described in detail in Chapter 4 of Volume 2. A smelter treats the metal-rich concentrate produced by the mill, to pyrometallurgically recover copper and nickel metal in suitable form for refining and/or for sale to manufacturers. During the pyrometallurgical operations, the bulk of the sulfur is removed by literally burning it to form sulfur dioxide. The model values (which are shown as specific values to the nearest metric ton only to satisfy material balance requirements) include an annual input of 165,542 mtpy of sulfur, which comes both from the concentrate and from the coal used as a fuel in the smelter. More than 99% of this total is contributed by the concentrate.

The fate of this input sulfur of course depends on the types of smelting and control technologies used. A single choice of smelting technology is used for all of the emission models, which reflect various control equipment possibilities. The basic operation modeled employs flash smelting, copper and nickel-

copper converters, and electric slag cleaning furnaces. An acid plant is assumed to treat the strong SO_2 gas streams for sulfur removal.

Four emission models are presented for analysis:

1) The basic model: This case uses no supplementary controls, and represents the case in which fugitive emissions are quite high due to lack of a hooding system to collect gases containing relatively low SO_2 concentrations. This case is not likely to occur in practice since secondary hooding now appears to be standard on new smelters. However, the model does illustrate the emissions which may occur in the event of a sudden breakdown of the secondary hooding system.

2) The base case model: This model emits the same total tonnage of SO_2 as the basic model. However, it contains a secondary hooding system which greatly reduces the low level emission of sulfur as fugitives, and instead diverts the gases through a tall stack.

3) The option 1 model: This case includes the use of a wet scrubber to remove a portion of the SO_2 from the secondary hooding gases prior to emission. In this model, all stack gases are cleaned to a concentration of 650 ppm SO_2 (by volume) prior to release.

4) The option 2 model: This case utilizes a wet scrubber to treat both the secondary hooding gas stream and the exhaust gases from the sulfuric acid plant. The scrubber sulfur removal efficiency used (90%) reflects performance representative of the best state-of-the-art devices.

Figures 77 through 80 summarize the sulfur balance for these four emission models. The values shown are as metric tons of sulfur per year. Those flows labeled stack emissions and fugitive emissions actually leave the facility as air

emissions in the form of sulfur dioxide (note that one metric ton of sulfur generates two metric tons of sulfur dioxide). The emissions from the various models, in units of metric tons of SO_2 released per year, are summarized in Table 65. Also shown are these same annual rates in grams/sec, and short-term rates, calculated on the basis of 350 operating days per year. The models contain fugitive emissions generally ranging from 1,000 to 10,000 mtpy SO_2, and stack emissions over this same general range. Total emissions thus range from some 2,000 mtpy to over 12,000 mtpy SO_2.

Figures 77-80, Table 65

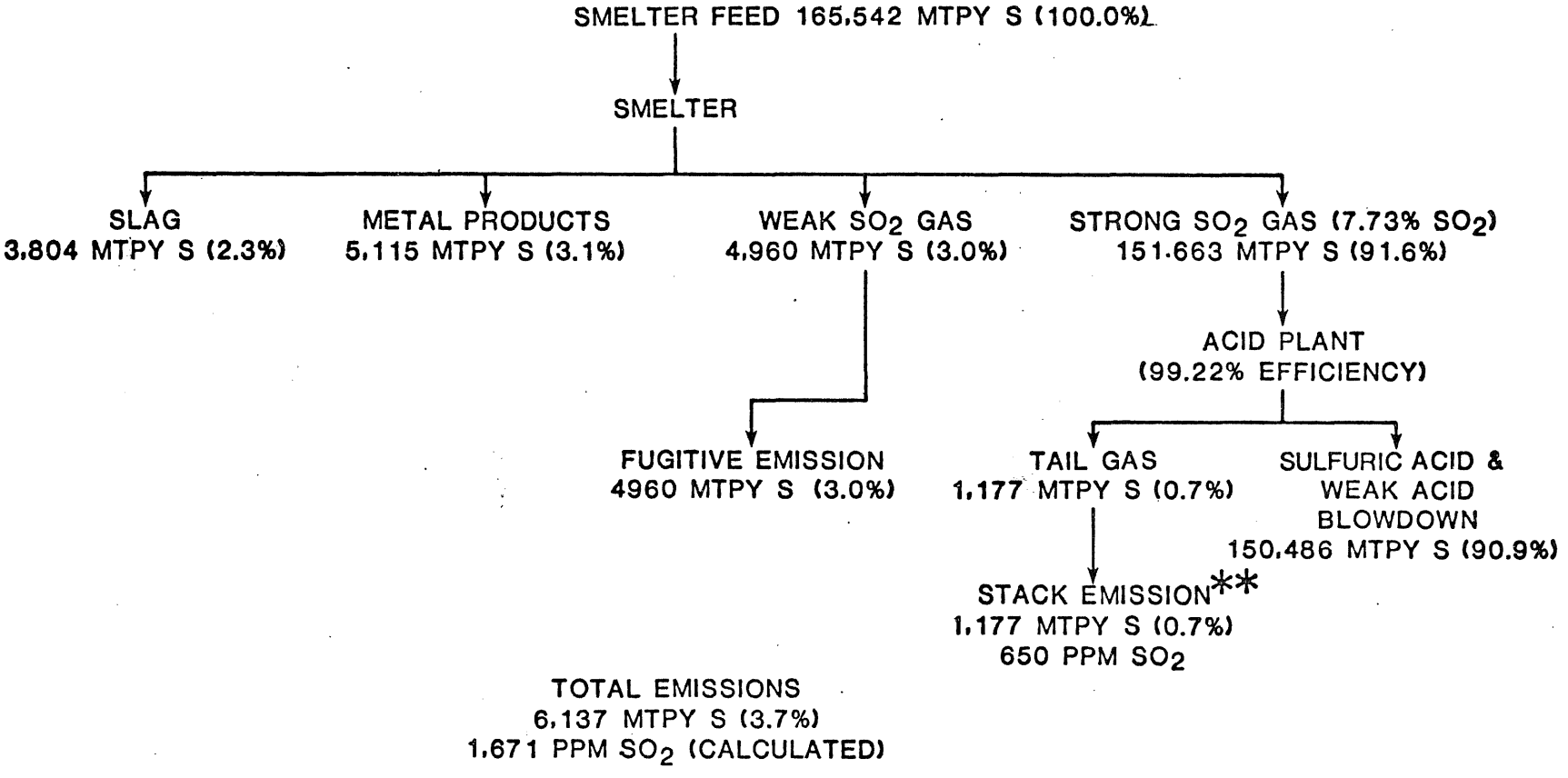
To place these emissions into perspective, Figure 81 shows the total SO_2 emissions from these four models on a scale with several other point sources of SO_2 in the state. Values for the Inco Copper Cliff smelter in Sudbury, Canada are also included. Note that the copper-nickel models have emissions ranging from 2 to 3 orders of magnitude (100 to 1,000 times) below the emissions rate at Copper Cliff in 1975. Further, the emissions shown for the Clay Boswell power plant, with the planned addition of unit 4 in 1980, are some 4 times the maximum emission rates modeled for a copper-nickel smelter.

Figure 81

In addition to the total SO_2 emissions, various other physical parameters associated with the smelter facility must also be modeled, since they play important roles in the subsequent dispersion in the atmosphere of the emitted SO_2. These parameters include the dimensions of the smelter building, the height of the stack, and a variety of stack exit parameters. Of these variables, the physical dimensions of the smelter building are determined by the physical

FIGURE 77

BASIC MODEL SULFUR BALANCE FOR FLASH FURNACE WITH ACID PLANT CONTROL OF STRONG SO_2 GAS STREAM TO 650 PPM SO_2. NO WEAK SO_2 GAS CONTROL*

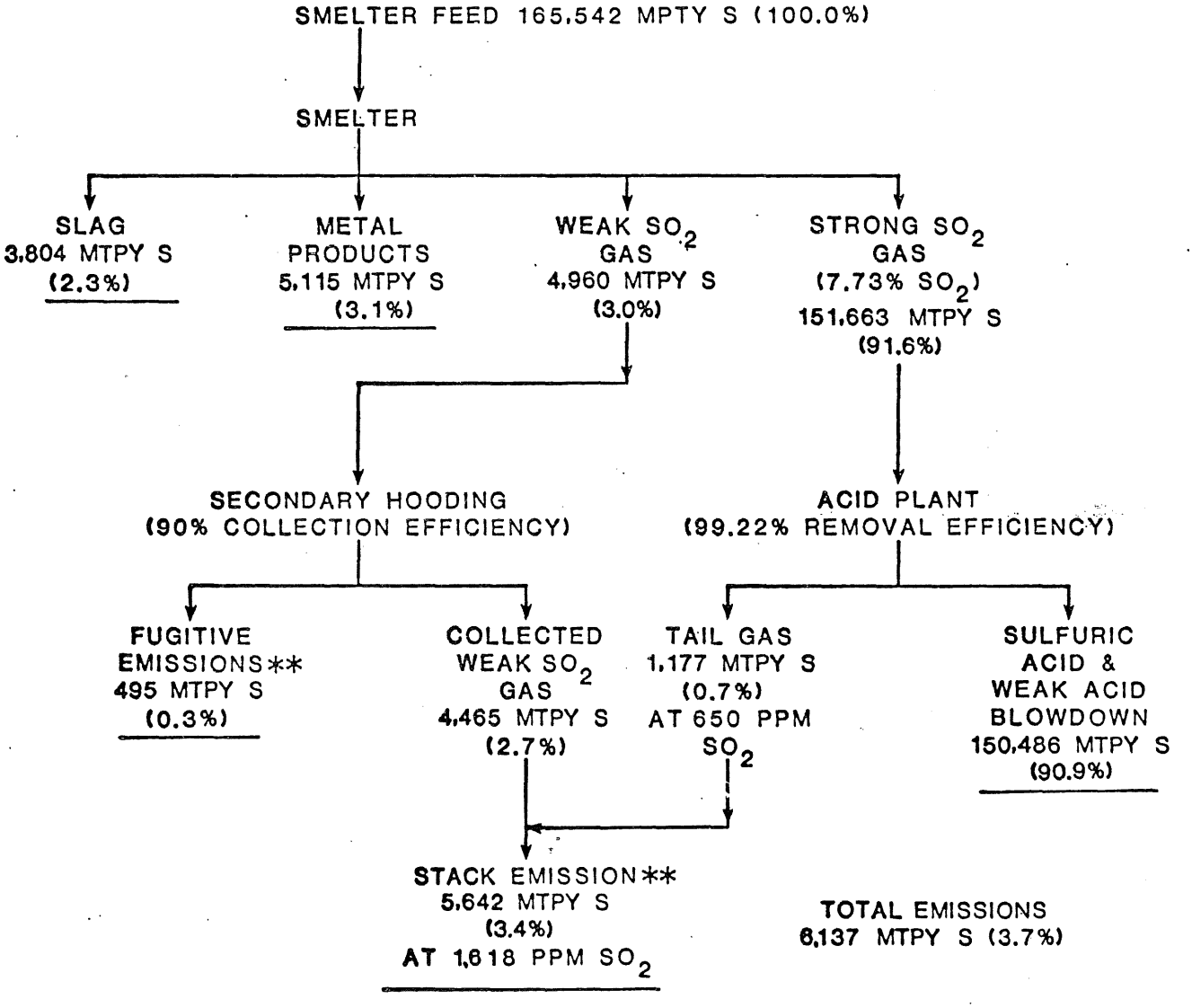


*NORMAL OPERATING CONDITIONS ARE ASSUMED

** EMITTED TO THE ATMOSPHERE AS SO_2 WITH EACH METRIC TON OF SULFUR CONSTITUTING 2 METRIC TONS OF SO_2

FIGURE 78

BASE CASE MODEL SULFUR BALANCE FOR FLASH FURNACE WITH ACID PLANT CONTROL OF STRONG SO_2 GAS TO 650 PPM SO_2, SECONDARY HOODING COLLECTION OF WEAK SO_2 GAS TO REDIRECT IT TO THE STACK DISCHARGE*

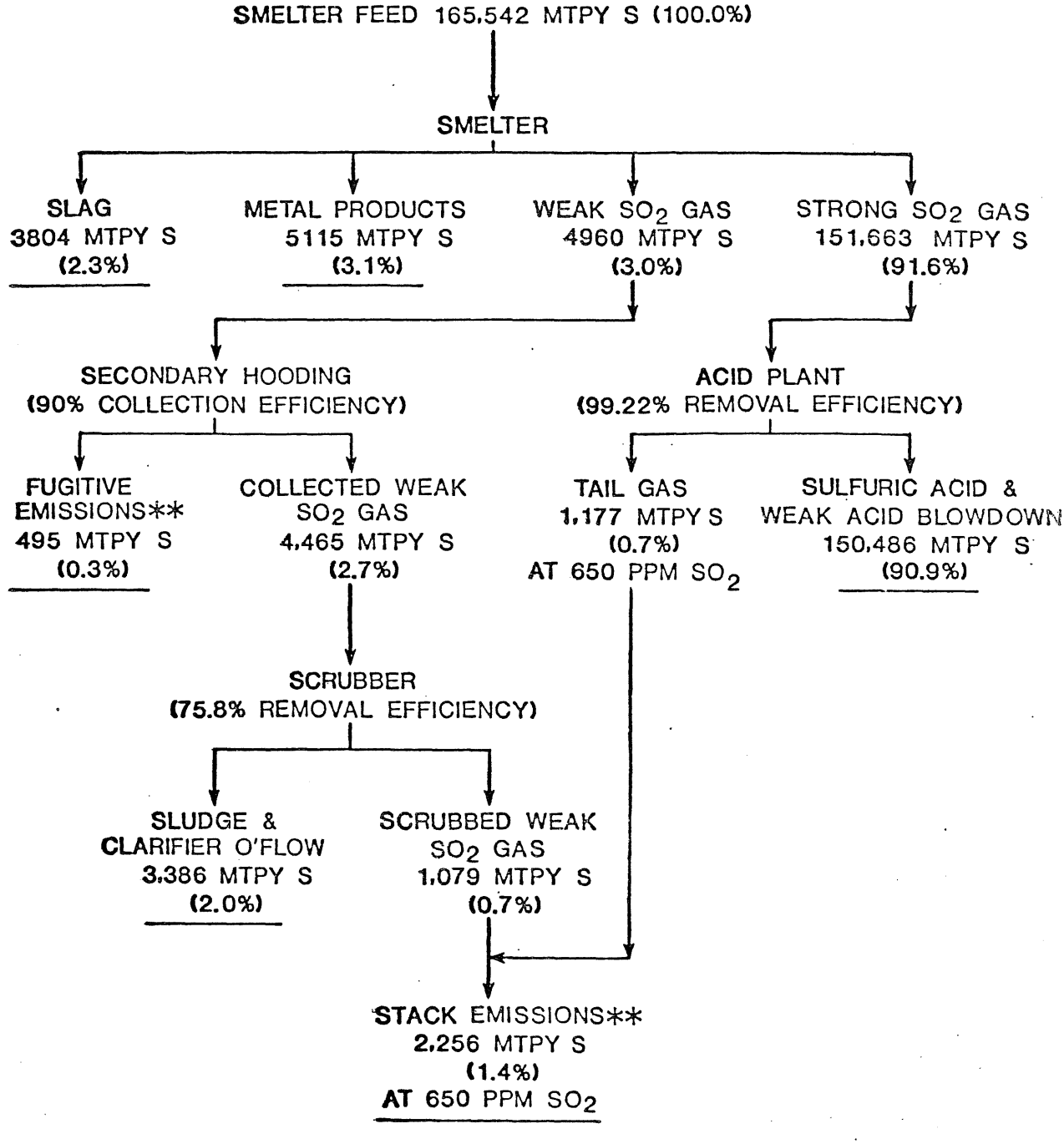


* NORMAL OPERATING CONDITIONS ARE ASSUMED.

** EMITTED TO THE ATMOSPHERE AS SO_2, WITH EACH METRIC TON OF SULFUR CONSTITUTING 2 METRIC TONS OF SO_2

FIGURE 79

OPTION 1 MODEL SULFUR BALANCE FOR FLASH FURNACE WITH ACID PLANT CONTROL OF STRONG SO_2 GAS TO 650 PPM SO_2, SECONDARY HOODING COLLECTION OF WEAK SO_2 GAS FOLLOWED BY SCRUBBING TO 650 PPM SO_2*



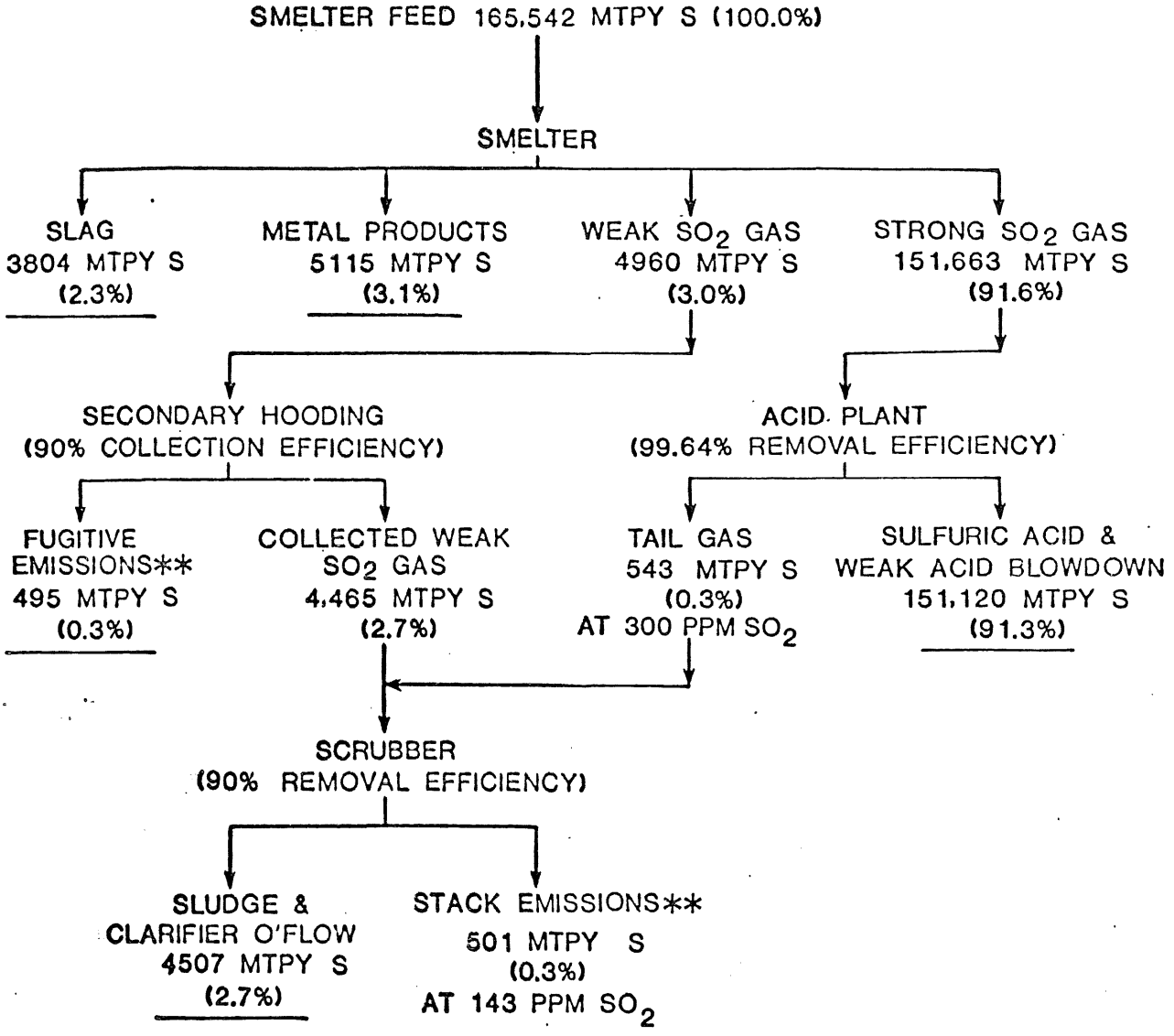
TOTAL EMISSIONS 2,751 MTPY S (1.7%)

* NORMAL OPERATING CONDITIONS ARE ASSUMED

** EMITTED TO THE ATMOSPHERE AS SO_2, WITH EACH METRIC TON OF SULFUR CONSTITUTING 2 METRIC TONS OF SO_2

FIGURE 80

OPTION 2 MODEL SULFUR BALANCE FOR FLASH FURNACE WITH ACID PLANT CONTROL OF STRONG SO_2 GAS TO 300 PPM SO_2, SECONDARY HOODING COLLECTION OF WEAK SO_2 GAS, AND SCRUBBING OF ACID PLANT TAIL GAS PLUS COLLECTED WEAK SO_2 GAS TO 143 PPM SO_2*



TOTAL EMISSIONS ,996 MTPY S (0.6%)

* NORMAL OPERATING CONDITIONS ARE ASSUMED

** EMITTED TO THE ATMOSPHERE AS SO_2, WITH EACH METRIC TON OF SULFUR CONSTITUTING 2 METRIC TONS OF SO_2

Table 65. Summary of SO_2 emissions from four control models for a smelter complex producing 100,000 MTPY of copper and nickel metal[a].

MODEL VARIATIONS	ANNUAL SO_2 EMISSIONS IN MTPY (and gm/sec)		
	Fugitive Emissions mtpy (gm/sec)	Stack Emissions mtpy (gm/sec)	Total Emissions mtpy (gm/sec)
Basic[b]	9920(315)	2354(75)	12274(389)
Base[c]	990(31)	11284(358)	12274(389)
Option 1[d]	990(31)	4512(143)	5502(174)
Option 2[e]	990(31)	1002(32)	1992(63)

MODEL VARIATIONS	SHORT TERM SO_2 EMISSIONS (BASED ON 350 OPERATING DAYS/YEAR)		
	Fugitive Emissions gm/sec	Stack Emissions gm/sec	Total Emissions gm/sec
Basic	328	78	406
Base	33	373	406
Option 1	33	149	182
Option 2	33	33	66

[a]All models assume normal operating conditions (see Volume 2-Chapter 4 for further details).

[b]Acid plant control of strong SO_2 gas to 650 ppm SO_2 only.

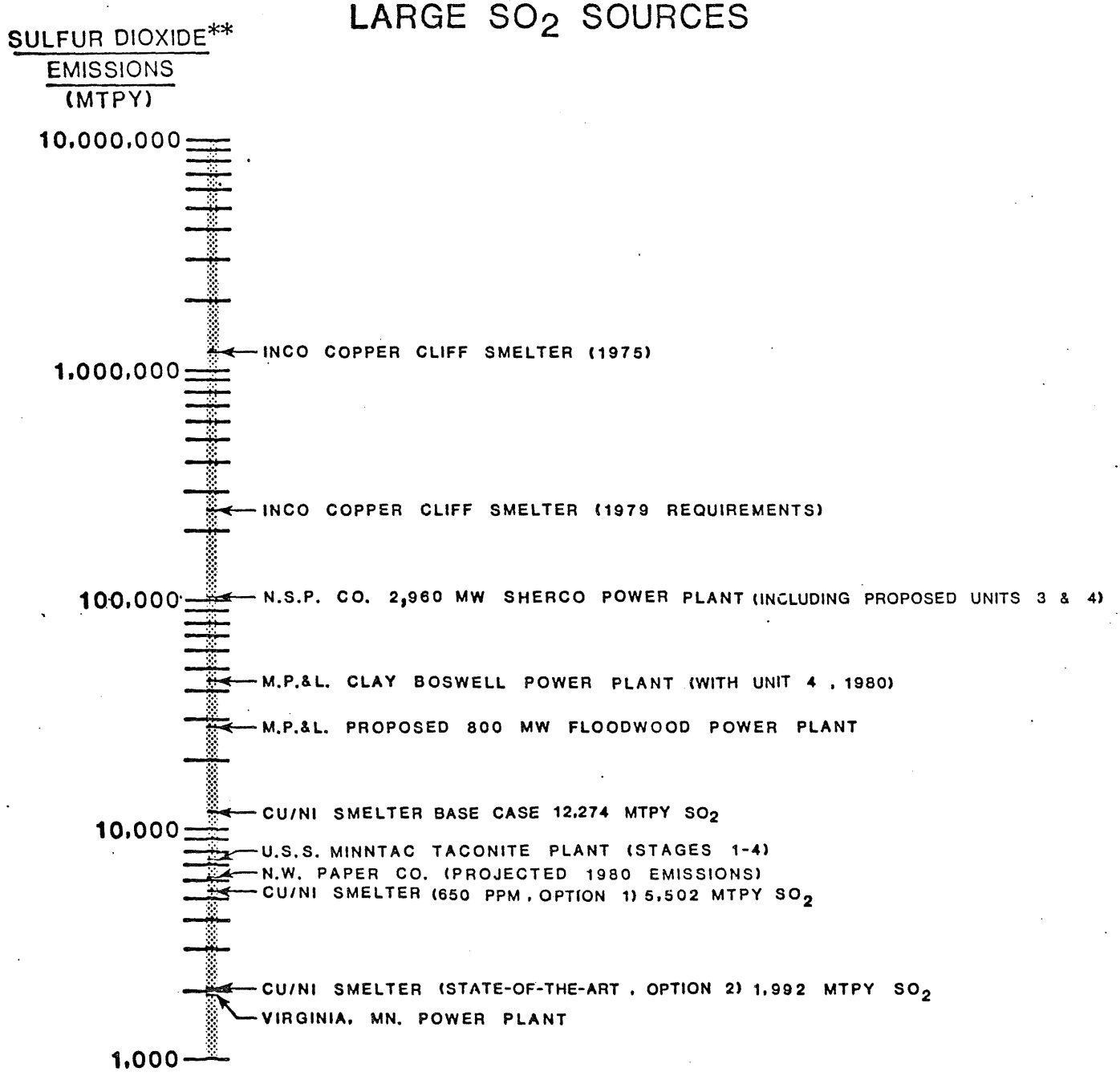
[c]Same as b plus redirection of weak SO_2 gas with secondary hooding.

[d]Same as c plus scrubbing of collected weak SO_2 gas to 650 ppm SO_2.

[e]Same as d with acid plant control of strong SO_2 gas to 300 ppm SO_2, plus scrubbing of acid plant tail gas and collected weak SO_2 gas to 143 ppm SO_2.

FIGURE 81

SUMMARY OF MODELED FLASH SMELTER SO_2 EMISSIONS* AND EMISSIONS FROM OTHER LARGE SO_2 SOURCES



*VALUES INCLUDE STACK PLUS FUGITIVE EMISSIONS

**VALUES SHOWN ARE MTPY OF SO_2 WHICH IS TWICE THE AMOUNT OF SULFUR

requirements of the technology being housed, and not by considerations of their effect on atmospheric dispersion of emissions. The stack and its various operating parameters, on the other hand, are specifically designed to achieve optimum dispersion of emissions.

The smelter building itself is quite large, having to encompass furnaces with dimensions up to 100 ft and more, as well as allowing room for the movement of large ladels of molten material. The basic space requirements are relatively independent of specific choices of furnace or converter types. A good example of the layout in a smelter building is provided by Nagano and Numura (1968) for the Onahama smelter in Japan. The building involved in that case, though irregular in shape, is just under 400 ft long and over 350 ft wide. For modeling purposes, building dimensions of 500 ft (152 m) by 400 ft (122 m) were selected for use here. The height of the building is determined by the requirements for devices such as large overhead cranes, used to move equipment and ladels of molten material, and storage bins for concentrate and flux to be fed to the smelting furnace. For example, a new flash smelter facility being planned in Louisana is shown as having a furnace building height of 162 ft, 4 in. above grade (Nelson 1977). For modeling purposes, a building height of 164 ft (50 m) was selected.

The height of the stack serving the acid plant and secondary hooding systems is also an important variable. In reality, more than one stack may be used at the site, but for simplicity here all gases are assumed to be combined for release through a single stack. For the new smelter facility envisioned for the treatment of copper-nickel concentrations, one or more acid plants would certainly be employed to remove the bulk of the SO_2 in process off-gases. Thus, unlike the extremely tall stacks (600-1200 ft) found in many conventional smelters with poor SO_2 removal, the stack for a new facility is likely to be relatively short.

This is illustrated at the new Hidalgo flash smelter in New Mexico, which has a stack for each of its two acid plants. There, the stacks are 200 ft (61 m) tall, (Neal 1978). The smelter under study in Louisana (Nelson 1977) would have a stack 61 m tall also. Thus, for modeling purposes, 60 m was selected as a round figure for the stack height. Although the stack is only 10 m taller than the smelter building, physical separation of the stack from the building and a sufficiently high exit velocity should prevent aerodynamic downwash of the stack plume caused by the building wake.

The other important model variables include inside stack diameter, as well as exit gas temperature and velocity. For the Hidalgo stacks mentioned earlier, the inside diameters are 7.5 ft (2.29 m) and 9.0 ft (2.74 m) with an exit gas temperature of 83°C in both cases. The planned Louisana smelter would utilize a 2 m inside diameter for the stack, with an exit temperature of 65°C. As representative values, the model developed here uses an inside diameter of 2.2 m, and an exit gas temperaure of 82°C.

The choice of an appropriate exit gas velocity for modeling purposes was based on an analysis of wind data for the Study Area. A value was selected to avoid stack downwash by using the value of 1.5 times the 95th percentile of wind speed measured at Hibbing and adjusted to 50 m under neutral stability by a formulation discussed by Endersen (1979). Neutral stability was used because it is the usual stability under strond winds. The resulting value was 22 m/sec. This value is high relative to figures of 10.3 m/sec and 9.15 m/sec for the two Hidalgo stacks, and 13.7 m/sec for the planned Louisiana facility. Nevertheless, it seems reasonable in light of wind conditions in the area, and was used for modeling purposes.

In addition to the parameters and SO_2 emissions rates noted above for the smelter models during periods of normal operation, a model was generated to represent emissions during an upset period. To simulate such a condition, it is assumed that some sort of failure forces the by-passing of the acid plant and any subsequent sulfur removal equipment. The resulting stack emissions contain all the SO_2 in the strong gas stream, as well as 90% of the SO_2 in the weak gas stream for an emission rate of 10,326 gm of SO_2 per second. Under these conditions the cooling provided by the acid plant is lost, and thus the exist gas temperature is raised to 300°C, reflecting the operating temperatures of the electrostatic precipitators prior to the acid plant (Coleman 1978).

The various physical parameters just described for the smelter models are summarized in Table 66. A few comments must be made since these parameters were used for all the emissions cases modeled. In reality this is not a rigerously valid assumption, since the volumes of gas being exhausted would vary for the different models, and the exit gas temperatures would also be expected to vary unless maintained by a heater. As a result, for fixed stack diameter the exit velocities would of course vary. For simplicity, this variation is neglected here.

Table 66

Air flows for the models utilizing secondary hooding are likely to fall in the range of 150,000 to 200,000 SCFM, with values of 100,000 SCFM or less in the absence of secondary hooding. No attempt is made here to rigerously justify the modeled air flow in terms of actual individual flow requirements for the various gas streams within the smelter, since such justification would not significantly improve the accuracy of the predictions resulting from the dispersion modeling

Table 66. Summary of the physical parameters used to describe the smelter for dispersion modeling purposes[a].

Building length	152 m
Building width	122 m
Building height	50 m
Stack height	60 m
Stack internal diameter	2.2 m
Exit gas velocity	22 m/sec
Normal exit gas temperature	82°C
Upset exit gas temperature	300°C

presented later. Only the SO_2 emission rates are varied from model to model, with the exception of the exit gas temperature in the upset case. The air quality implications of the SO_2 emissions from the smelter models presented here are discussed in section 3.7.

3.6.2 Particulates

Unlike the situation with sulfur dioxide emissions discussed earlier, several operations involved in a copper-nickel development may potentially act as significant sources of particulates. The discussion of particulates is further complicated by the question of the characteristics of the particulates emitted from various phases of an operation. One example of this complexity is seen in the question of the emission of mineral fibers or fiber-like fragments. Though these definitely constitute particulates (as opposed to gaseous) they form a special sub-class of particulates and thus will be discussed in a separate section.

Beyond the discussion of fibers as a distinct topic, the treatment of particulate emissions will be divided into discussions of emissions from point sources on the one hand, and those from area sources on the other. Each of these topics will include a discussion of potential total particulate emission rates, and the composition of such emissions will be considered for the smelter.

3.6.2.1 Point Sources--The only potentially significant point source of particulates associated with a copper-nickel development appears to be the smelter. Since the smelter treats a material high in metals content, the emissions from this source are of particular importance in terms of their potential load of heavy metals. The movement of particulates within the smelter facility is discussed in Volume 2-Chapter 4. A brief summary of that discussion, with model

values for stack particulate emissions are given here. Although fugitive particulates are treated later as though they came from a point source also, in reality they are produced from various area sources. Thus, this topic is discussed in the next section.

The major potential source of stack particulates likely to be present within the smelter appears to be the dryer, particularly if a spray dryer is used. Up to 10% of the concentrate is estimated to be carried out of the dryer as particulates entrained in the exit gases. This value of course depends on the consistency of the concentrate being treated and the design of the dryer (or possibly roaster in the case of a smelter using an electric furnace). Using a carryover value of 10% represents a worst case estimate.

Dryer gases, along with gas streams from secondary hooding devices, would certainly be passed through one or more particulate removal device such as an electrostatic precipitator. Such devices can be expected to remove the bulk of the entrained particulates (97 to 99+%). Selection of a value of 97% for an ESP is a reasonably conservative choice. This value is used here for modeling purposes.

Gases from a flash smelting furnace (assumed to be used here for modeling purposes) will also contain high dust loads. Again, the assumption of 10% carryover of the concentrate as dust is not unreasonable here. after passing through an ESP, these gases will move on to a sulfuric acid plant. Due to the operating requirements of the acid plant the incoming gases are cooled and cleaned of particulates by extremely efficient wet scrubbing units. The net effect of this treatment is to remove 99.9% or more of the entrained particulates. This high removal is required to prevent damage to the acid plant.

This means, for example, that in the case of an electric smelter not using a dryer, no significant particulate emissions are expected to occur.

In the event that wet scrubbers are used to remove SO_2 from the secondary hooding gases and possibly the acid plant tail gases, further particulate removal will occur. There is not a great deal of data available on the particulate removal efficiency of these types of wet scrubbers and associated prescrubbers, but based on what is known, removal efficiencies of 85% are assumed, as reasonable estimates.

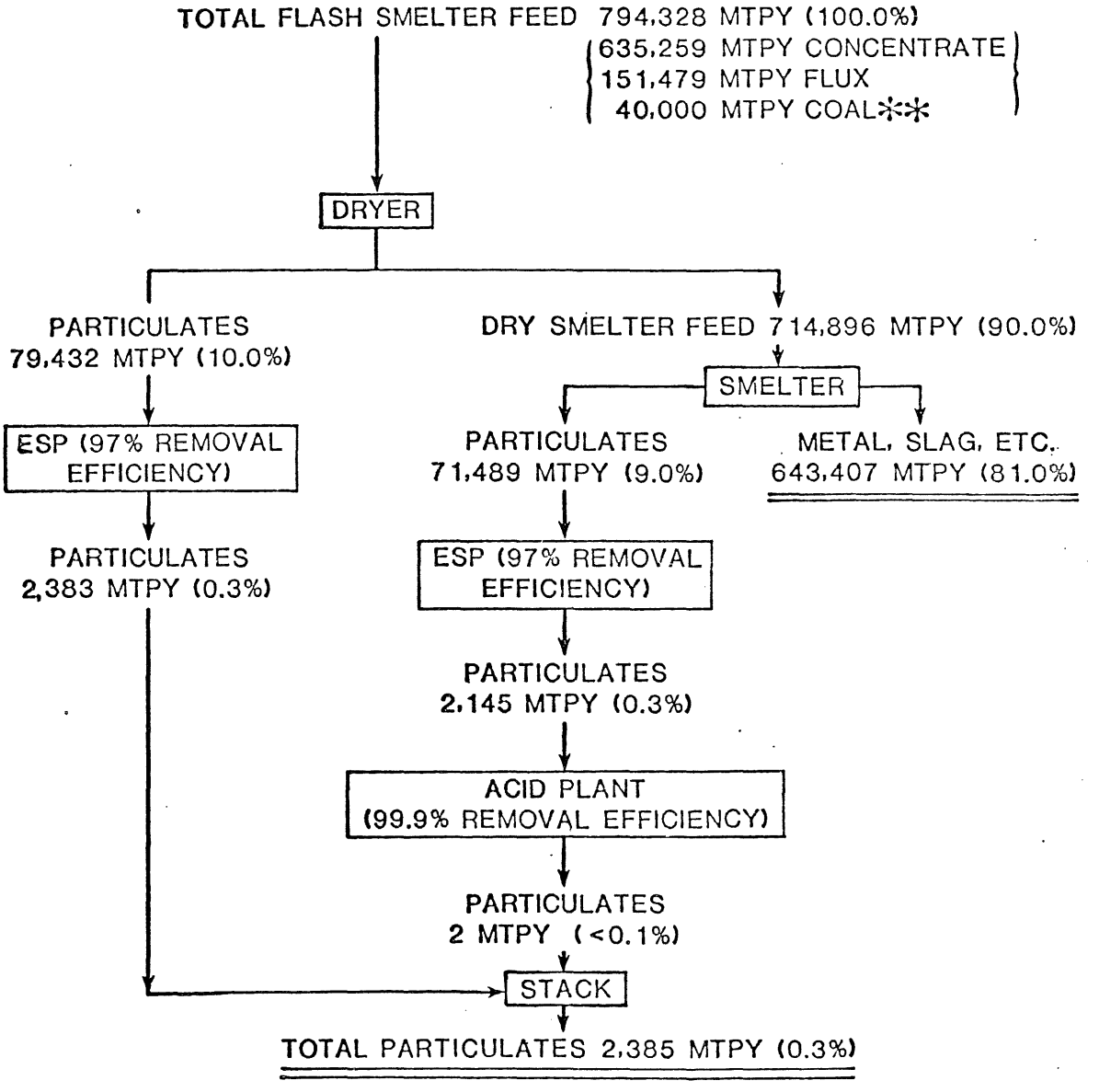
Based on the following considerations, two stack particulate models were generated based on a flash smelting facility with a spray dryer. As before, the facility is sized to produce 100,000 mtpy of copper and nickel metal. The two models (shown in Figures 82 and 83) reflect emissions with and without the use of scrubbing units treating the weak SO_2 gas streams. The modeled stack emissions are 2,385 mtpy without a scrubber, and 358 mtpy with a scrubber. It is clear from the figures that the gases coming from the furnaces contribute a negligible part of these emissions as a result of the high particulate removal prior to the acid plant. Figure 84 places these emissions in perspective with emissions from other point sources as shown in the regional particulate emissions inventory given earlier.

Figures 82, 83, and 84

It is important to note that the above models were generated as described simply to provide points of reference for impact analysis purposes. No attempt was made here to design the particulate models to meet any particular emission standards. Thus, depending on the specific volumes of gases and temperatures used, both the

FIGURE 82

MODEL FOR STACK EMISSIONS PARTICULATE BALANCE FOR BASE CASE SMELTER / REFINERY COMPLEX*



*NORMAL OPERATING CONDITIONS ARE ASSUMED, IGNORING FUGITIVES WHICH ARE UNKNOWN

**ONLY 7,590 MTPY OF THE 40,000 MTPY COAL ASSUMED TO REPORT AS PARTICULATE MATTER (SEE VOLUME 2, CHAPTER 4)

FIGURE 83

MODEL FOR STACK EMISSIONS
PARTICULATE BALANCE FOR OPTIONS 1 AND 2*

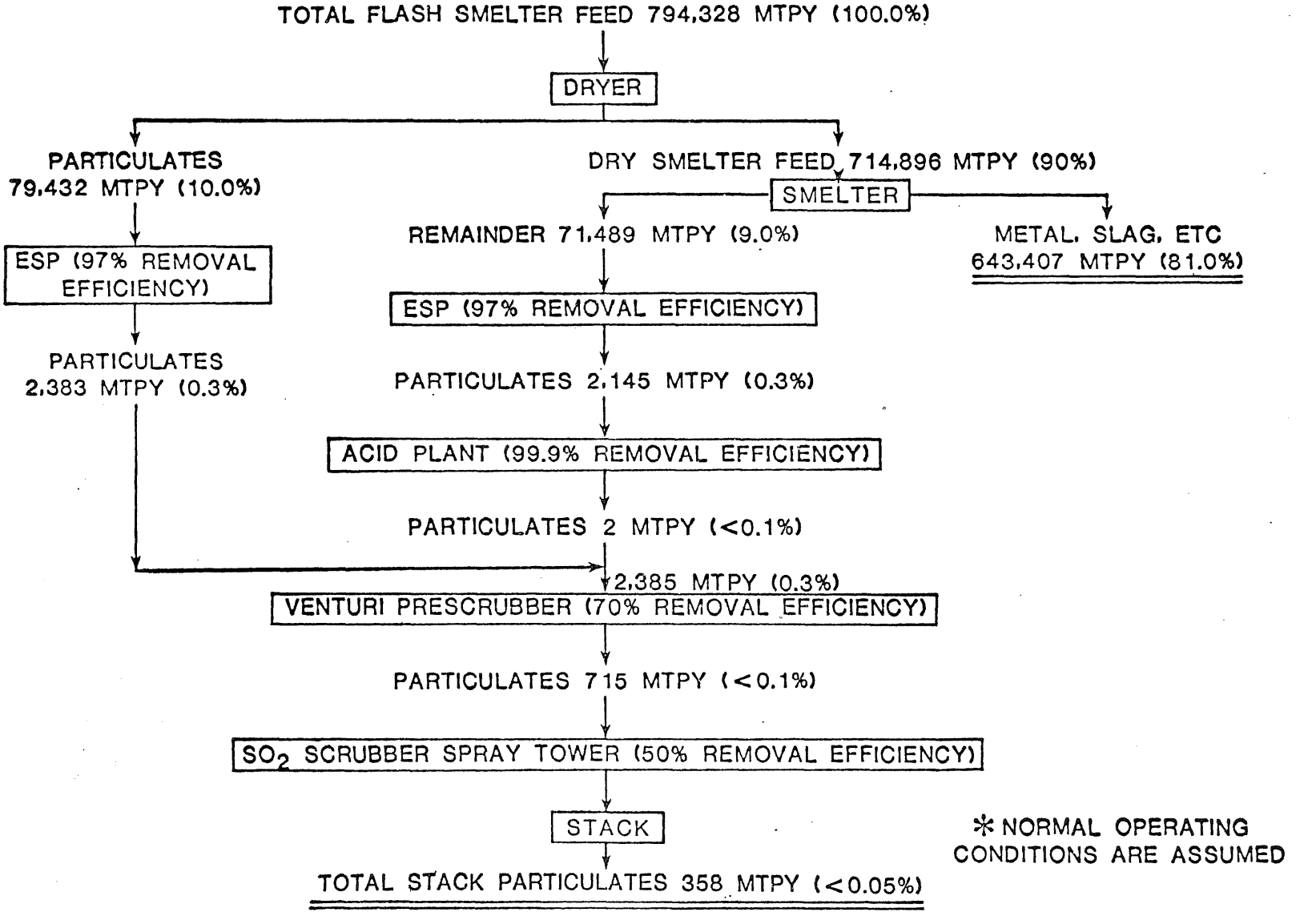
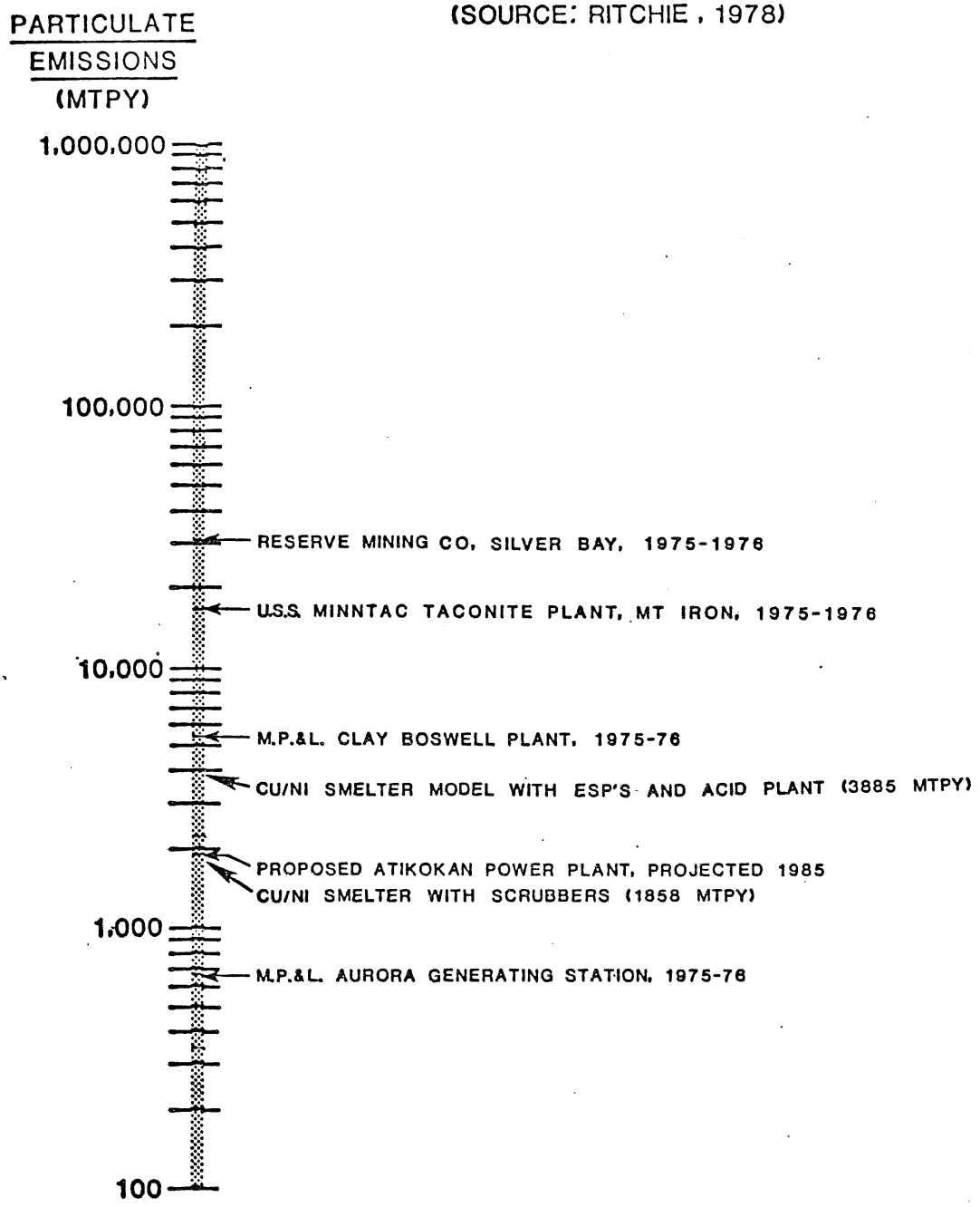


FIGURE 84

SUMMARY OF MODELED FLASH SMELTER TOTAL PARTICULATE EMISSIONS AND EMISSIONS FROM OTHER LARGE PARTICULATE SOURCES

(SOURCE: RITCHIE , 1978)



models given here may fail to meet the federal new source performance standards for dryers at new primary copper smelters (see section 3.2.5). This in no way indicates that available control devices are not capable of meeting these emission standards. In reality, particulate carryover from a dryer may be significantly lower than that used here for modeling purposes, with significantly higher removal efficiencies of control devices, especially electrostatic precipitators. The resulting emissions would be reduced, with a corresponding scaling down of air quality impacts in terms of ambient TSP concentrations and particulate deposition rates.

In terms of the composition of the particulate emissions modeled above, it is clear from the diagrams that they will have the same composition as the concentrate with associated flux and coal. No decomposition of the feed is likely to occur in the dryer due to the low temperatures used. It is not certain that input materials such as coal and flux will pass through the dryer. To simplify the modeling of the particulate composition, it is assumed here that it has the composition of the concentrate produced from the mill. This allows the concentrate model presented in Volume 3-Chapter 2, section 2.4.1.1 to be used here. In terms of heavy metals emissions, this is a worst case assumption, since the presence of coal and flux would tend to slightly reduce (about 20%) the relative amounts of metals present. The resulting annual emissions, in mtpy, of the various constituents composing the particulates emitted from the stack by this model, are shown in Table 67.

Table 67

A word of caution must be added here concerning the possibility for the emission of certain volatile constituents present in the concentrate and leaving the

Table 67. Emissions from a smelter complex producing 100,000 mtpy of Cu and Ni metal.

Stack Particulate Emission Models[a]

CONSTITUENT	BASE MODEL, mtpy[b]	OPTION 1-OPTION 2 MODEL, mtpy[c]
Si (SiO_2)	172.9 (370.4)	26.0 (55.6)
Al (Al_2O_3)	43.2 (81.8)	6.5 (12.3)
Fe (FeO)	60.3 (77.8)	9.1 (11.7)
Mg (MgO)	37.0 (61.3)	5.5 (9.2)
Ca (CaO)	27.2 (38.4)	4.1 (5.8)
Na (Na_2O)	9.3 (12.6)	1.4 (1.9)
K (K_2O)	1.9 (2.4)	.29 (.36)
Ti (TiO_2)	2.4 (4.1)	.36 (.61)
P (P_2O_5)	0.2 (0.7)	.036(.11)
Mn (MnO)	0.7 (1.0)	.11 (.14)
Cr (Cr_2O_3)	1.0 (1.4)	.14 (.21)
B	.74	.11
Ba	.31	.046
Be	.0001	.00002
Sr	.12	.018
V	.20	.031
Th	.007	.0011
Zr	.06	.0092
S	617	93
Cu	330	49
Ni	63	9.5
Fe(S)	716	107
Co	3.1	.47
Zn	2.7	.41
Pb	.14	.022
Ag	.08	.012
As	.074	.011
Hg	.0004	.00006
Mo	.067	.010
Cd	.10	.014
TOTAL	2,385	358

[a]The models assume the particulates will have the same composition as the concentrate. Normal operating conditions are assumed. Values have been rounded.

[b]Includes 97% particulate removal efficiency for ESP units and 99.9% particulate removal efficiency for the acid plant.

[c]Includes all of b plus 85% particulate removal efficiency for scrubbing units. There is no distinction between options 1 and 2 in terms of particulate removal efficiency (Chapter 4).

smelting furnace via the strong SO_2 gas stream. Elements of particular interest here include arsenic, and mercury and, to a lesser extent, lead, cadmium, and zinc. These elements tend to be carried out of the smelting furnace with the exhaust gases as either vapor or small particulates. The actual state of the element is a strong function of the temperature of the gas stream, as well as other variables such as oxygen content. These elements are all of concern for their potential effects on human health specifically, and biological systems generally.

There is not a great deal of information available on the likely behavior of these elements in a new smelter treating copper-nickel concentrates. However, information that is available indicates that the gas cleaning associated with an acid plant and any subsequent scrubbers, along with the collection of metallic dust in the ESP's will remove a large portion of these elements in the strong gas stream. As an example, Table 68 gives models for the percentage distribution of arsenic, cadmium, lead, mercury and zinc in a flash smelting operation using a wet scrubber which produces sludge and clarified water. This model is discussed further in Volume 2-Chapter 4 and in Coleman (1978).

Table 68

The elements noted above are of concern since they are both toxic to humans, and are preferentially present in smelter gas streams as a result of their volatility. This could act to magnify their presence in particulate emissions beyond the amount expected in particulates having the composition of the input concentrate and flux as was assumed in the previous discussion. However, the expected high degree of removal of these elements in passing through the ESP's, acid plant, and possibly wet scrubbers, coupled with the low levels of these

Table 68. Percentage distribution model for arsenic, cadmium, lead, mercury, and zinc input to a flash smelter using an acid plant and SO_2 scrubber.

	DISTRIBUTION OF ELEMENTS IN SMELTER EXIT STREAMS[a] (given as a percentage of the element in the concentrate)								
ELEMENT	STACK GAS	ACID	CLARIFIER OVERFLOW	SLUDGE	METAL-LIC DUST	ANODE COPPER	CU-NI MATTE	DISCARD SLAG	ESTIMATED ACCURACY[b] (%)
Arsenic	0	TR[c]	1	77	9	TR	1	12	20
Cadmium	0	TR	TR	7	93	TR	TR	TR	20
Lead	0	TR	2	21	30	TR	2	45	15
Mercury	30	12	28	28	2	0	0	0	20
Zinc	0	TR	TR	3	41	TR	6	50	15

SOURCE: Coleman 1978.

[a]Fugitive emissions not included.
[b]Percentage of total element flow which may be improperly distributed.
[c]TR = present as a trace element, less than 100 ppm.

elements expected to occur in Minnesota concentrates (see Volume 3-Chapter 2) appear to indicate that significant emissions of these elements will not occur, beyond those already accounted for by the models of particulate emissions from the dryer.

Based on these considerations, no elemental models of volatile constituents present in the strong gas stream are felt to be required here for impact analysis purposes. However, this discussion has listed the important assumptions being made in arriving at this conclusion. In any specific development proposal, it is vital that these assumptions be re-examined in light of specific data on the composition of materials to be processed and the technology to be employed. Significant changes may well necessitate the modeling of elevated emissions for one or more volatile elements.

3.6.2.2 Area Sources--Unlike the situation just discussed for point sources, copper-nickel development would add several new area sources for particulates to those already existing in the Study Area (see section 3.5 for discussion of present sources). The new sources resulting from development would include construction areas, mines, haul roads, mills, smelters, tailing basins and stockpiles of either lean ore or waste rock. Some of these area sources would be potential problems only during the operational phase of a development while others may represent continuing problems unless the areas are properly reclaimed following the termination of operations. In addition to the areas directly involved in a mining development, external secondary development such as new access roads may create area sources. Each of these areas may be a potential particulate source for many years and will respond differently to reclamation and/or control measures.

Construction activities may create significant area sources because they generally expose large areas of soil. Construction of the mine/mill facilities may take up to three years, and some level of construction can be expected to continue for several years as an operation goes into full scale production and as new roads are developed to reach areas where new facilities such as additional waste rock piles will be created. The particulate emissions from construction activities will result from excavation and exposure of soil for building sites and the development of internal road systems. Short term mitigation of emissions from these areas may occur naturally by precipitation or artificially throught the use of water or chemical control agents. Long-term mitigation of these areas may require permanent revegetation once activities cease.

Open pit mines are potential area sources for particulates because the mine area is cleared of all vegetation and the walls and floor of the mine are exposed to winds. The exposed surface area within the mine is greater, because of the addition of the surface of the walls, than the size of the surface opening. In addition to wind erosion, particulate emissions in an open pit mine are increased significantly by drilling and blasting operations and the internal haul road system used during the operation of the mine. Once operation is terminated wind erosion becomes the major factor in causing the emission of particulates from the mine area.

Underground mines present a much more limited potential for particulate emissions than do open pit mines because wind erosion from mining-exposed surfaces and haul roads are eliminated. In the case of underground operations, blasting becomes the major source of particulates in the occupational environment of the mine. One method of dust control in underground mines is the venting of dust to the surface, thus creating some potential for air emissions to the ambient

environment. Generally, however, due to the scale of operations likely to occur such emissions would not be significant. Because wind erosion is not a problem in underground mines, particulate emissions cease after the shut down of the mine.

Transfer of ore and waste rock/lean ore to the mill and storage piles respectively may be the largest sources of particulate emissions in a copper-nickel operation. The transport typically involves loading of trucks, travel over unpaved haul roads and dumping of ore, lean ore and waste rock. The distances travelled during the hauling operations are short for an individual trip but the number of trips made during a given time period is normally very large. Particulate emissions from hauling are important only during the operational phase of the mine, however the roads will be potential area sources even after truck movement is discontinued. Emissions from hauling operations can be decreased on a short term basis by utilizing water and/or chemical dust suppressants. Alternative methods of transport such as conveyor belts may also be considered and could significantly decrease particulate emissions.

Fugitive emissions from the mill are an intrinsic problem because the mill is transforming large rocks into small particle sizes. In this process large quantities of small particles are created. The volumes of particulates released during the size reduction process can be moderated by the choice of different processes and procedures including wet crushing and enclosure of the crushers. Fugitive particulates from the mills represent a potential problem only during the operational phase.

The large surface area (up to several thousand acres) of the basin and the dam walls make the tailing basin a potential major source for particulate emissions.

The fine tailing particles are subject to wind erosion in all exposed areas. The models presented in Volume 2-Chapter 5 indicates that up to 80% of the basin may be covered with water during the operation. Water and chemical dust suppressants may be used to temporarily control dust liftoff from the dike walls but long term control will probably be best achieved by revegetating both the dam and the basin surfaces. For any one basin, revegetation of dam walls can be initiated during its operation. However, the basin surface and the upper levels of the dam cannot be permanently planted until use of the basin ceases.

Lean ore and waste rock piles present problems similar to those of a tailing basin except in the case of these stockpiles often no permanent control measures can be initiated until the piles are completed. However, the relative amount of small particles capable of wind suspension is quite low in waste rock piles, by comparison to tailing basins. Dust liftoff from these piles will result from wind erosion, dumping, and truck travel, and will be relatively limited once the operation ceases.

The smelter installation is another area source of particulates. Several materials are handled here in bulk, involving rail unloading, storage piles, movement by loading equipment, and conveyor transport. materials of importance here include concentrate from the mill, silicate flux, coal, and lime or limestone. Many or all of these materials can be transferred and stored in enclosed areas, greatly reducing dust emissions. Fugitive particulate emissions from the various smelting operations themselves are also of concern. Such emissions may occur along with sulfur dioxide fugitive emissions from building vents and ventillation fans. Careful design of furnace and gas handling equipment and ducts, along with good housekeeping practices, can minimize such emissions.

It must be noted here that the future regulatory position on certain types of fugitive dust emissions is uncertain at this time. The Environmental Protection Agency has specifically excluded fugitive dust from the air quality impact assessment of a stationary source (USEPA 1978). Here, fugitive dust is defined as consisting of particles of native soil which is uncontaminated by pollutants resulting from industrial activity. Fugitive dust, under this definition, may come from haul roads or exposed surfaces through the action of man or the wind or both. In the context of a PSD analysis, such emissions are not now considered to consume a portion of the allowable increment. However, this policy is being followed on an interim basis only, and fugitive emissions are included in deciding whether the facility is subject to a PSD review. For the purposes of this study, all fugitive emissions are included in modeling air quality impacts.

Source Models--Modeling of particulate emissions from area sources requires a two-step process. Initially, emission factors must be developed for each of the sources that is being modeled. Most of the factors used in the following work were developed on the basis of models experimentally determined by Midwest Research Institute (MRI) as part of a study of the taconite mining industry (Cuscino 1978), and shown in Table 69. Once the emission factors are established a dispersion model (CDM here, see section 3.2.2.3) can be utilized to estimate the movement of the available particulates away from the sources.

Table 69

The accuracy of these modeling results is highly dependent on the values used for emission factors. In the case of the emission factor for haul roads, for example, the silt content of the roads was assumed to be 6% based on the size fractions observed during crushing experiments using Duluth Gabbro and taconite

Table 69. Emission factors used for area particulate sources, as experimentally determined by Midwest Research Institute (Cuscino, 1978).

SOURCE CATEGORY	MEASURE OF EXTENT	EMISSION FACTOR[a] (lb/unit of source extent)	RELIABILITY[b]	CORRECTION PARAMETERS
Unpaved roads	Vehicle miles traveled	$5.9 \left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.8}$	A-B	s = silt content of road surface material, aggregate, or eroding surface (%).
Paved roads	Vehicle miles traveled	$0.45 \left(\frac{s}{10}\right)\left(\frac{L}{5{,}000}\right)\left(\frac{W}{3}\right)^{0.8}$	B-C	S = Average vehicle speed (mph)
Aggregate storage piles	Tons of material put through storage			W = Vehicle weight (tons)
				L = Surface dust loading on traveled portion of road (lb/mile)
Continuous load-in (e.g., stacker, transfer station		$0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^2}$	B	U = Mean wind speed (mph)
				M = Unbound moisture content of aggregate (%)
Storage pile maintenance and traffic		$0.10\ K \left(\frac{s}{1.5}\right)\left(\frac{d}{235}\right)$	C	Y = Dumping device capacity (cu yd)
				K = Activity factor (= 1 for tested operation)
Storage pile wind erosion		$0.05 \left(\frac{s}{1.5}\right)\left(\frac{d}{235}\right)\left(\frac{f}{15}\right)\left(\frac{D}{90}\right)$	C	d = Number of dry days per year
				f = percentage of time wind speed exceeds 12 mph.
Batch load-out (e.g. front-end loader/truck)		$0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^2\left(\frac{Y}{6}\right)}$	B	D = Duration of material in storage (days)
Wind erosion of exposed areas	Acre-years of exposed land	$3{,}400 \frac{\left(\frac{e}{50}\right)\left(\frac{s}{15}\right)\left(\frac{f}{25}\right)}{\left(\frac{P-E}{50}\right)^2}$	C	e = Surface erodibility (tons/acre/year)
				P-E = Thornthwaite's precipitation-evaporation index

[a]Annual average emission of dust particles smaller than 30 um in diameter based on particle density of 2.5 g/cm^3.

[b]A = Excellent; numerous field measurements.
B = Above average; limited number of field measurements.
C = Average; Limited data and/or published emission factors where the accuracy is not stated.

material at the Minnesota Resources Research Center (Iwasaki et al. 1978). Considering the importance of the silt content in the emission factor proposed by MRI it is apparent that any change in silt will be directly translated to a change in emission rates. If the silt content is 12% rather than 6% the amount of particulates released during the hauling operation could as much as double and conversely if silt is decreased by 50% the dust lift off will be decreased by 50%. Although fugitive dust emissions constantly occur on a small scale, the bulk of the emissions occur in discrete stages, such as a truck driving over an unpaved road or a gust of wind causing dust lift-off from a tailings basin. Therefore, results from this simulation model must be considered order of magnitude estimates and not highly accurate determinations of particulate emissions.

Sources of fugitive dust included for this modeling effort are blasting, unpaved haul roads, waste rock dumping, crushing/grinding, waste rock piles, ore storage (surge piles) in the mill, conveyors and dumping onto surge piles, and a tailing basin; other sources are considered negligible (Ashbrook 1979). The mine model assumes an open pit mine producing 20 million metric ton of ore per year. Smaller open pit mines and underground mines would yield lower dust levels. Combining emission factor information as determined by MRI with details of the modeled open pit operation (see Volume 2-Chapters 2 and 3, with associated references) the following emission estimates were made:

1) Blasting: Data presented in the MRI study (Cuscino 1978) indicated emissions ranging from 0.00015-0.16 lb of particulates emitted per short ton blasted. For a mine producing 20 million mt of ore per year, plus 26 million mt of waste rock and lean ore, this amounts to emissions ranging from 2.45 to 3,680 mt of particulates per year. This is a very wide range, and clearly depends on many factors including the type of rock being blasted, weather conditions during

blasting, and blasting practices used (size of charge, stemming used in the tops of blastholes, etc.). For modeling purposes a value of 100 mt was selected, as being roughly the geometric mean of the two extremes. Further, since the open pit involved would be quite deep (1,000 ft) in the later stages of mining, it was assumed that only 10% of this emission actually escapes from the pit. Thus a value of 10 mtpy of particulate emissions was used for modeling blasting sources. Clearly, this estimate may be high or low by as much as a factor of 100 in specific cases where the assumptions used here are not valid.

2) Hauling: For this estimate, as noted earlier, a silt content of 6% was used for the road material. Vehicles weighing an average of 100 tons and traveling 16 mph were assumed. Using 240 dry days per year in the MRI emissions formula for unpaved roads yielded 17.1 lb of particulates emitted per vehicle mile traveled. Using an estimate of just over one-half million vehicle miles traveled per year for the 20 million mtpy operation, and assuming dust control practices with a 50% efficiency, an emission of 2,100 mtpy of particulates was derived.

3) Waste Rock Dumping: The MRI formula for continuous load-in was used, assuming a loader capacity of 100 yd^3 and a 1% silt content. Using a moisture content of 0.5% and an average wind speed of 8.84 mph, an emission estimate of 10 mtpy was produced.

4) Waste Rock Pile Erosion: Here two estimates were made, one, based on the MRI formula for wind erosion of exposed area, assumed a surface erodibility of 3.4 tons/acre/year and a silt content of 5%. Using a value of 112 for Thornthwaite's Precipitation-Evaporation Index, and assuming the wind in the area exceeds 12 mph 30% of the time, an emission rate of 18.43 lbs/acre/year was derived. Estimates of the mining operation, assuming a 5-year period to revegetate waste rock piles,

yielded 280 acres of waste exposed at any one time, for an overall emission of 2.4 mtpy. Another estimate was done using a different formula from Bohn et al. (1978). Here the emission factor (EF) is:

$$EF = 3.5\ (s/1.5)(d/235)D$$

Now the silt content, s, was taken as 0.5%, a more reasonable estimate in light of the very coarse nature of waste rock. The number of dry days per year, d, was taken as 240, with the duration of storage, D, being 365 days. Again, assuming 280 acres exposed at any given time, an emission estimate of 60 mtpy was derived. This larger estimate was used for modeling purposes.

5) Ore Storage: This estimate used the MRI formula for storage pile wind erosion, assuming a silt content of 4% and a maximum storage duration of 7 days for any given ton of material. Resulting emission estimates range from 210 mtpy with no control, to 2 mtpy with 99% control. For modeling purposes, a value of 10 mtpy emissions was used, assuming a control efficiency of 95%.

6) Conveyors in Mill: The MRI formula for continuous load-in was used, with a silt content of 4%, moisture of 1%, and wind speed of 8.84 mph. Assuming 90% control yields an emission estimate of 10 mtpy.

7) Crushing and Grinding: Here, data was not available from the literature for use in estimating emissions. As an alternative, an estimate was made by comparing with taconite operations. Discussions with Minnesota Pollution Control Agency staff (Rottschaefer, 1978) revealed estimates of emissions of 1000 tons/year with the stage 3 expansion at the Minntac Plant. Scaling this to the copper-nickel situation, and assuming the use of relatively efficient (95-99% baghouse filters) yielded an emission's estimate of 500 mtpy. It must be par-

ticularly stressed here that this is a very general estimate, good only to an order of magnitude. The actual control devices and practices used have a great effect upon actual emission rates.

8) Tailing Basin: The MRI formula for wind erosion of exposed areas was used here, assuming a silt content of 70% and a surface erodibility of 3.4 lbs/acre/year. For a tailing basin of 4,016 acres, with 20% exposed above water, an emission estimate of 100 mtpy was arrived at.

The above factors are summarized in Table 70, along with the major assumptions used. It can be seen that the major single activity contributing to dust emissions is the hauling of ore and wastes on unpaved roads. This provides 3/4 of the estimated emissions. Crushing and grinding has the potential of generating considerable emissions also (about 1/5 of the total in the model). Both of these operations are amenable to a wide variety of control practices. Roads may be watered or treated with a variety of dust suppressants. Crushing and grinding operations may be fully enclosed, with efficient particulate collection devices installed on all air ducts leaving the building. The tailing basin is another potential major source of emissions, though these can be minimized in an active basin by a combination of submersion under water, and treatement of exposed beached with dust suppressants.

Table 70

For use by the CDM model, the various area sources were arranged in a configuration simulating the layout of an actual mining operation. This arrangement was placed on a grid system to be used in locating a series of receptor points. The CDM model could then compute the annual average particulate concentrations in

Table 70. Summary of estimated fugitive dust emissions from a copper-nickel mine and mill.[a]

OPERATION	ESTIMATED RANGE OF EMISSIONS (mtpy)	ESTIMATE USED FOR MODEL (mtpy)	PERCENT OF TOTAL	COMMENTS
Mine:				
1) Blasting	1.5-1,600	10	0.4%	Assumes 100 mtpy as a midpoint estimate and 10% of dust escapes the pit
2) Hauling	840-4,200	2,100	74.8%	Assumes dust control of 50%
3) Waste rock dumping	8-400	10	0.4%	Uses most recent MRI formula
4) Waste rock pile erosion	2.4-400	60	2.1%	Uses most recent MRI formula (silt content = 0.5%)
Mill:				
5) Ore storage	2-210	10	0.4%	Assumes 95% control
6) Conveyors dumping on surge pile	1-100	10	0.4%	Assumes 90% control
7) Crushing/grinding	200-20,000	500	17.9%	Based on Minntac's new plant (stage 3) and discussion with MPCA
8) Tailing basin	0-480	100	3.6%	Assumes 80% of basin under water
TOTAL	1000-27,000	2800	100%	

SOURCE: Ashbrook 1979.

[a]Assumes an open pit mine producing 20 X 10^6 metric tons of ore per year and removing 26 X 10^6 metric tons of waste rock per year viewed late in its operating life. Estimates are for particulates less than 30 um.

the atmosphere at the various receptor sites based on the modeled emissions from the mining sources. Figure 85 shows the grid system and layout of the various area sources used. The open pit mine covers 523 acres at maximum development. Haul roads emerge from the east end of the pit to the waste rock piles and to the mill. The tailing basin covers 4,016 acres and is east of the mill. This orientation is reasonable for much of the mineral resource area (with the exception of the Inco areas). Over the 25-year life of the model mine there would be a total of 13 waste rock piles (which would appear as one pile by the end of the operation) of 60 hectares (148 acres) each. Reclamation of each waste rock pile and the tailing basin dam is assumed to take five years.

Figure 85

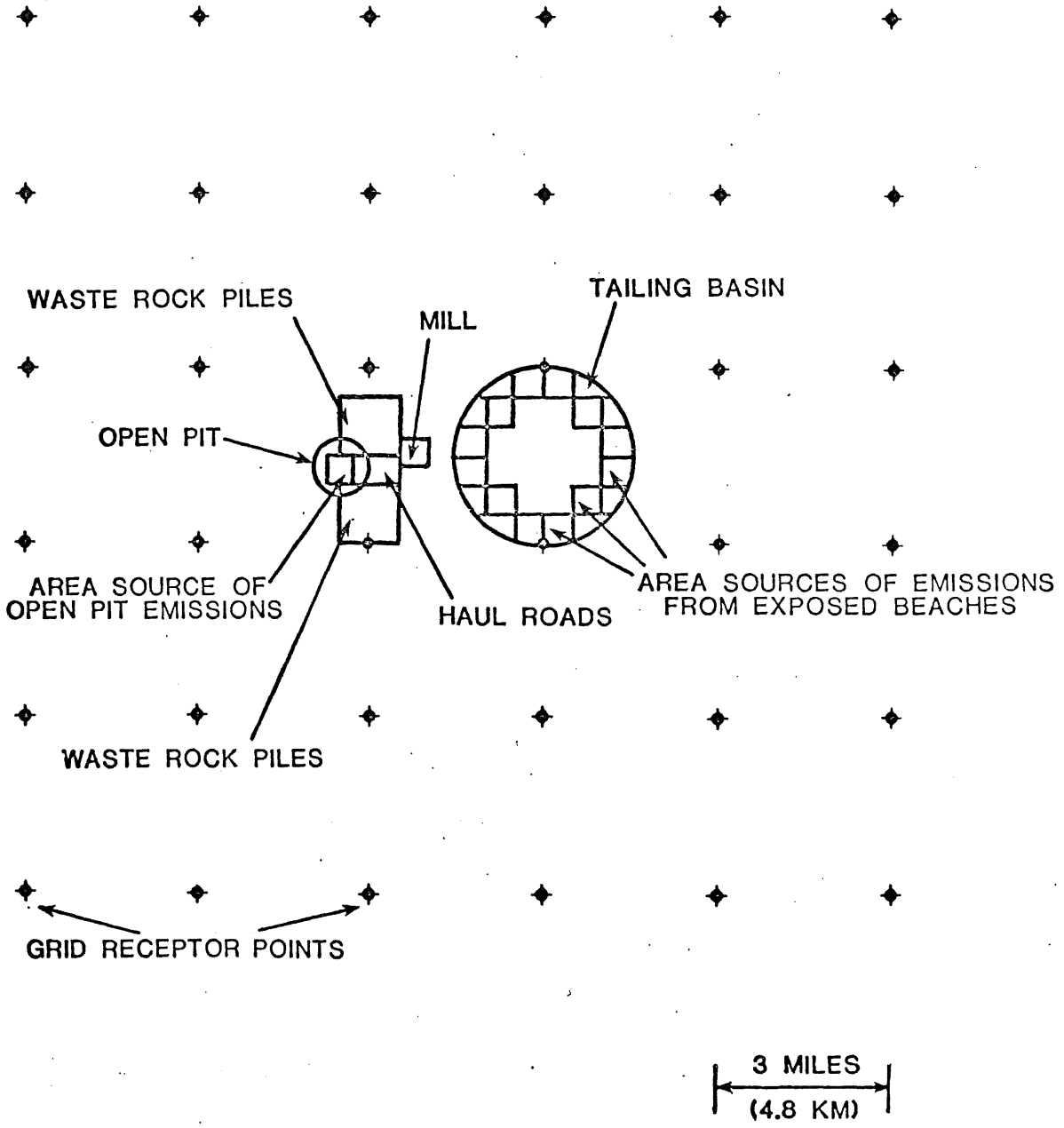
The results of the modeling using these emission source estimates are given later in section 3.8.1.2.

A discuss is now in order here concerning fugitive particulate emissions from a smelter/refinery complex. Since the smelter/refinery facility may well be sited far from the mine and mill, its emissions are considered separately. The discuss focuses on the smelter itself. The refinery operations are not modeled since there is no reason to expect them to be significant area sources of particulate emissions. As noted earlier, the results of this discussion are treated as point source emissions for impact analysis purposes. However, many of the contributions are area sources, justifying inclusion of this discussion here.

As was the case with several of the area dust sources in the mine and mill, there is not a great deal of well-documented data available upon which to base emission estimates. The model discussed here is based on information taken from two

FIGURE 85

GRID SYSTEM AND LAYOUT OF MINE AND MILL COMPONENTS FOR THE AREA SOURCE MODEL OF PARTICULATE EMISSIONS



SOURCE : ASHBROOK (1979)

principal sources. The first is a USEPA report on fugitive particulate emissions from industrial operations (USEPA 1977b). This report discusses emissions from a primary copper smelter and presents a model for the emission rate from a smelter using a reverberatory furnace and no particulate controls. This information was used to prepare a worst case model of fugitive particulate emissions.

The second information source was a report describing a prevention of significant deterioration analysis performed on a planned new copper smelter to be located in Louisiana (Nelson 1977). The smelter employes a flash furnace and utilizes state of the art control technology. Thus, it provides a reasonable basis for a best case emission estimate.

The information from both of the references mentioned was adjusted to the size of the smelter model discussed in Volume 2-Chapter 4 (100,000 mtpy of copper plus nickel capacity). Particulate sources associated with bulk material unloading, storage, and reclaim facilities, as well as charging of the furnace, were scaled to the input concentrate, flux, and coal requirements of the copper-nickel smelter model. Dust sources from operations beyond the smelting furnace in the smelter building were scaled to the total metal produced by the facility. Table 71 summarizes the range of emission estimates which resulted from this analysis. As was the case for emission estimates from crushing and grinding operations in the mill discussed earlier, these estimates vary by a factor of 100 from the lowest to the highest.

Table 71

The emissions from two source categories, material unloading and the smelter building, have the potential of emitting up to three or four thousand metric tons

Table 71. Range of estimated fugitive particulate emissions from a copper-nickel smelter producing 100,000 mtpy of copper and nickel metal.

EMISSION SOURCE CATEGORY	MINIMUM ESTIMATE[a] mtpy	MAXIMUM ESTIMATED[b] mtpy
Material Unloading (concentrate, flux, limestone, coal)	24	3200
Material Storage and Reclaim (concentrate, flux, limestone, coal)	37	131
Smelter Building	7	3700
TOTAL	68	7031

[a]Based on Nelson 1977.
[b]Based on USEPA 1977b.

of particulates per year. The material storage and reclaim operations have a much smaller emission potential, since the materials involved typically would be stored in covered areas, and handled using enclosed conveyor systems. The emissions from all sources are shown as being capable of reduction to levels as low as a few metric tons per year.

For modeling purposes, an emission rate of 1,500 mtpy was rather arbitrarily selected as falling in the middle of the range for either of the two largest source categories. It must be stressed that this value is not indicated as being more probable than another choice. It simply provides a mid-range reference point for use in the dispersion modeling which follows. Due to the large range of possible emissions, it is important that specific estimates be made for any particular proposed development. These estimates can then be compared to the 1,500 mtpy rate used here, and the resulting impacts scaled accordingly.

The answers to questions of the particle size distribution and elemental composition of these emissions are rather obscure. From the preceeding discussion it is clear that depending on the degree of particulate control applied to the various aspects of the operation, any one of the potential source categories mentioned could dominate the emissions and thus determine its composition. The sources related to materials unloading, storage, and handling involve smelter feed mateials and fuel. Of these, the mill concentrate constitutes the bulk of the tonnage (modeled as 78%, see Volume 2-Chapter 4, section 4.7.2.8) and has the highest levels of heavy metals. Based on the compositional model for the concentrate presented in the discussion of feed materials to the smelter (Volume 3-Chapter 2, section 2.4.1.1), Table 72 shows a model for the composition of 1,500 mtpy of particulates potentially emitted as fugitives from a smelter/refinery complex. The model assumes that the particulates are dominated

by emissions from concentrate handling and storage, and thus have the composition of this concentrate.

Table 72

The particles emitted as fugitives would be expected to be typically less than 30 um in diameter in order to be transported any distance in the atmosphere. Based on studies by the EPA of emissions from copper smelters (Statnick 1974), a mass median diameter of 2.8 um (with a deposition velocity of 1.1 cm/sec after Cawse 1974) was used to characterize all smelter particulate emissions for modeling purposes. This small diameter represents a conservative estimate in that these particles may be carried a greater distance and thus affect a wider area than would be the case for larger particles.

The compositional model above assumes that fugitive particulates are not dominated by emissions from pyrometallurgical operations in the smelter building. Such emissions might contain elevated levels of certain volatile elements such as zinc and lead, which have escaped from smelter operations as vapor and then condensed as particulates. Such emissions do not appear likely to constitute a significant portion of the expected fugitives, due both to the apparent low levels of such elements in the concentrate to be treated, and to the high degree of capture expected for emissions within the smelter as a result of the modern technology likely to be employed. It is vital to emphasize, however, that in the context of the preliminary nature of the data available to date, it is certainly not possible to rule out the occurrance of significant emissions of this type. It is essential that each individual operation be examined, in light of detailed data on the composition of the concentrate to be treated and the technology to be employed, to assess the nature and extent of potential fugitive particulate emissions from the pyrometallugical processes used.

Table 72. Model for the constituents in the fugitive particulate emissions from a flash smelter facility generating 100,000 mtpy of copper and nickel metal.[a]

CONSTITUENT	MODELED FUGITIVE EMISSION RATE (mtpy)
Si (SiO_2)	109 (233)
Al (Al_2O_3)	27 (51)
Fe (FeO)	38 (49)
Mg (MgO)	23 (39)
Ca (CaO)	17 (24)
Na (Na_2O)	5.8 (7.9)
K (K_2O)	1.2 (1.5)
Ti (TiO_2)	1.5 (2.5)
P (P_2O_5)	.15 (.45)
Mn (MnO)	.45 (.60)
Cr (Cr_2O_3)	.60 (.90)
B	.46
Ba	.19
Be	.00009
Sr	.075
V	.13
Th	.0045
Zr	.039
S	388
Cu	207
Ni	40
Fe(S)	450
Co	2.0
Zn	1.7
Pb	.091
Ag	.051
As	.046
Hg	.0003
Mo	.042
Cd	.060
TOTAL	1500

[a]The model assumes the emission of 1,500 mtpy of particulates having the composition of the concentrate from the mill. See Volume 3-Chapter 2, section 2.4.1.1. Normal operating conditions are assumed. Values are rounded.

The modeling estimates of ambient particulate concentrations and deposition rates resulting from the smelter emissions just discussed are presented in section 3.8.1.2.

3.6.2.3 Mineral Fibers--The question of possible changes in ambient concentrations of mineral fibers in the atmosphere is difficult to address because of a lack of information concerning the injection of the particles into the atmosphere. Fiber studies conducted on potential ore material indicate that while the occurrence of true asbestiform minerals is quite rare, cleavage fragments are generated during processing which meet current definitions of mineral fibers observed under the transmission electron microscope. Tailing material was found to contain from 10^9 to 10^{10} fibers per gram of dry tailing. This topic is discussed in the geology and mineralogy report, Volume 3-Chapter 1, section 1.4.3.5 and in the mineral resources potential report, Volume 3-Chapter 2, section 2.4.4.

There is no information available on the emission factors for fibers of known concentration in a bulk material. However, some simplified assumptions may be made to obtain a first estimate of possible ambient concentrations. The focus here is on tailing and concentrate material. Due to the amount of crushing and grinding, the tailing and concentrate products from the mill are expected to contain far higher mineral fiber concentrations as a result of cleavage fragment formation than are the coarse waste rock and lean ore materials. The concentrate is processed at high temperatures in the smelter where the fibers would be expected to be destroyed. However, there is the possibility that the dryer in the smelting operation could be a source of fibers, particularly if a spray dryer is used. Similarly, tailing stored in a basin and allowed to dry may be another potential fiber source.

For modeling purposes here, it is simply assumed that all smelter particulate emissions (and all tailing basin dust emissions) contain 10^9-10^{10} fibers/gm, based on analysis of the bulk materials in bench scale tests. This conversion factor is used in section 3.8.3 to discuss the potential impacts on air quality by mineral fiber emissions from the smelter and tailing basin.

3.7 IMPACT ANALYSIS FOR SULFUR EMISSIONS

In section 3.6.1 the various possible sources of atmospheric emissions of sulfur related to a copper-nickel operation were discussed. The major source of concern was identified as the smelting phase of the operation which may release sulfur to the atmosphere as stack and fugitive emissions of gaseous SO_2. To aid in quantifying the potential air quality impacts of these emissions a set of 4 hypothetical smelter emissions models were presented. In this section, the air quality impacts of these models are discussed based on the results of atmospheric modeling studies.

The purpose of the atmospheric modeling program was to estimate the spatial and temporal impacts of emissions from the various smelter cases and thus to provide a consistent comparison of development alternatives. The selected atmospheric dispersion models predict the atmospheric impacts of both stack and fugitive emissions.

Short-range models simulate the effects of smelter operation on ambient air quality close to the source (less than 10 km). Atmospheric impacts of stack emissions near the source were modeled using the Texas Air Control Board's Texas Episodic Model (TEM)(Christianson 1976) for time periods of 3 and 24 hours. A building source model developed by the H.E. Cramer Company (Cramer, et al. 1975) was used to calculate the dispersion of short-term smelter fugitive emissions.

Annual smelter stack and fugitive emissions impacts close to the source were predicted using the Climatological Dispersion Model (CDM) (Busse and Zimmerman 1973; Brubaker et al. 1977). See section 3.2.2.3 for a further discussion of the short-range models.

The modified gaussian model (section 3.2.2.4) simulates the mesoscale disperison and deposition of smelter stack and fugitive emissions as well as regional source emissions for distances as close as 5 km and as far as 150 km from the source. Annual and 24-hour time periods are considered in the impact analysis.

Ideally, all possible smelter locations in the Region would have been considered by the modeling program. A separate model run for each site, however, was unrealistic based on time and expense involved. Therefore, geographic areas of modeling similarity were identified on the basis of terrain features and wind regimes. The modeling effort was concentrated on the part of the air quality study region near the copper-nickel ore body where atmospheric dispersion patterns are considered to be fairly uniform. The implications of a smelter site in Duluth, which is meteorologically quite different from the Study Area, is discussed briefly in section 3.7.1.4.

In previous sections the atmospheric sulfur and particulate impacts of regional growth were discussed. In this section and section 3.8, the atmospheric impacts of copper-nickel development in northeastern Minnesota will be assessed alone and then compared to anticipated regional growth to make general statements about the regulatory, health and environmental implications of regional development.

3.7.1 Ambient SO_2 Concentrations

The following discussion of mesoscale modeling results is a summary of the work performed by Ingrid Ritchie, Joe Bowman, and George Burnett. The discussion of short-range modeling results is a summary of the work described in detail in Endersen (1979).

This section discusses the predicted ambient annual, 24-hour, and 3-hour SO_2 concentrations resulting from point sources (smelter stack and fugitive emissions along with existing and projected regional point source emissions) in terms of ambient air quality standards and allowable PSD increments. Section 3.4.2.1 discussed the regulatory implications of regional growth without copper-nickel development. This section will first focus on the atmospheric impacts of the three smelter cases and then discuss the combined impacts of projected regional growth in 1985 and potential copper-nickel development on the region's ambient air quality.

3.7.1.1 Annual Concentrations--In modeling annual average SO_2 concentrations only 3 of the model smelter cases were considered, the base case and options 1 and 2. The basic model, with its high SO_2 emission rate is felt to be totally unrepresentative of the smelter SO_2 control technology available today since it does not employ secondary hooding of weak SO_2 gas streams. A new facility would not be expected to be built without these devices so this model would not reflect the long-term performance of such a facility. It's value lies in its use to assess potential short term impacts such as may occur during upset conditions which result in control devices being temporarily bypassed.

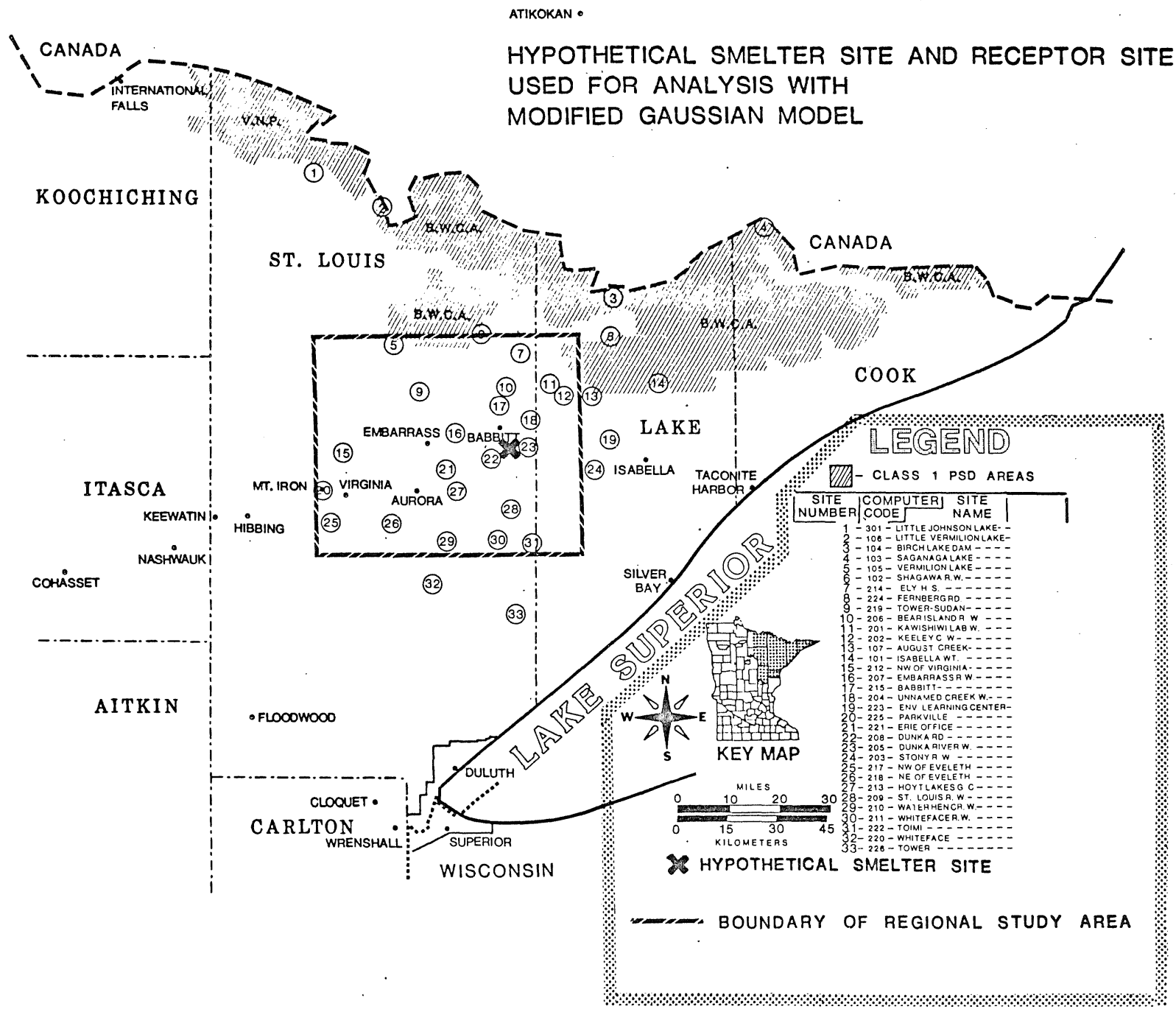
It must be noted at the outset that the following discussion will mention exceedances of various ambient air quality standards. This does not necessarily imply that a violation of the standard is predicted. The distinction is noted

for two basic reasons. First the occurrence of a violation is a legal determination (based on accepted monitoring and modeling techniques and possibly involving consideration of variances and other factors) to be made only by a properly authorized body such as the Minnesota Pollution Control Agency. Second, the standards involved do not consider one 24-hour value in excess of the standard per year at a given site as a violation and much of the discussion which follows is in the context of the single maximum 24-hour value predicted at a given receptor site. Thus, this discussion does not make legal determinations but rather focuses on environmental conditions and highlights situations where problems appear most likely to arise in the context of present air quality regulations.

To provide a spatial reference point in the Study Area, a hypothetical smelter site for the point source emissions was selected at a location 3 miles south of Babbitt. The reader is strongly cautioned not to infer that this reference location implies that a smelter has been proposed or is being recommended for this location. Neither of these is the case. The site selected does lie adjacent to the most active mining exploration site in the Area so that it is not unreasonable to consider the implications of a smelter in the vicinity. Further, the site is generally in the center of the Regional Copper-Nickel Study Area, making it fairly easy to extrapolate the results of modeling at this site to other potential sites in the Area. The map in Figure 86 shows the hypothetical smelter site in relation to the various receptor sites in the modified gaussian model.

Figure 86

FIGURE 86


ATIKOKAN
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
B.W.C.A.
ST. LOUIS
CANADA
B.W.C.A.
B.W.C.A.
B.W.C.A.
COOK
LAKE
EMBARRASS
BABBITT
ISABELLA
TACONITE HARBOR
ITASCA
MT. IRON
VIRGINIA
AURORA
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
HYPOTHETICAL SMELTER SITE AND RECEPTOR SITES
USED FOR ANALYSIS WITH
MODIFIED GAUSSIAN MODEL
LEGEND
- CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME
1 - 301 - LITTLE JOHNSON LAKE-
2 - 106 - LITTLE VERMILION LAKE-
3 - 104 - BIRCH LAKE DAM
4 - 103 - SAGANAGA LAKE
5 - 105 - VERMILION LAKE
6 - 102 - SHAGAWA R.W.
7 - 214 - ELY H.S.
8 - 224 - FERNBERG RD.
9 - 219 - TOWER-SUDAN-
10 - 206 - BEAR ISLAND R. W.
11 - 201 - KAWISHIWI LAB W.
12 - 202 - KEELEY C. W-
13 - 107 - AUGUST CREEK-
14 - 101 - ISABELLA W.T.
15 - 212 - NW OF VIRGINIA-
16 - 207 - EMBARRASS R. W.
17 - 215 - BABBITT-
18 - 204 - UNNAMED CREEK W.-
19 - 223 - ENV. LEARNING CENTER-
20 - 225 - PARKVILLE
21 - 221 - ERIE OFFICE
22 - 208 - DUNKA RD.
23 - 205 - DUNKA RIVER W.
24 - 203 - STONY R. W.
25 - 217 - NW OF EVELETH
26 - 218 - NE OF EVELETH
27 - 213 - HOYT LAKES G. C.
28 - 209 - ST. LOUIS R. W.
29 - 210 - WATERHEN CR. W.
30 - 211 - WHITEFACE R. W.
31 - 222 - TOIMI
32 - 220 - WHITEFACE
33 - 226 - TOWER
N
W
E
S
KEY MAP
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE
BOUNDARY OF REGIONAL STUDY AREA

With these locational caveats in mind, the 3 smelter models were placed at the indicated site and the modified gaussian model was used to predict annual SO_2 concentrations at the various receptor sites in the region. The results are shown in Figures 87, 88, and 89. The modified gaussian model predicts that the annual ambient air quality SO_2 standards would not be exceeded by any of the three smelter models. The closest receptor to the hypothetical smelter site is the Dunka River Watershed receptor, some 5 km east of the source. The highest predicted annual average for the region is 4.7 ug/m^3 which, of course, occurs for the base case model at the Dunka River Watershed receptor. This is only about 6% of the national primary annual ambient air quality standard. The highest annual average predicted for the option 1 and 2 models are 2.1 ug/m^3 and .79 ug/m^3 or about 3% and 1% of the primary standard, respectively.

Figures 87, 88, and 89

The results also indicate that for this location in the region, none of the smelter models alone are predicted to exceed the Class I or Class II annual PSD increments (2 and 20 ug/m^3, respectively) at any of the receptor sites. The highest concentrations (occurring for the base case smelter of course) in Class I and II areas are .47 ug/m^3 and 4.7 ug/m^3, respectively. These values are both about one quarter of the allowed increments. Using option 1 in the simulations drops these highs by about 50% to .21 ug/m^3 and 2.1 ug/m^3, respectively. Option 2 results in further decreases to .08 ug/m^3 and .79 ug/m^3, respectively.

Assuming a factor of two error in the modeling results, neither of the annual PSD increments would be in jeopardy at greater than 5 km from the source using these modeling results. However, recalling that the smelter location here is rather arbitrary, it is seen that with a factor of 2 error, the receptor site 5 km east

FIGURE 87

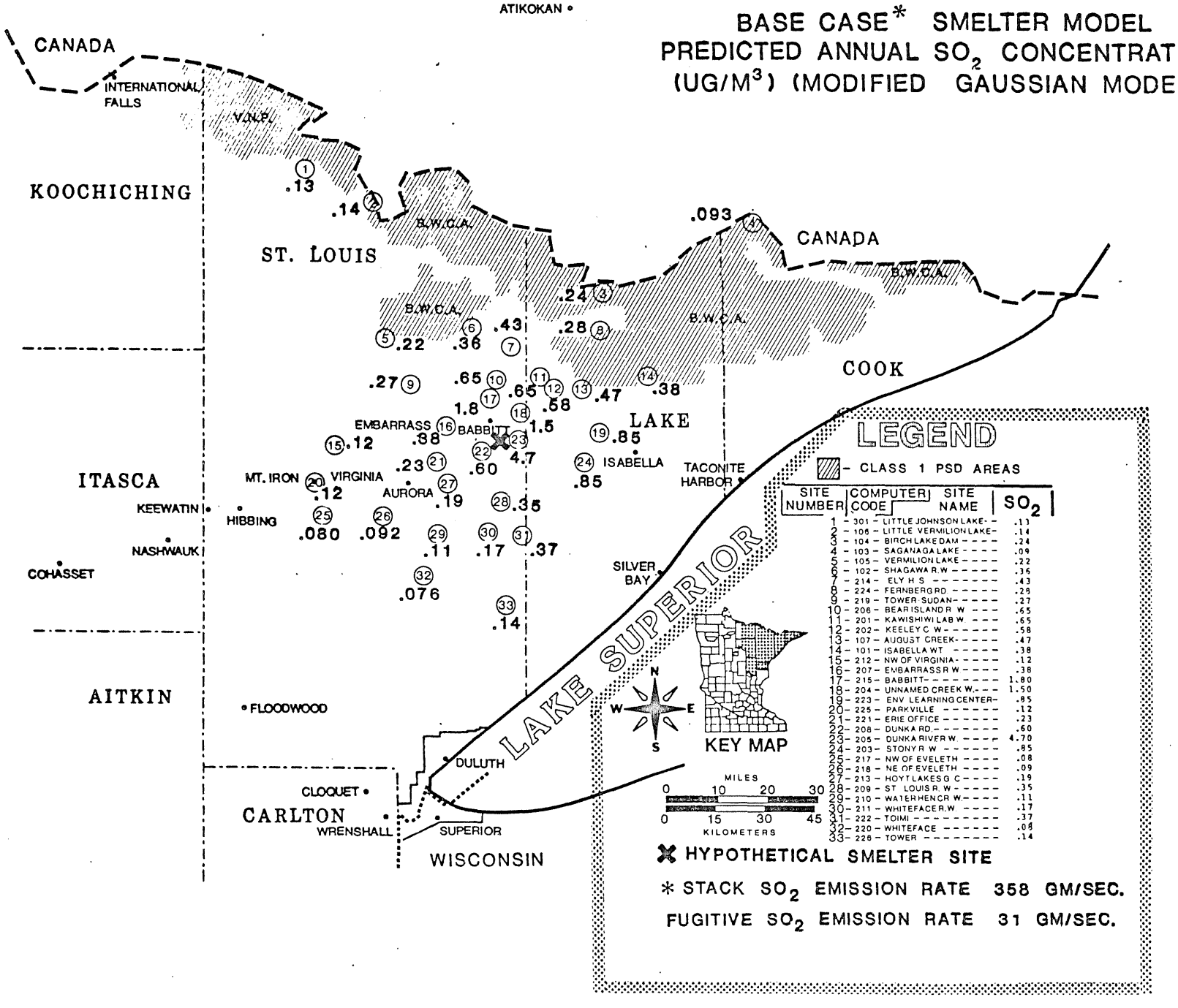

BASE CASE* SMELTER MODEL
PREDICTED ANNUAL SO2 CONCENTRATIONS
(UG/M3) (MODIFIED GAUSSIAN MODEL)
ATIKOKAN
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
MT. IRON
VIRGINIA
AURORA
EMBARRASS
BABBITT
ISABELLA
TACONITE HARBOR
SILVER BAY
LAKE SUPERIOR
KEEWATIN
HIBBING
NASHWAUK
COHASSET
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
.13
.14
.093
.24
.22
.36
.43
.28
.27
.65
.65
.47
.38
1.8
.58
1.5
.85
.12
.38
.23
.60
4.7
.85
.12
.19
.35
.080
.092
.11
.17
.37
.076
.14
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO2
1 - 301 - LITTLE JOHNSON LAKE - .11
2 - 106 - LITTLE VERMILION LAKE - .14
3 - 104 - BIRCH LAKE DAM - .24
4 - 103 - SAGANAGA LAKE - .09
5 - 105 - VERMILION LAKE - .22
6 - 102 - SHAGAWA R.W - .36
7 - 214 - ELY H S - .43
8 - 224 - FERNBERG RD. - .28
9 - 219 - TOWER-SUDAN - .27
10 - 206 - BEAR ISLAND R. W - .65
11 - 201 - KAWISHIWI LAB W. - .65
12 - 202 - KEELEY C W - .58
13 - 107 - AUGUST CREEK - .47
14 - 101 - ISABELLA WT - .38
15 - 212 - NW OF VIRGINIA - .12
16 - 207 - EMBARRASS R W - .38
17 - 215 - BABBITT - 1.80
18 - 204 - UNNAMED CREEK W. - 1.50
19 - 223 - ENV. LEARNING CENTER - .85
20 - 225 - PARKVILLE - .12
21 - 221 - ERIE OFFICE - .23
22 - 208 - DUNKA RD. - .60
23 - 205 - DUNKA RIVER W. - 4.70
24 - 203 - STONY R. W - .85
25 - 217 - NW OF EVELETH - .08
26 - 218 - NE OF EVELETH - .09
27 - 213 - HOYT LAKES G. C - .19
28 - 209 - ST. LOUIS R. W - .35
29 - 210 - WATER HEN CR. W - .11
30 - 211 - WHITEFACE R. W. - .17
31 - 222 - TOIMI - .37
32 - 220 - WHITEFACE - .08
33 - 226 - TOWER - .14
KEY MAP
N
W
E
S
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE
* STACK SO2 EMISSION RATE 358 GM/SEC.
FUGITIVE SO2 EMISSION RATE 31 GM/SEC.

FIGURE 88

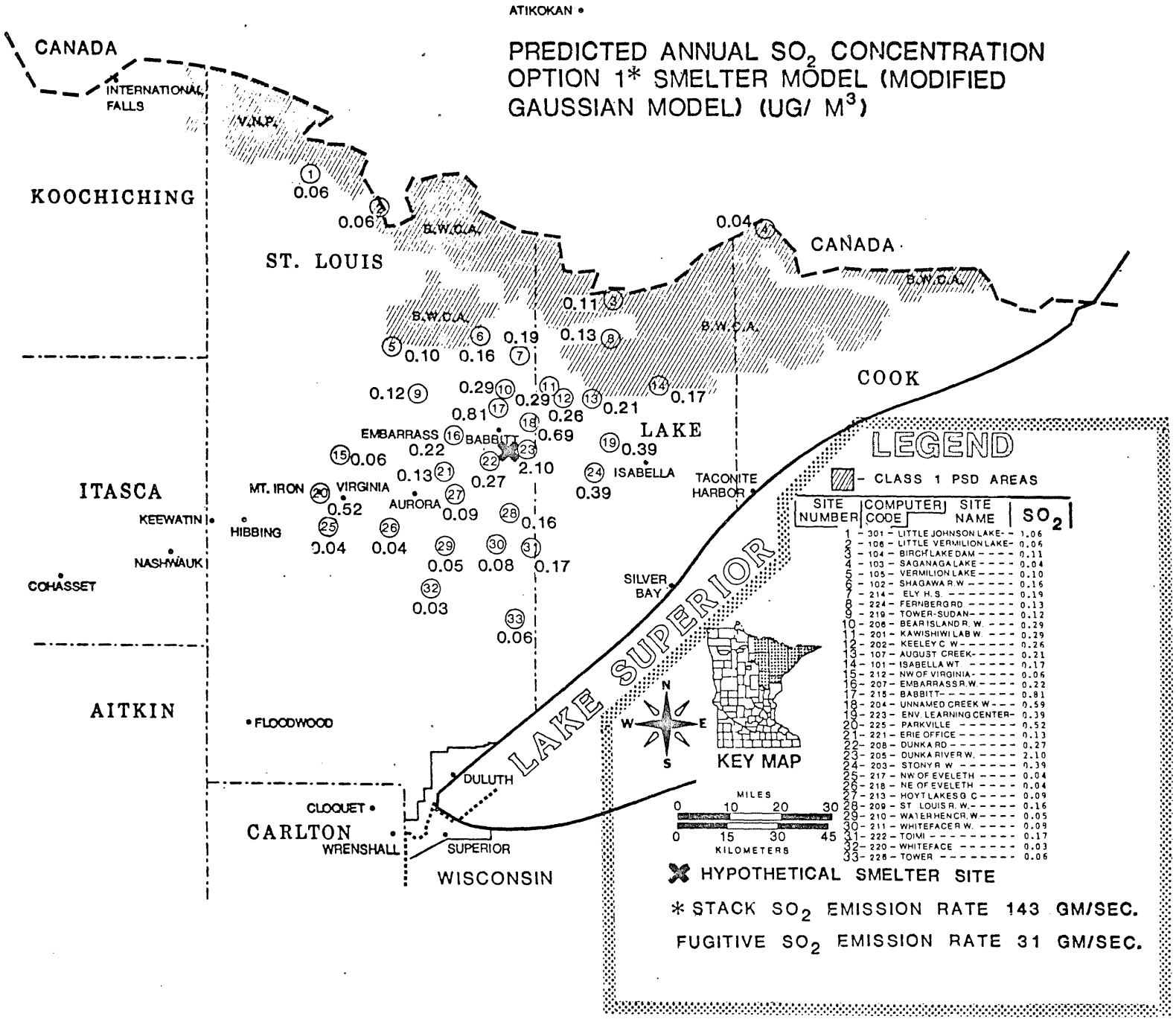
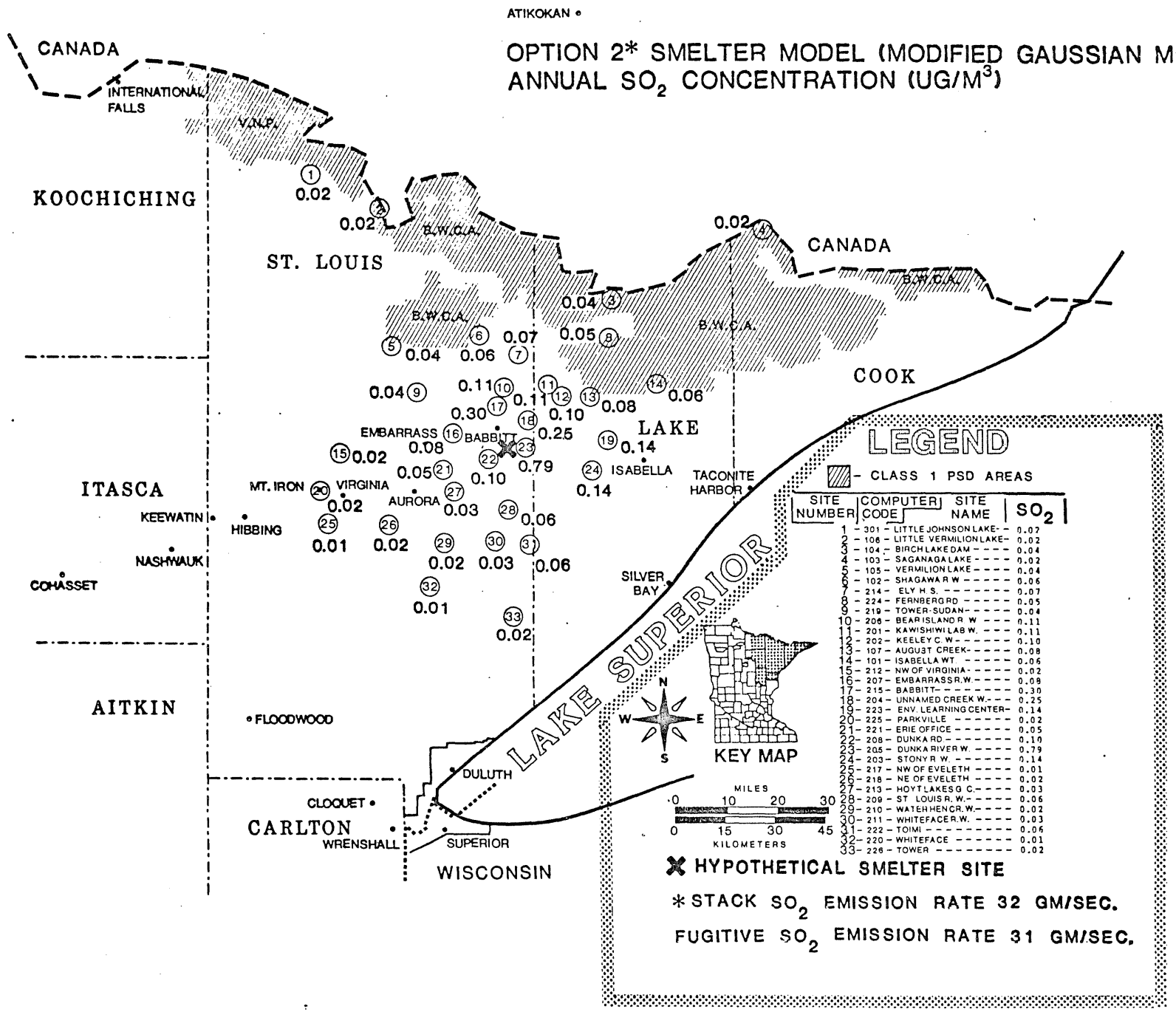

ATIKOKAN
PREDICTED ANNUAL SO_2 CONCENTRATION OPTION 1* SMELTER MODEL (MODIFIED GAUSSIAN MODEL) (UG/ M^3)
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
EMBARRASS
BABBITT
MT. IRON
VIRGINIA
AURORA
ISABELLA
TACONITE HARBOR
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
0.06
0.06
0.04
0.11
0.10
0.16
0.19
0.13
0.12
0.29
0.29
0.21
0.17
0.81
0.26
0.69
0.39
0.22
0.06
0.13
0.27
2.10
0.39
0.52
0.09
0.16
0.04
0.04
0.05
0.08
0.17
0.03
0.06
LEGEND
- CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO_2
1 - 301 - LITTLE JOHNSON LAKE- 1.06
2 - 106 - LITTLE VERMILION LAKE- 0.06
3 - 104 - BIRCH LAKE DAM 0.11
4 - 103 - SAGANAGA LAKE 0.04
5 - 105 - VERMILION LAKE 0.10
6 - 102 - SHAGAWA R.W 0.16
7 - 214 - ELY H.S. 0.19
8 - 224 - FERNBERG RD 0.13
9 - 219 - TOWER-SUDAN- 0.12
10 - 206 - BEAR ISLAND R. W. 0.29
11 - 201 - KAWISHIWI LAB W. 0.29
12 - 202 - KEELEY C W- 0.26
13 - 107 - AUGUST CREEK- 0.21
14 - 101 - ISABELLA WT 0.17
15 - 212 - NW OF VIRGINIA 0.06
16 - 207 - EMBARRASS R.W. 0.22
17 - 215 - BABBITT- 0.81
18 - 204 - UNNAMED CREEK W 0.59
19 - 223 - ENV. LEARNING CENTER- 0.39
20 - 225 - PARKVILLE 0.52
21 - 221 - ERIE OFFICE 0.13
22 - 208 - DUNKA RD 0.27
23 - 205 - DUNKA RIVER W. 2.10
24 - 203 - STONY R W 0.39
25 - 217 - NW OF EVELETH 0.04
26 - 218 - NE OF EVELETH 0.04
27 - 213 - HOYT LAKES G C 0.09
28 - 209 - ST. LOUIS R. W. 0.16
29 - 210 - WATERHEN CR. W 0.05
30 - 211 - WHITEFACE R W. 0.09
31 - 222 - TOIMI 0.17
32 - 220 - WHITEFACE 0.03
33 - 226 - TOWER 0.06
KEY MAP
N
W
E
S
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE
* STACK SO_2 EMISSION RATE 143 GM/SEC.
FUGITIVE SO_2 EMISSION RATE 31 GM/SEC.

FIGURE 89



SITE NUMBER	COMPUTER CODE	SITE NAME	SO_2
1	301	LITTLE JOHNSON LAKE	0.07
2	106	LITTLE VERMILION LAKE	0.02
3	104	BIRCH LAKE DAM	0.04
4	103	SAGANAGA LAKE	0.02
5	105	VERMILION LAKE	0.04
6	102	SHAGAWA R.W.	0.06
7	214	ELY H.S.	0.07
8	224	FERNBERG RD	0.05
9	219	TOWER-SUDAN	0.04
10	206	BEAR ISLAND R.W.	0.11
11	201	KAWISHIWI LAB W.	0.11
12	202	KEELEY C.W.	0.10
13	107	AUGUST CREEK	0.08
14	101	ISABELLA WT.	0.06
15	212	NW OF VIRGINIA	0.02
16	207	EMBARRASS R.W.	0.08
17	215	BABBITT	0.30
18	204	UNNAMED CREEK W.	0.25
19	223	ENV. LEARNING CENTER	0.14
20	225	PARKVILLE	0.02
21	221	ERIE OFFICE	0.05
22	208	DUNKA RD.	0.10
23	205	DUNKA RIVER W.	0.79
24	203	STONY R.W.	0.14
25	217	NW OF EVELETH	0.01
26	218	NE OF EVELETH	0.02
27	213	HOYT LAKES G.C.	0.03
28	209	ST. LOUIS R.W.	0.06
29	210	WATER HEN CR.W.	0.02
30	211	WHITEFACE R.W.	0.03
31	222	TOIMI	0.06
32	220	WHITEFACE	0.01
33	226	TOWER	0.02

of the source might easily result in exceedance of the Class I annual increment with the base case model if the smelter site were moved so that this receptor fell into a Class I area. The long range modeling here indicates the need to use short range modeling to investigate possible air quality problems close to the smelter site.

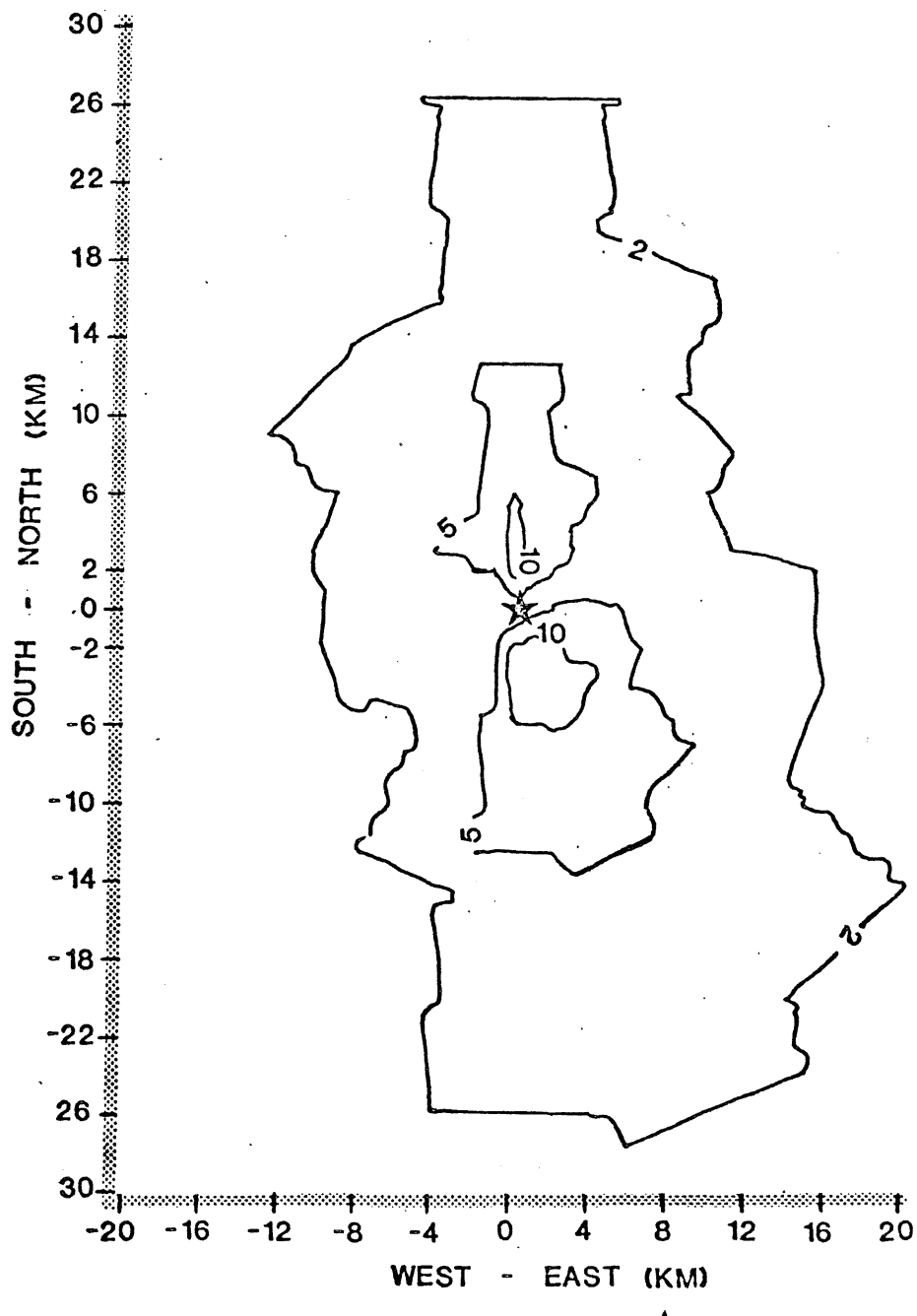
The CDM model, as mentioned earlier was used to investigate the short range problem noted above. Figure 90 presents the results for the base case model, with isopleths showing annual average concentrations of 2, 5, and 10 ug/m^3. The figure shows that the resulting average dispersion pattern, as expected, strongly reflects the annual wind rose. A large area of computed concentrations between 10 and 15 ug/m^3 lies to the SSE of the smelter and a smaller area lies to the north. Computed concentrations at all points are less than the Class II PSD allowable increment of 20 ug/m^3, but a possible factor of two error in the modeling could lead to exceedances of the level. The Class I increment, 2 ug/m^3, is estimated to be exceeded out to about 30 km to the SSE and to about 10 km in all directions. Model accuracy deteriorates somewhat with distance, but it is clear that the Class I increment would be jeopardized over a considerable area. Figure 90A shows the results for the option 2 model. Note the greatly reduced area in which the Class I increment is predicted to be exceeded.

Figures 90 and 90A

It is interesting to note that the two dispersions models used here generally produce results which agree within the factor of the accuracy attributed to each model. However, the high reading from the modified gaussian model receptor 5 km east of the smelter site underestimated the extent of the area affected by such elevated readings. This occurred since the receptor was not located on a pre-

FIGURE 90

PREDICTED ANNUAL AVERAGE SO_2 CONCENTRATIONS FOR THE BASE CASE SMELTER WITH THE CLIMATOLOGICAL DISPERSION MODEL* (UG/M^3)

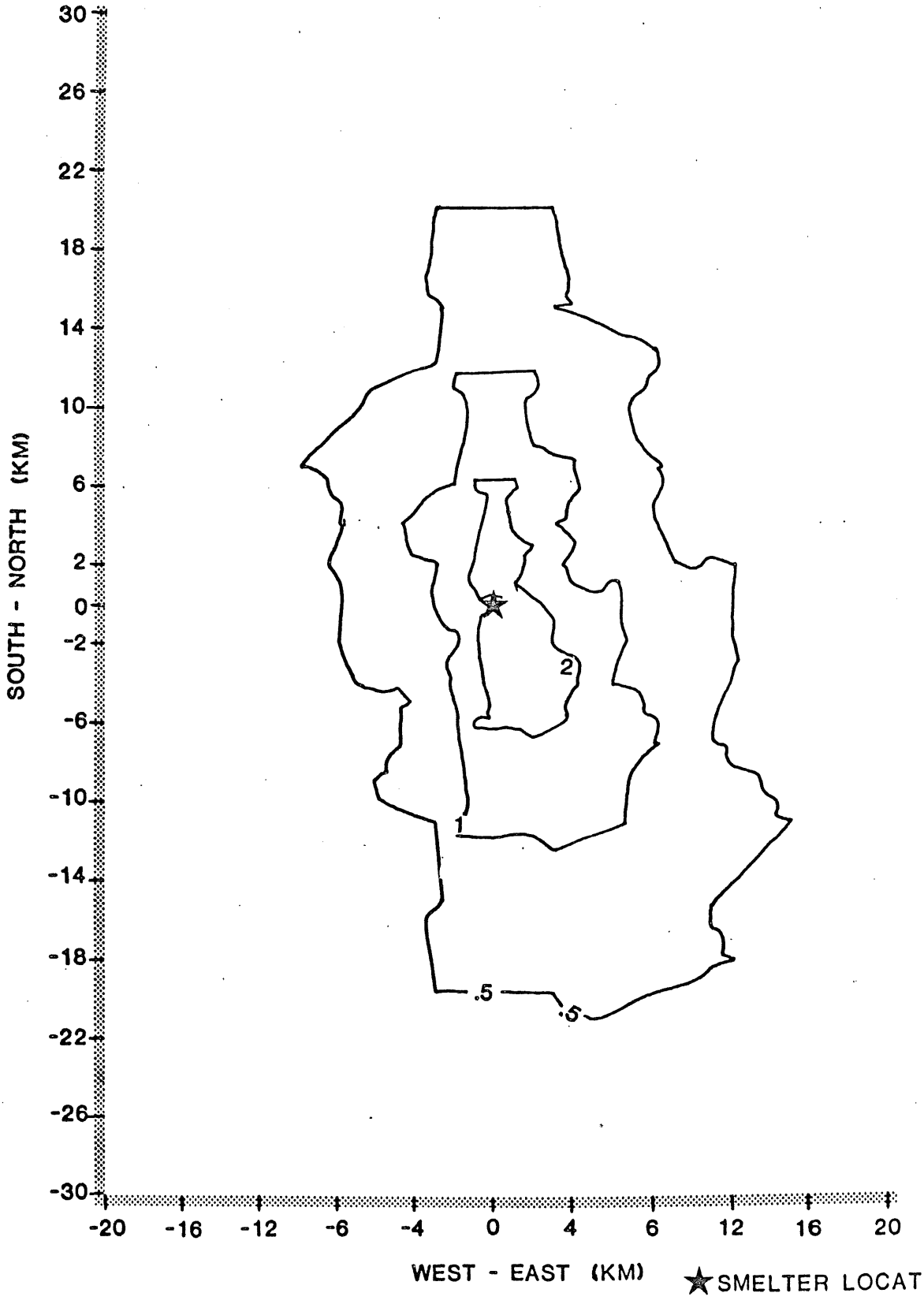


*BASED ON 1976 HIBBING WIND DATA

SOURCE : ENDERSEN, (1979)

FIGURE 90 A

PREDICTED ANNUAL AVERAGE SO_2 CONCENTRATIONS FOR THE OPTION 2 SMELTER WITH THE CLIMATOLOGICAL DISPERSION MODEL* (UG/M^3)



SOURCE : ENDERSEN, (1979)

*BASED ON 1976 HIBBING WIND DATA

ferred wind axis from the smelter location. Clearly, both types of modeling, short and long range, as used here are needed to obtain a clear picture of possible air quality impacts.

The annual average SO_2 concentrations presented for the various models must be considered in the context of other SO_2 sources in the region. This is essential since the exceedance or non-exceedance of standards occurs a a result of the ambient concentrations created by all sources combined. The effect of adding a smelter to those sources already expected to be present in the Air Quality Study Region in 1985 was examined. The evaluation was again performed assuming a hypothetical smelter site 3 miles south of Babbitt. The analysis was conducted both with and without the proposed Atikokan power plant (assumed here to be 800 MW) to determine its effect on the region as well.

The analysis results are summarized for the following cases:

1) 1985 Region

2) 1985 Region excluding the proposed Atikokan power plant

3) 1985 Region with copper-nickel development: base case, option 1 and option 2 smelters

4) 1985 Region with option 1 development excluding the proposed Atikokan power plant

Figure 91 presents the results of this analysis. Included for reference are the predicted annual 1977 Regional and PSD averages, and 1985 results with and without the Atikokan power plant. Recall that the 1977 regional baseline differs slightly from the corresponding PSD baseline in that it reflects slightly different values for the SO_2 point source emission inventory (see section 3.4.1.1). The analysis presents the annual SO_2 averages for receptors in Class I areas, Class II areas, and for the region as a whole. The Class I average is

computed from the 8 Class I receptors and the Class II average is computed from the remaining 25 receptors. The regional average is computed by averaging the SO_2 concentrations at all 33 receptors in the region.

Figure 91

The annual primary SO_2 ambient air quality standard of 80 ug/m^3 is not expected to be exceeded by any of the copper-nickel smelter configurations with anticipated 1985 regional growth. The highest predicted annual SO_2 average (5.7 ug/m^3 at Parkville) is less than about 7% of the standard. Substituting the option 1 or 2 cases into the simulation has little effect on the highest values. The regional sources predominate (with less than 10% effect from the smelter) in the southwest corner of the region from Parkville up to about 20 km from the smelter along the concentrated line of emission sources paralleling the Iron Range. In other directions the base case smelter impact is greater than 10%.

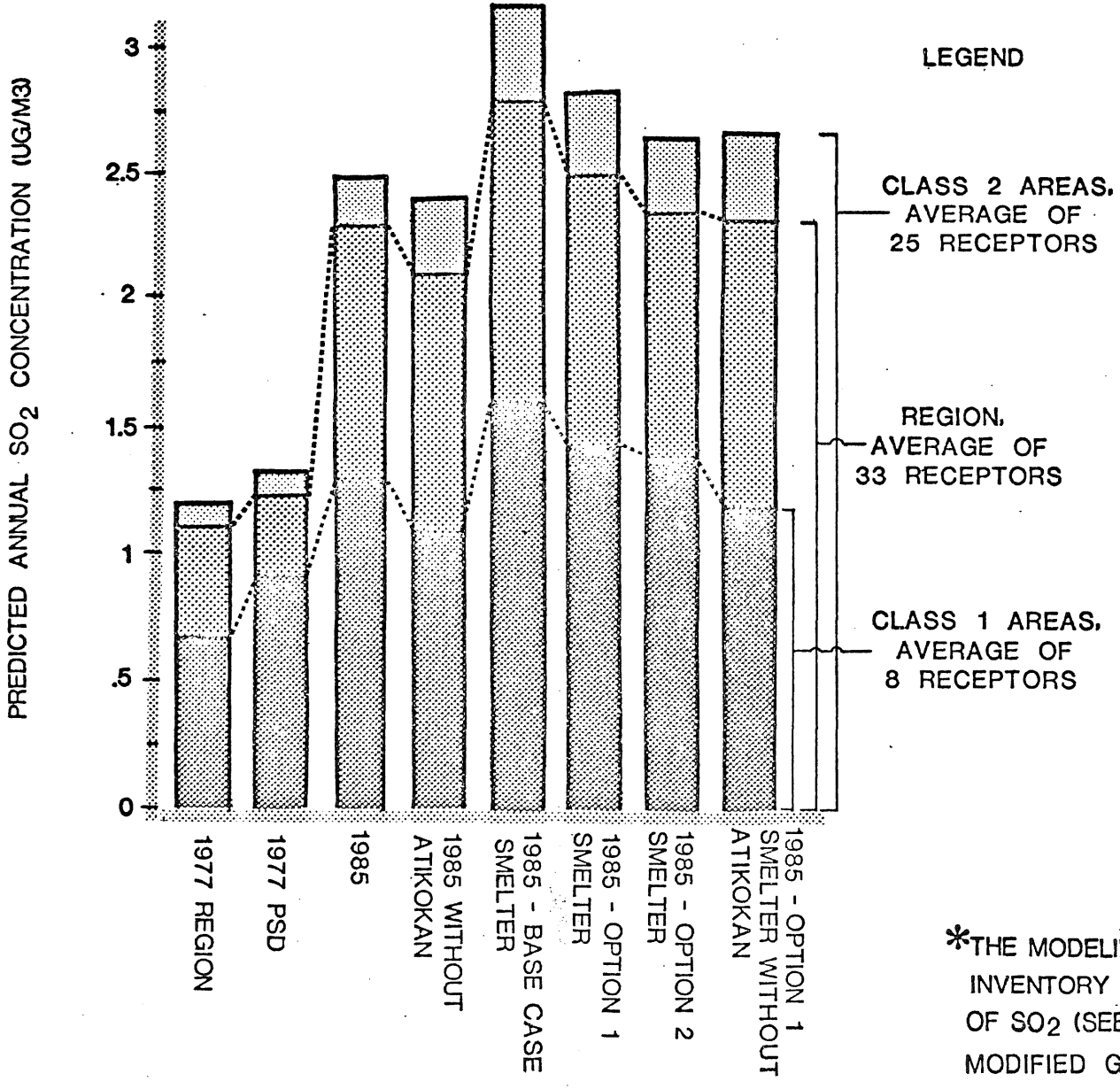
Figures 92, 93, 94, and 95, which show the predicted annual SO_2 concentration at each receptor of each of the regional runs with copper-nickel development, are discussed below.

Figures 92, 93, 94 and 95

The option 1 smelter case results in a regional annual SO_2 average (2.5 ug/m^3) that is about 9% higher than without copper-nickel development. The annual average in Class I and Class II areas is 1.4 ug/m^3 and 2.8 ug/m^3, respectively compared to 1.3 ug/m^3 and 2.5 ug/m^3, respectively, without copper-nickel development.

FIGURE 91

PREDICTED ANNUAL CLASS 1, CLASS 2 AND REGIONAL SO_2 AVERAGES WITH SELECTED SMELTER CASES (BASED ON A HYPOTHETICAL SMELTER SITE 3 MILES SOUTH OF BABBITT)*



*THE MODELING IS BASED ON THE EMISSIONS INVENTORY FOR LOCAL POINT SOURCES OF SO_2 (SEE SECTIONS 3.4.1.1), USING THE MODIFIED GAUSSIAN MODEL.

FIGURE 92

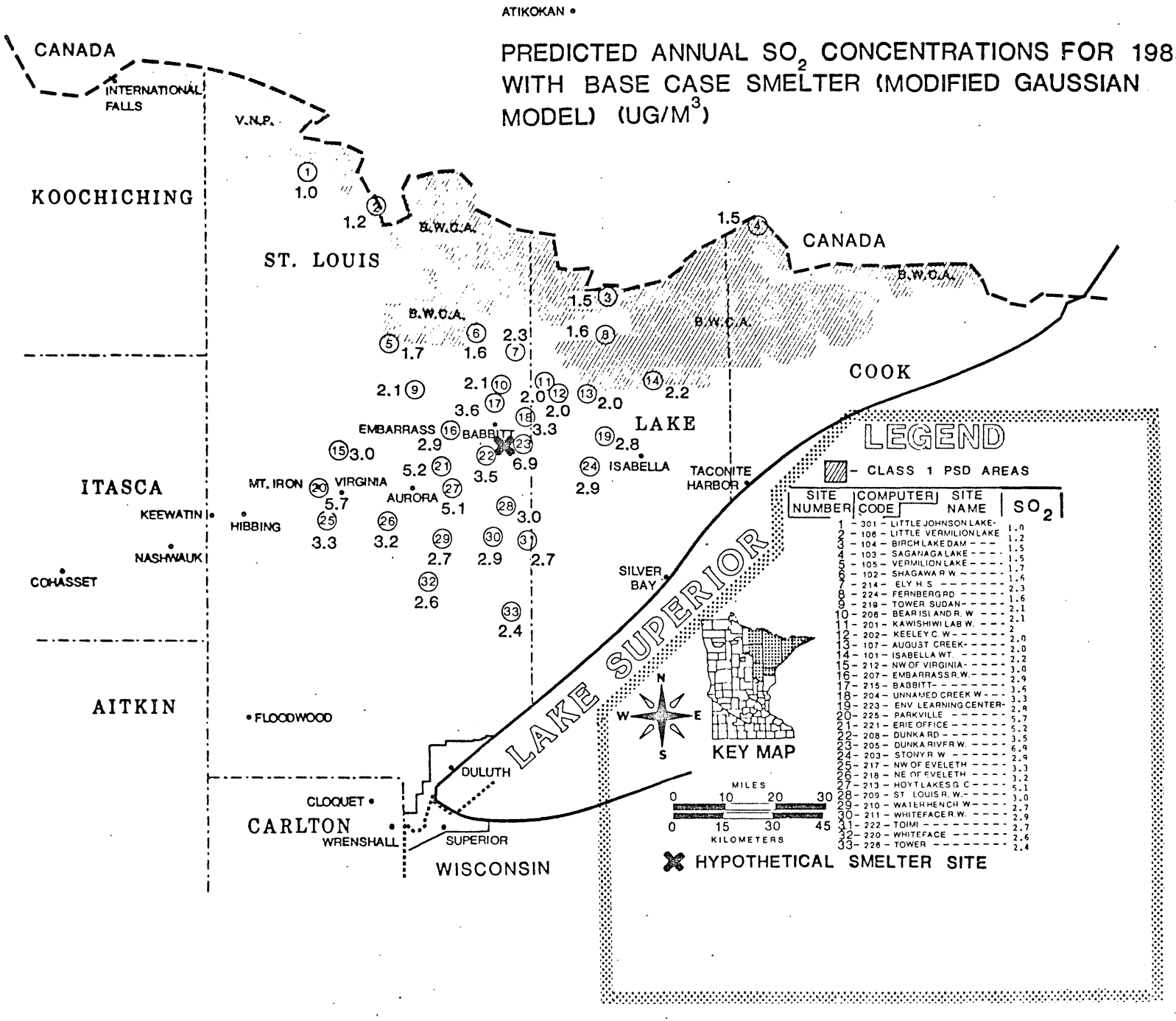

ATIKOKAN
PREDICTED ANNUAL SO_2 CONCENTRATIONS FOR 1985 WITH BASE CASE SMELTER (MODIFIED GAUSSIAN MODEL) (UG/M^3)
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
MT. IRON
VIRGINIA
AURORA
EMBARRASS
BABBITT
ISABELLA
TACONITE HARBOR
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO_2
1 – 301 – LITTLE JOHNSON LAKE – 1.0
2 – 106 – LITTLE VERMILION LAKE – 1.2
3 – 104 – BIRCH LAKE DAM – 1.5
4 – 103 – SAGANAGA LAKE – 1.5
5 – 105 – VERMILION LAKE – 1.7
6 – 102 – SHAGAWA R.W. – 1.6
7 – 214 – ELY H.S. – 2.3
8 – 224 – FERNBERG RD – 1.6
9 – 219 – TOWER SUDAN – 2.1
10 – 206 – BEAR ISLAND R.W. – 2.1
11 – 201 – KAWISHIWI LAB W. – 2
12 – 202 – KEELEY C.W. – 2.0
13 – 107 – AUGUST CREEK – 2.0
14 – 101 – ISABELLA WT. – 2.2
15 – 212 – NW OF VIRGINIA – 3.0
16 – 207 – EMBARRASS R.W. – 2.9
17 – 215 – BABBITT – 3.6
18 – 204 – UNNAMED CREEK W. – 3.3
19 – 223 – ENV. LEARNING CENTER – 2.8
20 – 225 – PARKVILLE – 5.7
21 – 221 – ERIE OFFICE – 5.2
22 – 208 – DUNKA RD – 3.5
23 – 205 – DUNKA RIVER W. – 6.9
24 – 203 – STONY R.W. – 2.9
25 – 217 – NW OF EVELETH – 3.3
26 – 218 – NE OF EVELETH – 3.2
27 – 213 – HOYT LAKES S.C. – 5.1
28 – 209 – ST. LOUIS R.W. – 3.0
29 – 210 – WATER BENCH W. – 2.7
30 – 211 – WHITEFACE R.W. – 2.9
31 – 222 – TOIMI – 2.7
32 – 220 – WHITEFACE – 2.6
33 – 226 – TOWER – 2.4
KEY MAP
N
W
E
S
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE

FIGURE 93

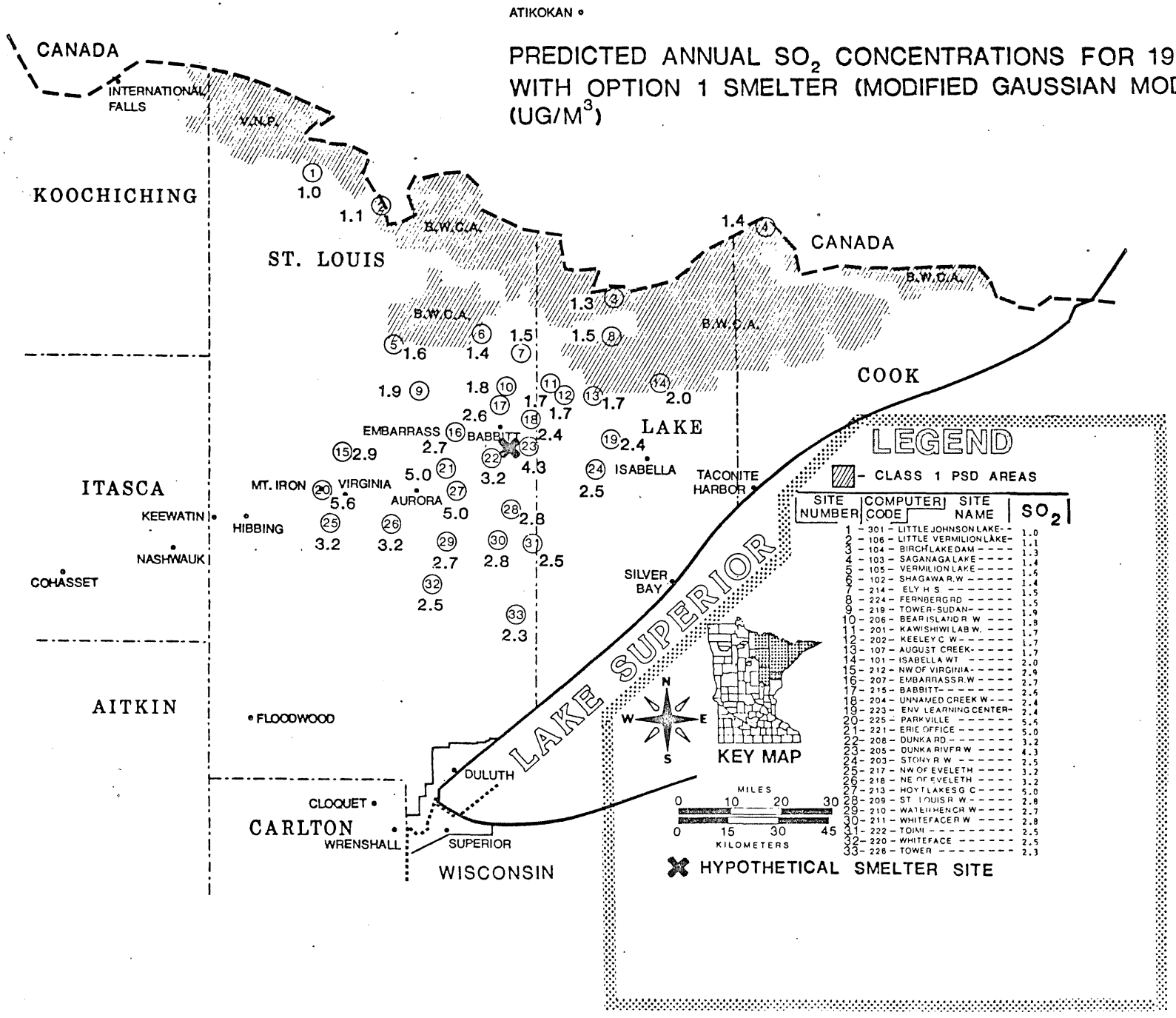

ATIKOKAN
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
B.W.C.A.
B.W.C.A.
B.W.C.A.
COOK
LAKE
EMBARRASS
BABBITT
ISABELLA
TACONITE HARBOR
ITASCA
MT. IRON
VIRGINIA
AURORA
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
1.0
1.1
1.4
1.3
1.5
1.5
1.6
1.4
1.9
1.8
1.7
1.7
2.0
2.6
1.7
2.4
2.4
2.7
2.9
5.0
3.2
4.3
2.5
5.6
5.0
2.8
3.2
3.2
2.7
2.8
2.5
2.5
2.3
PREDICTED ANNUAL SO_2 CONCENTRATIONS FOR 1985 WITH OPTION 1 SMELTER (MODIFIED GAUSSIAN MODEL) (UG/M^3)
LEGEND
- CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO_2
1 - 301 - LITTLE JOHNSON LAKE - 1.0
2 - 106 - LITTLE VERMILION LAKE - 1.1
3 - 104 - BIRCH LAKE DAM - 1.3
4 - 103 - SAGANAGA LAKE - 1.4
5 - 105 - VERMILION LAKE - 1.5
6 - 102 - SHAGAWA R.W - 1.4
7 - 214 - ELY H.S. - 1.5
8 - 224 - FERNBERG RD - 1.5
9 - 219 - TOWER-SUDAN - 1.9
10 - 206 - BEAR ISLAND R.W - 1.8
11 - 201 - KAWISHIWI LAB W. - 1.7
12 - 202 - KEELEY C.W - 1.7
13 - 107 - AUGUST CREEK - 1.7
14 - 101 - ISABELLA WT - 2.0
15 - 212 - NW OF VIRGINIA - 2.9
16 - 207 - EMBARRASS R.W - 2.7
17 - 215 - BABBITT - 2.6
18 - 204 - UNNAMED CREEK W - 2.4
19 - 223 - ENV. LEARNING CENTER - 2.4
20 - 225 - PARKVILLE - 5.6
21 - 221 - ERIE OFFICE - 5.0
22 - 208 - DUNKA RD - 3.2
23 - 205 - DUNKA RIVER W - 4.3
24 - 203 - STONY R.W - 2.5
25 - 217 - NW OF EVELETH - 3.2
26 - 218 - NE OF EVELETH - 3.2
27 - 213 - HOYT LAKES G.C - 5.0
28 - 209 - ST. LOUIS R.W - 2.8
29 - 210 - WATER HENCR W - 2.7
30 - 211 - WHITEFACE R.W - 2.8
31 - 222 - TOIMI - 2.5
32 - 220 - WHITEFACE - 2.5
33 - 226 - TOWER - 2.3
N
W
E
S
KEY MAP
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE

FIGURE 94

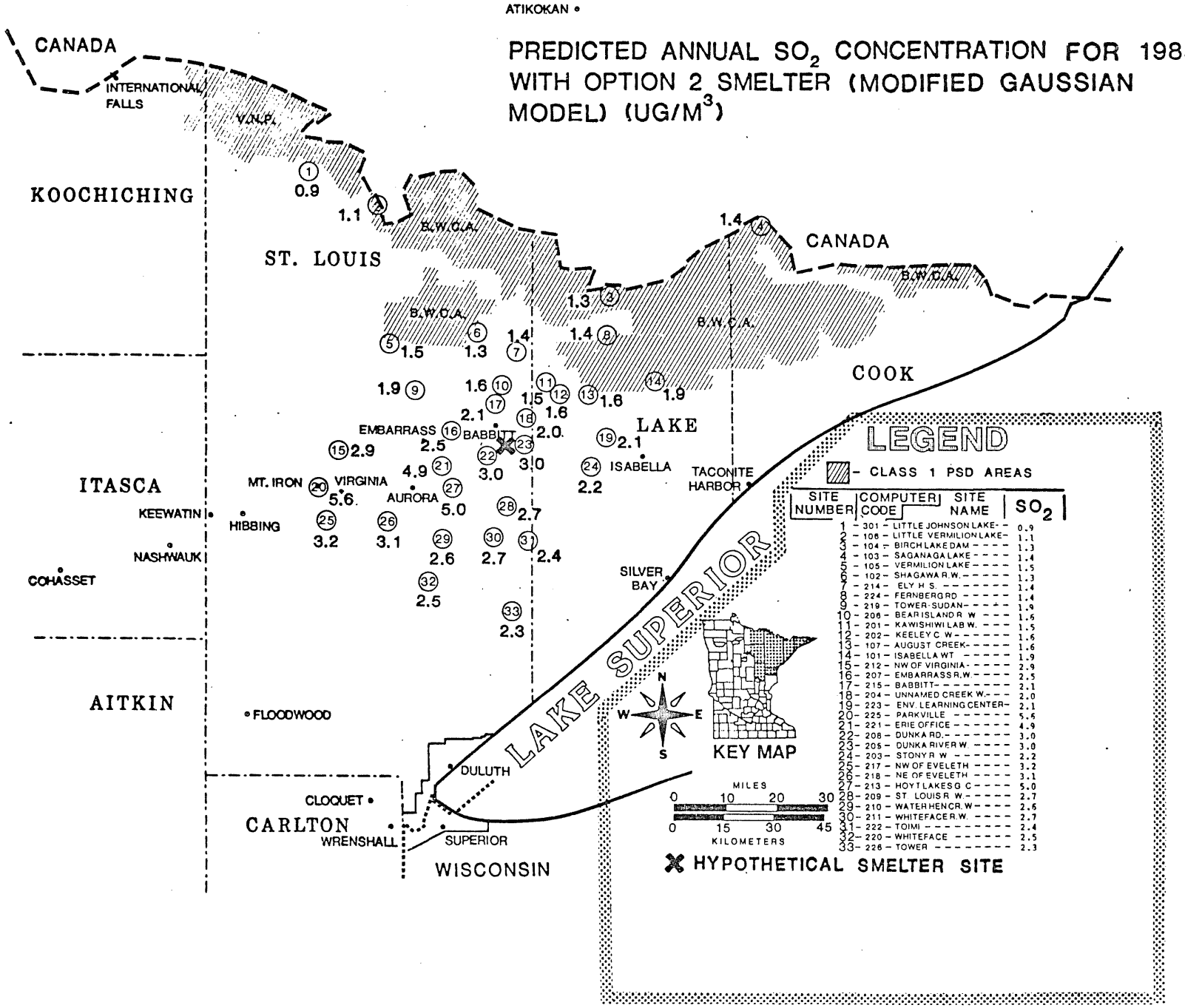
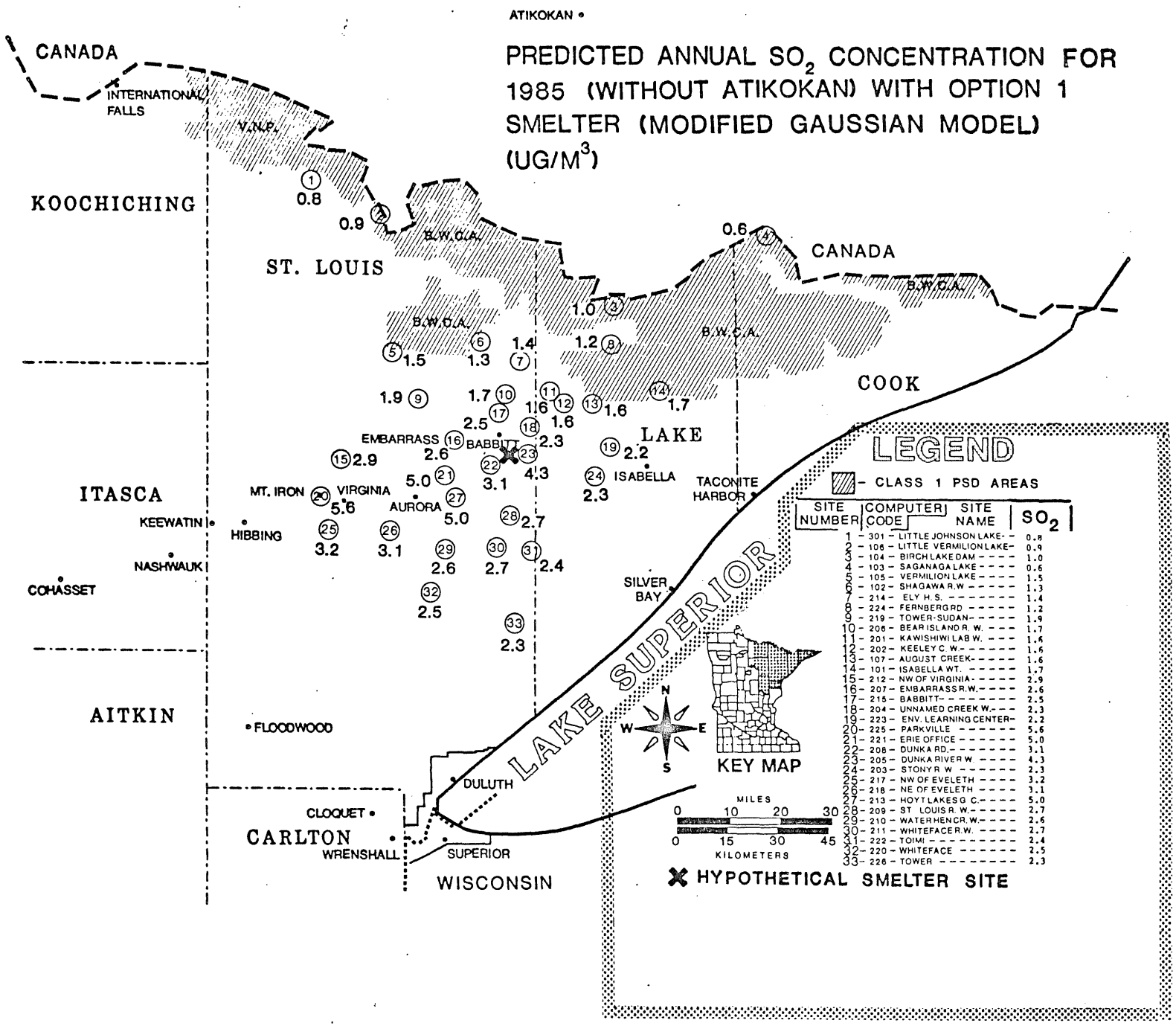

ATIKOKAN
PREDICTED ANNUAL SO_2 CONCENTRATION FOR 1985 WITH OPTION 2 SMELTER (MODIFIED GAUSSIAN MODEL) (UG/M^3)
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
EMBARRASS
BABBITT
MT. IRON
VIRGINIA
AURORA
ISABELLA
TACONITE HARBOR
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO_2
1 - 301 - LITTLE JOHNSON LAKE - 0.9
2 - 106 - LITTLE VERMILION LAKE - 1.1
3 - 104 - BIRCH LAKE DAM - 1.3
4 - 103 - SAGANAGA LAKE - 1.4
5 - 105 - VERMILION LAKE - 1.5
6 - 102 - SHAGAWA R.W. - 1.3
7 - 214 - ELY H.S. - 1.4
8 - 224 - FERNBERG RD - 1.4
9 - 219 - TOWER-SUDAN - 1.9
10 - 206 - BEAR ISLAND R. W. - 1.6
11 - 201 - KAWISHIWI LAB W. - 1.5
12 - 202 - KEELEY C. W. - 1.6
13 - 107 - AUGUST CREEK - 1.6
14 - 101 - ISABELLA WT - 1.9
15 - 212 - NW OF VIRGINIA - 2.9
16 - 207 - EMBARRASS R.W. - 2.5
17 - 215 - BABBITT - 2.1
18 - 204 - UNNAMED CREEK W. - 2.0
19 - 223 - ENV. LEARNING CENTER - 2.1
20 - 225 - PARKVILLE - 5.6
21 - 221 - ERIE OFFICE - 4.9
22 - 208 - DUNKA RD. - 3.0
23 - 205 - DUNKA RIVER W. - 3.0
24 - 203 - STONY R W - 2.2
25 - 217 - NW OF EVELETH - 3.2
26 - 218 - NE OF EVELETH - 3.1
27 - 213 - HOYT LAKES G. C. - 5.0
28 - 209 - ST. LOUIS R. W. - 2.7
29 - 210 - WATER HEN CR. W. - 2.6
30 - 211 - WHITEFACE R.W. - 2.7
31 - 222 - TOIMI - 2.4
32 - 220 - WHITEFACE - 2.5
33 - 226 - TOWER - 2.3
N
W
E
S
KEY MAP
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE

FIGURE 95


ATIKOKAN
PREDICTED ANNUAL SO_2 CONCENTRATION FOR 1985 (WITHOUT ATIKOKAN) WITH OPTION 1 SMELTER (MODIFIED GAUSSIAN MODEL) (UG/M^3)
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
B.W.C.A.
COOK
LAKE
EMBARRASS
BABBITT
ISABELLA
TACONITE HARBOR
ITASCA
MT. IRON
VIRGINIA
AURORA
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO_2
1 - 301 - LITTLE JOHNSON LAKE - 0.8
2 - 106 - LITTLE VERMILION LAKE - 0.9
3 - 104 - BIRCH LAKE DAM - 1.0
4 - 103 - SAGANAGA LAKE - 0.6
5 - 105 - VERMILION LAKE - 1.5
6 - 102 - SHAGAWA R.W - 1.3
7 - 214 - ELY H.S. - 1.4
8 - 224 - FERNBERG RD - 1.2
9 - 219 - TOWER-SUDAN - 1.9
10 - 206 - BEAR ISLAND R. W. - 1.7
11 - 201 - KAWISHIWI LAB W. - 1.6
12 - 202 - KEELEY C. W. - 1.6
13 - 107 - AUGUST CREEK - 1.6
14 - 101 - ISABELLA WT. - 1.7
15 - 212 - NW OF VIRGINIA - 2.9
16 - 207 - EMBARRASS R.W. - 2.6
17 - 215 - BABBITT - 2.5
18 - 204 - UNNAMED CREEK W. - 2.3
19 - 223 - ENV. LEARNING CENTER - 2.2
20 - 225 - PARKVILLE - 5.6
21 - 221 - ERIE OFFICE - 5.0
22 - 208 - DUNKA RD. - 3.1
23 - 205 - DUNKA RIVER W. - 4.3
24 - 203 - STONY R. W. - 2.3
25 - 217 - NW OF EVELETH - 3.2
26 - 218 - NE OF EVELETH - 3.1
27 - 213 - HOYT LAKES G. C. - 5.0
28 - 209 - ST. LOUIS R. W. - 2.7
29 - 210 - WATERHEN CR. W. - 2.6
30 - 211 - WHITEFACE R.W. - 2.7
31 - 222 - TOIMI - 2.4
32 - 220 - WHITEFACE - 2.5
33 - 226 - TOWER - 2.3
KEY MAP
MILES
KILOMETERS
HYPOTHETICAL SMELTER SITE

The highest annual average SO_2 concentration with the option 1 smelter in Class I and Class II areas was 2 ug/m^3 at Isabella Watershed and 5.6 ug/m^3 at Parkville, respectively compared to high of 1.8ug/m^3 (Isabella Watershed) and 5.6 ug/m^3 (Parkville) without copper-nickel development. The option 1 smelter case has little effect on the annual concentrations in the Class II area except at sites located 20 km to the north and east and sites located 30 km to the south and east. The most dramatic figures occur at Dunka River Watershed where the annual average is 4.3 ug/m^3 with an option 1 development compared to 2.2 ug/m^3 without copper-nickel development.

If a smelter uses state of the art controls (option 2) then the annual regional SO_2 average drops to about 2.3 ug/m^3 and the Class I and Class II annual average are 1.4 ug/m^3 and 2.7 ug/m^3, respectively.

If the smelter is controlled only to the level of the base case model, then the regional Class I and Class II averages increase over option 1 by about 12%. Removing the proposed Atikokan power plant from the annual regional runs with the option 1 smelter case has the effect of decreasing the Class I annual SO_2 average to 1.2 ug/m^3 (a 14% decrease), the Class II average to 2.7 ug/m^3 (a 4% decrease) and the regional average to 2.3 ug/m^3. Annual SO_2 averages for the 1985 simulations with the 3 copper-nickel development models are summarized for selected sites (those showing the most variation for the three smelter configurations) in Table 73. As previously discussed, neither the SO_2 annual PSD Class I (2 ug/m^3) nor the Class II (20 ug/m^3) increments are expected to be exceeded at receptor sites. The largest difference in the Class I area (based on the base case smelter) is about 20% of the increment while in the Class II area the largest difference is only about 7% of the increment. Allowing for modeling uncertainties of a factor of two still would not jeopardize either of the

increments.

Table 73

The above discussion reveals that irrespective of the smelter site loction, none of the 3 model smelters in combination with other regional sources appear likely to cause violations of the allowed annual average SO_2 PSD increment in a Class II area.

The same conclusion is not true, however, for Class I areas. For example, the closest receptor site to the smelter (site #23 some 5 km east) shows increases of 4.7 and 2.1 ug/m^3 for the base case and option 1 smelters, respectively, over the 1985 predicted levels without copper-nickel development. Thus, if the smelter site were translated to lie 5 km west of a Class I area, these results indicate the strong possibility that the Class I annual PSD increment would be exceeded. This would be true for all cases except the option 2 smelter. Clearly, the distance between any smelter site and a Class I area will be a major factor in the ability of the facility to meet annual PSD regulations for SO_2 in the Class I area. This conclusion is clearly supported both by the results of the mesoscale modified gaussian model and, as discussed earlier, the short range CDM analysis. Siting limitations based on annual averages will not be discussed further since the next section will reveal that the 24-hour PSD requirements will place even more stringent restrictions on smelter siting. The question of siting zones around a Class I PSD area is considered in the following section.

3.7.1.2 24-Hour Concentrations--It is in the context of short term averaging periods that the greatest potential siting problems for a smelter facility appear. This is true for the 3-hour period, but is discussed in the greatest

Table 73. Summary of SO_2 annual concentrations at selected sites for the various copper-nickel development cases, with a comparison to 1977 and 1985 predictions without copper-nickel development.

RECEPTOR SITE NO.	RECEPTOR SITE NAME	RECEPTOR RELATION TO HYPOTHETICAL SMELTER SITE[a]	1977 PSD/REGION		1985	1985 + base case	1985 + option 1	1985 + option 2
11	Kawishiwi Lab	22km. N.E.	.79	.75	1.5	2.0	1.7	1.5
24	Stony River W.	26km. E., S.E.	1.2	1.2	2.1	2.9	2.5	2.0
18	Unnamed Creek W.	9km. N.E.	.93	.87	1.7	3.3	2.4	2.0
23	Dunka River W.	5km. E.	1.2	1.2	2.2	6.9	4.3	3.0
10	Bear Island River W.	18km. N	.82	.77	1.5	2.1	1.8	1.6
22	Dunka Road	7km. S.W.	1.3	1.2	2.9	3.5	3.2	3.0
19	Env. Learning Center	28km. E.	1.2	1.1	2.0	2.8	2.4	2.1
Region ave.		----	1.2	1.1	2.3	2.8	2.5	2.3

[a]See map, Figure 86.

detail here in terms of 24-hour averaging periods. This is done since the various modeled emission rates for the 3 smelter cases under discussion are considered to be quite realistic in the context of a 24-hour period. Such a period, for example, may involve 2 to 3 complete cycles of the copper converters. However, for periods as short as 3 hours, the credibility of the emissions model weakens considerably as large short term fluctuations in emissions may occur, particularly for fugitive emissions.

Again, it must be noted that the following discussion will mention that the various ambient air quality standards are exceeded. This does not imply that a violation of the standard is predicted (see the comments on this in the previous section).

The discussion here of 24-hour concentrations will be presented in two parts. First, in parallel with the previous discussion of annual average SO_2 concentrations, the focus will be on a hypothetial smelter site located centrally in the Study Area, some 3 miles south of Babbitt. The various smelter models are discussed at this site in terms of their absolute 24-hour SO_2 concentrations as well as their effect in combination with other (1985) sources. Second, since the Babbitt site is used only as a reference point, a non site-specific discussion follows, with general summary conclusions concerning the potential restrictions of smelter sites implied by present Class I PSD standards.

In terms of the hypothetical smelter site south of Babbitt, Figures 96, 97, and 98 show the predicted maximum 24-hour SO_2 concentrations at each receptor for the base case, option 1 and option 2 smelter models where each model is the only emissions source. The results indicate that the ambient standards are not predicted to be exceeded at any receptor site. However, one site in the base case

run shows an SO_2 concentration of 120 ug/m^3 (Dunka River) which, considering the model accuracy, raises the possibility that the state ambient standard (260 ug/m^3) will be exceeded close to the smelter site. No such problems appear to exist for the option 1 or option 2 cases.

Figures 96, 97, and 98

In terms of the 24-hour PSD increments, however, the modified gaussian model predicts that the PSD increments will be exceeded. It is predicted that the base case smelter will exceed the maximum 24-hour PSD increments at 7 of 8 Class I receptors and 1 of 25 Class II receptors. The maximum predicted concentration in the Class I area is 23 ug/m^3 at August Creek (29 km from the source) followed by a second high of 19 ug/m^3 at Shagawa River Watershed (35 km from the source). The highest SO_2 concentration in the Class II area is 120 ug/m^3 at Dunka River Watershed which is 5 km from the source. A second high of 99 ug/m^3 also occurred at that site.

Ambient SO_2 concentrations are 55% lower for the option 1 smelter than for the base case, and the PSD increments are predicted to be exceeded at only two of 8 Class I receptors. The Class II increment is not exceeded. Further control of smelter SO_2 gases to reach the option 2 smelter results in an 84% reduction in ambient concentrations compared to the base case levels. None of the PSD increments are predicted to be exceeded on the basis of absolute numbers by the option 2 smelter but uncertainties in the modeling result of a factor of two could jeopardize the Class I increment.

The previous comments applied to SO_2 concentrations from the various smelter models alone. These are now placed in perspective against the background of

FIGURE 96

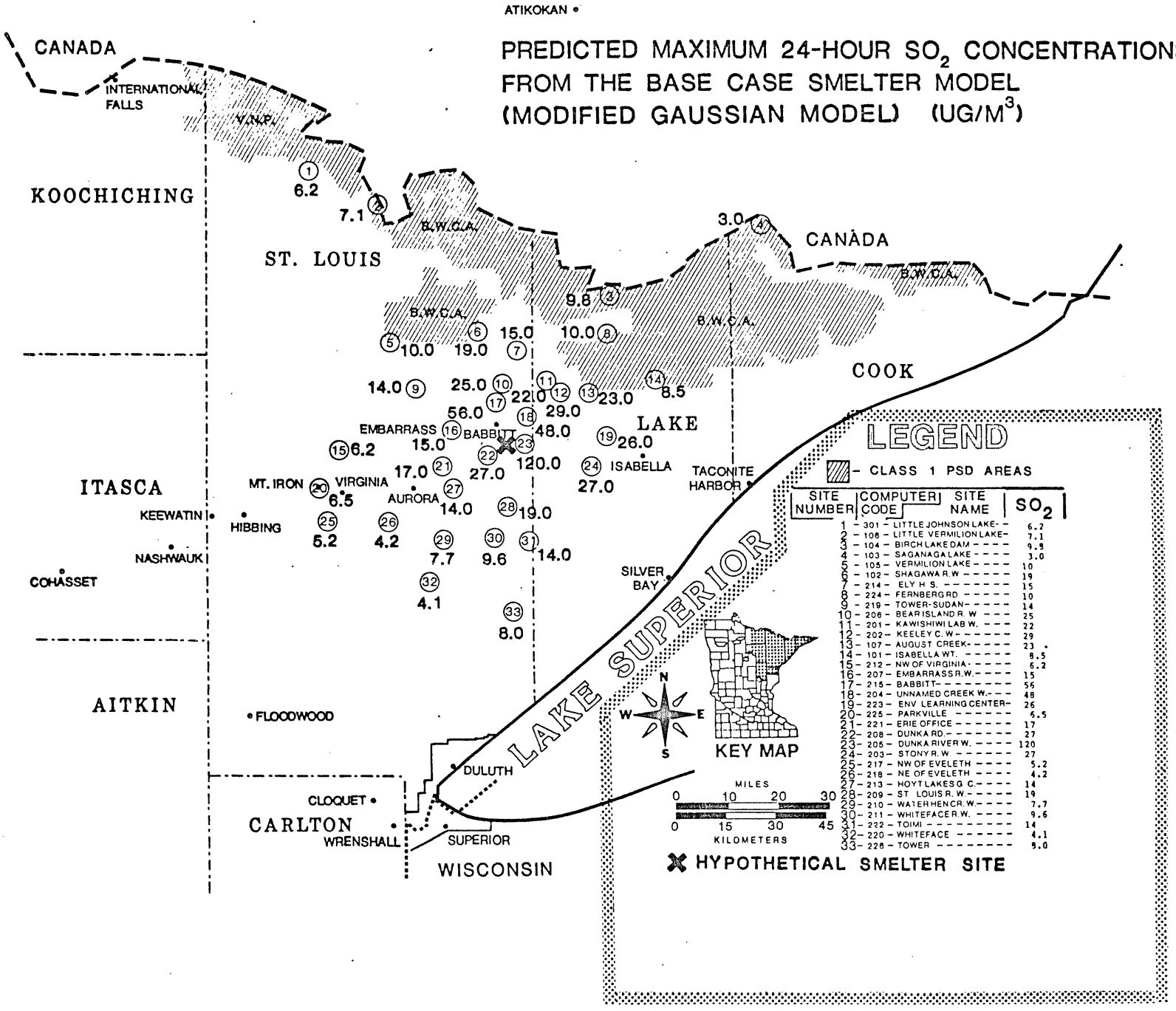

ATIKOKAN
PREDICTED MAXIMUM 24-HOUR SO_2 CONCENTRATIONS FROM THE BASE CASE SMELTER MODEL (MODIFIED GAUSSIAN MODEL) (UG/M^3)
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
EMBARRASS
BABBITT
ITASCA
MT. IRON
VIRGINIA
AURORA
ISABELLA
TACONITE HARBOR
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
1 6.2
2 7.1
3 9.8
4 3.0
5 10.0
6 15.0
7 19.0
8 10.0
9 14.0
10 25.0
11 22.0
12
13 23.0
14 8.5
15 6.2
16
17 56.0
18 29.0
19 26.0
20 6.5
21 17.0
22 27.0
23 48.0
24 27.0
25 5.2
26 4.2
27 14.0
28 19.0
29 7.7
30 9.6
31 14.0
32 4.1
33 8.0
120.0
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO_2
1 – 301 – LITTLE JOHNSON LAKE – 6.2
2 – 106 – LITTLE VERMILION LAKE – 7.1
3 – 104 – BIRCH LAKE DAM – 9.8
4 – 103 – SAGANAGA LAKE – 3.0
5 – 105 – VERMILION LAKE – 10
6 – 102 – SHAGAWA R.W – 19
7 – 214 – ELY H.S. – 15
8 – 224 – FERNBERG RD – 10
9 – 219 – TOWER-SUDAN – 14
10 – 206 – BEAR ISLAND R.W – 25
11 – 201 – KAWISHIWI LAB W. – 22
12 – 202 – KEELEY C.W. – 29
13 – 107 – AUGUST CREEK – 23
14 – 101 – ISABELLA WT. – 8.5
15 – 212 – NW OF VIRGINIA – 6.2
16 – 207 – EMBARRASS R.W. – 15
17 – 215 – BABBITT – 56
18 – 204 – UNNAMED CREEK W. – 48
19 – 223 – ENV. LEARNING CENTER – 26
20 – 225 – PARKVILLE – 6.5
21 – 221 – ERIE OFFICE – 17
22 – 208 – DUNKA RD. – 27
23 – 205 – DUNKA RIVER W. – 120
24 – 203 – STONY R.W. – 27
25 – 217 – NW OF EVELETH – 5.2
26 – 218 – NE OF EVELETH – 4.2
27 – 213 – HOYT LAKES G.C. – 14
28 – 209 – ST. LOUIS R.W. – 19
29 – 210 – WATER HEN CR.W. – 7.7
30 – 211 – WHITEFACE R.W. – 9.6
31 – 222 – TOIMI – 14
32 – 220 – WHITEFACE – 4.1
33 – 226 – TOWER – 9.0
N
W
E
S
KEY MAP
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE

FIGURE 97

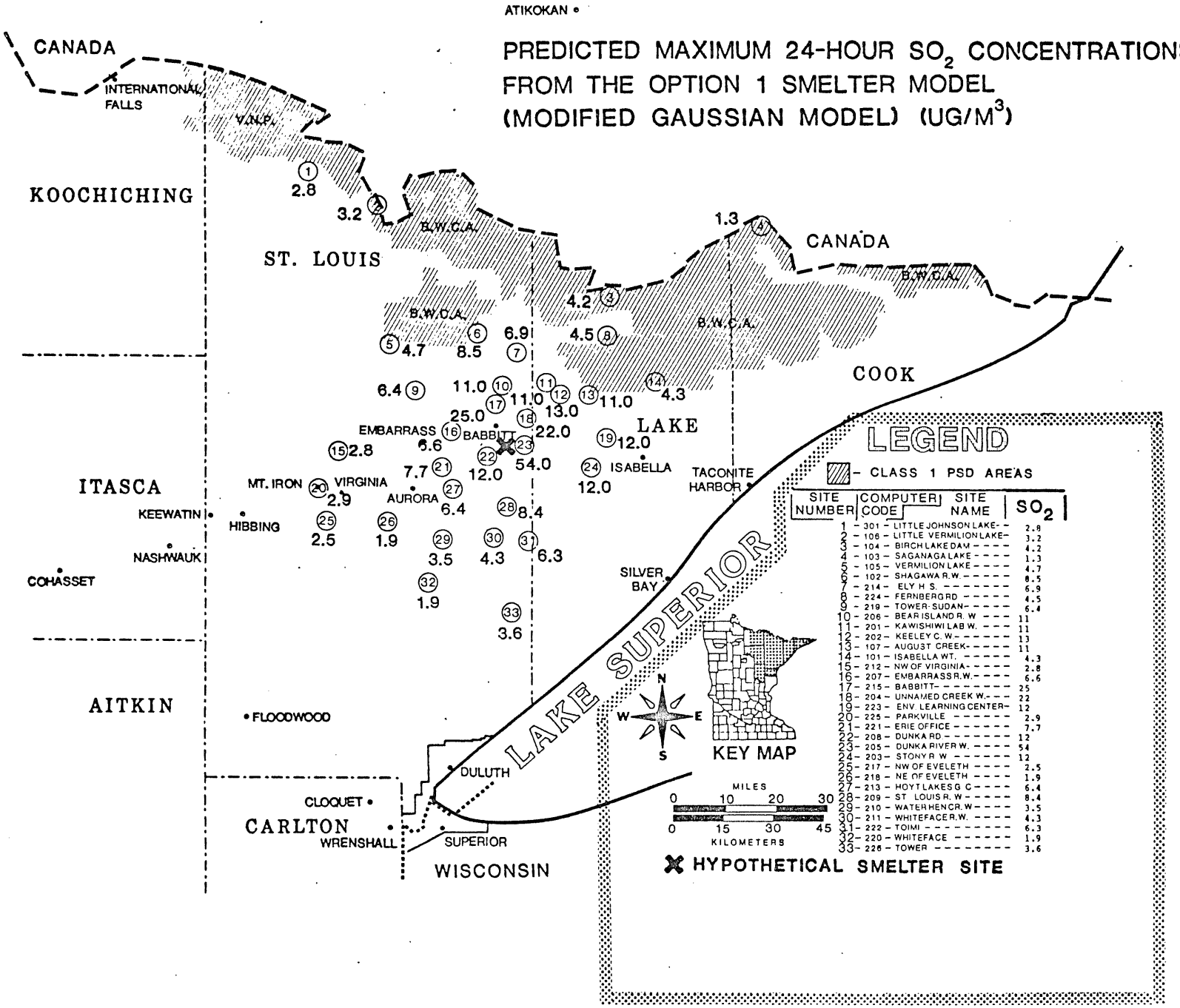
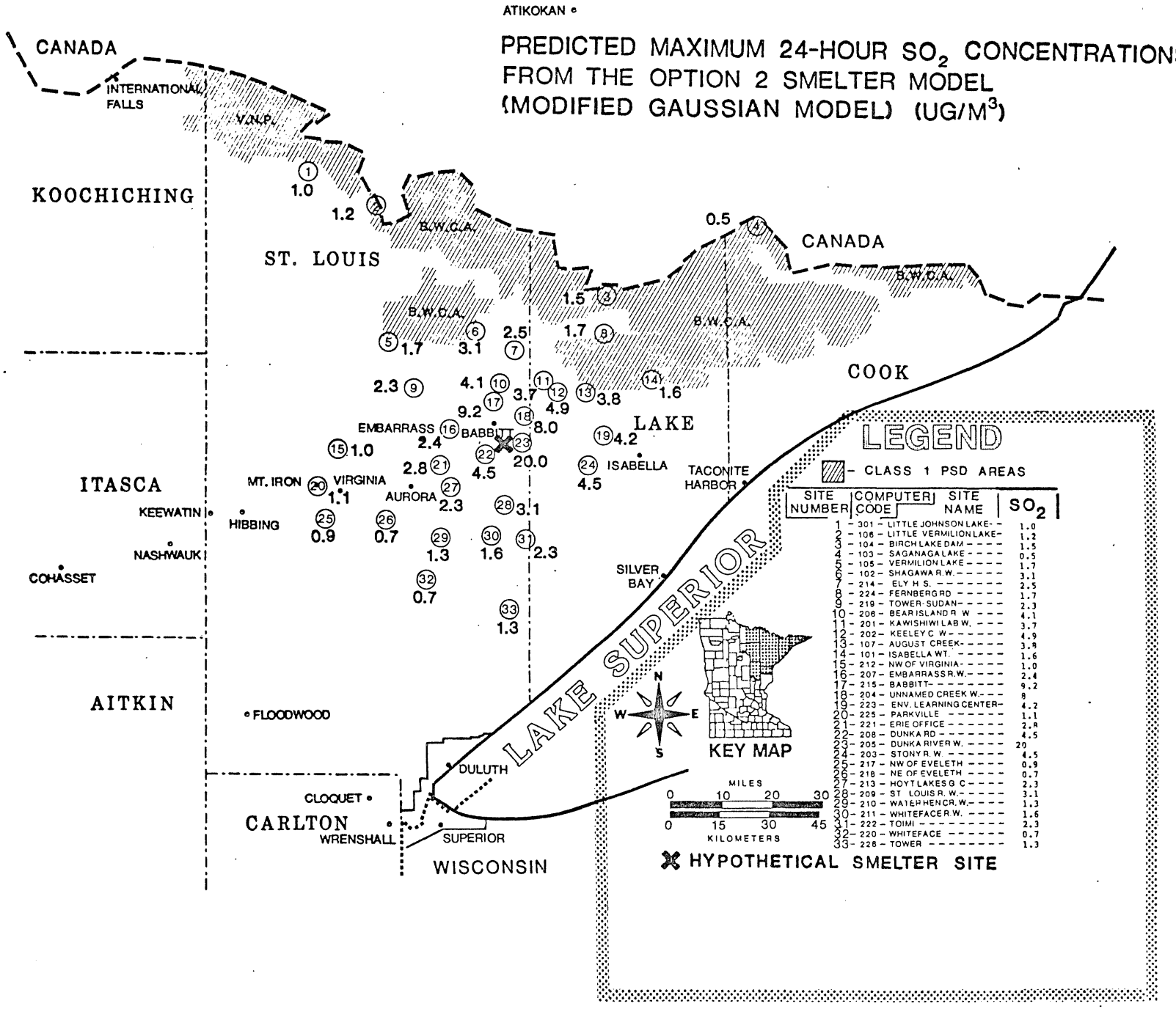

ATIKOKAN
PREDICTED MAXIMUM 24-HOUR SO_2 CONCENTRATIONS FROM THE OPTION 1 SMELTER MODEL (MODIFIED GAUSSIAN MODEL) (UG/M^3)
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
AITKIN
EMBARRASS
BABBITT
MT. IRON
VIRGINIA
AURORA
ISABELLA
TACONITE HARBOR
SILVER BAY
KEEWATIN
HIBBING
NASHWAUK
COHASSET
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
LAKE SUPERIOR
1 2.8
2 3.2
3 4.2
4 1.3
5 4.7
6 8.5
7 6.9
8 4.5
9 6.4
10 11.0
11 11.0
12 13.0
13 11.0
14 4.3
15 2.8
16 5.6
17 25.0
18 22.0
19 12.0
20 2.9
21 7.7
22 12.0
23 54.0
24 12.0
25 2.5
26 1.9
27 6.4
28 8.4
29 3.5
30 4.3
31 6.3
32 1.9
33 3.6
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO_2
1 - 301 - LITTLE JOHNSON LAKE - 2.8
2 - 106 - LITTLE VERMILION LAKE - 3.2
3 - 104 - BIRCH LAKE DAM - 4.2
4 - 103 - SAGANAGA LAKE - 1.3
5 - 105 - VERMILION LAKE - 4.7
6 - 102 - SHAGAWA R.W. - 8.5
7 - 214 - ELY H.S. - 6.9
8 - 224 - FERNBERG RD - 4.5
9 - 219 - TOWER: SUDAN - 6.4
10 - 206 - BEAR ISLAND R. W - 11
11 - 201 - KAWISHIWI LAB W. - 11
12 - 202 - KEELEY C. W. - 13
13 - 107 - AUGUST CREEK - 11
14 - 101 - ISABELLA WT. - 4.3
15 - 212 - NW OF VIRGINIA - 2.8
16 - 207 - EMBARRASS R.W. - 6.6
17 - 215 - BABBITT - 25
18 - 204 - UNNAMED CREEK W. - 22
19 - 223 - ENV. LEARNING CENTER - 12
20 - 225 - PARKVILLE - 2.9
21 - 221 - ERIE OFFICE - 7.7
22 - 208 - DUNKA RD. - 12
23 - 205 - DUNKA RIVER W. - 54
24 - 203 - STONY R. W - 12
25 - 217 - NW OF EVELETH - 2.5
26 - 218 - NE OF EVELETH - 1.9
27 - 213 - HOYT LAKES G. C - 6.4
28 - 209 - ST. LOUIS R. W - 8.4
29 - 210 - WATER HEN CR. W - 3.5
30 - 211 - WHITEFACE R.W. - 4.3
31 - 222 - TOIMI - 6.3
32 - 220 - WHITEFACE - 1.9
33 - 226 - TOWER - 3.6
N
W
E
S
KEY MAP
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE

FIGURE 98


ATIKOKAN
PREDICTED MAXIMUM 24-HOUR SO_2 CONCENTRATIONS
FROM THE OPTION 2 SMELTER MODEL
(MODIFIED GAUSSIAN MODEL) (UG/M^3)
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
EMBARRASS
BABBITT
MT. IRON
VIRGINIA
AURORA
ISABELLA
TACONITE HARBOR
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO_2
1 - 301 - LITTLE JOHNSON LAKE - 1.0
2 - 106 - LITTLE VERMILION LAKE - 1.2
3 - 104 - BIRCH LAKE DAM - 1.5
4 - 103 - SAGANAGA LAKE - 0.5
5 - 105 - VERMILION LAKE - 1.7
6 - 102 - SHAGAWA R.W. - 3.1
7 - 214 - ELY H.S. - 2.5
8 - 224 - FERNBERG RD - 1.7
9 - 219 - TOWER-SUDAN - 2.3
10 - 206 - BEAR ISLAND R.W. - 4.1
11 - 201 - KAWISHIWI LAB W. - 3.7
12 - 202 - KEELEY C.W. - 4.9
13 - 107 - AUGUST CREEK - 3.8
14 - 101 - ISABELLA WT. - 1.6
15 - 212 - NW OF VIRGINIA - 1.0
16 - 207 - EMBARRASS R.W. - 2.4
17 - 215 - BABBITT - 9.2
18 - 204 - UNNAMED CREEK W. - 8
19 - 223 - ENV. LEARNING CENTER - 4.2
20 - 225 - PARKVILLE - 1.1
21 - 221 - ERIE OFFICE - 2.8
22 - 208 - DUNKA RD - 4.5
23 - 205 - DUNKA RIVER W. - 20
24 - 203 - STONY R.W. - 4.5
25 - 217 - NW OF EVELETH - 0.9
26 - 218 - NE OF EVELETH - 0.7
27 - 213 - HOYT LAKES G.C. - 2.3
28 - 209 - ST. LOUIS R.W. - 3.1
29 - 210 - WATER HEN CR.W. - 1.3
30 - 211 - WHITEFACE R.W. - 1.6
31 - 222 - TOIMI - 2.3
32 - 220 - WHITEFACE - 0.7
33 - 228 - TOWER - 1.3
KEY MAP
N
W
E
S
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE

predicted 1985 concentrations expected without copper-nickel development. The predicted maximum 24-hour concentrations at each receptor site in the region is shown in Figures 99, 100, 101, and 102 for the 3 smelter cases along with other sources expected in the region in 1985. Again, neither the federal (365 ug/m^3) nor the state (260 ug/m^3) 24-hour ambient standards are predicted to be exceeded at any receptor site, with the possible exception of the Dunka River site with the base case smelter where a factor of two error makes it impossible to rule out exceedance of the state ambient standard. The highest predicted 24-hour SO_2 concentration for the base case smelter with 1985 growth (140 ug/m^3 at Dunka River Watershed) is about 38% of the standard.

Figures 99, 100, 101, and 102

Substituting the option 1 smelter into the simulation decreases the maximum 24-hour concentration by about 50% (78 ug/m^3 at Dunka River Watershed).

A second site, Hoyt Lakes Golf Course, is also predicted to have a high of 78 ug/m^3. Substituting the option 2 smelter into the simulation further decreases the maximum 24-hour concentration at Dunka River watershed to 44 ug/m^3 but does not affect the predicted concentration of 78 ug/m^3 at Hoyt Lakes Golf Course.

In summary, Figure 103 shows the general areas impacted by the three smelter cases. These are areas where maximum 24-hour concentrations are different from the 1985 simulation in the absence of any copper-nickel development in the form of a smelter in the region.

Figure 103

FIGURE 99

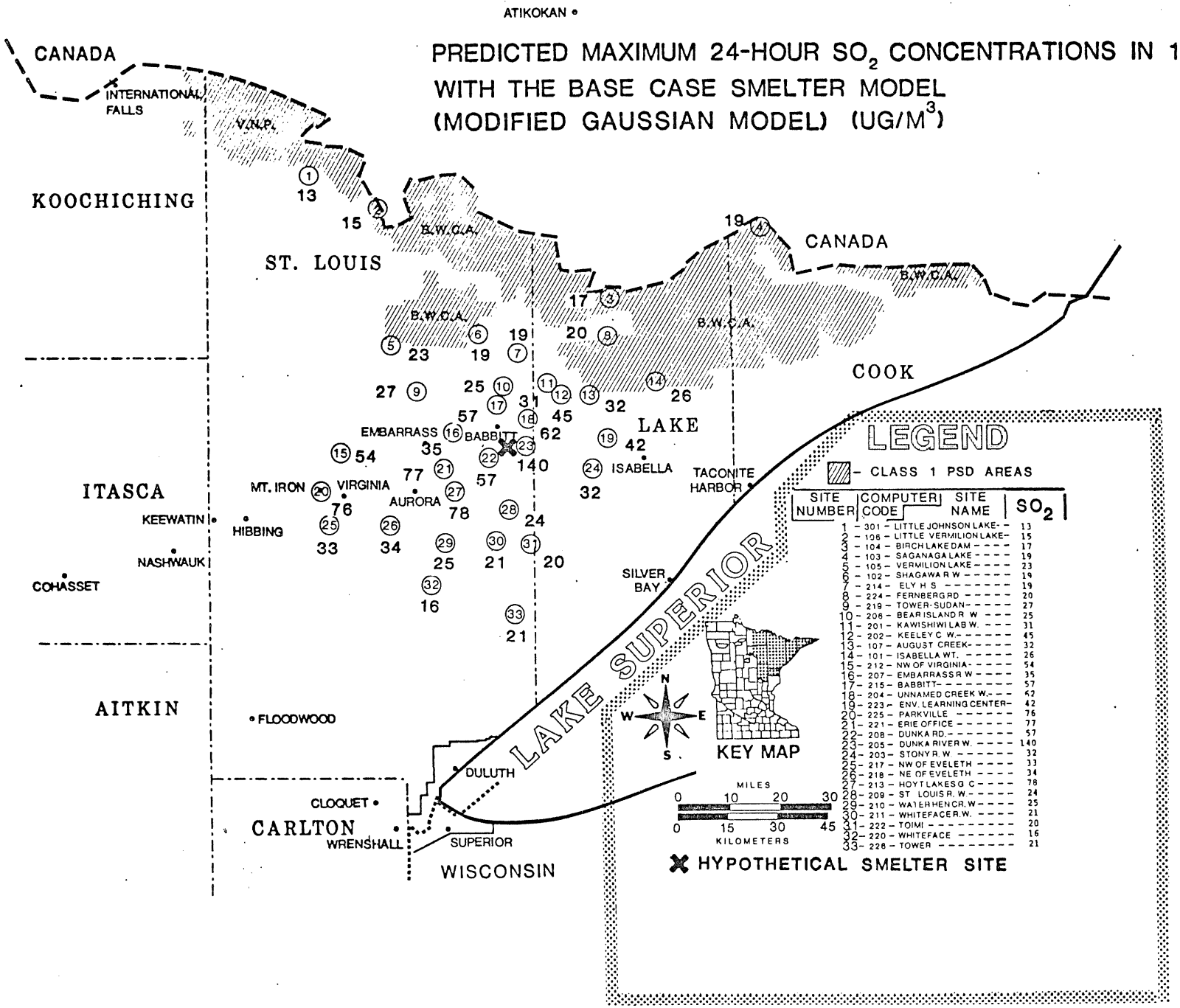

ATIKOKAN
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
B.W.C.A.
B.W.C.A.
B.W.C.A.
COOK
LAKE
EMBARRASS
BABBITT
TACONITE HARBOR
ISABELLA
ITASCA
MT. IRON
VIRGINIA
AURORA
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
PREDICTED MAXIMUM 24-HOUR SO_2 CONCENTRATIONS IN 1985
WITH THE BASE CASE SMELTER MODEL
(MODIFIED GAUSSIAN MODEL) (UG/M^3)
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO_2
1 - 301 - LITTLE JOHNSON LAKE- - 13
2 - 106 - LITTLE VERMILION LAKE- 15
3 - 104 - BIRCH LAKE DAM - - - - 17
4 - 103 - SAGANAGA LAKE - - - - 19
5 - 105 - VERMILION LAKE - - - - 23
6 - 102 - SHAGAWA R W - - - - - 19
7 - 214 - ELY H S - - - - - - - - 19
8 - 224 - FERNBERG RD - - - - - 20
9 - 219 - TOWER-SUDAN- - - - - 27
10 - 206 - BEAR ISLAND R W - - - 25
11 - 201 - KAWISHIWI LAB W. - - - 31
12 - 202 - KEELEY C W.- - - - - - 45
13 - 107 - AUGUST CREEK- - - - - 32
14 - 101 - ISABELLA WT. - - - - - 26
15 - 212 - NW OF VIRGINIA- - - - 54
16 - 207 - EMBARRASS R W - - - - 35
17 - 215 - BABBITT- - - - - - - - 57
18 - 204 - UNNAMED CREEK W.- - - 62
19 - 223 - ENV. LEARNING CENTER- 42
20 - 225 - PARKVILLE - - - - - - 76
21 - 221 - ERIE OFFICE - - - - - 77
22 - 208 - DUNKA RD.- - - - - - - 57
23 - 205 - DUNKA RIVER W. - - - - 140
24 - 203 - STONY R. W. - - - - - - 32
25 - 217 - NW OF EVELETH - - - - 33
26 - 218 - NE OF EVELETH - - - - 34
27 - 213 - HOYT LAKES G C - - - - 78
28 - 209 - ST. LOUIS R. W. - - - - 24
29 - 210 - WATERHEN CR. W - - - - 25
30 - 211 - WHITEFACE R. W. - - - - 21
31 - 222 - TOIMI - - - - - - - - - 20
32 - 220 - WHITEFACE - - - - - - 16
33 - 226 - TOWER - - - - - - - - 21
N
W
E
S
KEY MAP
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE

FIGURE 100

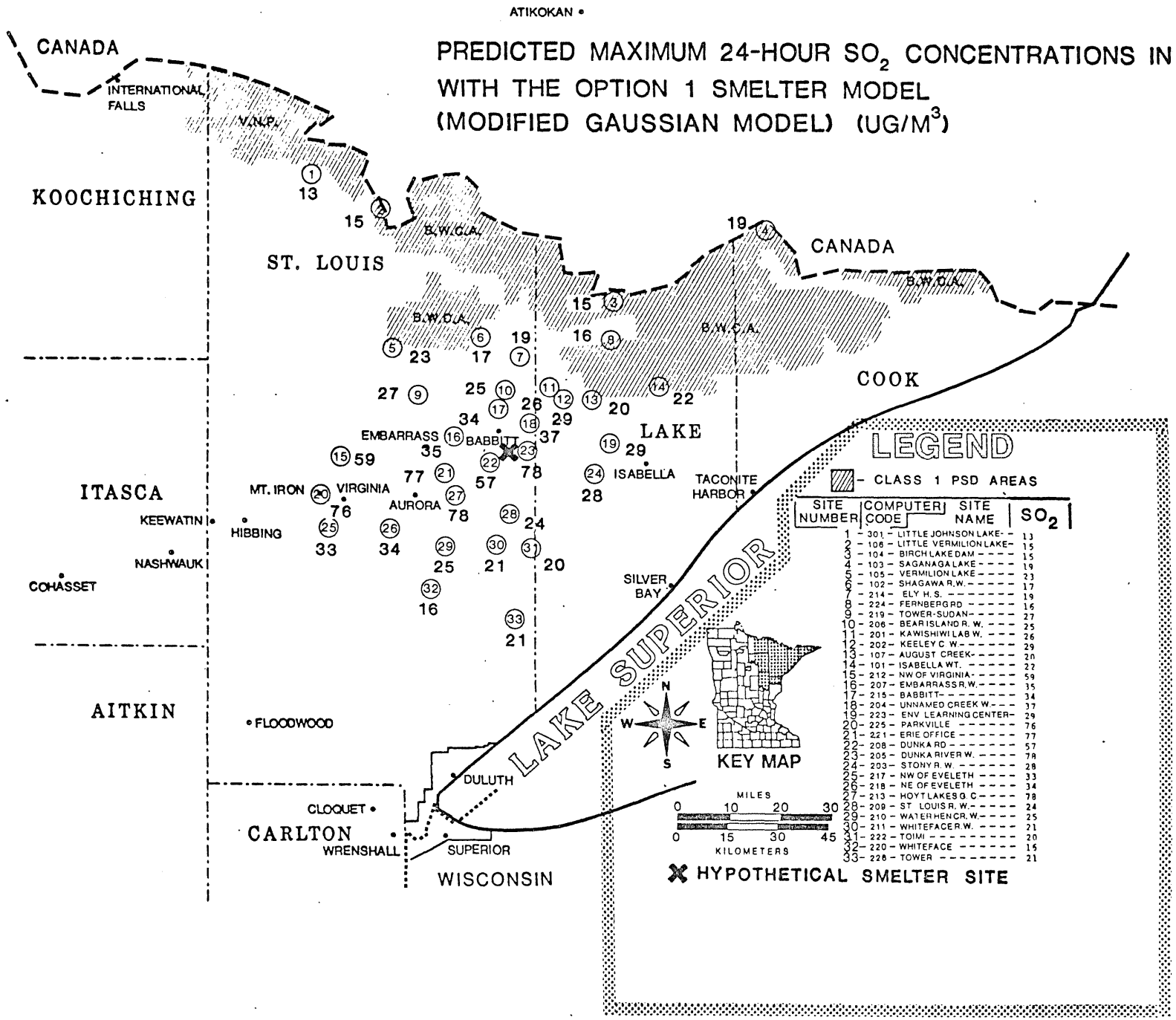

ATIKOKAN
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
EMBARRASS
BABBITT
MT. IRON
VIRGINIA
AURORA
ISABELLA
TACONITE HARBOR
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
PREDICTED MAXIMUM 24-HOUR SO2 CONCENTRATIONS IN 1985
WITH THE OPTION 1 SMELTER MODEL
(MODIFIED GAUSSIAN MODEL) (UG/M3)
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO2
1 - 301 - LITTLE JOHNSON LAKE - 13
2 - 106 - LITTLE VERMILION LAKE - 15
3 - 104 - BIRCH LAKE DAM - 15
4 - 103 - SAGANAGA LAKE - 19
5 - 105 - VERMILION LAKE - 23
6 - 102 - SHAGAWA R.W. - 17
7 - 214 - ELY H.S. - 19
8 - 224 - FERNBERG RD - 16
9 - 219 - TOWER-SUDAN - 27
10 - 206 - BEAR ISLAND R. W. - 25
11 - 201 - KAWISHIWI LAB W. - 26
12 - 202 - KEELEY C. W. - 29
13 - 107 - AUGUST CREEK - 20
14 - 101 - ISABELLA WT. - 22
15 - 212 - NW OF VIRGINIA - 59
16 - 207 - EMBARRASS R.W. - 35
17 - 215 - BABBITT - 34
18 - 204 - UNNAMED CREEK W. - 37
19 - 223 - ENV. LEARNING CENTER - 29
20 - 225 - PARKVILLE - 76
21 - 221 - ERIE OFFICE - 77
22 - 208 - DUNKA RD - 57
23 - 205 - DUNKA RIVER W. - 78
24 - 203 - STONY R. W. - 28
25 - 217 - NW OF EVELETH - 33
26 - 218 - NE OF EVELETH - 34
27 - 213 - HOYT LAKES G. C. - 78
28 - 209 - ST. LOUIS R. W. - 24
29 - 210 - WATER HEN CR. W. - 25
30 - 211 - WHITEFACE R.W. - 21
31 - 222 - TOIMI - 20
32 - 220 - WHITEFACE - 15
33 - 226 - TOWER - 21
KEY MAP
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE

FIGURE 101

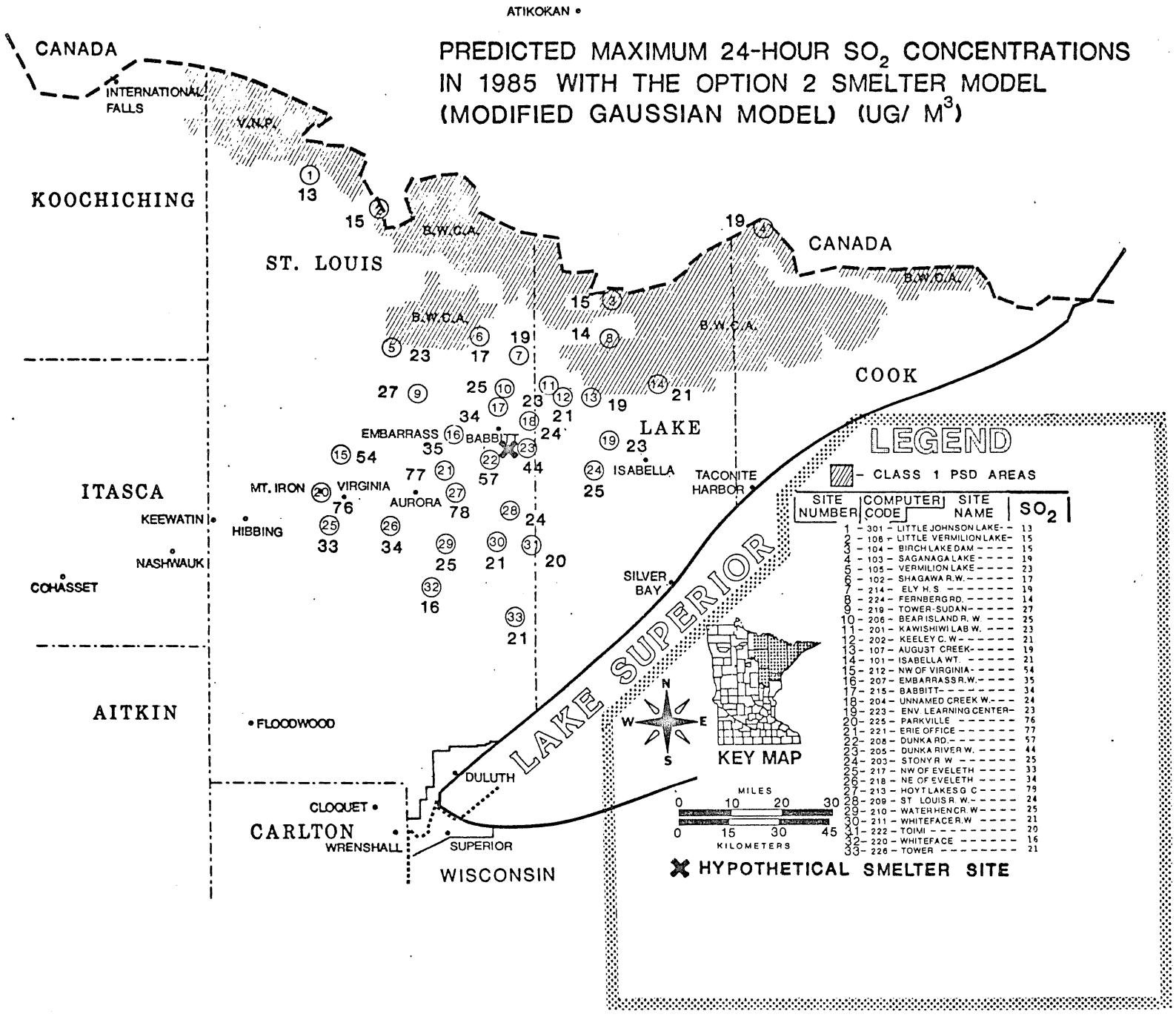

ATIKOKAN
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
EMBARRASS
BABBITT
ISABELLA
TACONITE HARBOR
MT. IRON
VIRGINIA
AURORA
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
PREDICTED MAXIMUM 24-HOUR SO_2 CONCENTRATIONS IN 1985 WITH THE OPTION 2 SMELTER MODEL (MODIFIED GAUSSIAN MODEL) (UG/ M^3)
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO_2
1 - 301 - LITTLE JOHNSON LAKE - 13
2 - 106 - LITTLE VERMILION LAKE - 15
3 - 104 - BIRCH LAKE DAM - 15
4 - 103 - SAGANAGA LAKE - 19
5 - 105 - VERMILION LAKE - 23
6 - 102 - SHAGAWA R.W. - 17
7 - 214 - ELY H.S - 19
8 - 224 - FERNBERG RD. - 14
9 - 219 - TOWER-SUDAN - 27
10 - 206 - BEAR ISLAND R. W - 25
11 - 201 - KAWISHIWI LAB W. - 23
12 - 202 - KEELEY C. W - 21
13 - 107 - AUGUST CREEK - 19
14 - 101 - ISABELLA WT. - 21
15 - 212 - NW OF VIRGINIA - 54
16 - 207 - EMBARRASS R.W. - 35
17 - 215 - BABBITT - 34
18 - 204 - UNNAMED CREEK W. - 24
19 - 223 - ENV. LEARNING CENTER - 23
20 - 225 - PARKVILLE - 76
21 - 221 - ERIE OFFICE - 77
22 - 208 - DUNKA RD. - 57
23 - 205 - DUNKA RIVER W. - 44
24 - 203 - STONY R. W - 25
25 - 217 - NW OF EVELETH - 33
26 - 218 - NE OF EVELETH - 34
27 - 213 - HOYT LAKES G C - 79
28 - 209 - ST. LOUIS R. W. - 24
29 - 210 - WATER HEN CR. W - 25
30 - 211 - WHITEFACE R. W - 21
31 - 222 - TOIMI - 20
32 - 220 - WHITEFACE - 16
33 - 226 - TOWER - 21
KEY MAP
N
W
E
S
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE

FIGURE 102

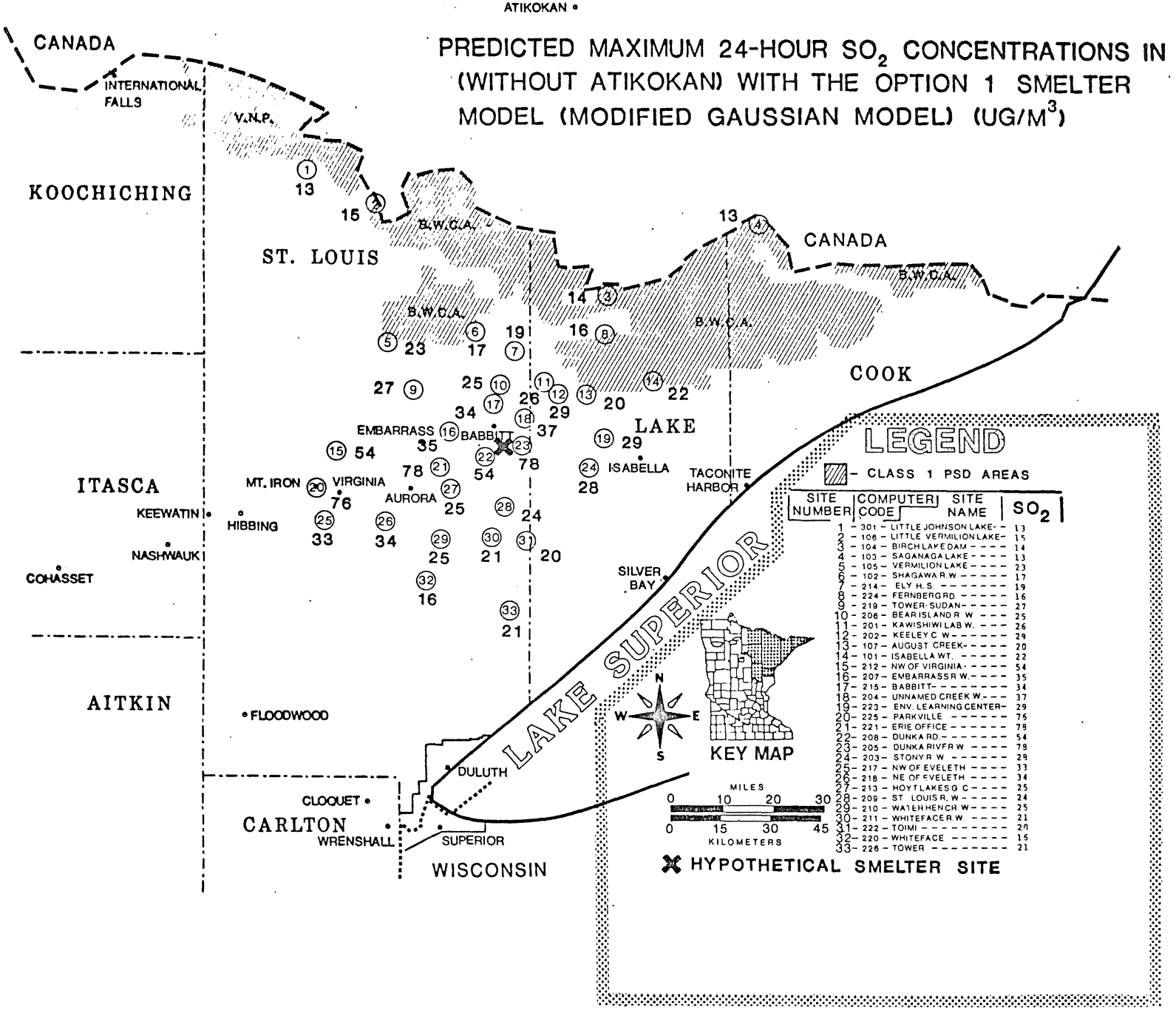
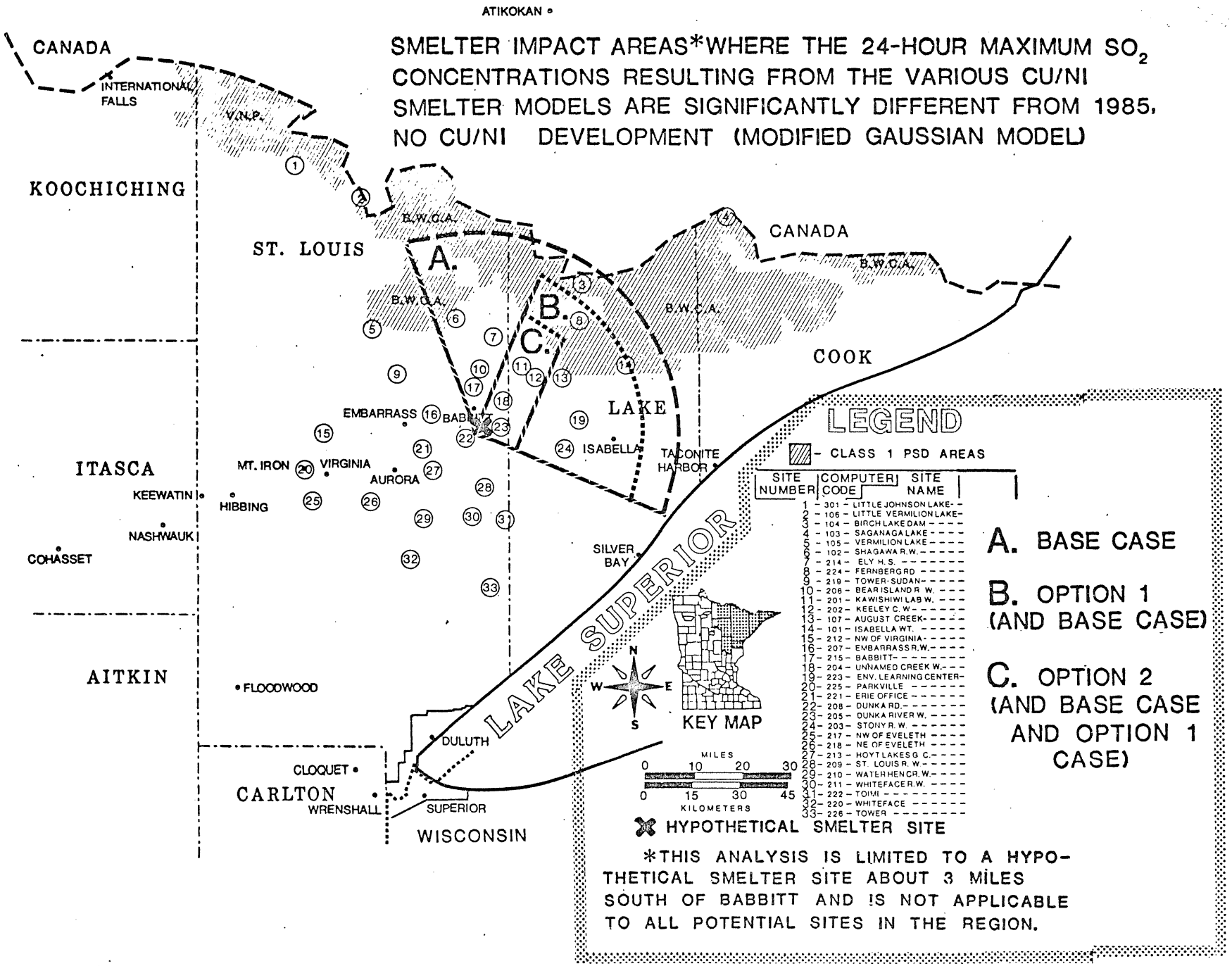

ATIKOKAN
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
COOK
LAKE
ITASCA
EMBARRASS
BABBITT
MT. IRON
VIRGINIA
AURORA
ISABELLA
TACONITE HARBOR
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
PREDICTED MAXIMUM 24-HOUR SO_2 CONCENTRATIONS IN 1985 (WITHOUT ATIKOKAN) WITH THE OPTION 1 SMELTER MODEL (MODIFIED GAUSSIAN MODEL) (UG/M^3)
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | SO_2
1 - 301 - LITTLE JOHNSON LAKE - 13
2 - 106 - LITTLE VERMILION LAKE - 15
3 - 104 - BIRCH LAKE DAM - 14
4 - 103 - SAGANAGA LAKE - 13
5 - 105 - VERMILION LAKE - 23
6 - 102 - SHAGAWA R.W. - 17
7 - 214 - ELY H.S. - 19
8 - 224 - FERNBERG RD. - 16
9 - 219 - TOWER-SUDAN - 27
10 - 206 - BEAR ISLAND R. W - 25
11 - 201 - KAWISHIWI LAB W. - 26
12 - 202 - KEELEY C. W. - 29
13 - 107 - AUGUST CREEK - 20
14 - 101 - ISABELLA WT. - 22
15 - 212 - NW OF VIRGINIA - 54
16 - 207 - EMBARRASS R W. - 35
17 - 215 - BABBITT - 34
18 - 204 - UNNAMED CREEK W. - 37
19 - 223 - ENV. LEARNING CENTER - 29
20 - 225 - PARKVILLE - 76
21 - 221 - ERIE OFFICE - 78
22 - 208 - DUNKA RD. - 54
23 - 205 - DUNKA RIVER W - 78
24 - 203 - STONY R. W - 28
25 - 217 - NW OF EVELETH - 33
26 - 218 - NE OF EVELETH - 34
27 - 213 - HOYT LAKES G. C. - 25
28 - 209 - ST. LOUIS R. W. - 24
29 - 210 - WATERHENCH W. - 25
30 - 211 - WHITEFACE R.W. - 21
31 - 222 - TOIMI - 20
32 - 220 - WHITEFACE - 15
33 - 226 - TOWER - 21
KEY MAP
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE

FIGURE 103


ATIKOKAN
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
A.
B.
C.
CANADA
B.W.C.A.
COOK
LAKE
EMBARRASS
BABBITT
ISABELLA
TACONITE HARBOR
ITASCA
MT. IRON
VIRGINIA
AURORA
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
SMELTER IMPACT AREAS*WHERE THE 24-HOUR MAXIMUM SO2 CONCENTRATIONS RESULTING FROM THE VARIOUS CU/NI SMELTER MODELS ARE SIGNIFICANTLY DIFFERENT FROM 1985, NO CU/NI DEVELOPMENT (MODIFIED GAUSSIAN MODEL)
LEGEND
- CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME
1 - 301 - LITTLE JOHNSON LAKE
2 - 106 - LITTLE VERMILION LAKE
3 - 104 - BIRCH LAKE DAM
4 - 103 - SAGANAGA LAKE
5 - 105 - VERMILION LAKE
6 - 102 - SHAGAWA R.W.
7 - 214 - ELY H.S.
8 - 224 - FERNBERG RD
9 - 219 - TOWER-SUDAN
10 - 206 - BEAR ISLAND R. W.
11 - 201 - KAWISHIWI LAB W.
12 - 202 - KEELEY C. W.
13 - 107 - AUGUST CREEK
14 - 101 - ISABELLA WT.
15 - 212 - NW OF VIRGINIA
16 - 207 - EMBARRASS R.W.
17 - 215 - BABBITT
18 - 204 - UNNAMED CREEK W.
19 - 223 - ENV. LEARNING CENTER
20 - 225 - PARKVILLE
21 - 221 - ERIE OFFICE
22 - 208 - DUNKA RD.
23 - 205 - DUNKA RIVER W.
24 - 203 - STONY R. W.
25 - 217 - NW OF EVELETH
26 - 218 - NE OF EVELETH
27 - 213 - HOYT LAKES G. C.
28 - 209 - ST. LOUIS R. W.
29 - 210 - WATER HEN CR. W.
30 - 211 - WHITEFACE R.W.
31 - 222 - TOIMI
32 - 220 - WHITEFACE
33 - 226 - TOWER
A. BASE CASE
B. OPTION 1 (AND BASE CASE)
C. OPTION 2 (AND BASE CASE AND OPTION 1 CASE)
KEY MAP
N
W
E
S
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE
*THIS ANALYSIS IS LIMITED TO A HYPOTHETICAL SMELTER SITE ABOUT 3 MILES SOUTH OF BABBITT AND IS NOT APPLICABLE TO ALL POTENTIAL SITES IN THE REGION.

Maximum and second high 24-hour SO_2 concentrations for the 1985 simulation with copper-nickel development are summarized in Table 74 for those sites showing the most variation for the three smelter configurations. Predicted maximum 24-hour and second high concentrations at receptors in Class I and II areas for the various modeling simulations are shown in Figure 104. The 1977 regional, 1977 PSD and 1985 high values are also included for comparison.

Table 74, Figure 104

The maximum and second high 24-hour concentration for the base case smelter in the Class I area are 32 ug/m^3 (August Creek) and 26 ug/m^3 (Isabella Watershed), respectively. These values are about a third higher than the maximum and second high values predicted for 1985 without copper-nickel development, 23 ug/m^3 (Vermilion Lake) and 20 ug/m^3 (Isabella Watershed).

In the Class II area the maximum and 2nd high values are 140 ug/m^3 (Dunka River Watershed) and 125 ug/m^3 (Dunka River Watershed), respectively, for the base case smelter. These values are about 80% and 55% higher than the maximum and 2nd high concentrations predicted for 1985 without copper-nickel development, 78 ug/m^3 (Hoyt lakes Golf Course) and 77 ug/m^3 (Erie Office), respectively.

Substituting the option 1 smelter into the simulation results in a high of 23 ug/m^3 (Vermilion Lake) followed by a second high of 22 ug/m^3 (August Creek) in the Class I areas. In the Class II areas the high and the 2nd high are both 78 ug/m^3 (Dunka River Watershed, Hoyt Lakes Golf Course). These values are about the same as in the 1985 simulation without copper-nickel development.

Substituting the option 2 smelter results in maximum and 2nd high values that are almost the same as for the 1985 simulation without copper-nickel development.

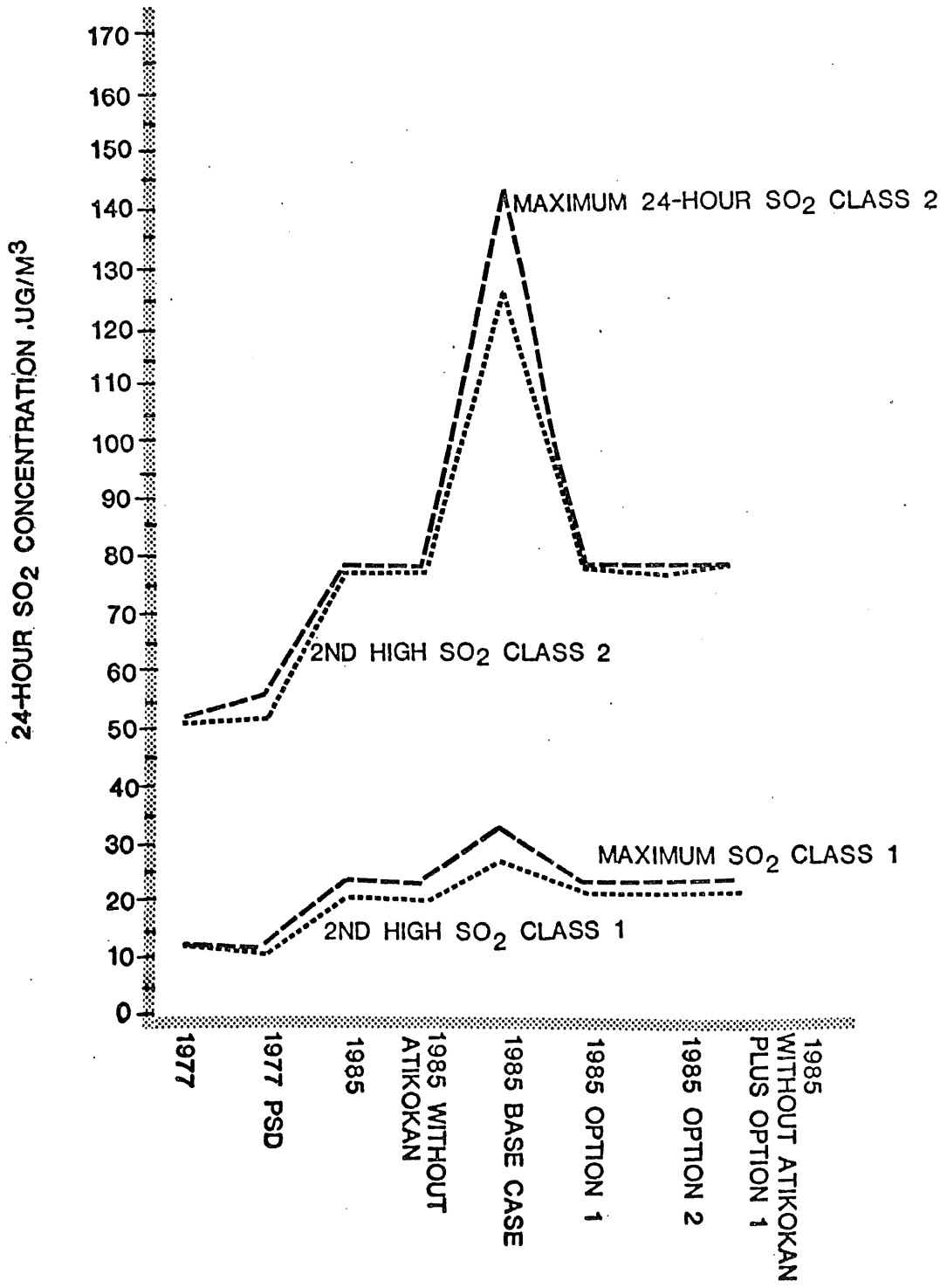
Table 74. Summary of 24-hour maximum and second highest SO_2 concentrations at selected sites for copper-nickel development cases in 1985.[a]

RECEPTOR SITE NO.	RECEPTOR NAME	1985 + base case high	1985 + base case 2nd high	1985 + option 1 high	1985 + option 1 2nd high	1985 + option 2 high	1985 + option 2 2nd high
11	Kawishiwi Lab	31	30	26	20	23	18
24	Stony River W.	32	30	28	22	24	23
18	Unnamed Creek W.	62	53	37	27	24	23
23	Dunka River W.	143	125	78	71	44	43
10	Bear Island R. W.	25	25	25	21	25	21
22	Dunka Road	57	40	57	40	57	40
19	Env. Learning Ctr.	42	41	29	27	23	23
Regional High		43	125	78	71	57	40

[a]For smelter arbitrarily sited 3 miles south of Babbitt, with other expected 1985 sources also included.

FIGURE 104

SUMMARY OF HIGHEST AND 2ND HIGHEST 24-HOUR SO_2 CONCENTRATION PREDICTED AT ANY RECEPTOR IN CLASS 1 AND CLASS 2 AREAS, RESPECTIVELY, FOR VARIOUS SCENARIOS (MODIFIED GAUSSIAN MODEL)



The option 2 smelter at this location has relatively little effect on the 24-hour concentrations.

Removing the Atikokan power plant from the analysis with the option 1 smelter results in maximum and 2nd high 24-hour SO_2 concentrations in the Class I and Class II areas that are essentially unchange. Maximum 24-hour concentration are decreased only at two sites on the Canada-Minnesota border.

In terms of the allowed PSD increments, both the 24-hour PSD Class I increment (5 ug/m^3) and the Class II increment (91 ug/m^3) are predicted to be exceeded by one or more of the modeled smelter cases together with other sources expected by 1985. The predicted values greater than the increments are listed in Table 75.

Table 75

Using the maximum 24-hour concentration the Class I increment is exceeded at 8 sites for the base case smelter scenario, 7 sites for the option 1 smelter scenario and 7 sites for the option 2 smelter scenario. These numbers drop to 6, 4 and 4, respectively, when the second high is used. If Atikokan is excluded from the 1985 plus option 1 emissions inventory then the increment is exceeded at 6 sites using the maximum concentration and 3 sites using the 2nd high. The Class II increment is exceeded at only one site and only for the base case smelter scenario.

In order to more fully determine the magnitude of the values greater than the PSD increment just highlighted, as well as facilitate comparison to predictions without copper-nickel development, the PSD analysis was made for each day of the year at each site rather than just using the high or second high values at each site in the region. For example, the calculated SO_2 concentration on January 1,

Table 75. A summary of the predicted Class I and Class II 24-hour PSD increment exceedances in 1985 with the various smelter models[a] (ug/m^3).

RECEPTOR SITE NO.	RECEPTOR SITE NAMES	Base Case Smelter, 1985		Option 1 Smelter, 1985		Option 2 Smelter, 1985		Option 1 Smelter, 1985 without Atikokan	
Class I		High	2nd High	High	2nd High	High	2nd High	High	2nd High
14	Isabella W.	14	8	10	(4)[b]	9	(3)	10	(4)
6	Shagawa River W.	11.2	9.2	9.2	8.2	9.2	8.2	9.2	8.2
4	Saganaga Lake	7	(4)[b]	7	(4)	7	(4)	(1)	(0)
3	Birch Lake Dam	6	5	(4)	(3)	(4)	(2)	(3)	(1)
5	Vermillion Lake	15.6	9.6	15.6	9.6	15.6	9.6	15.6	9.6
2	Little Vermillion L.	9.1	5.1	9.1	5.1	9.1	5.1	9.1	(4.1)
13	August Creek	23.3	I7.3	11.3	10.3	10.3	7.3	11.3	10.3
1	Little Johnson Lake	5.7	(3.7)	5.7	(3.7)	5.7	(3.7)	5.7	(3.7)
Class II									
23	Dunka River W.	128	110	(63)	(56)	(29)	(28)	(63)	(56)

[a]The values shown are the differences between the highest (or second highest) value predicted for the modeling case and the 1977 PSD baseline value.

[b]Values shown in parenthesis do not constitute exceedances of the respective increment (5 ug/m^3 - Class I; 91 ug/m^3 -Class II).

1977 was subtracted from the predicted concentration on January 1, 1985 and so forth for each day in the year, using the same weather for both years. Figures 105 to 109 show the resulting SO_2 concentration increments which were greater than the PSD Class I increment. The data are plotted for each of the Class I sites; plots of the projected 1985 data without development are shown in Figure 105 for comparison.

Figures 105 to 109

Regional point source growth in 1985 is predicted to result in a total of 91 24-hour values which exceed the PSD increment over the 8 Class I sites, without any copper-nickel development (Figure 105). Most of the excess values are concentrated in the range of 5-6 ug/m^3 but go as high as 14 and 17 ug/m^3. When the Atikokan power plant is removed from the regional inventory (Figure 106), the number of 24-hour values causing the increment to be exceeded decreases to 60, a 34% decrease. The Class I sites that are most impacted by Atikokan are site numbers 14, 4, and 3.

When the base case smelter is included in the simulation (Figure 107), the PSD Class I increment is exceeded 151 times, an increase of 66% over 1985 point source growth alone. With the option 1 smelter in the simulations (Figure 108) the number of values exceeding the Class I increment is 119, a 31% increase over those due to 1985 regional point source growth alone. Most of the excess values are in the 5-7 ug/m^3 range. The impact of the option 1 smelter is greatest at sites 14, 3, and 13, which are east and northeast of the smelter.

The option 2 smelter (Figure 109) results in only 101 Class I increment exceedances, an increase of only 11% over predicted 1985 point source growth

FIGURE 105

24-AMBIENT SO_2 CONCENTRATIONS GREATER THAN THE CLASS 1 PSD INCREMENT, 1985 WITHOUT CU/NI DEVELOPMENT (MODIFIED GAUSSIAN MODEL)

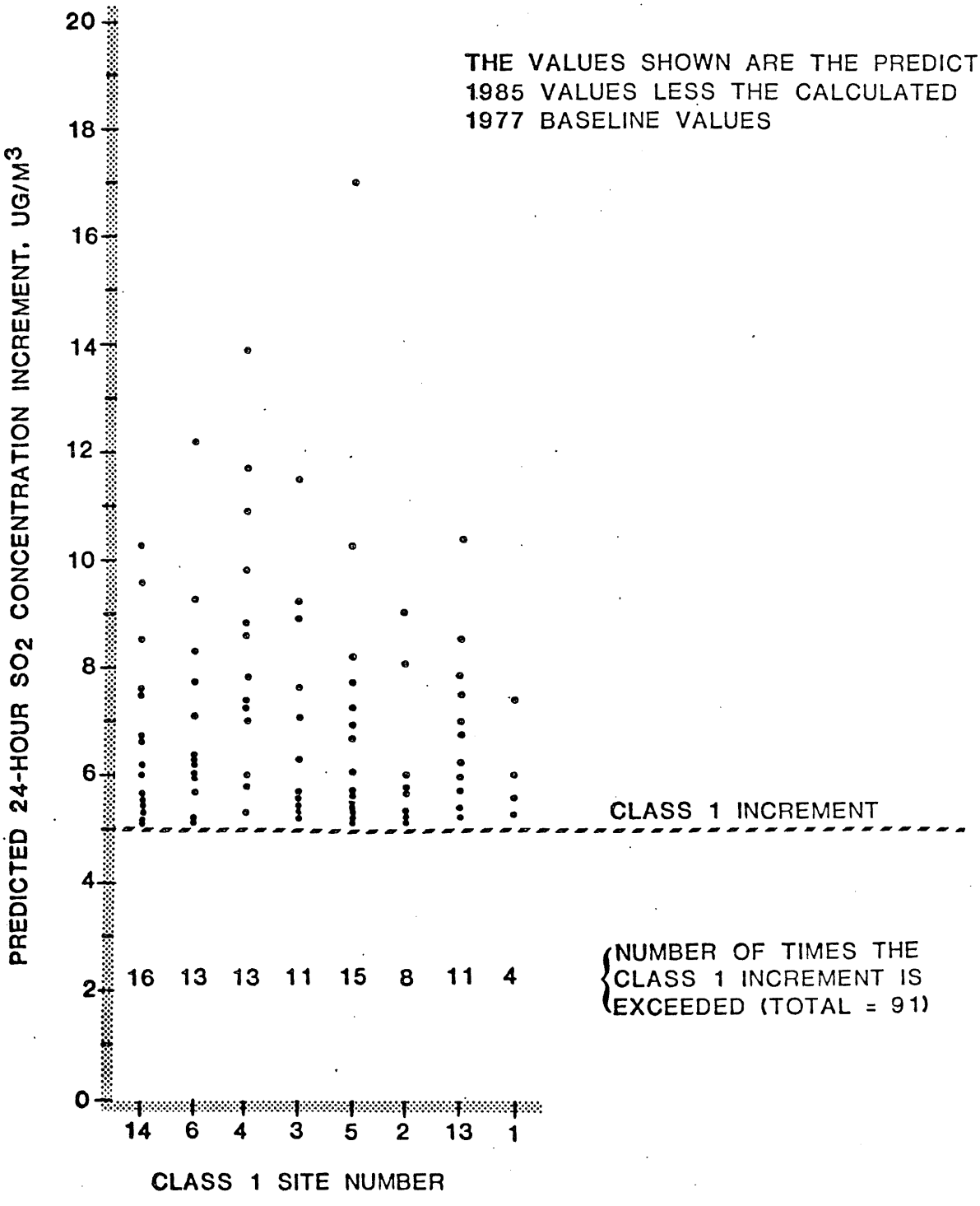


FIGURE 106

24-HOUR AMBIENT SO_2 CONCENTRATIONS GREATER THAN THE CLASS 1 PSD INCREMENT, 1985 EXCLUDING ATIKOKAN (MODIFIED GAUSSIAN MODEL)

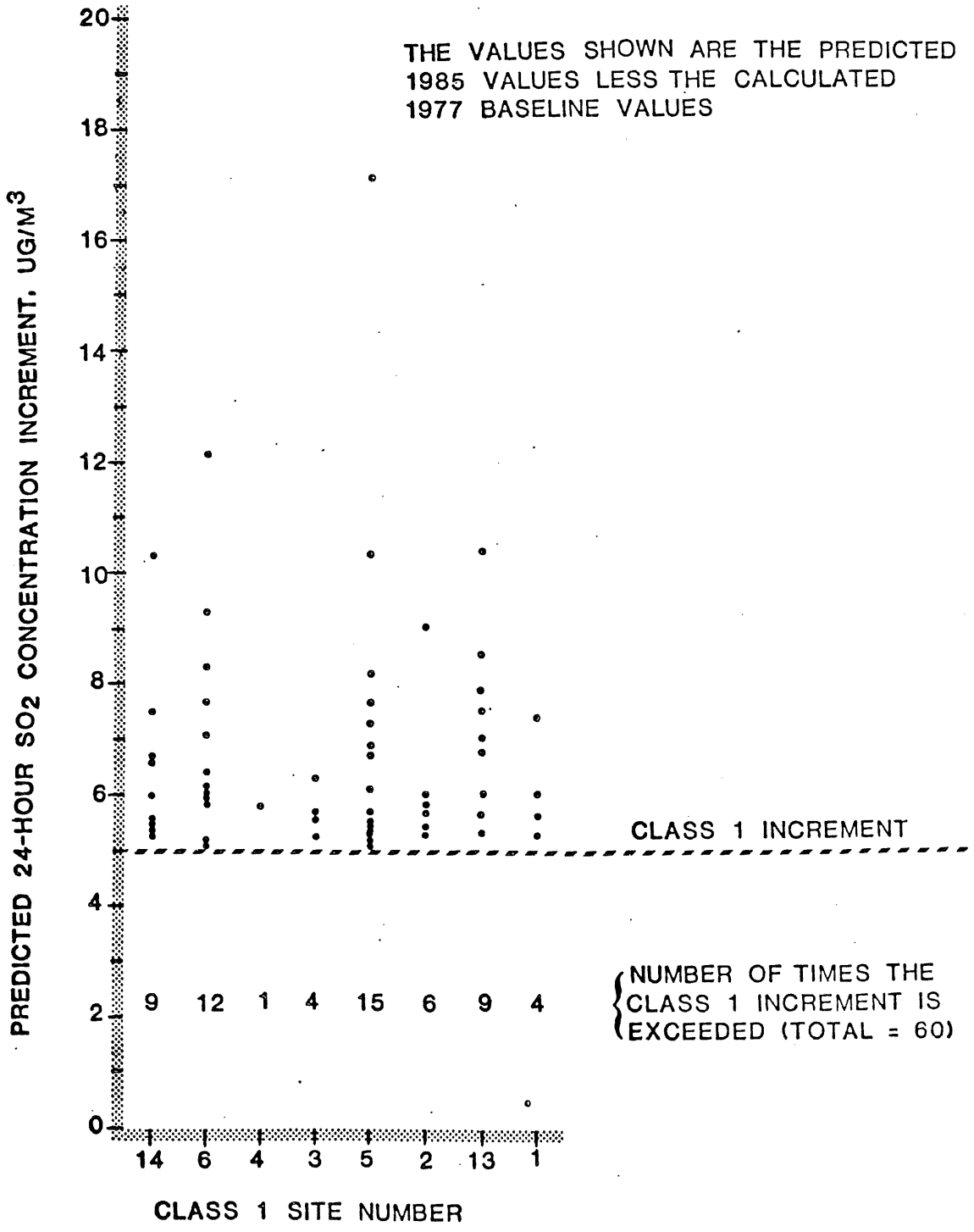


FIGURE 107

24-HOUR AMBIENT SO_2 CONCENTRATIONS GREATER THAN THE CLASS 1 PSD INCREMENT, 1985 WITH BASE CASE SMELTER MODEL (MODIFIED GAUSSIAN MODEL)

THE VALUES SHOWN ARE THE PRECICTED 1985 VALUES LESS THE CALCULATED 1977 BASELINE VALUES

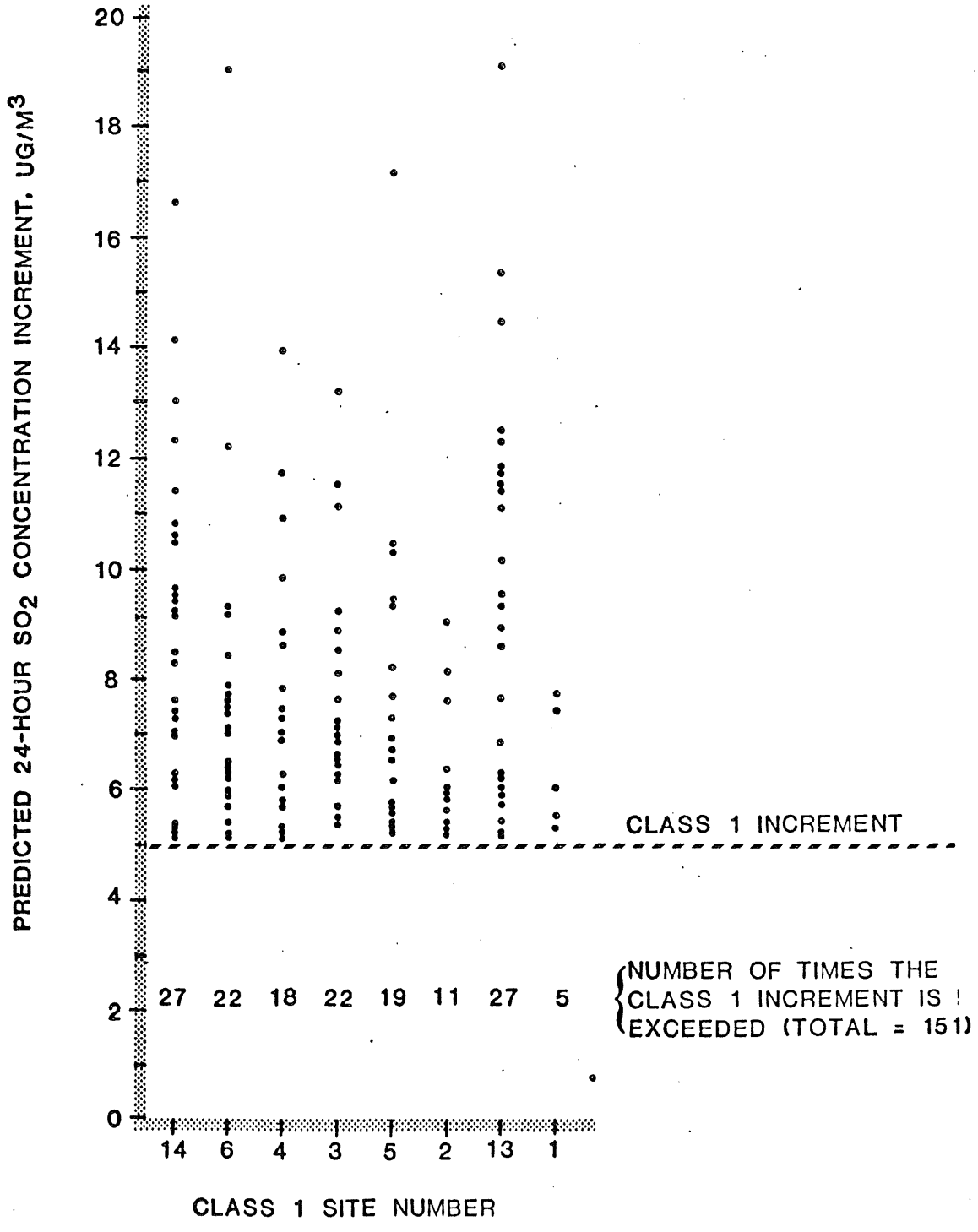


FIGURE 108

24-HOUR AMBIENT SO_2 CONCENTRATIONS GREATER THAN THE CLASS 1 PSD INCREMENT, 1985 WITH OPTION 1 SMELTER MODEL (MODIFIED GAUSSIAN MODEL)

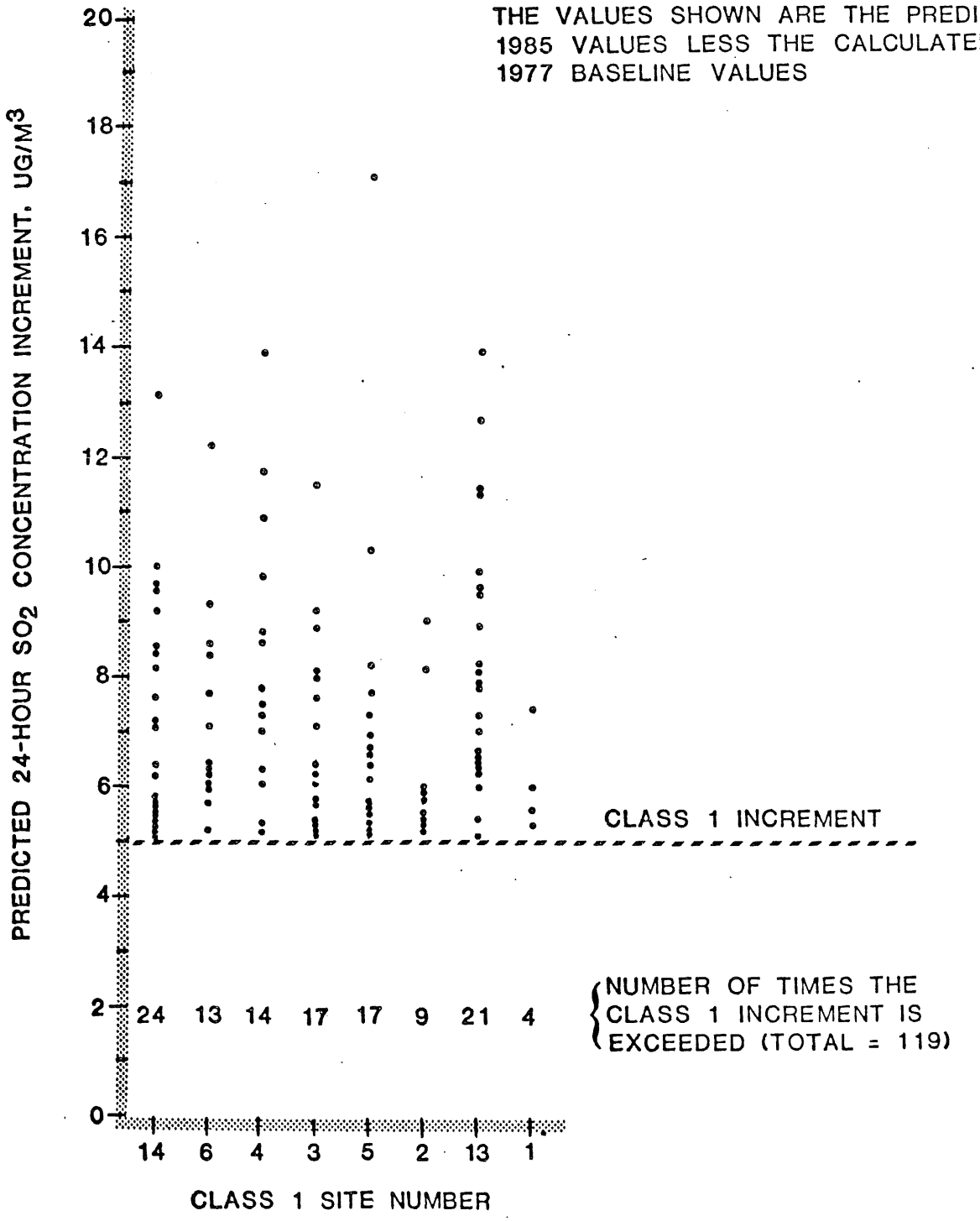
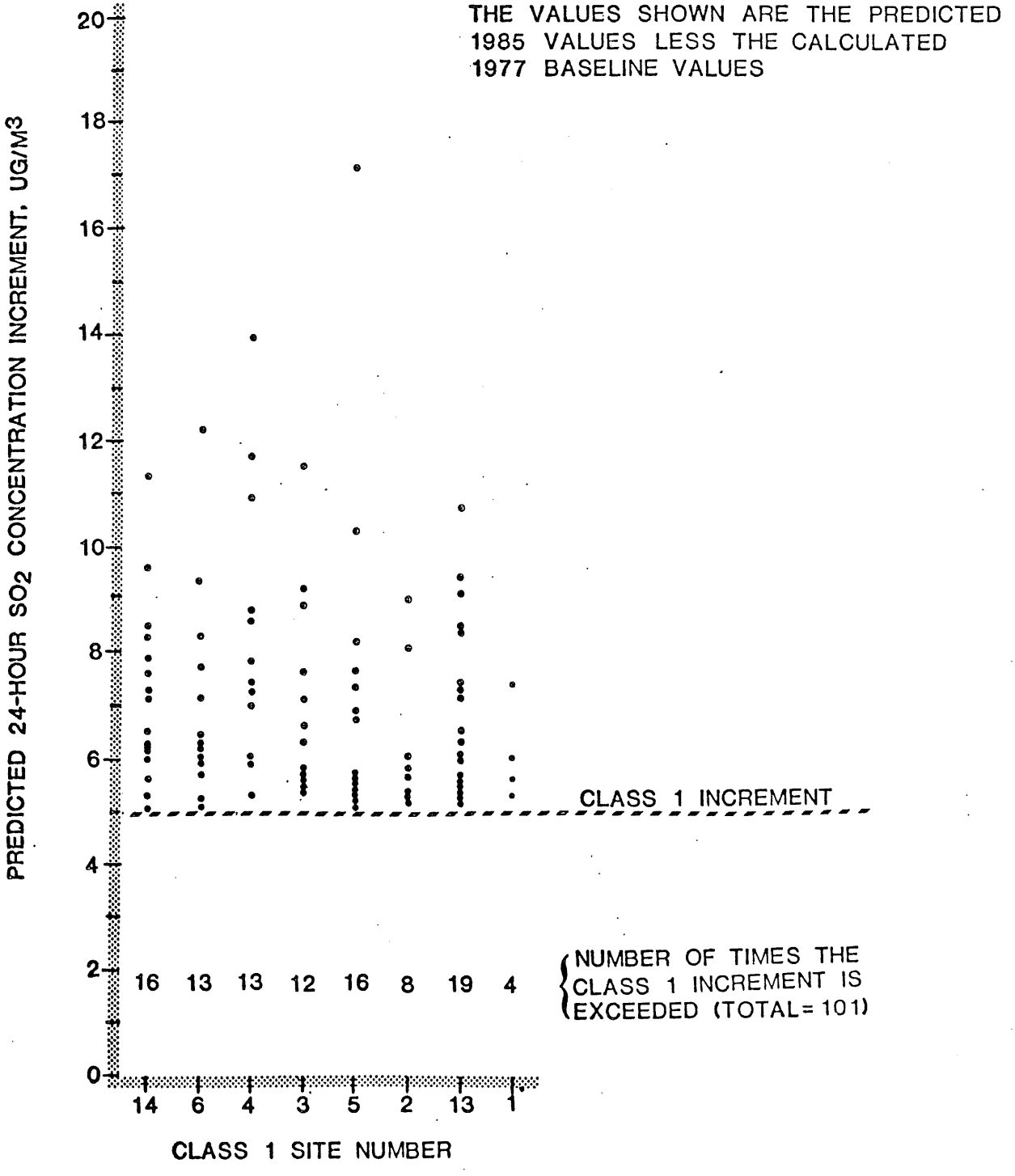


FIGURE 109

24-HOUR AMBIENT SO_2 CONCENTRATIONS GREATER THAN THE CLASS 1 PSD INCREMENT, 1985 WITH OPTION 2 SMELTER MODEL (MODIFIED GAUSSIAN MODEL)



alone. The major conclusion here is that, even though the PSD class I increment is predicted to be exceeded several times at several sites with any of the smelter models, it is predicted to be exceeded in any case as a result of the projected growth of regional SO_2 point sources without any copper-nickel development. For the option 2 smelter, the effect of the smelter is minor, in terms of the number of predicted values greater than the increments in comparison to those caused by the cumulative effect of the other regional sources.

The 24-hour Class II standard is not predicted to be exceeded (using this difference method) at any of the sites in Class II areas. The highest difference occurred (with the base case smelter model) at Parkville, where a difference of 55 ug/m^3 is predicted. It must be noted that the discrepancy between this figure and the single value greater than the increment which was predicted earlier when the differences were based on the maximum values is due to the method of computation used. When figured on a day-by-day basis the meteorology remains the same for the baseline and projected years and only the emissions change. This results in high values occurring on the same day for baseline and projected years which in effect decreases the spread between the values.

Table 76 presents a summary of the number of times the 24-hour increments are exceeded on a month by month and annual basis for each of the simulation cases in Class I and Class II areas. Most of the values greater than the increments (70-85%) occur during the fall and winter months when atmospheric conditions favor limited mixing and dispersion of pollutants.

Table 76

The previous discussion, based on a hypothetical smelter site south of Babbitt has shown that of the 24-hour ambient SO_2 PSD increment is expected to be

Table 76. Summary of the number of times the 24-hour SO_2 Class I[a] PSD increments are predicted to be exceeded by month at all Class I receptor sites based on day-by-day simulations.

	MONTH												ANNUAL
	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
1985-Baseline No Cu-Ni development	11	14	2	3	2	0	4	3	11	12	13	16	91
1985-Baseline Atikokan excluded	10	8	2	3	2	0	0	0	8	8	8	11	60
1985-Baseline with the base case smelter model	22	19	7	4	6	3	5	6	15	22	17	25	151
1985-Baseline with the option 1 smelter model	17	17	6	3	3	2	4	4	13	18	14	18	119
1985-Baseline with the option 2 smelter model	13	15	3	3	2	1	4	4	13	13	13	17	101

[a]The Class II 24-hour increment is not predicted to be exceeded.

exceeded in Class I areas for all the smelter models, and that the increment is predicted to be exceeded even without a smelter. In terms of the smelter location, it is clear that its distance from Class I areas will constitute a major factor in the ability of the facility to meet PSD standards. This problem was further analyzed by computing the ambient 24-hour SO_2 concentrations from a smelter point source simply as a function of distance from the source. No specific location was selected. The analysis was carried out using two different dispersion models. The mesoscale modified gaussian model developed by study staff was used in addition to the standard short range TEM model for stack emissions coupled with a building source model for fugitives (Cramer et al. 1975). The results of each of these approaches are described below.

The short range models employed the smelter source parameters discussed earlier in section 3.6.1. The approach taken toward modeling a potential smelter was to model stack and fugitive plume dispersion over gently rolling, uncomplicated terrain and to use the results to describe dispersion over the majority of the Study Area. The results would not apply where local topography produces major changes in the dispersion patterns. For example, specific analyses would have to be performed for any proposed smelter site where the plume could impact elevated terrain (such as the Giants Range), where plume dispersion could be hindered by the sides of a valley or an inversion capping the cold air in the valley in the morning, or where the plume could become stable by transport over water.

Meteorological input data for the 24-hour dispersion model runs were generally selected from data collected at the Federal Aviation Agency Flight Service Station at the Hibbing Airport during 1976-1977. Because of the probable low release heights from the smelter, worst case dispersion days (that is, those days causing the highest ground level concentrations) were selected on the basis of wind presistence and lack of precipitation.

Days during which the wind direction varies through only a small compass angle (less than about 40°) are not at all uncommon, and most often occur during the cold season with steady northwesterly winds (see Figure 26, section 3.3.2.2). Winds are generally less persistent in the summer and are more likely to become calm at night. Eight days were selected for modeling because of their very persistent winds. They can be considered representative of typical worst case days for ambient ground level concentrations of pollutants released from a model smelter and are similar to days likely to occur during any year.

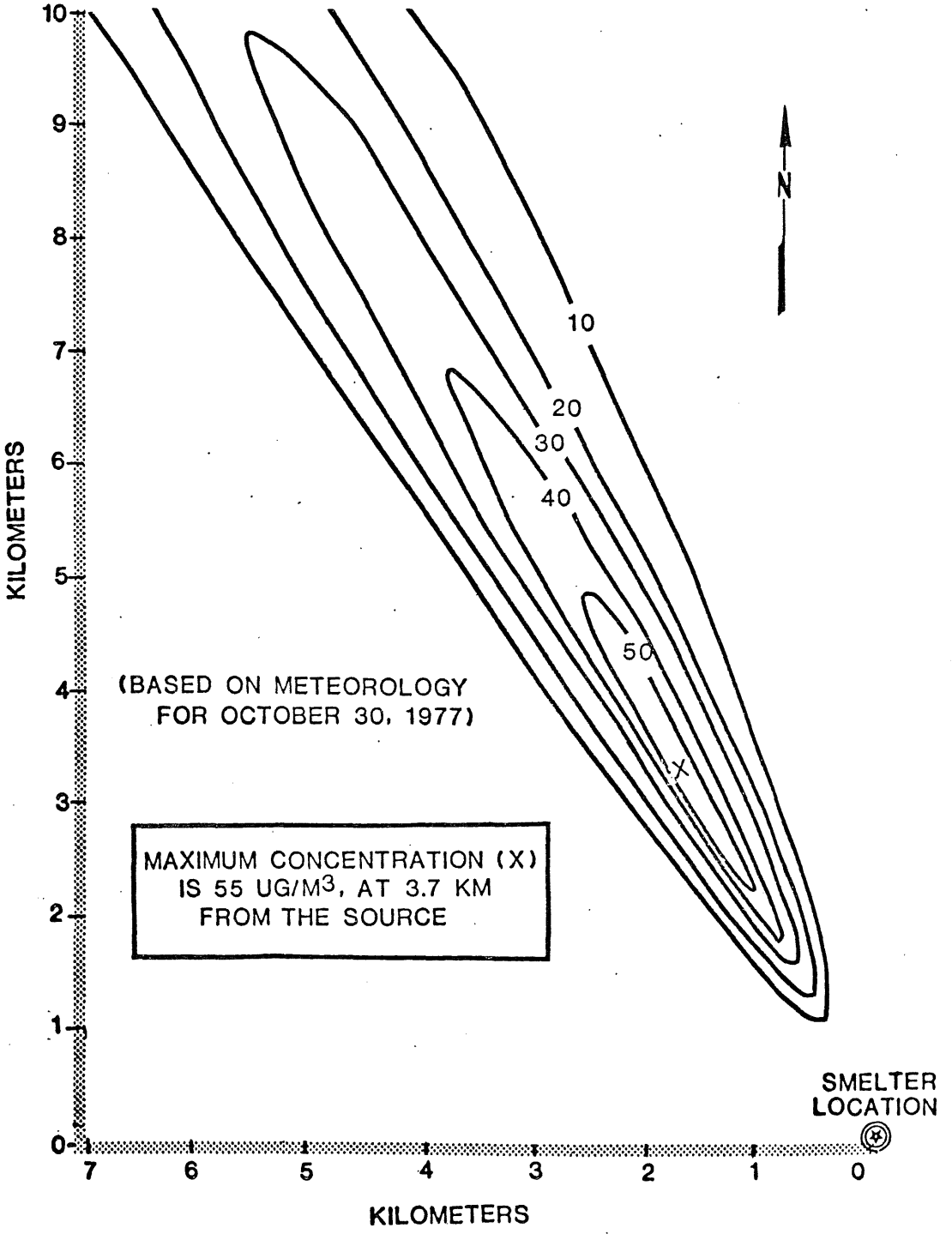
Specific details of the short-range models and input data used, along with the results for the 8 days selected for analysis are presented in Endersen (1978), for the various smelter emissions models. As a typical example, Figures 110 and 111 present isopleths of 24-hour ambient SO_2 concentrations from the base case smelter for stack and fugitive emissions, respectively. This example is based on hourly meteorology data for October 30, 1977. The maximum stack concentration was 55 ug/m^3, at 3.7 km northwest of the smelter. This maximum was typical of the other cases run. Stack maximums ranged from 33 to 55 ug/m^3, at distances varying from 3.25 to 5.1 km from the smelter. Such maximums might occur in any direction from the smelter.

Figures 110 and 111

The actual air quality is determined by the sum of the stack and fugitive emissions since both occur simultaneously and continuously. In reality, the centerlines of the two plumes may differ due to local terrain features as well as meteorological conditions. For example, low level wind shear could cause the two plumes to be transported in different directions, resulting in lower concentrations and broader areas of impact. However, for the uniform conditions

FIGURE 110

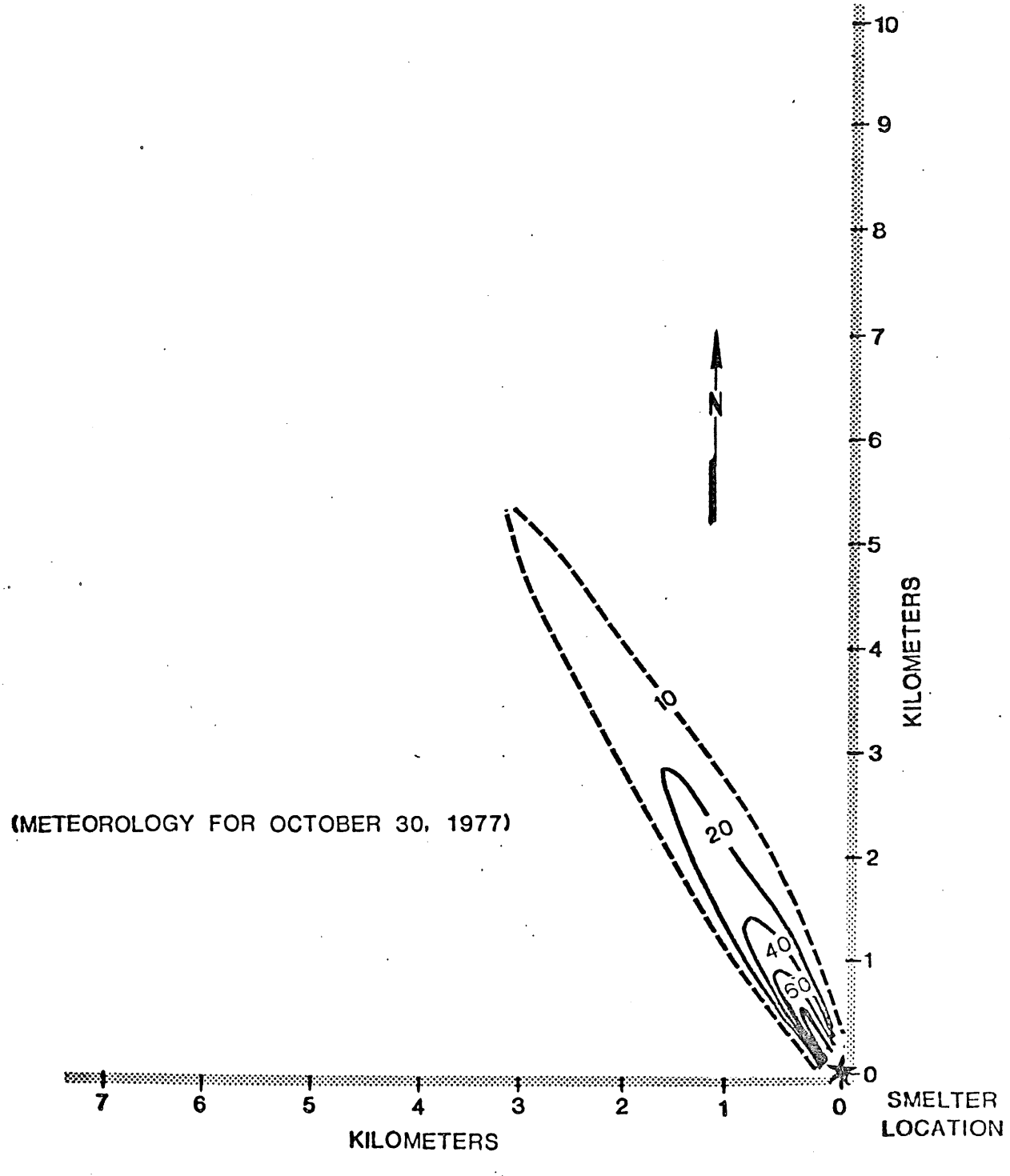
ISOPLETHS OF 24-HOUR AMBIENT SO_2 CONCENTRATIONS FROM THE STACK EMISSIONS FOR THE BASE CASE SMELTER MODEL (UG/M^3)



SOURCE : ENDERSEN (1979)

FIGURE 111

ISOPLETHS OF 24-HOUR AMBIENT SO_2 CONCENTRATIONS FROM THE FUGITIVE EMISSIONS FOR THE BASE CASE SMELTER MODEL (UG/M3)



SOURCE : ENDERSEN (1979)

assumed here,it is reasonable to further assume the two plumes will be parallel. The greatest air quality impact resulting from the superposition of the plumes can then be seen by evaluating the concentrations along their centerline. These two concentrations and their sum are shown in Figure 112 for the October 30 example just presented. Figure 112A shows the same results on an expanded axis to place the concentrations in perspective with respect to the 24-hour ambient SO_2 standards, as well as the PSD increments.

Figures 112 and 112A

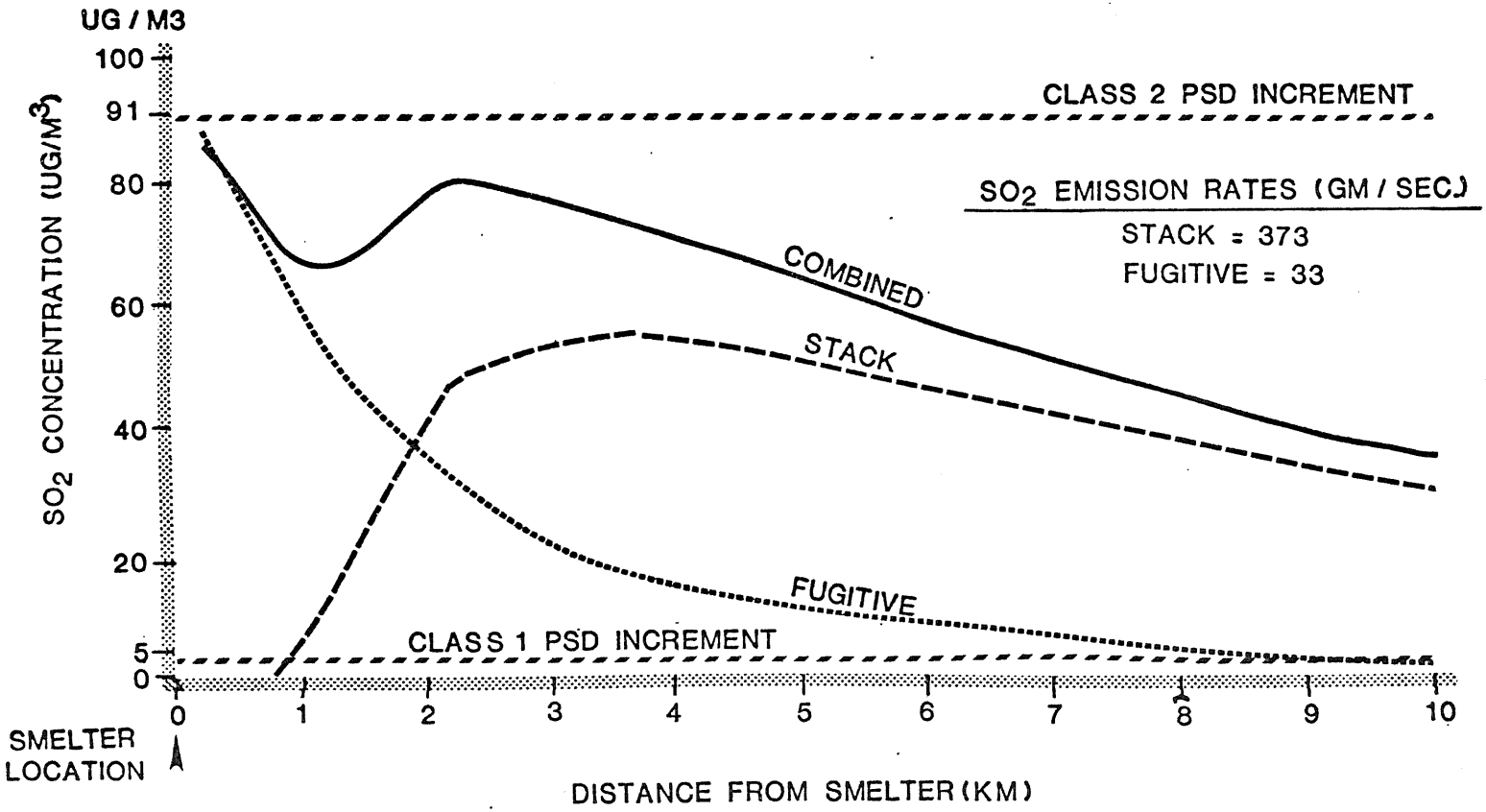
Note that the stack concentration has a broad peak ranging from 2 to 6 km out from the smelter, while the fugitive contribution is highest at the source and rapidly falls off with distance. The results shown here are typical of all 8 of the worst case days modeled, where maximum 24-hour concentrations ranged from approximately 50 to 90 ug/m^3 for the base case smelter model. The distance from the source at which the maximum concentrations occurred ranged from roughly 2 to 5 km.

The seasonal probability of the occurrance of conditions leading to worst case dispersion patterns typified be the example just given were investigated. The results indicate that maximum impacts would occur closer to the source during the warm season when the daytime atmosphere is generally more unstable and turbulent than during the cold season. The magnitude of these maximum impacts, however, seems to depend more on wind persistence than atmospheric stability. A careful examination of 1976-1977 meteorological data collected at the Hibbing Airport Flight Service Station clearly showed a much larger diurnal variation in wind direction during summer than during winter. This greater wind persistance during the cold season yielded many more worst case dispersion days during that part of

FIGURE 112

MAXIMUM PREDICTED 24 - HOUR SO_2 CONCENTRATIONS ALONG THE COMBINED PLUME CENTERLINE FOR THE BASE CASE SMELTER MODEL

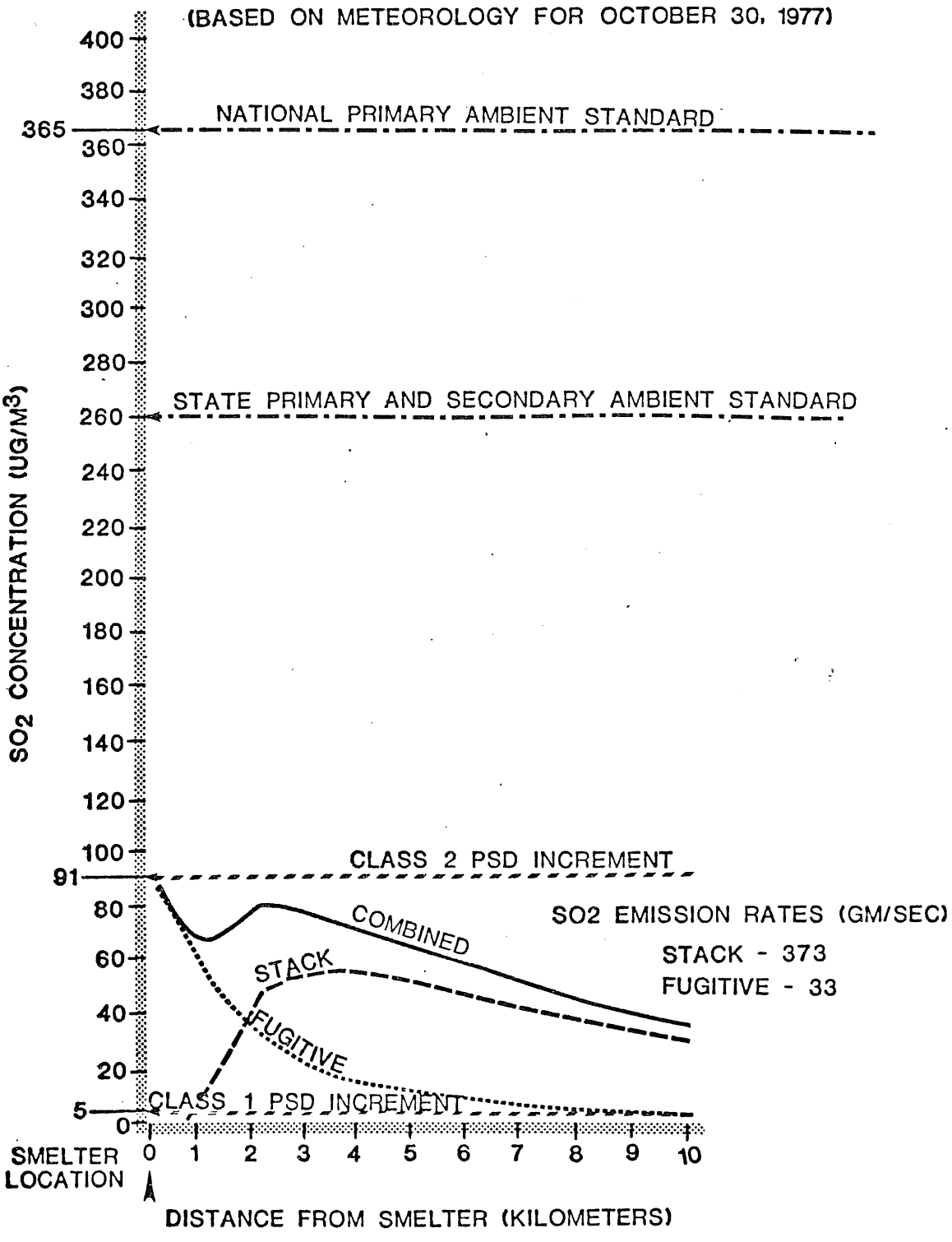
(BASED ON METEOROLOGY FOR OCTOBER 30,1977)



SOURCE : ENDERSEN, (1979)

FIGURE 112A

MAXIMUM PREDICTED 24-HOUR SO_2 CONCENTRATIONS ALONG THE COMBINED PLUME CENTERLINE FOR THE BASE CASE SMELTER MODEL



SOURCE : ENDERSEN (1979)

the year. Cold season plumes would generally be stable to slightly unstable and produce narrow areas of impact. Worst case dispersion days occasionally occur during the warm season, however, and could produce 24-hour maximum concentrations of stack emissions similar to those during winter. However, the warm season area of impact would be much broader than that for the cold season because of the generally more variable wind direction and enhanced dispersion.

With the plume centerline concentrations for the base case smelter model as a reference, it is interesting to look at the predicted effect of additional SO_2 emission controls as represented by the option 1 and option 2 smelter models. Figures 113 and 114 show the computed results for these models under the same meteorological conditions (October 30, 1977) as those used for the base case situation just presented.

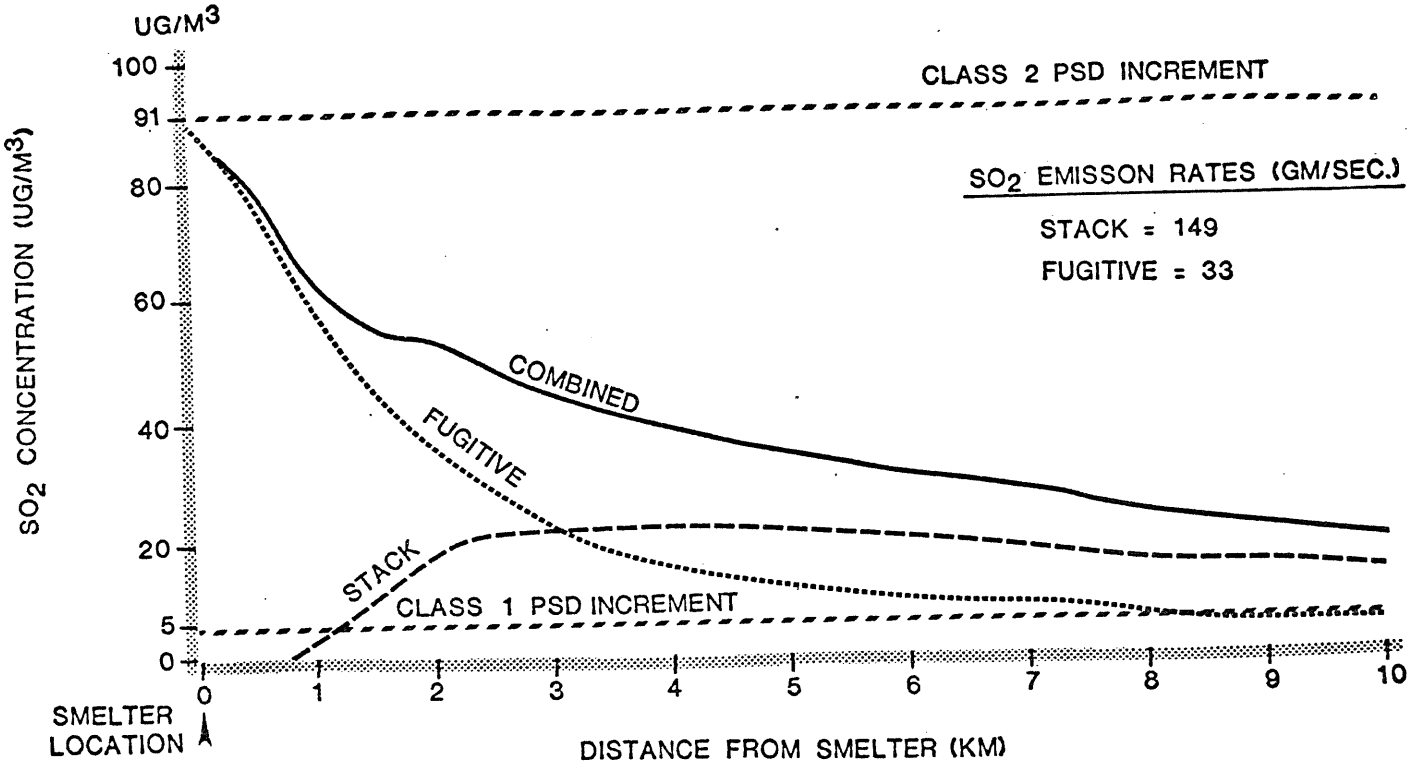
Figures 113 and 114

The first observation is that the fugitive contributions are the same for all three of these cases, since identical fugitive controls are assumed with good secondary hooding used throughout the smelter facility. The stack contributions vary with options 1 and 2 representing successively lower stack emissions through the application of scrubbers. The figures show that none of the three smelter models alone are predicted to exceed the Class II PSD increment beyond roughly 1/2 km from the source, but within the factor of 2 accuracy of the model, this increment could be exceeded. None of the smelter models will meet the Class I increment out to 10 km as shown in the figures. However, it is apparent that while the predicted base case concentrations will not fall below the Class I increment for many multiples of the 10 km distance show, the option 2 smelter (given the factor of 2 accuracy attributed to the model) could conceivable fall

FIGURE 113

MAXIMUM PREDICTED 24-HOUR SO_2 CONCENTRATIONS ALONG THE COMBINED PLUME CENTERLINE FOR THE OPTION 1 SMELTER MODEL

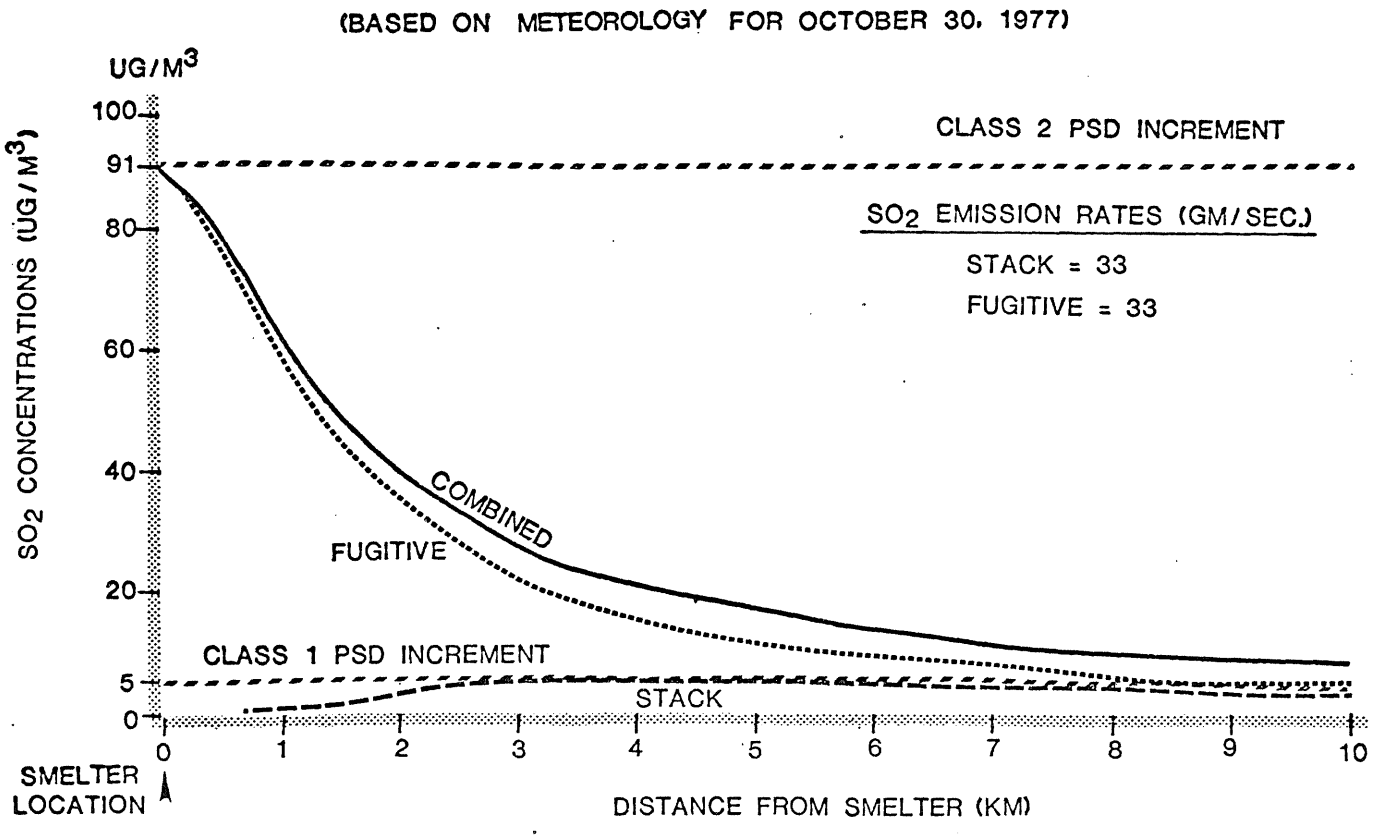
(BASED ON METEOROLOGY FOR OCT. 30, 1977)



SOURCE: ENDERSEN, (1979)

FIGURE 114

MAXIMUM PREDICTED 24-HOUR SO_2 CONCENTRATIONS ALONG THE COMBINED PLUME CENTERLINE FOR THE OPTION 2 SMELTER MODEL



SOURCE : ENDERSEN (1979)

below the increment even at 10 km. These results illustrate the important role of SO_2 control of stack emissions. The fugitive emissions have a high impact close to the source, while the stack effects are delayed and become dominant at greater distances. It is these effects which will likely determine how close a smelter may be located to a Class I PSD area.

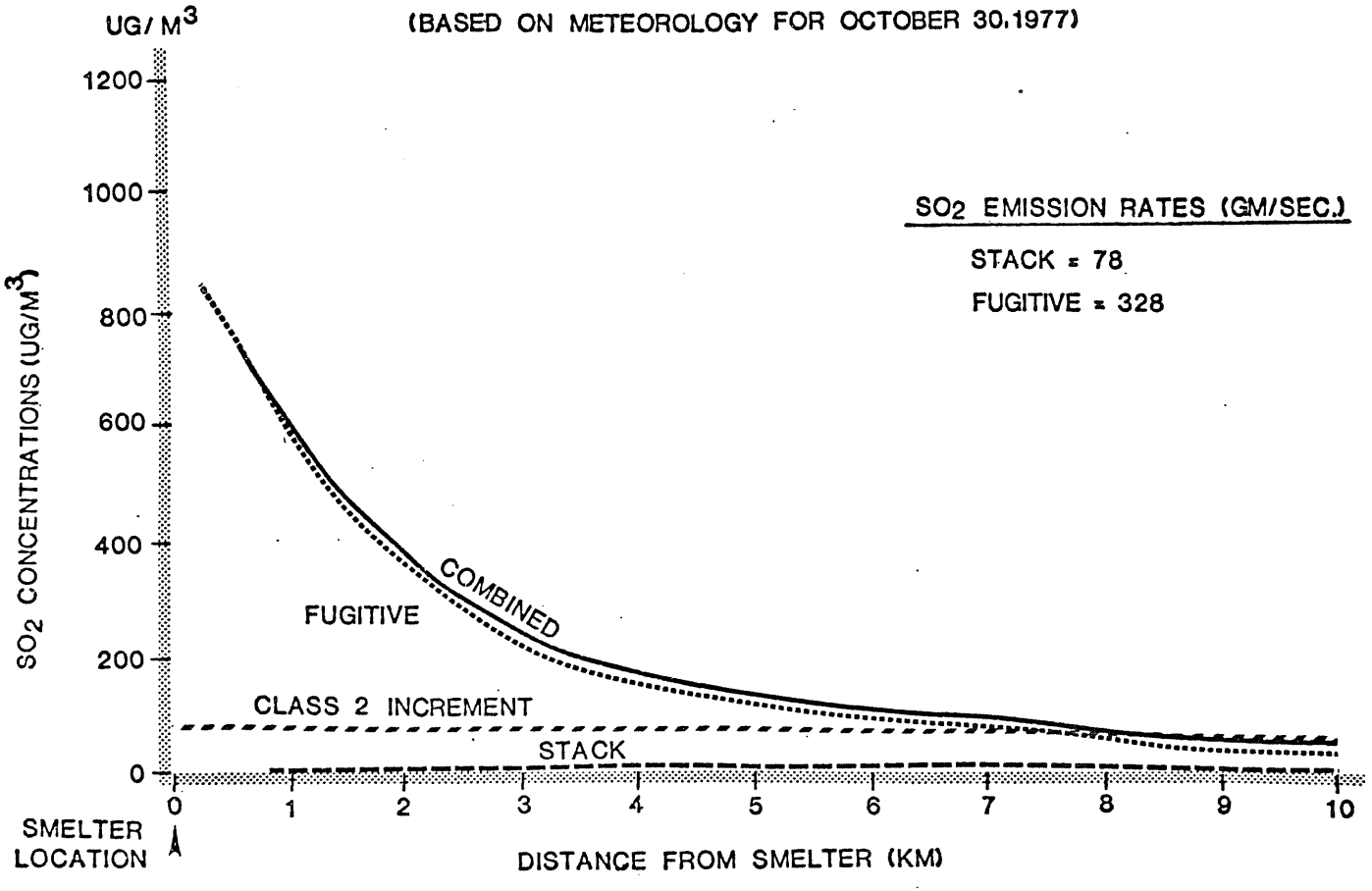
To further demonstrate the nature of air quality impacts due to fugitive emissions, the concentrations resulting from the basic smelter model were calculated and are shown in Figure 115. Recall that this smelter model has no secondary hooding collection of weak SO_2 gas streams. As such, it does not reflect the type of controls which would most certainly be incorporated in a new smelting facility. However, it is important to model this case to provide a picture of the implications of a failure of the complete secondary hooding system without a curtailment of the overall smelting operation. Clearly, the results indicate extremely high SO_2 concentrations, well above the Class II PSD increment within 3 to 4 km of the plant. In reality such levels could be prevented by immediate plant curtailment in the event of such an upset.

Figure 115

The short-range modeling results just presented provide a picture of potential smelter-induced 24-hour concentrations to some 10 km downwind of the smelter site. To complete the picture, the mesoscale modified gaussian model was used to compute plume centerline concentrations out to 75 km. As with the short-range model, specific days were selected for which meteorological conditions would tend to produce maximum SO_2 concentrations downwind of the smelter. Table 77 lists the days chosen and summary meteorological data for those days. Combined plume centerline concentrations were computed.

FIGURE 115

MAXIMUM PREDICTED 24-HOUR SO_2 CONCENTRATIONS ALONG THE COMBINED PLUME CENTERLINE FOR THE BASIC SMELTER MODEL (NO SECONDARY HOODING)



SOURCE : ENDERSEN, (1979)

Table 77

Figure 116 shows the results for one of the days (November 6, 1976) for the base case smelter model. Recalling that the long range model is not reliable close to the source (less than 5 km), the results are quite consistent with those of the short-range model given earlier in Figure 113. Both models show clearly that at 10 km from the source, the fugitive contribution from the base case smelter model is essentially negligible relative to that of the stack. Total concentrations are in the range of 35-40 ug/m^3 according to both models. This is typical of the results from all 5 of the days modeled. Further, the long-range model indicates that on 3 of the 5 days, the Class I SO_2 increment is exceeded even at 75 km from the source. On the remaining two days, the increment is exceeded up to 55 km from the source.

Figure 116

On the basis of these results it appears that a smelter with emissions similar to those in the base case model could not be sited within 75 km of a Class I area without causing the increment to be exceeded in that area. The spatial restrictions are reduced for the option 1 and option 2 smelter models, which have successively lower stack emission rates. Figure 117 shows the total predicted SO_2 concentrations for all 3 smelter models, again using November 6, 1976 as a reference day. The results indicate that the option 1 smelter model alone drops below the Class I increment at roughly 35 km and the option 2 smelter drops below at about 13 km.

Figure 117

Table 77. Meteorology for selected single day runs of the modified gaussian model.

DATE	WIND DIRECTION	WIND SPEED (km/hr)	STABILITY	MIXING HEIGHT (m)
10/28/76	SSW	22.2	neutral	1100
11/6/76	WNW	24.6	neutral	1100
12/20/76	NW	23.4	neutral	650
1/15/77	WNW	19.6	neutral	650
2/28/77	NW	16.9	neutral	1150

FIGURE 116

MAXIMUM PREDICTED 24-HOUR SO_2 CONCENTRATIONS ALONG THE COMBINED PLUME CENTERLINE FOR THE BASE CASE SMELTER MODEL (MODIFIED GAUSSIAN MODEL)

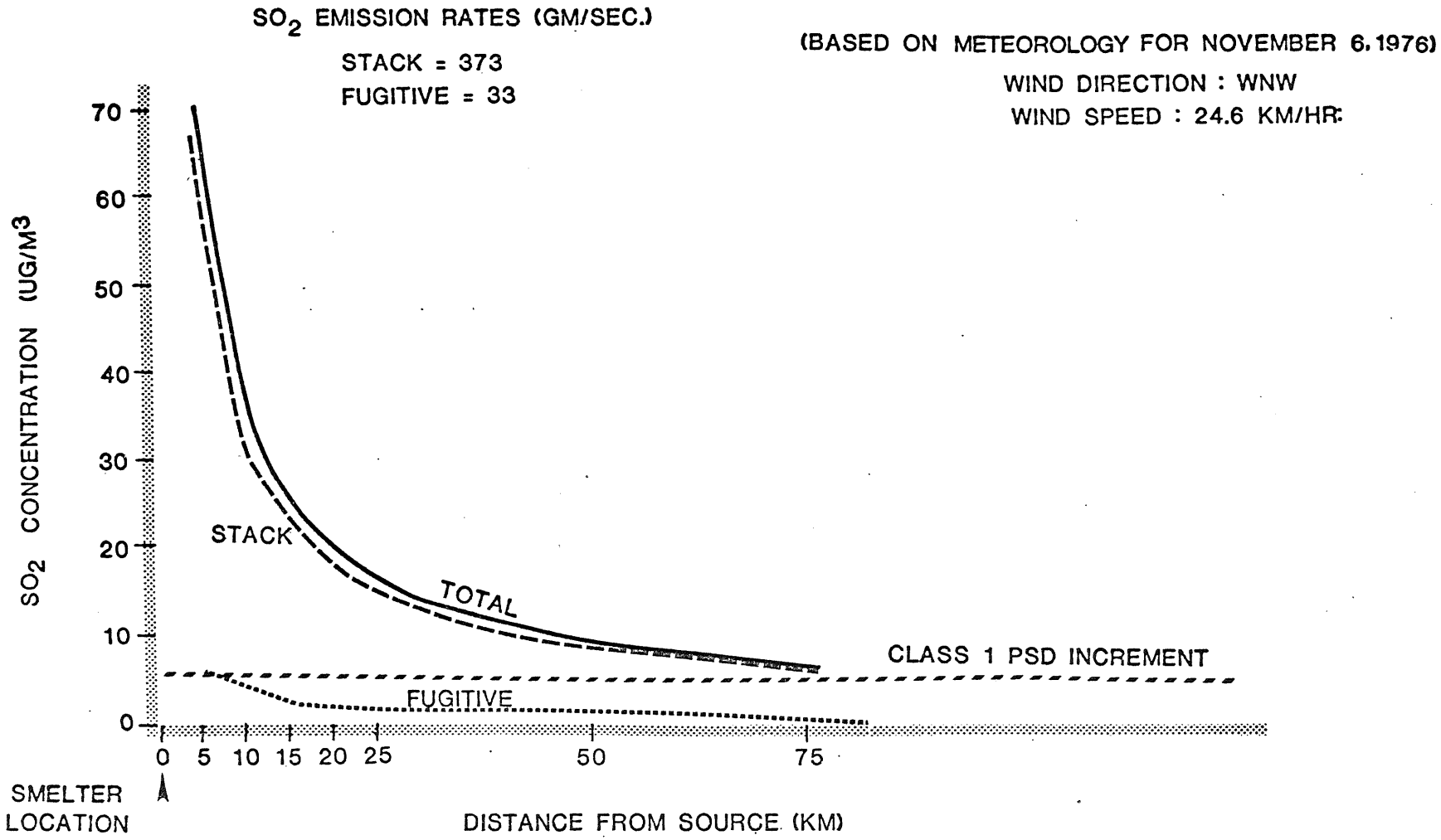
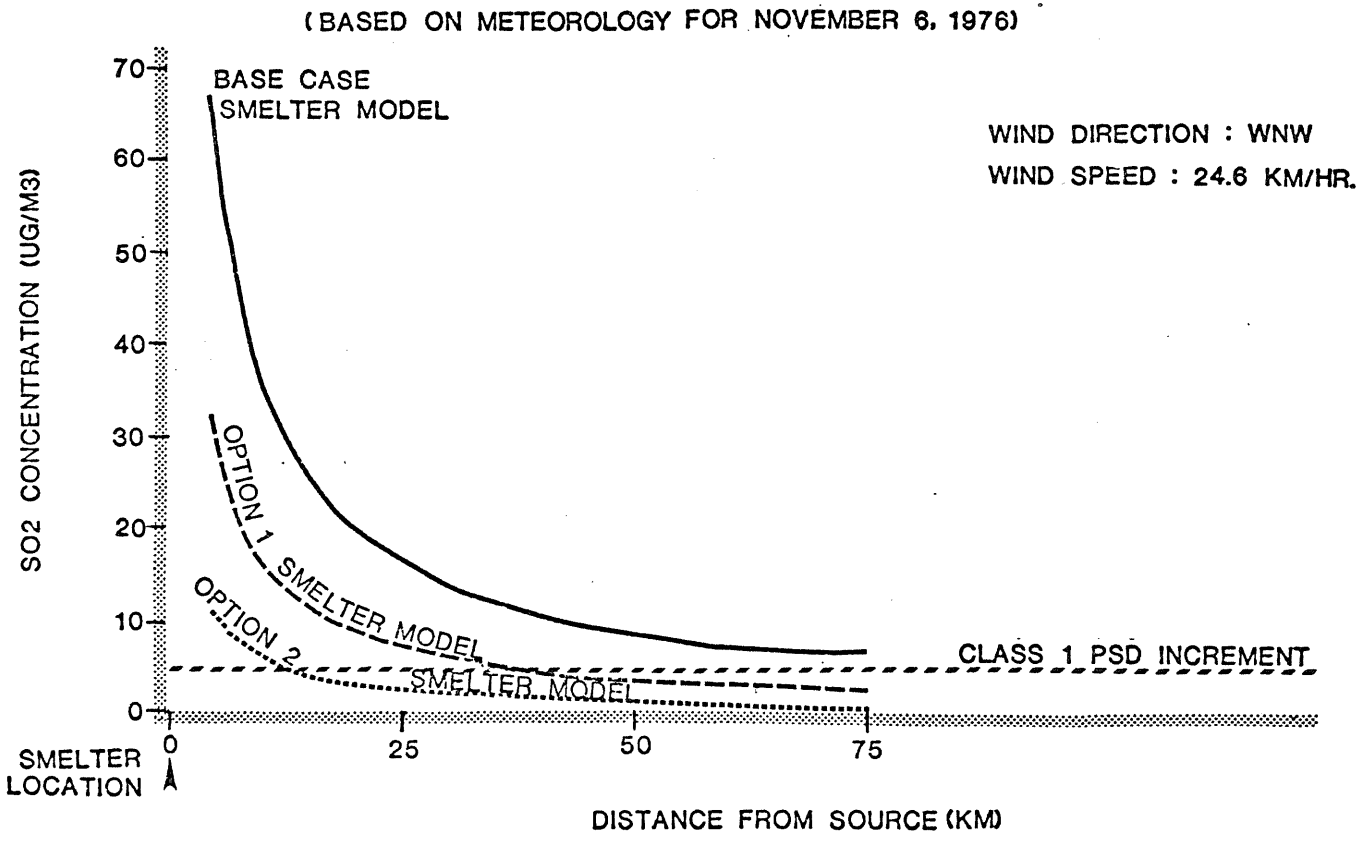


FIGURE 117

MAXIMUM PREDICTED 24-HOUR SO_2 CONCENTRATIONS RESULTING FROM THREE MODEL SMELTER CASES (USING THE MODIFIED GAUSSIAN MODEL)



Based on these results, it is possible to rather generally zone the space surrounding any Class I areas. The zones refer only to the ability of a smelter facility to avoid exceeding the Class I 24-hour SO_2 PSD increment when acting alone. The effect of other sources utilizing a portion of the increment would be to increase the distances needed between the Class I area and the smelter site. Figure 118 indicates the zones based on the 5 single day runs of the modified gaussian model just presented. Of course, the distances could be off by a factor of 2 based on the accuracy attributed to this model.

Figure 118

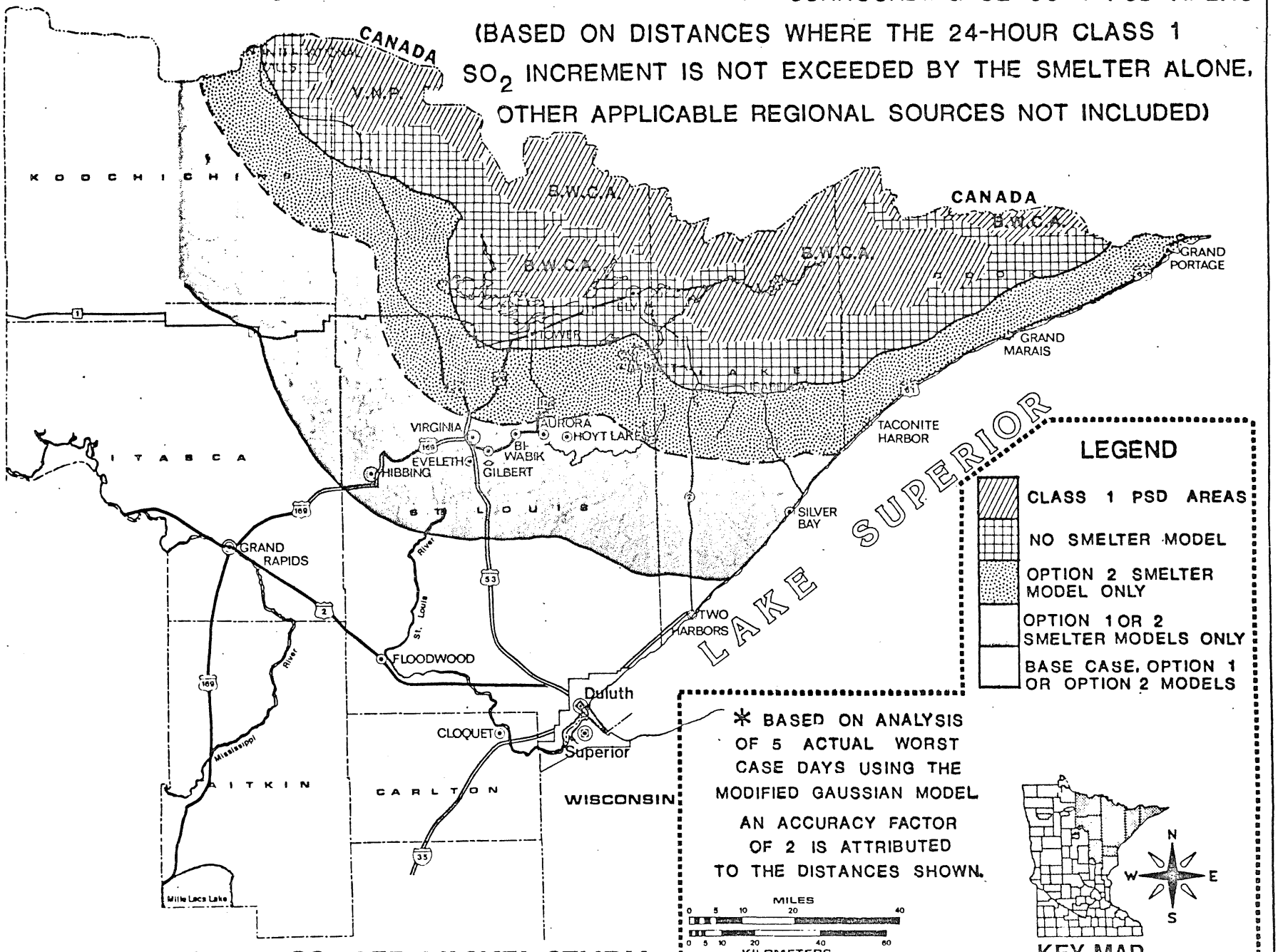
When these data are applied to the Regional Copper-Nickel Study's development zones (Figure 119) it is seen that none of the smelter models (acting alone) are predicted to be capable of meeting the 24-hour PSD Class I increment in zones 1 or 2. The option 2 smelter could meet requirements in zones 3 and 4, while the option 1 (and 2 of course) could meet the increment requirements in zones 5, 6, and 7. The base case smelter could not meet the increment in any of the development zones. Within the factor of 2 accuracy of the model, at worst, none of the smelters could meet the increment in zones 1, 2, 3 and 4, and only the option 2 smelter could be located in zones 5, 6, and 7. The other smelter models would not meet requirements in any of the zones. Again, the above assumes that the entire increment is given to the smelter alone.

Figure 119

As noted earlier, exceedances of the 24-hour Class I PSD increment are predicted at several receptors even without any copper-nickel development. Taking this into consideration, smelter siting would appear to be excluded in areas which are

FIGURE 118 SMELTER SITING ZONES* SURROUNDING CLASS 1 PSD AREAS

(BASED ON DISTANCES WHERE THE 24-HOUR CLASS 1 SO_2 INCREMENT IS NOT EXCEEDED BY THE SMELTER ALONE, OTHER APPLICABLE REGIONAL SOURCES NOT INCLUDED)



MEQB REGIONAL COPPER-NICKEL STUDY

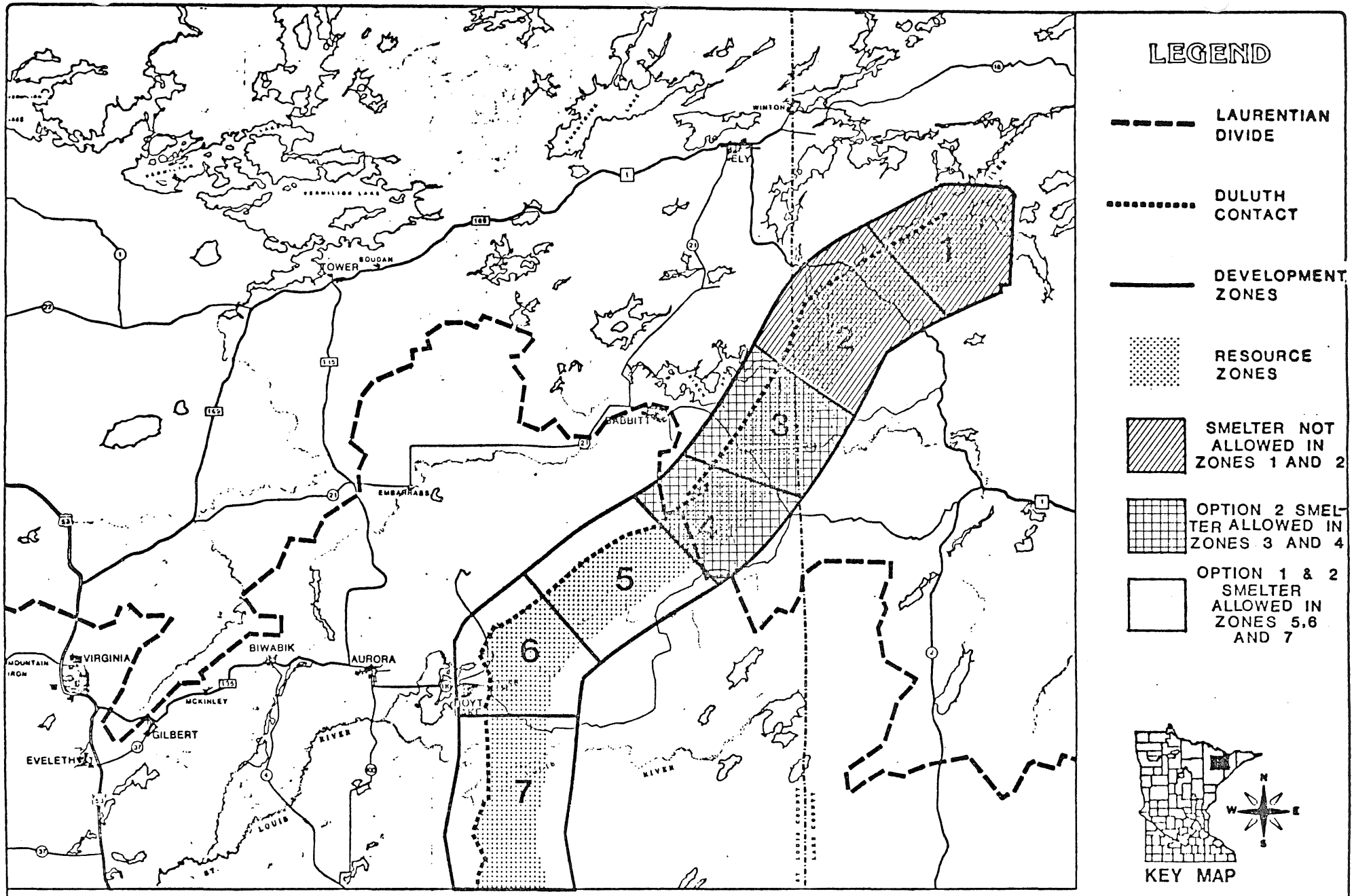


FIGURE 119 **MEQB REGIONAL COPPER-NICKEL STUDY**

RESTRICTIONS ON SMELTER SITING IN MN CU/NI DEVELOPMENT ZONES
BASED ON SO_2 CONCENTRATIONS ON 5 SINGLE WORST CASE DAYS

between the expected concentration of sources along the Iron Range, and any Class I areas. Thus, siting in development zones 1, 2, 3, and possibly 4 and 5 as well may be precluded due to this consideration alone. This conclusion is independent of the degree of SO_2 control achieved by the smelter, since the increment is already expected to be consumed by planned new or expanded SO_2 point sources. Sites which move off the lines from the Iron Range to Class I areas may avoid this difficulty, making zones 6 and 7 look most promising in this regard.

The above discussion and associated zone designations are not intended to indicate the desirability or acceptability of a smelter site in any particular area. This is a question to be determined by the appropriate authorities. Rather, this discussion is intended to illustrate the major air quality factors which will have to be considered in making this determination. It is apparent that the 24-hour PSD increment in a Class I area is one of the standards that will have a major influence on smelter siting in the Study Area if the standard is to be met. The effect of other new SO_2 sources is also important, since they may consume some or all of the allowed increment, potentially excluding a smelter from the region. Clearly, the decisions to be made here must involve the long range planning (such as might be reflected by emission density zoning) for any future industrial development in the Study Area as a whole. These conclusions are supported by both modeling approaches used.

3.7.1.3 3-Hour Concentrations

In order to investigate the possible short-term concentrations resulting from smelter emissions, the base case smelter model was used along with the short range stack and fugitive dispersion models (see Endersen 1979). Eleven hypothetical meteorological scenarios covering a range of conditions were used,

and 3-hour SO_2 concentrations were calculated. The resulting concentrations were found to be strongly dependent on stability class. Increasing atmospheric stability causes the distance to the maximum concentration to increase, and the resulting concentrations decrease more slowly with distance.

The effect of stability class on the distance to the downwind maximum is shown in Table 78, along with the maximum concentration. Stability class E produced the highest maximum downwind concentration, 281 ug/m^3. This condition could occur at night during any season. Figures 120, 121, and 122 illustrate the falloff of concentration with distance for stability classes C, DD and E, resepectively. Note that as the stability increases, the downwind peak due to stack emissions moves out, and concentrations fall off more slowly from the peak value.

Table 78, Figures 120, 121, and 122

For these 3-hour scenarios with the base case smelter model acting alone, all computed concentrations are below the Class II PSD increment of 512 ug/m^3. However, only the stability B case dropped below the Class I increment of 25 ug/m^3 within 10 km of the source. In all but the most stable cases, the increment is exceeded principally due to the stack emissions. Thus, as the stack emissions are reduced the concentrations far downwind decrease correspondingly. For the option 2 smelter, for example, stack emissions are roughly one tenth those of the base case model so that for stability C (Figure 120) the concentration would drop below the Class I increment within 6-8 km of the site. For the class E stability case (figure 122), the option 2 smelter would still exceed the class I increment at 10 km due to the fugitive emissions alone. However, concentrations are dropping off and would be predicted to fall below the increment not far beyond the 10 km range shown on the graph.

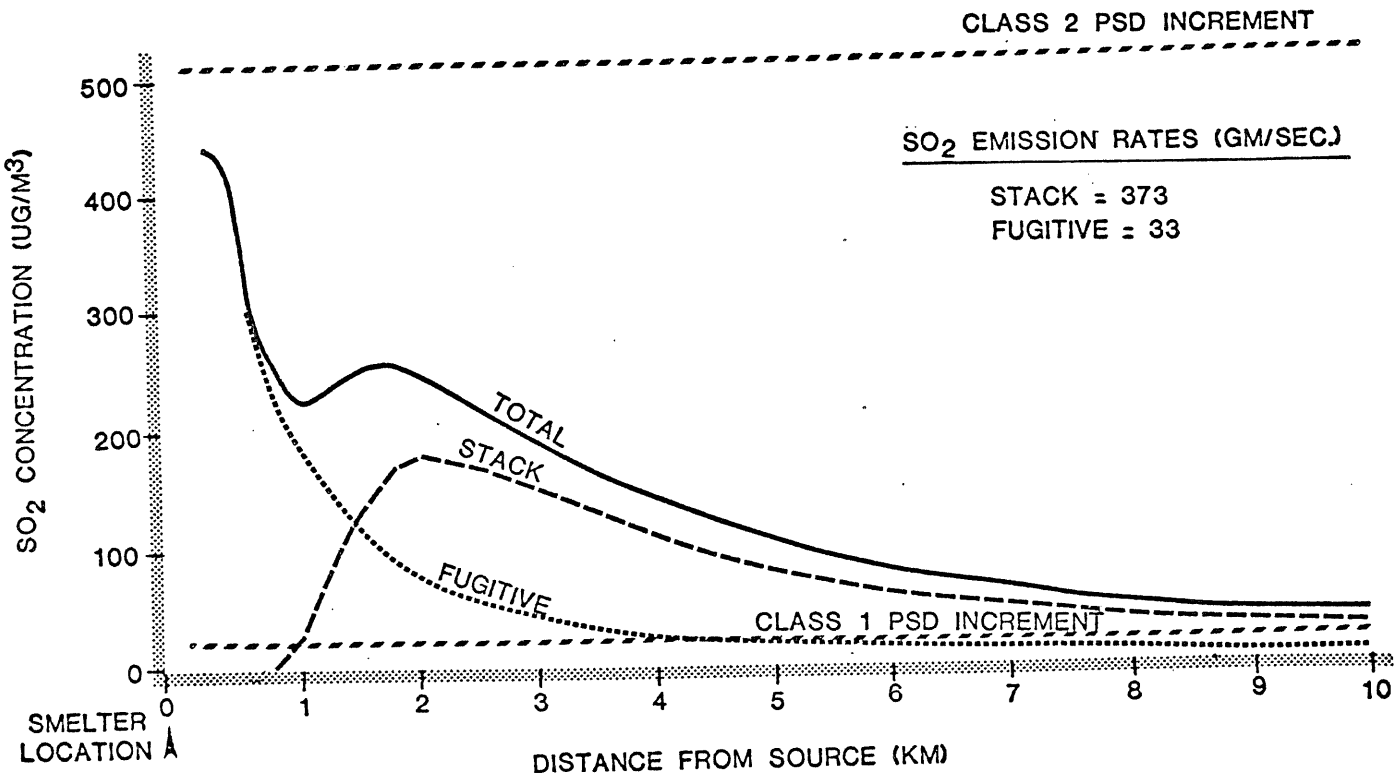
Table 78. Predicted maximum downwind 3-hour SO_2 concentrations for the base case smelter model.

STABILITY CLASS	MAXIMUM CONCENTRATION DOWNWIND (ug/m^3)	DISTANCE (km)
B	233	1.1
C	254	1.8
DD	202	2.8
E	281	5.0
F	164	9.2

SOURCE: Endersen 1979.

FIGURE 120

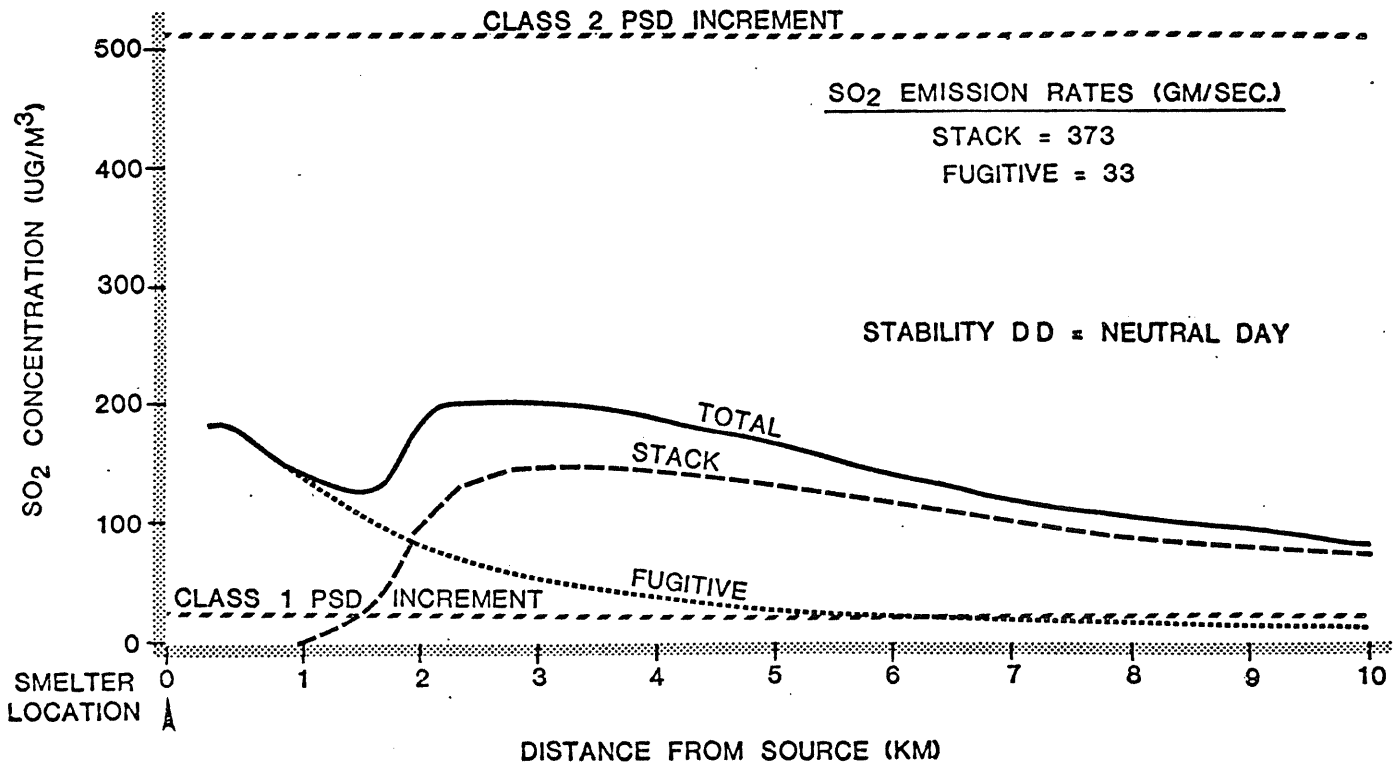
PREDICTED MAXIMUM 3-HOUR SO_2 CONCENTRATIONS ALONG THE COMBINED PLUME CENTERLINE FOR THE BASE CASE SMELTER MODEL WITH STABILITY C CONDITIONS



SOURCE : ENDERSEN (1979)

FIGURE 121

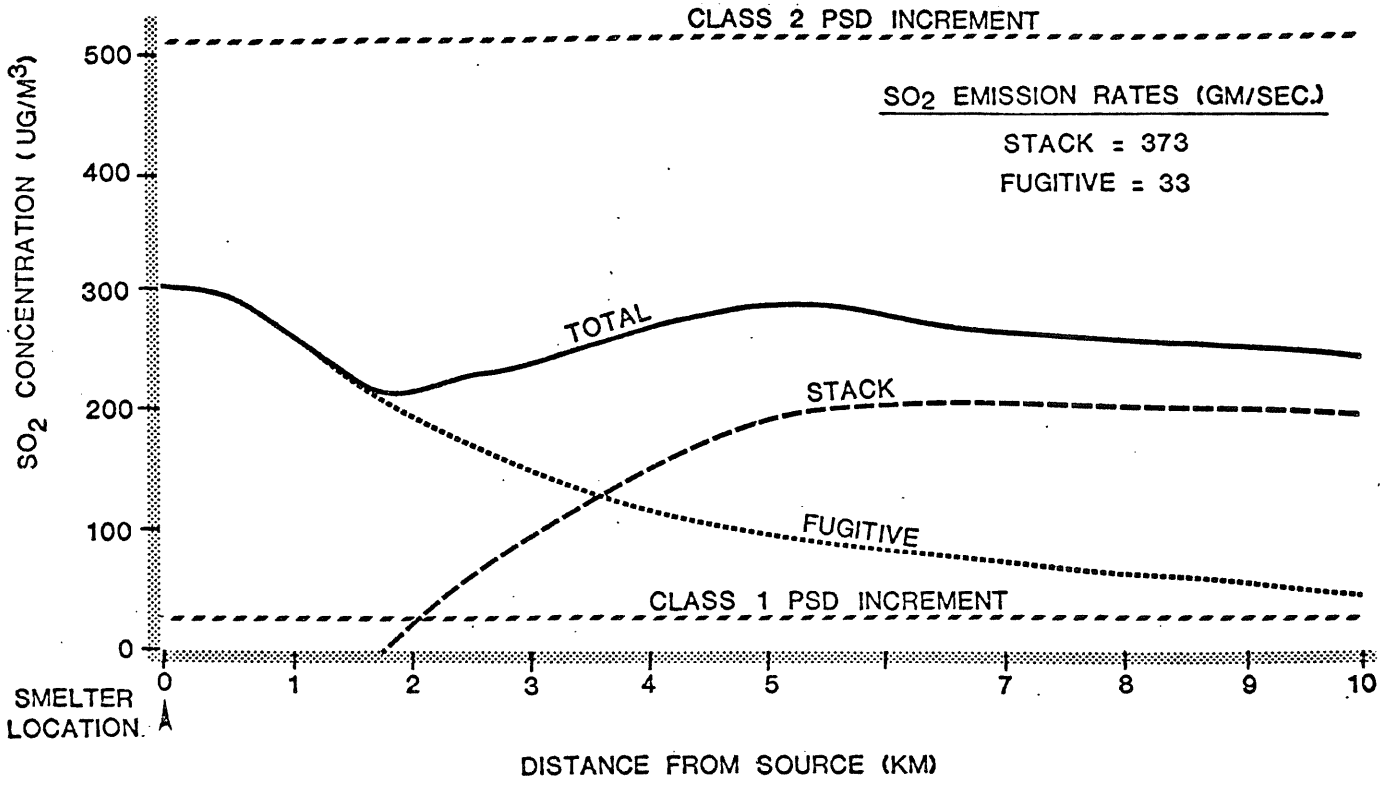
PREDICTED MAXIMUM 3-HOUR SO_2 CONCENTRATIONS ALONG THE COMBINED PLUME CENTERLINE FOR THE BASE CASE SMELTER MODEL WITH STABILITY D D (D-DAY) CONDITIONS



SOURCE : ENDERSEN, (1979)

FIGURE 122

PREDICTED MAXIMUM 3-HOUR SO_2 CONCENTRATIONS ALONG THE COMBINED PLUME CENTERLINE FOR THE BASE CASE SMELTER MODEL WITH STABILITY E CONDITIONS



SOURCE: ENDERSEN, (1979)

As was the case with the 24-hour concentrations, this analysis shows that the Class I PSD increments are predicted to be exceeded by a smelter if it is located too close to a Class I area. Highest concentrations occur under the more stable conditions, but these conditions occur frequently in the area. Based on data from International Falls from 1970-1974 stability DD (D-day) occurs some 33% of the time. Stability DN (D-night) and E occur 29% and 27% of the time, respectively (see the meteorology discussion, section 3.3.2.4).

The reliability of the short term emission estimates for the smelter is lower for 3-hour periods than for 24-hour periods since short term fluctuations may occur. Thus the siting implications of Class I PSD regulations were considered in the context of the 24-hour increment. It is clear, however, that the 3-hour increment would also be in jeopardy with a smelter located too close to a Class I area. Even without a more detailed analysis, it is valid to conclude that the basic zones discussed in the 24-hour analysis are reinforced by these results.

One further situation must be considered in the context of 3-hour SO_2 concentrations, that of possible equipment failure or other upset conditions occurring at a smelter. The emissions possibilities from such upsets are too numerous to discuss in a comprehensive manner. Nevertheless, it is important to look at one or two upset scenarios simply to place the problem in focus. No attempt is made to consider the probability of occurrance of the two upset scenarios to be considered. This is an area which would require specific performance data on individual devices and must be treated on a site-by-site basis.

In order to address the upset questions, the short range models were used to compute combined plume centerline concentrations from two basic upset scenarios. Both scenarios are modifications of the base case smelter model. The first is a

stack scenario which considers the implications of a greatly increased stack emission rate while the second considers increased fugitive emissions. The cases are:

1) Stack Upset: This case might conceivably occur during the failure of a major piece of air pollution control equipment such as the acid plant. All the SO_2 normally treated by the control equipment is assumed to by-pass the acid plant and be released directly to the atmosphere through the stack. This SO_2 release would include all of the strong gas stream (10,031 gm/sec) as well as 90% of the weak gas stream normally collected by the secondary hoods (295 gm/sec) for a total of 10,326 gm/sec of SO_2. Stack parameters were the same as for normal operating conditions except that the exit gas temperature was assumed to be raised to 300°C to reflect the loss of cooling which normally occurs during acid manufacturing. The normal operating conditions for fugitive SO_2 release (at 33 gm/sec) is assumed to continue to occur unaltered.

It is assummed that this type of upset condition might occur for up to a few hours (during which repairs would be made or smelter operations would be brought to a halt). For modeling purposes, these emission rates were assumed to last for three hours.

2) Fugitive Upset: The second upset case is intended to simulate a situation which might occur if a major catastrophic failure were to lead to the low level release of most or all the SO_2 normally treated by the air pollution control equipment. Such a freak occurrence, though highly unlikely, is conceivable and could cause the release of all of the strong and weak SO_2 streams, a total of 10,359 gm/sec, as fugitive emissions. This emergency situation would certainly lead to a smelter shut-down as soon as possible. In reality, the period of

release could be from a few minutes to a few hours, depending on the nature of the smelting equipment being used and the response of the smelter personnel. Purely for modeling purposes, such emissions were assumed to last for three hours.

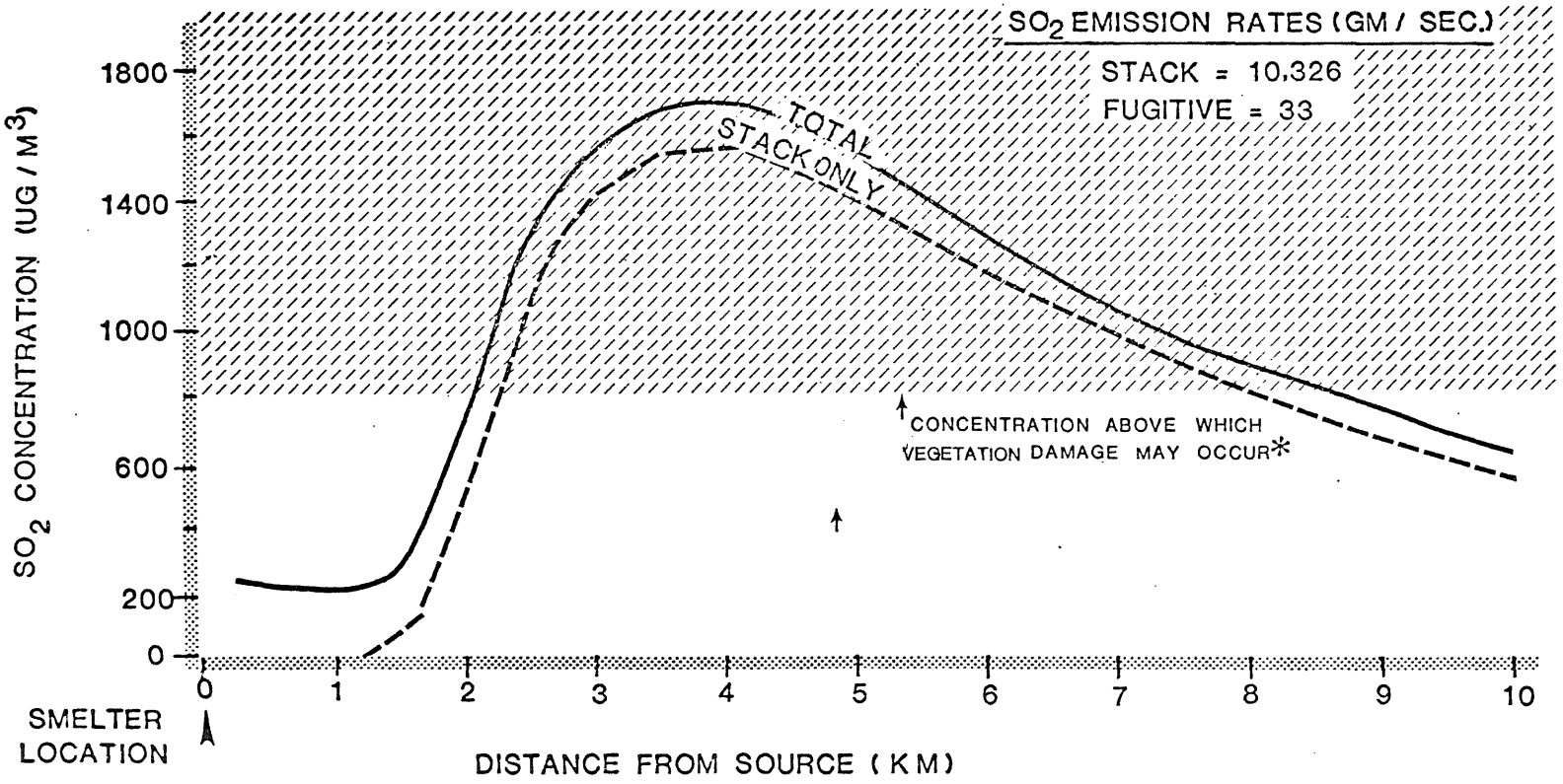
For the stack upset scenario, a typical worst case would occur during periods of light wind with unstable conditions such as occur during sunny summer days. The conditions used in the models were the same as those used to compute the 3-hour C stability for the base case smelter model results just discussed. The results are presented in Figure 123. The maximum concentration is 1,690 ug/m^3 at 3.8 km downwind which exceeds all ambient air quality standards. This value is about seven times greater than the concentration for the base case model during normal operations with the same meteorological conditions. The peak concentrations would also occur farther downwind than under normal conditions because the higher exit gas temperature results in greater plume rise. For comparison, the shaded area in the figure indicates the concentration range within (or above) which visible damage to vegetation may occur (see Volume 4-Chapter 2). Vegetation damage is a distinct possibility should such an upset situation occur.

Figure 123

A worst dispersion case for the fugitive upset release, on the other hand, occurs with a stable atmosphere which prevents a plume released near ground level from dispersing rapidly downwind. The case selected for modeling was F stability conditions used for the 3-hour cases discussed earlier (see Endersen, 1979). This case estimates concentrations under stability conditions which typically occur at night during all seasons. Results of computations with the fugitive model are presented in Figure 124. Computed concentrations are extremely high.

FIGURE 123

PREDICTED MAXIMUM 3 - HOUR SO_2 CONCENTRATIONS ALONG THE COMBINED PLUME CENTERLINE FOR THE STACK UPSET SMELTER SCENARIO WITH STABILITY C CONDITIONS



SOURCE : ENDERSEN, (1979)

* BASED ON THE OCCURRENCE OF VISIBLE DAMAGE FOR A 3-HOUR EXPOSURE FOR A SELECTED NATIVE SPECIES (SEE VOLUME 4, CHAPTER 2, SECTION 2.9.1.2.)

The level is about 76,000 ug/m^3 at 0.25 km and decreases exponentially with distance. These concentrations are much higher than those computed for the upset stack release; in fact, they are about 27 times greater than the concentrations for the stack release case at 3.8 km, the distance of maximum stack release concentrations. For comparison, it should be noted that coughing, sneezing, and other discomforts occur in humans exposed to concentrations from 20 to 100 ppm (53,000-270,000 ug/m^3) (Schuman et al. 1977). The shaded area in the figure shows concentrations above 20 ppm. Should such an upset occur, persons within 1 to 2 km of the smelter may experience acute discomfort.

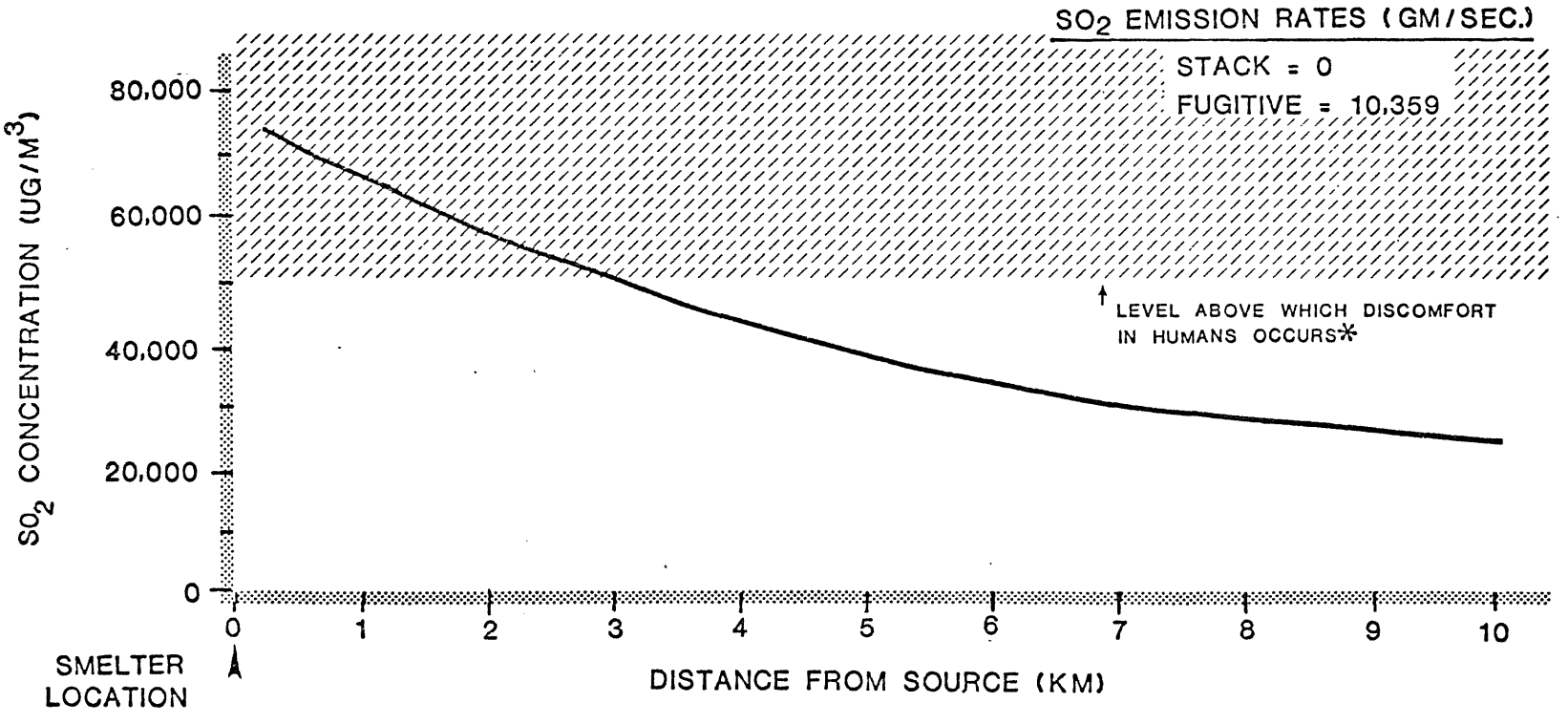
Figure 124

Most of the difference between these two sets of results is real. A plume released into very stable air near the surface is expected to cause considerably higher concentrations than is a hot plume released through a stack. Part of this difference, however, may be artificial. Gaussian models do not deal well with stable conditions, and, as discussed previously, the Fugitive Model is considered to be conservative for stable atmospheres. Thus, the specific values predicted here should be viewed only as order of magnitude projections. Nevertheless, the extremely high potential concentrations, particularly from low level fugitive emissions, underscore the need for emergency procedures. Plans for dealing with major upsets, as well as proper staff training in the immediate implementation of the emergency plans can constitute a major safeguard against such emissions occurring for more than minutes should a major upset take place.

3.7.1.4 Lakeshore Influences--The previous discussion focused on the potential air quality impacts of SO_2 emissions from a smelter located in the Study Area. The analysis is based on a site in gently rolling terrain with little local

FIGURE 124

PREDICTED MAXIMUM 3 - HOUR SO_2 CONCENTRATIONS ALONG THE COMBINED PLUME CENTERLINE FOR THE FUGITIVE UPSET SMELTER SCENARIO WITH STABILITY F CONDITIONS



SOURCE.: ENDERSEN, (1979)

*BASED ON SHORT TERM EXPOSURE ABOVE 20 PPM CAUSING COUGHING.SNEEZING. AND OTHER DISCOMFORTS (SCHUMAN ET. AL., 1977)

relief. Meteorological data from Hibbing and other stations in the area were used. These inputs are reasonably valid for any site in and adjacent to the Study Area, but cannot be expected to hold if the site location moves to a region with radically different meteorological or topographical characteristics.

The Duluth-Superior area, which is a potential location for smelting and/or refining facilities to treat Minnesota copper-nickel concentrates, presents such a radically different environment. As discussed in the meteorology characterization, section 3.3.3, the presence of Lake Superior and the high bluffs surrounding portions of the city act to create an extremely complex meteorological environment in the area. A great deal of monitoring and modeling work would be needed to adequately predict the air quality impacts of SO_2 emissions from a smelter in this area. Such a study was beyond the scope of this project. However, a few general observations may be made to indicate the types of air quality impacts which might be expected to occur. These observations may then serve to aid in the planning for more site-specific studies.

Two basic situations inhibiting the dispersion of stack plumes adjacent to a large, cold lake are discussed by Lyons and Cole (1973). The situations might occur during spring or summer days with stable onshore air flow from the lake. The resulting effects on a stack emission may lead to plume trapping or fumigation. Each of these phenomena will be briefly described.

Plume trapping is a condition which may occur principally during spring and summer when cold onshore flows of air move under warmer air masses from the land surface. If a plume is injected through the cold layer into the warmer air above no problems occur. However, plumes from a relatively short stack may be injected into the cold surface layer and be trapped by the overlying inversion. The

resulting reduced mixing height creates poor dispersion conditions which can enhance ground level SO_2 concentrations over those modeled earlier for the Study Area.

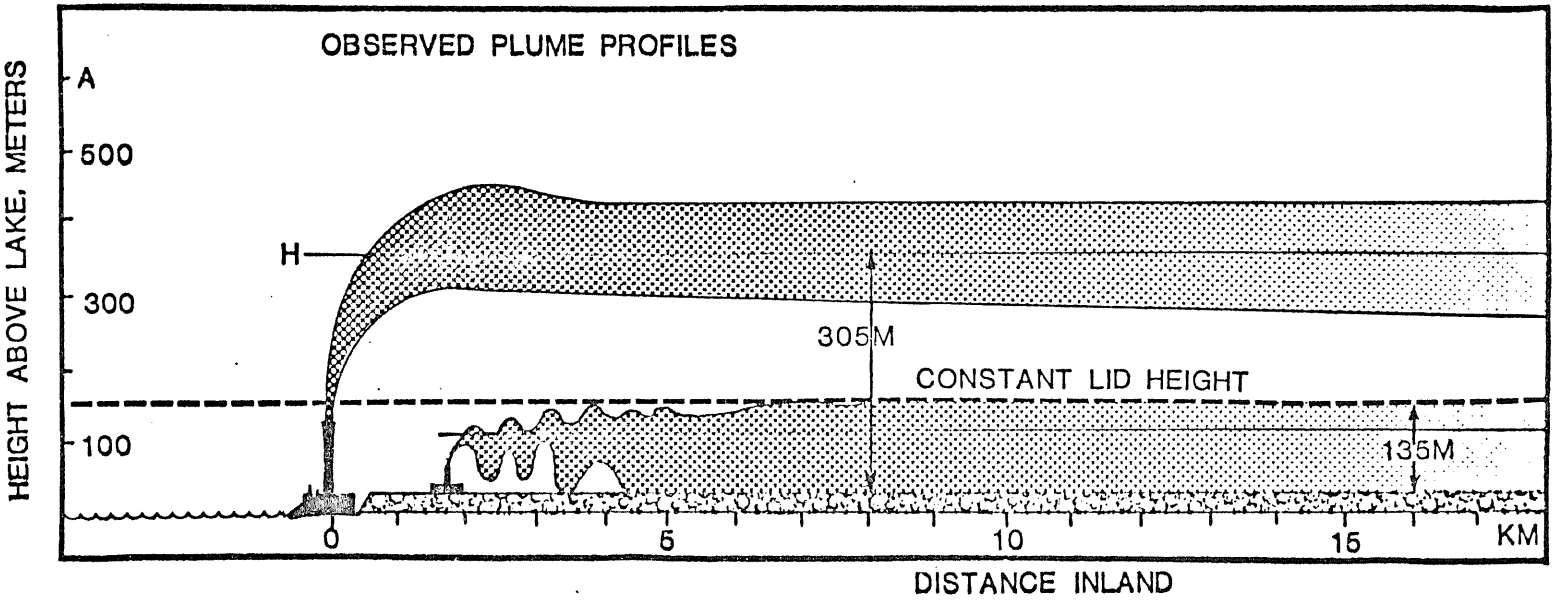
The trapping problem can be further complicated on cloudy spring days, for example, if the cold incoming air from the far offshore portion of the lake is briefly warmed at the bottom by warmer surface water temperature in the shallow areas near the shore. This brief warming destroys the strong inversion present at the surface due to conduction from the cold offshore waters, and a shallow surface layer of turbulence is created. Studies conducted on Lake Michigan indicate this layer may be 100 to 200 m thick (Lyons and Cole 1973). Plumes injected into this layer experience a very limited effective mixing height and may be strongly mixed to the ground due to the turbulence in the layer. The resulting elevated SO_2 concentrations could persist for kilometers as the air flows inland with relatively little warming as a result of the overcast conditions. Figure 125 schematically illustrates the behavior of two plumes (one injected into the turbulent surface layer and one above it) observed in a Lake Michigan study (Lyons and Cole 1973).

Figure 125

The second condition, fumigation, may occur under conditions somewhat similar to those described above when cold stable lake air moves inland during the daytime in spring or summer. However, unlike the trapping situation above, this condition occurs during sunny days when the surface air temperature warms rapidly with distance inland. The result is the formation of a "thermal internal boundary layer" (Lyons and Cole 1973) beginning at the shoreline and moving up in a general parabolic shape with distance inland. The layer separates the stable

FIGURE 125

EXAMPLE OF PLUME TRAPPING OF EMISSIONS FROM A SHORT STACK INTO TURBULENT SURFACE LAYER DURING ON SHORE FLOW FROM A LARGE LAKE (TALL STACK EMISSIONS ARE INJECTED INTO STABLE AIR ALOFT AND ESCAPE TRAPPING)



SOURCE: LYONS AND COLE (1973)

incoming lake air from the warmer unstable air heated over the land. A stack emission close to the lake shore would inject a plume into the stable onshore flow above the boundary layer. When this plume flows inland and strikes the unstable air at the internal boundary layer, the resulting strong downward mixing may result in rapid fumigation of the plume to the ground. Figure 126 schematically illustrates this mixing regime.

Figure 126

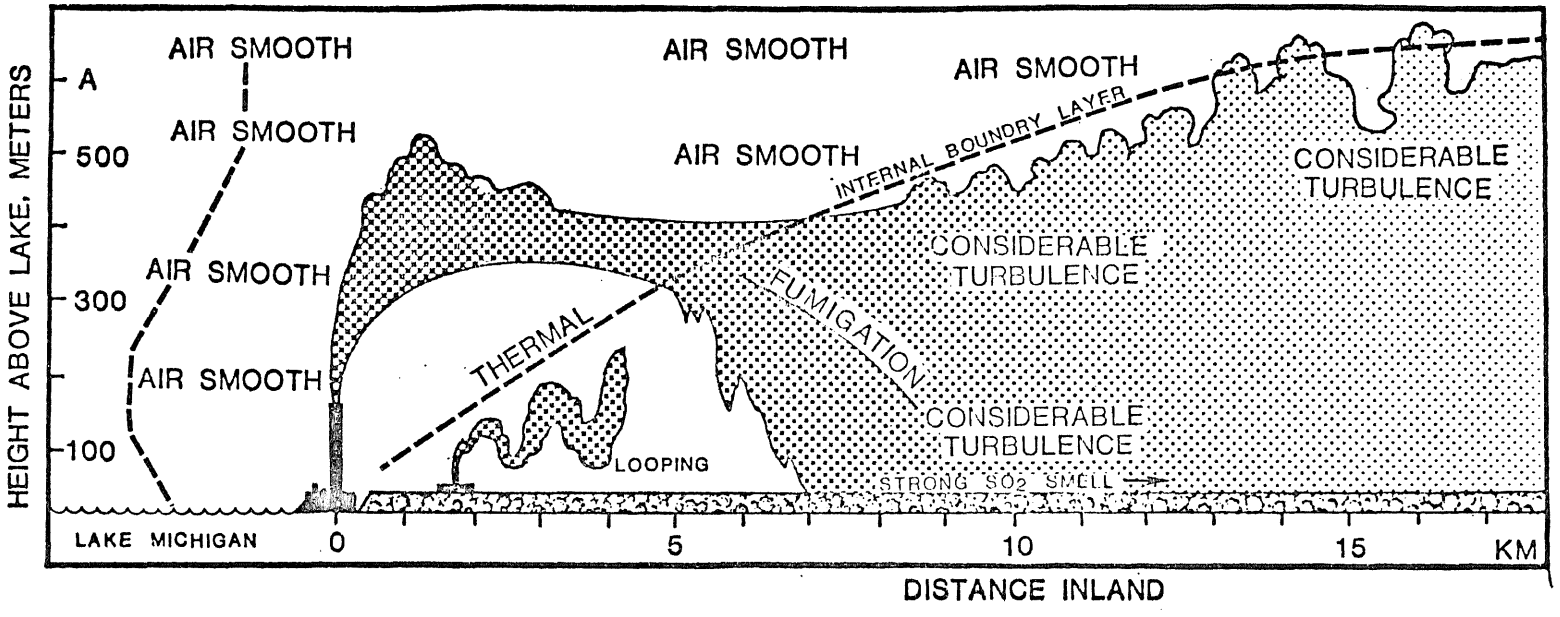
The lake effects discussed above all basically derive from the fact that a large cold body of water like Lake Superior will invariably be the source of cold stable onshore air flows that create strong inversions at certain times of the year, particularly during the spring and summer when air flows from land surfaces are relatively warm. Emissions into these cold layers experience poor dispersion conditions that may act to increase ground level concentrations of pollutants, principally SO_2 in the case of a smelter. In Duluth, the presence of bluffs further complicates this situation by acting to trap cold air, creating the potential for stagnant inversions beneath the bluffs. This greatly complicates the meterological situation as well, and little work has been done to model air emissions in this situation. The interested reader is referred to Lyons (1978) for a discussion of a modeling approach to fumigation in the Duluth area. Further work in this area is vital if a smelter is proposed for siting in the Duluth area and there is a need to quantify the potential air quality impacts to aid in siting and control technology decision-making.

3.7.2 Ambient-Sulfate Concentrations

In section 3.4.2.2 it was shown that average ambient sulfate concentrations in the region are in the range of 1 to 3 ug/m^3. It must be noted that this result

FIGURE 126

EXAMPLE OF FUMIGATION DURING STABLE ON SHORE FLOW WITH THE FORMATION OF A THERMAL INTERNAL BOUNDRY LAYER



SOURCE: LYONS AND COLE (1979)

is based on a total sulfur analysis and assumes that sulfur present in the atmosphere at a sampling site as gaseous SO_2 is not converted by the sampling process to species which are collected on the membrane filter when the gas is drawn through the sampler. The only sulfur contributed to this concentration range by emissions sources is thus sulfur which is emitted as sulfate or has undergone conversion from SO_2 to sulfate in the atmosphere, prior to being drawn into the sampling device. This is expected to be a reasonable assumption, particularly in the context of the extremely low ambient SO_2 concentrations in the region.

Modeling work with the modified gaussian model indicated that local point sources of SO_2 contributed less than 1% of this sulfate total in 1977 (an annual average of .005 ug/m^3 for the region). The modeling simulations, of course, consider only the sulfate which results from SO_2 conversion. Sulfur emitted directly from the sources as sulfate is not included in the emissions inventory because the data were not available. However, direct source contributions of sulfate are not expected to be significant. Thus, the modeling result along with the uniformity of the measured values at all sites, suggests that the bulk of the ambient sulfate in the region is transported from sources outside the region. The model predicts that expected increases in SO_2 emissions in the area by 1985 will increase the regional average ambient sulfate concentration to .08 ug/m^3. This is a factor of 15 increase over the calculated 1977 local contribution. Recall that this increase occurs against a background (likely dominated by long-range transport) which may double (to 2-6 ug/m^3 of ambient sulfate) by 1985. It is in this context that the sulfate concentrations from a smelter in the region are considered.

The modified gaussian model was used to predict the ambient sulfate concentrations from a smelter located south of Babbitt as previously discussed. The results at selected sites are shown in Table 79 for the 3 smelter models along with the available measured values at these sites. Regional averages are also given. A comparison of the predicted average of the 9 receptor sites with the average from measurements at 8 sites shows that the base case model smelter is predicted to contribute about 7.5% of the measured atmospheric sulfur (assumed present as sulfate) in 1977. The corresponding values for the option 1 and option 2 models are 1.3% and 1.1%, respectively. In reality (though no quantitative data are available for documentation) these precentages would be expected to be even smaller, possibly by a factor of 2 or more, as a result of increased ambient sulfate concentrations due to increases in remote source emissions by the time a smelter could become operational in the region (1985 at the earliest).

Table 79

The above results indicate that the predicted contribution of a local smelter to ambient sulfate concentrations is quite small relative to the expected levels which seem to be attributable to remote sources. There is a large difference (approximately a factor of 6) between the base case smelter and the other two options. In terms of the calculated contribution due to local sources in 1977 (regional average of .005 ug/m^3) any of the smelter models would increase this local contribution several fold. The predicted 1985 local contribution (without copper-nickel) of .084 ug/m^3 would be increased 86%, 15%, and 10%, respectively, for the base case, option 1, and option 2 smelter models, respectively (based on the regional averages of 33 receptors). Although these average increases

Table 79. Predicted annual average sulfate concentrations for three smelter models located south of Babbitt, and measured sulfate concentrations at selected sites.

	SULFATE CONCENTRATIONS (ug/m^3)			
SITE	Base Case Model	Option 1 Model	Option 2 Model	Measured[a] Average
Babbitt	.25	.048	.038	2.09
Whiteface	.0093	.0015	.0014	2.28
Hoyt Lakes	.026	.0047	.0039	1.89
Erie	.038	.0067	.0057	1.07
Dunka Road	.085	.016	.013	1.97
Fernberg	.034	.0052	.0051	2.12
Isabella (ELC)	.11	.018	.016	2.03
Toimi	.049	.008	.007	1.40
Dunka River W.	.65	.12	.099	--[b]
Average	.139[c]	.025[c]	.021[c]	[illegible]
Regional Ave.	.072[e]	.013[e]	.013[e]	

[a]Eisenreich, Hollod and Langevin (1978), (based on 1977-78 data).
[b]No sampling station was located at the Dunka River watershed receptor site used in the model. The site is included to show the predicted concentration at the closest receptor to the smelter site.
[c]Average of above 9 results.
[d]Average of above 8 results.
[e]Average of 33 receptors.

constitute a minor portion of the overall sulfate concentrations, increases are much larger in the immediate vicinity of the smelter location as Table 79 shows.

It must be recalled that atmospheric sulfate is of major interest since it provides a source for sulfate deposition onto land and water surfaces (along with SO_2 which may convert to sulfate following impaction on the surface). This deposition is of major concern, particularly in the BWCA area, due to indications that many of the weakly buffered lakes in the area are particularly susceptible to acidification by increased acid input. This problem is discussed in detail in the water report, Volume 3-Chapter 4. As a result, it may not be possible to dismiss the importance of any new SO_2 (and thus also sulfate) source in the area.

The specific location of the source is also clearly important in this respect. For example, with the base case smelter the predicted regional average sulfate concentration based on 33 receptors of .072 ug/m^3 is only some 4% of the measured regional average of 1.85 ug/m^3. However, the receptor closest to the hypothetical smelter site (the Dunka River watershed some 5 km east) shows a predicted concentration of .65 ug/m^3, which is about 35% of the measured regional average. This is a substantial increase over the measured regional average sulfate concentration. Thus, although on a regional average basis, particularly with the option 1 or 2 smelters the predicted smelter contribution to regional ambient sulfate levels may be quite small, the effects could be large on the local basis. This issue requires careful site-specific investigation to determine drainage patterns for watershed areas immediately surrounding a smelter, as well as the susceptibility to acidification of any lakes in the immediate area or fed by runoff from the area.

3.7.3 Sulfate Deposition

As in the previous section, the potential contribution of a smelter to sulfate deposition in the Study Area must be considered in the context of the existing and predicted deposition in the absence of copper-nickel development. This was discussed in detail in section 3.4.3. Recall that the measured geometric mean deposition rate for the region was 14.4 kg/ha/yr based on bulk deposition data. The calculated dry deposition rate based on measurements of ambient sulfate concentrations was 1.78 kg/ha/yr. Calculations using the modified gaussian model to predict both wet and dry deposition from local sources indicated that the bulk of the local contribution (91-96%) occurs as dry deposition and this generally corresponds to the calculated dry deposition rate based on ambient concentrations. Calculated deposition (wet and dry from local sources) for the region, based on an average of 33 modeled receptor sites, was 2.2 kg/ha/yr from 1977 point sources and 4.6 kg/ha/yr from projected 1985 point sources.

Against this background, the deposition from the various smelter models sited 3 miles south of Babbitt was predicted using the modified gaussian model. The results of these predictions are shown in Table 80, along with measured and computed values in the absence of copper-nickel development for reference.

Table 80

In broad terms, the table indicates that the base case smelter deposition rates averaged over the sites listed, is predicted to be comparable to the present dry deposition rate in the region (calculated as 1.8 kg/ha/yr). Recall that this dry deposition essentially represents the contribution from local SO_2 point sources. This local input is predicted to increase to 5.5 kg/ha/yr, for the sites shown,

Table 80. Predicted annual average sulfate deposition for various smelter models located south of Babbitt, with non-copper-nickel values for comparison.

SITE		SULFATE DEPOSITION RATES (kg/ha/yr)				
		Predicted (modified gaussian model)				Calculated[a]
Receptor Number	Receptor Name	Base Case Smelter	Option 1 Smelter	Option 2 Smelter	1985 (no smelter)	Dry Deposition (1977-78)
17	Babbitt	4.7	2.0	.77	3.8	1.98
32	Whiteface	.24	.10	.04	4.5	2.13
27	Hoyt Lakes G.C.	.63	.27	.10	8.8	1.79
21	Erie Office	.73	.32	.12	11	1.01
22	Dunka Road	2.1	.86	.34	5.5	1.86
8	Fernberg Road	.58	.26	.096	3.5	2.01
19	Isabella (ELC)	1.5	.65	.24	4.1	1.92
31	Toimi	.98	.43	.16	4.1	1.32
23	Dunka River W.	8.2	3.6	1.4	4.3	---[b]
	Average	2.2[c]	.94[c]	.36[c]	5.5[c]	1.8[d]
	Regional Ave.	1.2[e]	.52[e]	.25[e]	4.7[e]	

[a]Based on ambient concentration data.

[b]No sampling station was located at the Dunka River Watershed receptor site used in the model. The site is included to show the predicted concentration at the closest receptor to the smelter site.

[c]Average of above 9 values.

[d]Average of above 8 values.

[e]Average of 33 receptors.

by 1985 (these values includes both dry and wet deposition). Using this 1985 value as a reference, the averages shown for the various smelter models represent increases of 40%, 17% and 7% for the base case, option 1 and option 2 models, respectively. Of course, all of the increases are due to local contributions only and occur against the background bulk deposition that is currently in the range of 15 kg/ha/yr. The bulk deposition value is dominated by wet deposition during the spring, summer, and autumn and appears to be the result of transport from remote sources, probably to the south and east. Regional bulk depostion is expected to increase (possibly double) by 1985.

The conclusions here are quite similar to those discussed in the previous section. Sulfate deposition is of major concern for water quality. It appears that regional deposition will continue to be dominated by wet deposition from remote sources. Nevertheless, any new sources in the area simply aggrevate existing problems. Further, site specific problems are again a major consideration. The Dunka River Watershed receptor site 5 km east of the hypothetical smelter location shows a predicted deposition rate for the base case model that is almost 4 times that of the average of all 9 receptors, and is a 57% increase over the geometric mean deposition rate recorded by the bulk samplers. Although this increase is reduced to 25% and 10%, respectively, for the option 1 and option 2 cases these remain significant deposition increases at this close receptor. Sensitive lakes close to the smelter site or receiving a large portion of their inflow from areas surrounding the smelter might experience serious acidification impacts. This may be particularly important during spring runoff when sulfate from local sources which has accumulated during the winter is released into surface waters. This question must be investigated on a site-by-site basis.

3.8 IMPACT ANALYSIS FOR PARTICULATE EMISSIONS

This section presents the ambient concentrations and surface deposition rates for particulates likely to result from copper-nickel development in the Study Area. The impacts from both point and area sources are considered, with a brief discussion of the potential elemental composition of the particulates. It must be mentioned at the outset that the analyses to be presented here required input data which in many cases was not directly available. As a result, best estimates have been made based on available information from other comparable situations. Thus, the conclusions here are subject to a wider margin of error than must be assigned, for example, to the discussion of SO_2 impacts. Generally, the results here should be considered as order of magnitude estimates of what may, in reality, occur.

3.8.1 Ambient Particulate Concentrations

Particulates from a copper-nickel development may be released from both point and area sources. Point source emissions will result from a smelting operation. For purposes of discussion all other sources will be treated as area sources. It must be remembered that modeled particulate increases occur in the context of annual geometric mean TSP concentrations ranging from 10 ug/m^3 (background sites in the region) to means above 50 ug/m^3 (population centers near mining operations). Short-term concentrations (24-hour) of several hundred ug/m^3 occur, particularly adjacent to local sources (see section 3.5).

3.8.1.1 Point Sources--The following discussion of mesoscale modeling of particulate levels is a summary of the work performed by Ingrid Ritchie, Jow Bowman, and George Burnett.

The smelter facility, as a potential point source of atmospheric particulates, was discussed in section 3.6.2.1. Two models were presented for smelter stack emissions representing two levels of emission controls. The base case smelter model was assigned an emission rate of 2,385 mtpy of particulates. The option 1 and option 2 models representing different scrubber SO_2 removal efficiencies have identical particulate removal efficiencies and thus constitute one particulate emissions model. This model releases 358 mtpy of particulates. All particulates were assumed to have a mass median diameter of 1.1 um based on EPA studies of smelter emissions (Statnick 1974).

Estimates of fugitive particulate emissions were also presented, in section 3.6.2.2. In reality, certain of the fugitive emissions may occur as area source emissions rather than as point emissions. However, for modeling purposes, these emissions are treated as occurring from a low-level point source. This is a reasonably valid assumption, for example, where the major dust-producing operations are enclosed in a single large building with a roof vent and fan to maintain a good working environment for smelter personnel.

The emissions estimate selected for modeling fugitives was 1,500 mtpy of particulates. Again, for lack of better data, a mass median diameter of 1.1 um was used. This size may vary depending on the specific source of particulates within the smelter operation. If the mass median diameter is larger, fugitive particulates would tend to settle out faster than the following analysis would indicate. Further, fugitive particulate emissions are only about 40% of the total base case emissions, but constitute 80% of the total option 1 and option 2 smelter emissions. Uncertainties in the size and character of the fugitive emission estimates, therefore, have a greater effect on the predicted air quality impacts from the option 1-option 2 model than from the base case model. This

should be considered when interpreting the results presented here. Emissions from the two smelter models are summarized in Table 81.

Table 81

The modified gaussian model was used to predict particulate concentrations in a manner similar to the analysis for SO_2 and sulfate presented in the last section. A hypothetical smelter site 3 miles south of Babbitt was selected for modeling purposes. Annual average and worst case 24-hour concentrations were computed. The highest predicted annual average concentrations for the base case model were on the order of 10^{-4} to 10^{-3} ug/m^3. These values are negligible relative to both ambient and PSD standards. It does not appear that annual ambient particulate concentrations will be a factor in smelter siting considerations. Thus, this topic will not be discussed further.

Predicted maximum 24-hour TSP values were computed by selecting meteorology for worst case days as for the SO_2 analysis. The results for the two smelter models are presented in Figures 127 and 128. For the base case model, the maximum 24-hour predicted TSP concentrations are 5.6 ug/m^3 at August Creek (Class I) and 36 ug/m^3 at Dunka River Watershed (Class II). These values are 56% and 92%, respectively, of the Class I and Class II increments. The corresponding values for the option 1-option 2 models are 2.7 ug/m^3 at August Creek (27% of the Class I increment) and 18 ug/m^3 at Dunka River (49% of the Class II increment). Generally, the concentrations from the option 1-option 2 models are half those from the base case model. This is consistent with the fact that total emission rates for the two models differ by a factor of 2.

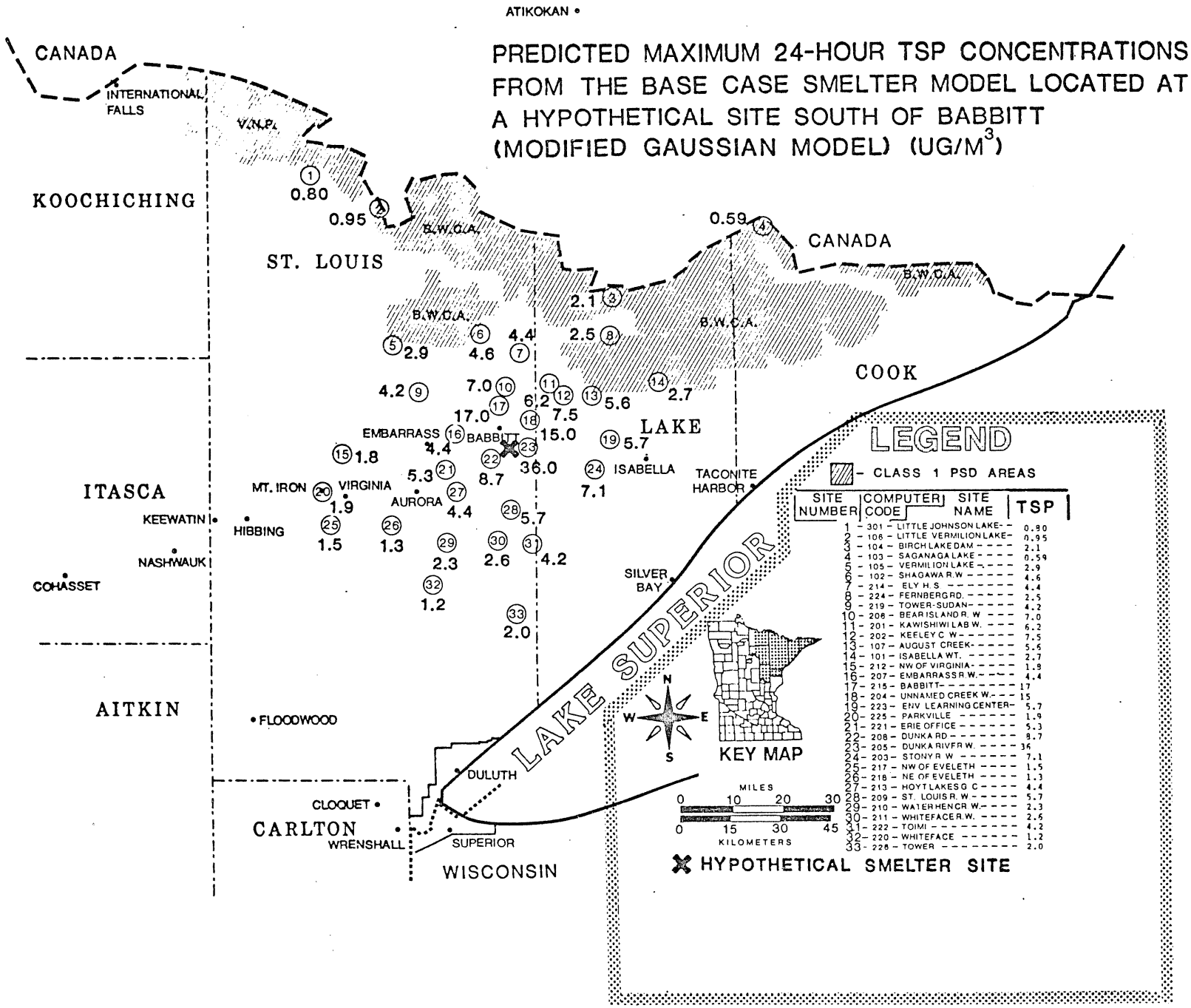
Figures 127 and 128

Table 81. Summary of particulate emission rates for the smelter models.[a]

MODEL	EMISSIONS (mtpy) Stack	Fugitive	Total
Base Case	2,385 (61%)	1,500 (39%)	3,885 (100%)
Option 1-Option 2	358 (19%)	1,500 (81%)	1,858 (100%)

[a]The models represent a facility with a capacity of 100,000 mtpy of copper plus nickel. See section 3.6.2 for derivations of these estimates.

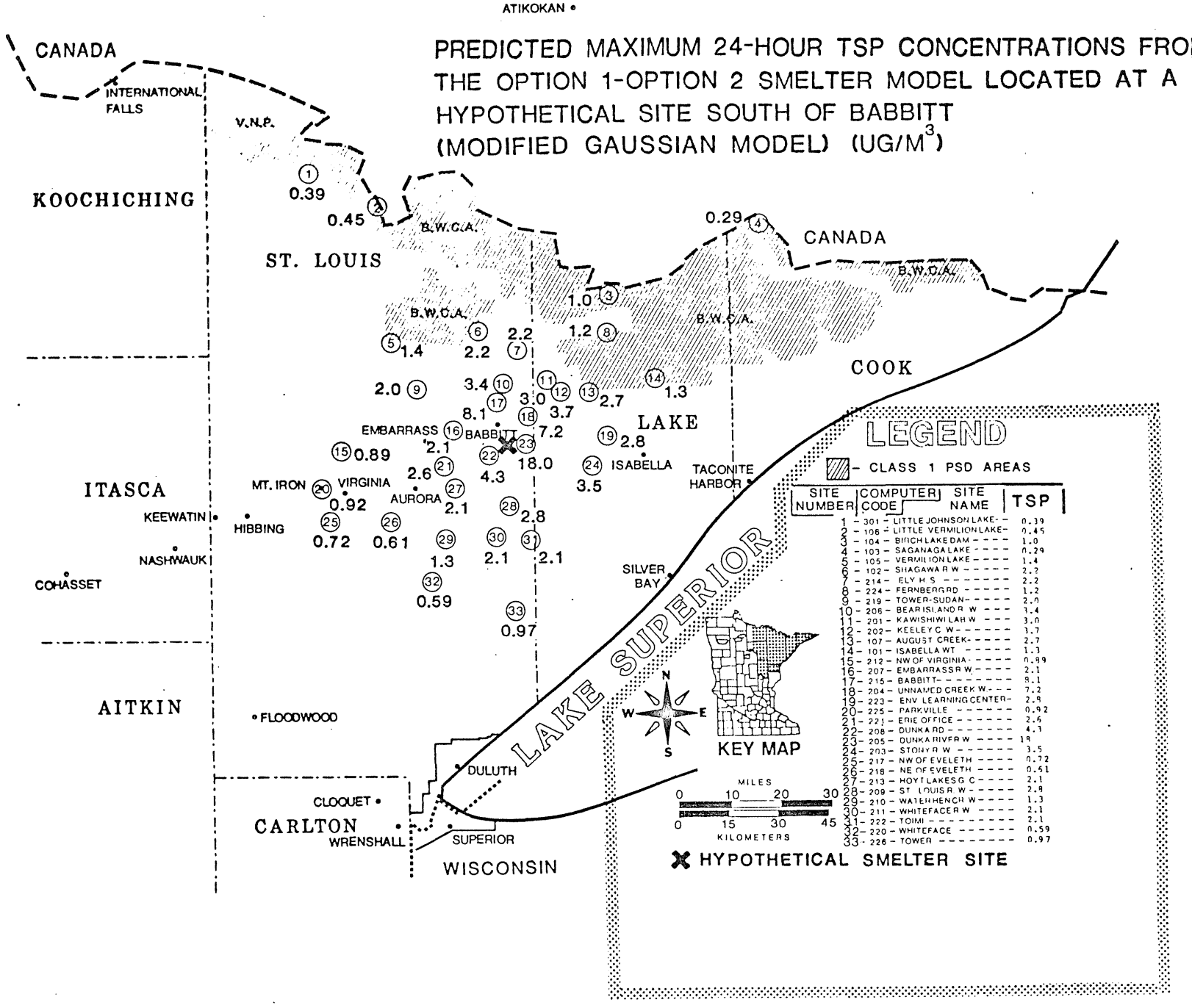
FIGURE 127



PREDICTED MAXIMUM 24-HOUR TSP CONCENTRATIONS FROM THE BASE CASE SMELTER MODEL LOCATED AT A HYPOTHETICAL SITE SOUTH OF BABBITT (MODIFIED GAUSSIAN MODEL) (UG/M^3)

SITE NUMBER	COMPUTER CODE	SITE NAME	TSP
1	301	LITTLE JOHNSON LAKE	0.80
2	106	LITTLE VERMILION LAKE	0.95
3	104	BIRCH LAKE DAM	2.1
4	103	SAGANAGA LAKE	0.59
5	105	VERMILION LAKE	2.9
6	102	SHAGAWA R.W	4.6
7	214	ELY H.S	4.4
8	224	FERNBERG RD.	2.5
9	219	TOWER-SUDAN	4.2
10	206	BEAR ISLAND R. W	7.0
11	201	KAWISHIWI LAB W.	6.2
12	202	KEELEY C. W	7.5
13	107	AUGUST CREEK	5.6
14	101	ISABELLA WT.	2.7
15	212	NW OF VIRGINIA	1.9
16	207	EMBARRASS R.W.	4.4
17	215	BABBITT	17
18	204	UNNAMED CREEK W.	15
19	223	ENV. LEARNING CENTER	5.7
20	225	PARKVILLE	1.9
21	221	ERIE OFFICE	5.3
22	208	DUNKA RD	8.7
23	205	DUNKA RIVER W.	36
24	203	STONY R. W	7.1
25	217	NW OF EVELETH	1.5
26	218	NE OF EVELETH	1.3
27	213	HOYT LAKES G. C	4.4
28	209	ST. LOUIS R. W	5.7
29	210	WATER HEN CR. W.	2.3
30	211	WHITEFACE R.W.	2.6
31	222	TOIMI	4.2
32	220	WHITEFACE	1.2
33	226	TOWER	2.0

FIGURE 128


ATIKOKAN
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
ST. LOUIS
B.W.C.A.
CANADA
B.W.C.A.
B.W.C.A.
B.W.C.A.
COOK
LAKE
EMBARRASS
BABBITT
ITASCA
MT. IRON
VIRGINIA
AURORA
ISABELLA
TACONITE HARBOR
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
0.39
0.45
0.29
1.0
1.4
2.2
2.2
1.2
2.0
3.4
3.0
3.7
2.7
1.3
8.1
7.2
2.8
0.89
2.1
2.6
4.3
18.0
3.5
0.92
2.1
2.8
0.72
0.61
1.3
2.1
2.1
0.59
0.97
PREDICTED MAXIMUM 24-HOUR TSP CONCENTRATIONS FROM THE OPTION 1-OPTION 2 SMELTER MODEL LOCATED AT A HYPOTHETICAL SITE SOUTH OF BABBITT (MODIFIED GAUSSIAN MODEL) (UG/M3)
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER | COMPUTER CODE | SITE NAME | TSP
1 - 301 - LITTLE JOHNSON LAKE - 0.39
2 - 106 - LITTLE VERMILION LAKE - 0.45
3 - 104 - BIRCH LAKE DAM - 1.0
4 - 103 - SAGANAGA LAKE - 0.29
5 - 105 - VERMILION LAKE - 1.4
6 - 102 - SHAGAWA R W - 2.2
7 - 214 - ELY H S - 2.2
8 - 224 - FERNBERG RD - 1.2
9 - 219 - TOWER-SUDAN - 2.0
10 - 206 - BEAR ISLAND R W - 3.4
11 - 201 - KAWISHIWI LAH W - 3.0
12 - 202 - KEELEY C W - 3.7
13 - 107 - AUGUST CREEK - 2.7
14 - 101 - ISABELLA WT - 1.3
15 - 212 - NW OF VIRGINIA - 0.89
16 - 207 - EMBARRASS R W - 2.1
17 - 215 - BABBITT - 8.1
18 - 204 - UNNAMED CREEK W - 7.2
19 - 223 - ENV. LEARNING CENTER - 2.8
20 - 225 - PARKVILLE - 0.92
21 - 221 - ERIE OFFICE - 2.6
22 - 208 - DUNKA RD - 4.3
23 - 205 - DUNKA RIVER W - 18
24 - 203 - STONY R W - 3.5
25 - 217 - NW OF EVELETH - 0.72
26 - 218 - NE OF EVELETH - 0.61
27 - 213 - HOYT LAKES G C - 2.1
28 - 209 - ST. LOUIS R W - 2.8
29 - 210 - WATERHENCH W - 1.3
30 - 211 - WHITEFACE R W - 2.1
31 - 222 - TOIMI - 2.1
32 - 220 - WHITEFACE - 0.59
33 - 226 - TOWER - 0.97
N
W
E
S
KEY MAP
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE

Even if a factor of 2 uncertainty is incorporated into the above results, it does not appear that the Class I increment would be exceeded by either smelter as sited in this analysis. The Class II increment might, however, be exceeded by the base case model, but not by the option 1-option 2 model. This analysis is based on a smelter located at a specific site, 3 miles south of Babbitt and does not consider concentrations within 5 km of the source.

In order to generalize the above analysis, 24-hour TSP concentrations were also predicted for a non-site specific case. The analysis was made for 5 days likely to result in high ambient concentrations as was done in the analysis of SO_2 impacts. Figure 129 presents the results for the base case smelter model, using meteorology data for November 6, 1976. The results shown are typical of the days modeled. TSP concentrations were below the Class I increment at about 15 km from the smelter. This distance was reduced to about 6 km for the option 1-option 2 case where the fugitive component dominates. Applying the factor of two modeling uncertainty to the above results could increase the distances from the source at which the Class I increment is met to about 30 km for the base case smelter and 12 km for the option 1-option 2 model.

Figure 129

Following the impact analysis for SO_2, the above results for the smelter alone are now put into perspective in the context of particulate concentrations expected from other point sources in the region. This analysis is important in terms of allowable PSD increments. The discussion of expected TSP concentrations due to new (non copper-nickel) particulate point sources in the region by 1985 (see section 3.5.1.2) indicated that the Class I increment is not predicted to be exceeded. However, the Class II increment was predicted to be exceeded at two

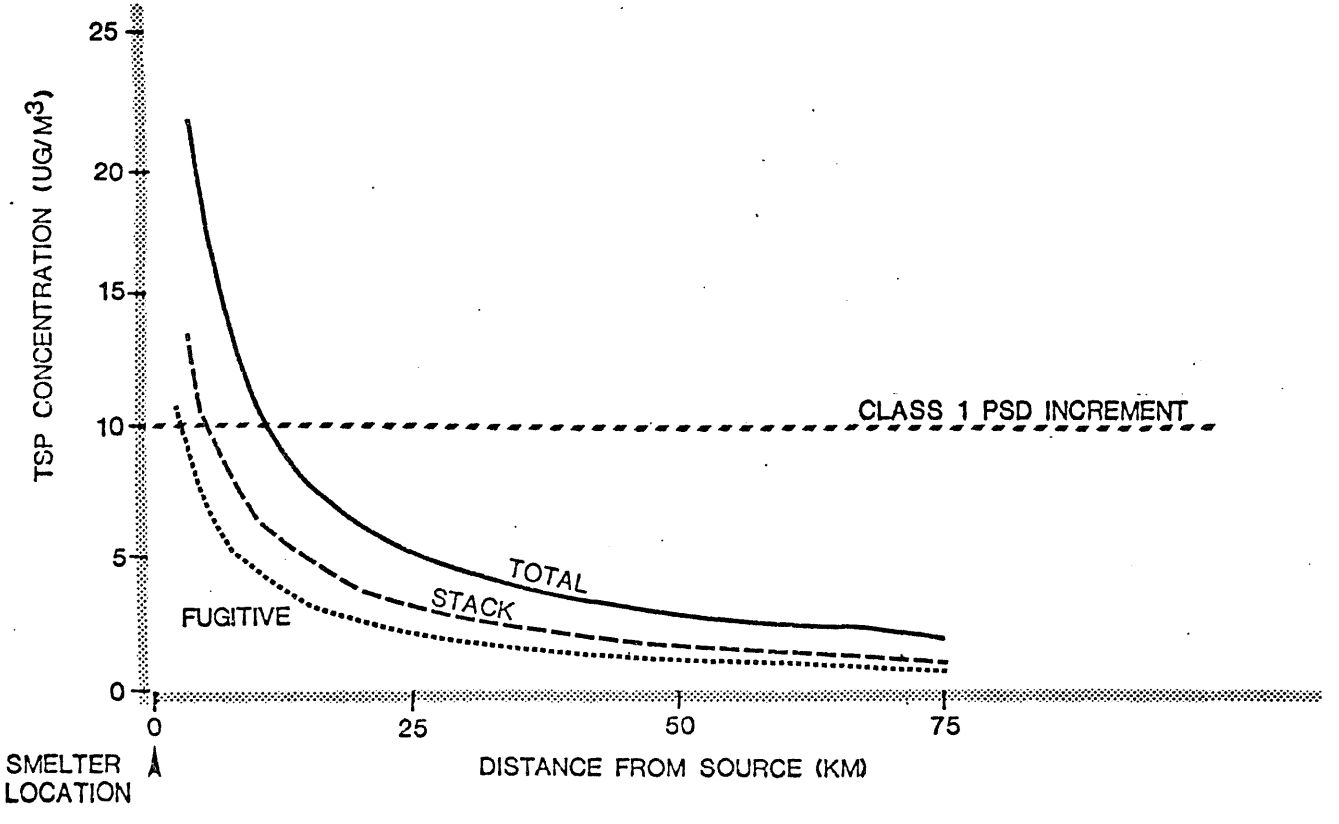
FIGURE 129

PREDICTED STACK AND FUGITIVE CONTRIBUTIONS TO 24-HOUR TSP CONCENTRATIONS ALONG A COMBINED PLUME CENTERLINE FOR THE BASE CASE SMELTER MODEL (USING THE MODIFIED GAUSSIAN MODEL)

(BASED ON METEOROLOGICAL DATA FOR NOVEMBER 6, 1976)

WIND DIRECTION : WNW

WIND SPEED : 24.6 KM/HR.



receptor sites, Erie and Parkville. Considering a factor of 2 accuracy in the modeling, this indicates that new particulate sources planned for the region may be significant factors in siting plans for a smelter in the Class II area.

When the smelter models, sited south of Babbitt, are included along with the other particulate point sources in the 1985 emissions inventory list, the resulting TSP concentrations are not predicted to exceed either annual average ambient air quality standards or annual PSD increments. The focus of interest is on the 24-hour predictions. It is interesting to display the expected trend in the maximum particulate concentrations predicted at any receptor in Class I and Class II areas. Figure 130 shows both the predicted maximum and second high concentrations for these 2 areas. The 1977 regional and PSD baselines are shown, along with 1985 values without a smelter, and with the 2 smelter models.

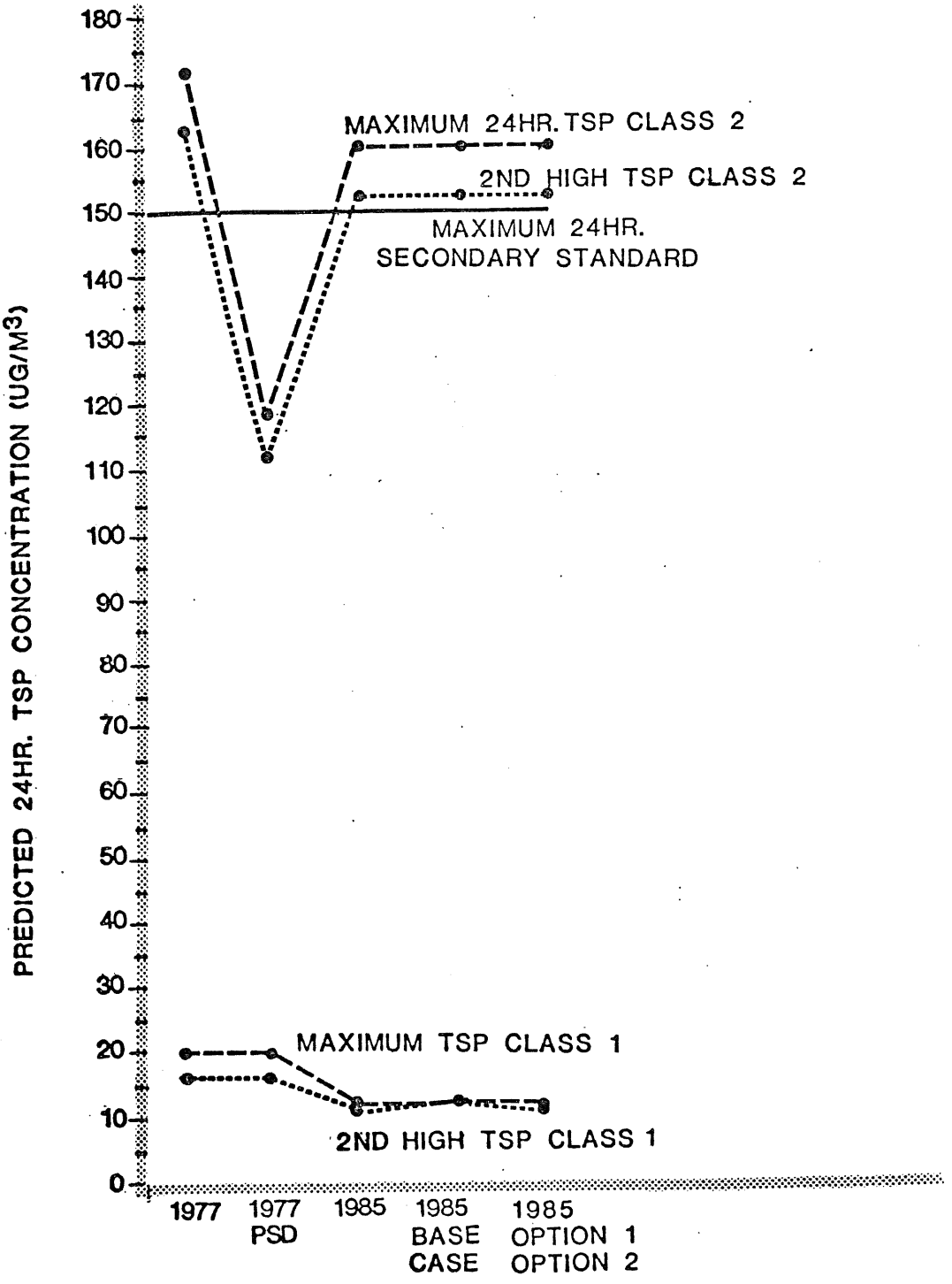
Figure 130

The figure indicates that the maximum concentrations in the Class I area are predicted to decrease about 6-8 ug/m^3 by 1985, with or without the modeled smelter sources. The ambient air quality standards are not exceeded. However, for the Class II site (the Erie receptor), the 24-hour secondary standard of 150 ug/m^3 is predicted to be exceeded by both the maximum (160 ug/m^3) and second high (152 ug/m^3) values. This prediction is not affected by the presence of either of the smelter models. Note also that the computed 1977 PSD baseline at the Erie receptor is significantly lower than the 1977 regional baseline, resulting in the prediction that the Class II PSD increment will be exceeded.

The absence of a smelter effect in the above results is an important point to understand since the maximum 24-hour concentration predicted earlier for the base

FIGURE 130

PREDICTED 24-HOUR MAXIMUM AND 2ND HIGH TSP CONCENTRATIONS IN CLASS 1 AND CLASS 2 AREAS FOR SELECTED RECEPTORS (MODIFIED GAUSSIAN MODEL)



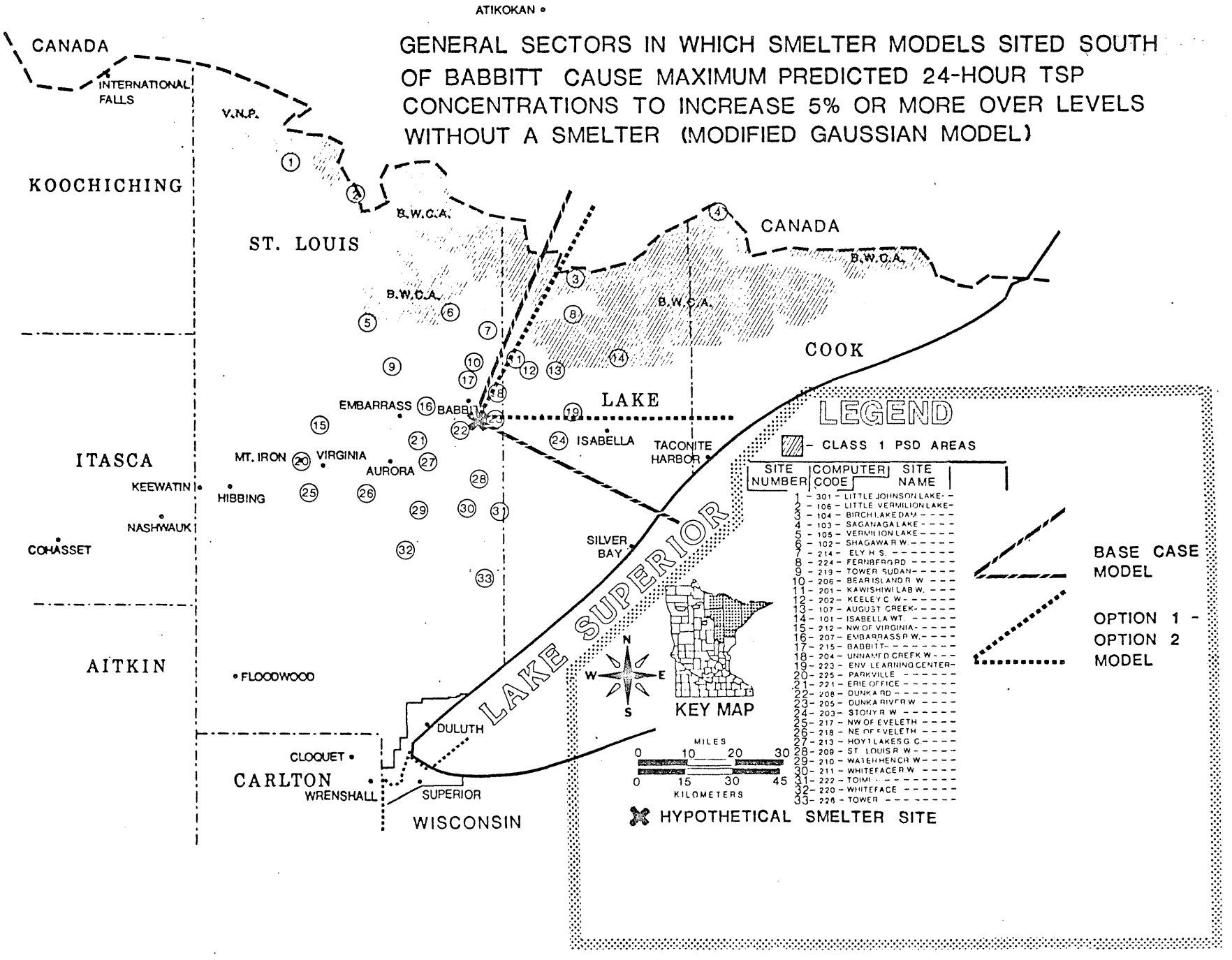
case smelter alone was 5.3 ug/m^3 at the Erie receptor. However, when modeled along with other point sources in the region, the juxtaposition of the site south of Babbitt with respect to other sources was such that during the days at which the highest cumulative concentrations occurred at Erie, winds were not blowing in directions that allowed the smelter to contribute significantly to those concentrations. Clearly, the relative orientations of point sources with respect to receptor sites plays a major role in the resulting short-term concentrations at those sites. This consideration would indicate that locating several point sources along a single line, particularly oriented along major wind axes, should be avoided if ambient TSP concentrations downwind of the sources are to be minimized.

To provide a summary of the general directions impacted by the two smelter models sited south of Babbitt, Figure 131 shows the sectors containing receptors which showed at least a 5% increase in 24-hour TSP levels over those predicted for 1985 in the absence of a smelter. The modeling predicts that at the Dunka River watershed receptor, which experiences the largest smelter impact, the maximum 24-hour TSP concentration with base case development is 60 ug/m^3 (40% of the secondary standard; 23% of the primary standard) compared to 24 ug/m^3 without development. The option 1-option 2 model results in a maximum 24-hour concentration of 41 ug/m^3, a 32% decrease over the base case smelter.

Figure 131

The next highest 24-hour concentration in the area impacted by the smelter is at the Unnamed Creek Watershed receptor. The base case smelter results in a maximum 24-hour concentration of 23 ug/m^3 compared to 19 ug/m^3 with no Cu-Ni development, about a 20% difference. The option 1-option 2 model gives 19 ug/m^3, which is the

FIGURE 131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GENERAL SECTORS IN WHICH SMELTER MODELS SITED SOUTH OF BABBITT CAUSE MAXIMUM PREDICTED 24-HOUR TSP CONCENTRATIONS TO INCREASE 5% OR MORE OVER LEVELS WITHOUT A SMELTER (MODIFIED GAUSSIAN MODEL)
CANADA
INTERNATIONAL FALLS
V.N.P.
KOOCHICHING
B.W.C.A.
ST. LOUIS
CANADA
B.W.C.A.
B.W.C.A.
B.W.C.A.
COOK
LAKE
EMBARRASS
BABBITT
ISABELLA
TACONITE HARBOR
ITASCA
MT. IRON
VIRGINIA
AURORA
KEEWATIN
HIBBING
NASHWAUK
COHASSET
SILVER BAY
LAKE SUPERIOR
AITKIN
FLOODWOOD
DULUTH
CLOQUET
CARLTON
WRENSHALL
SUPERIOR
WISCONSIN
LEGEND
CLASS 1 PSD AREAS
SITE NUMBER
COMPUTER CODE
SITE NAME
1 - 301 - LITTLE JOHNSON LAKE
2 - 106 - LITTLE VERMILION LAKE
3 - 104 - BIRCH LAKE DAM
4 - 103 - SAGANAGA LAKE
5 - 105 - VERMILION LAKE
6 - 102 - SHAGAWA R.W.
7 - 214 - ELY H.S.
8 - 224 - FERNBERG RD
9 - 219 - TOWER SUDAN
10 - 206 - BEAR ISLAND R.W.
11 - 201 - KAWISHIWI LAB W.
12 - 202 - KEELEY C.W.
13 - 107 - AUGUST CREEK
14 - 101 - ISABELLA WT.
15 - 212 - NW OF VIRGINIA
16 - 207 - EMBARRASS R.W.
17 - 215 - BABBITT
18 - 204 - UNNAMED CREEK W.
19 - 223 - ENV. LEARNING CENTER
20 - 225 - PARKVILLE
21 - 221 - ERIE OFFICE
22 - 208 - DUNKA RD
23 - 205 - DUNKA RIVER R.W.
24 - 203 - STONY R.W.
25 - 217 - NW OF EVELETH
26 - 218 - NE OF EVELETH
27 - 213 - HOYT LAKES G.C.
28 - 209 - ST. LOUIS R.W.
29 - 210 - WATERHEN CR.W.
30 - 211 - WHITEFACE R.W.
31 - 222 - TOIMI
32 - 220 - WHITEFACE
33 - 226 - TOWER
BASE CASE MODEL
OPTION 1 - OPTION 2 MODEL
KEY MAP
N
W
E
S
MILES
0 10 20 30
0 15 30 45
KILOMETERS
HYPOTHETICAL SMELTER SITE

same as 1985 without development. Table 82 provides a comparison of maximum 24-hour TSP concentrations resulting from the smelter development cases that are different from 1985 estimates due to regional point source emissions with no smelter.

Table 82

The conclusions here are similar to those in the SO_2 impact discussion. The problem occurs for short-term averaging periods when PSD increments might be exceeded close to the smelter. Siting a facility too close to a Class I area poses the real possibility of this restrictive standard being exceeded. Distances of 15-30 km from the Class I areas for the base case smelter model appear to be adequate to prevent the increment from being exceeded. This is a less restrictive distance than that imposed by SO_2 considerations for the same model smelter.

The ambient concentrations of various elemental constituents in smelter particulates should be discussed briefly. Little data is available to provide reliable estimates of the composition of smelter particulates. For reference, it is assumed here that the particulates have the same composition as the concentrate fed to the smelter. This is a reasonable assumption for stack particulates which may be dominated by dust from the concentrate dryer, and it is probably a worst case assumption for fugitive particulates, which may also contain appreciable amounts of dust from coal, silica flux, and limestone. Table 83 lists the composition of particulate emissions using the concentrate as a model (see the discussion of concentrate composition in Volume 3-Chapter 2, section 2.4.1.1). The dominant components are iron (30% as sulfide plus 2½% as oxide), sulfur (26%), and copper (14%) with constituents such as lead, arsenic, and

Table 82. Predicted maximum 24-hour TSP concentrations (with and without smelter models) at receptor sites impacted by the model smelters located south of Babbitt (ug/m^3).

RECEPTOR LOCATION (No.)	1985 No Smelter	1985 + Base Case Smelter	1985 + Option 1-Option 2 Smelter
Isabella Watershed (14)	11	12	12
Saganaga Lake (4)	4.6	4.9	4.7
Birch Lake Dam (3)	5.5	6.4	5.9
August Creek (13)	12	13	13
Kawishiwi Lab Watershed (11)	15	17	16
Keeley Creek Watershed (12)	13	17	14
Stony River Watershed (24)	14	15	13
Unnamed Creek Watershed (18)	19	23	19
Dunka River Watershed (23)	24	60	41
Isabella (ELC) (19)	13	16	15
Fernberg Road (8)	7.4	8.2	7.9

calcium present in the ppm range.

Table 83

The model for particulate composition just presented is used to apportion predicted TSP concentrations among the various elemental constituents comprising the particles in order to provide an estimate of worst case 24-hour concentrations downwind of a smelter. As an example, values were computed for various distances downwind of the base case smelter model using the predicted TSP concentrations along the combined plume centerline for the worst case situation typified by the plot shown in Figure 129. The TSP concentrations used for calculational purposes were 22 ug/m^3, 7 ug/m^3, and 3 ug/m^3, respectively, for distances of 5 km, 20 km, and 50 km downwind of the model smelter. The resulting elemental concentrations (in ng/m^3) are shown in Table 84. For comparison, the table also presents the regional average and maximum concentrations recorded during field sampling in the region (see section 3.5.2.1).

Table 84

The predicted elemental concentration values represent an order-of-magnitude estimate as a result of uncertainty in concentrate and emissions compositions, as well as air dispersion modeling errors. However, the results may be used to indicate elemental constituents which may cause significant increases above existing elemental concentrations. For the base case model, the results indicated that copper and nickel are the constituents with the greatest potential to significantly alter existing maximum ambient concentrations. This is not an unexpected result given the nature of the smelting operation.

Table 83. Model composition for particulates from a copper-nickel smelter.[a]

ELEMENT	CONCENTRATION	UNITS
Si (SiO_2)	7.25 (15.53)	PCT[b]
Al (Al_2O_3)	1.81 (3.43)	PCT
Fe (FeO)	2.53 (3.26)	PCT
Mg (MgO)	1.55 (2.57)	PCT
Ca (CaO)	1.14 (1.61)	PCT
Na (Na_2O)	0.39 (0.53)	PCT
K (K_2O)	0.08 (0.10)	PCT
Ti (TiO_2)	0.10 (0.17)	PCT
P (P_2O_5)	0.01 (0.03)	PCT
Mn (MnO)	0.03 (0.04)	PCT
Cr (Cr_2O_3)	0.04 (0.06)	PCT
B	310.1	PPM[c]
Ba	129.6	PPM
Be	0.06	PPM
Sr	50.2	PPM
V	85.5	PPM
Th	3.0	PPM
Zr	25.7	PPM
S	25.870	PCT
Cu	13.825	PCT
Ni	2.647	PCT
Fe(S)	30.001	PCT
Co	0.132	PCT
Zn	1137.0	PPM
Pb	60.7	PPM
Ag	34.3	PPM
As	31	PPM
Hg	.174	PPM
Mo	28.1	PPM
Cd	40	PPM

[a]It is assumed that the particulates have the same composition as the concentrate fed to the smelter (see Volume 3-Chapter 2, section 2.4.1.1).

[b]Percent composition by weight.

[c]Parts per million by weight.

Table 84. Maximum predicted 24-hour ambient elemental concentrations in particulates downwind of the base case smelter model assuming particulates have the composition of the model concentrate fed to the smelter, compared to measured values in the region (all values in ng/m^3).

ELEMENT	24-HOUR CONCENTRATIONS MEASURED IN THE REGION[a] Average[b]	Maximum	PREDICTED MAXIMUM 24-HOUR CONCENTRATION DOWNWIND OF THE BASE CASE SMELTER MODEL, ALONG COMBINED PLUME CENTERLINE[g] 5 km[c]	20 km[d]	50 km[e]
Si	911	8,880	1,600	507	217
Al	299.	3,050	398	127	54
Mg	NA[f]	NA	341	108	47
Ca	321	5,020	251	80	34
Na	NA	NA	86	27	12
K	163	1,260	18	5.7	2.4
Ti	56	453	22	7.0	3.0
P	51	249	2.2	.70	.30
Mn	19	156	6.6	2.1	.90
Cr	10	40	8.8	2.8	1.2
B	NA	NA	6.8	2.2	.93
Ba	34	185	2.8	.91	.39
Sr	5	26	1.1	.35	.15
V	11	22	1.9	.60	.26
Th	NA	NA	.066	.021	.009
Zr	NA	NA	.57	.18	.077
S	692	5,620	5,690	1,810	776
Cu	12	109	3,040	967	415
Ni	4	27	582	185	79
Fe(total)	1,050	12,900	7,160	2,280	976
Co	8	43	29	9.2	4.0
Zn	23	1,850	25	8.0	3.4
Pb	59	734	1.3	.42	.18
As	7	51	.68	.22	.09
Hg	3	11	.0038	.0012	.0005
Mo	NA	NA	.62	.20	.08
Cd	9	132	.88	.28	.12

[a]Data from analysis of 24-hour membrane samples (Eisenreich, Hollod and Langevin 1978).

[b]Average for all stations, with not-detectable data omitted (see section 3.5.2.1).

[c]Values assume a TSP concentration of 22 ug/m^3 at 5 km downwind.

[d]Values assume a TSP concentration of 7 ug/m^3 at 20 km downwind.

[e]Values assume a TSP concentration of 3 ug/m^3 at 50 km downwind.

[f]NA = element not analyzed.

[g]Several significant figures are shown for calculational purposes only. The values should be read as order-of-magnitude concentration estimates.

The two elements just listed have the potential to increase ambient concentrations an order of magnitude or more above observed existing maximum levels. A second group of elements may add concentrations roughly comparable to those present now. These elements include sulfur (as sulfide), cobalt, and possibly iron. Note that the sulfur concentration shown represents sulfur as sulfide in particulates. The contribution due to SO_2 or sulfate, discussed earlier in section 3.7, must be added to obtain total ambient sulfur. These conclusions apply close to the smelter (5-10 km) with concentrations dropping half an order of magnitude from 5 km to 50 km.

It should also be noted that this analysis indicates that certain elements do not appear to pose a problem. Mercury appears to be a minor constituent of the ore and thus would not be a significant atmospheric problem according to this model, even close to the smelter site. Arsenic levels, often of concern at other smelting operations around the world, appears to occur at relatively low levels. Similarly, zinc and cadmium appear at reduced levels. Of course, these conclusions depend on the validity of the available data and modeling assumptions and must be verified or altered based on site specific data for any proposed operation. For example, volatiles such as arsenic are assumed here to be well controlled in the strong SO_2 gas stream by SO_2 control devices. If this were not in fact verified by more detailed studies, predicted levels of mercury, arsenic and other volatiles may increase.

The above conclusions are based on an analysis of the base case smelter. However, they are essentially unaltered for the option 1-option 2 model which has emissions roughly half that of the base case model, achieved by reducing stack emissions. Ambient concentrations are generally reduced by a factor of 2 at most, which is smaller than the errors expected in this analysis. Emissions

would have to be reduced an order of magnitude or more to alter the impacts discussed, and that would depend largely on the ability to reduce fugitive emissions such as from unloading and material transfer operations.

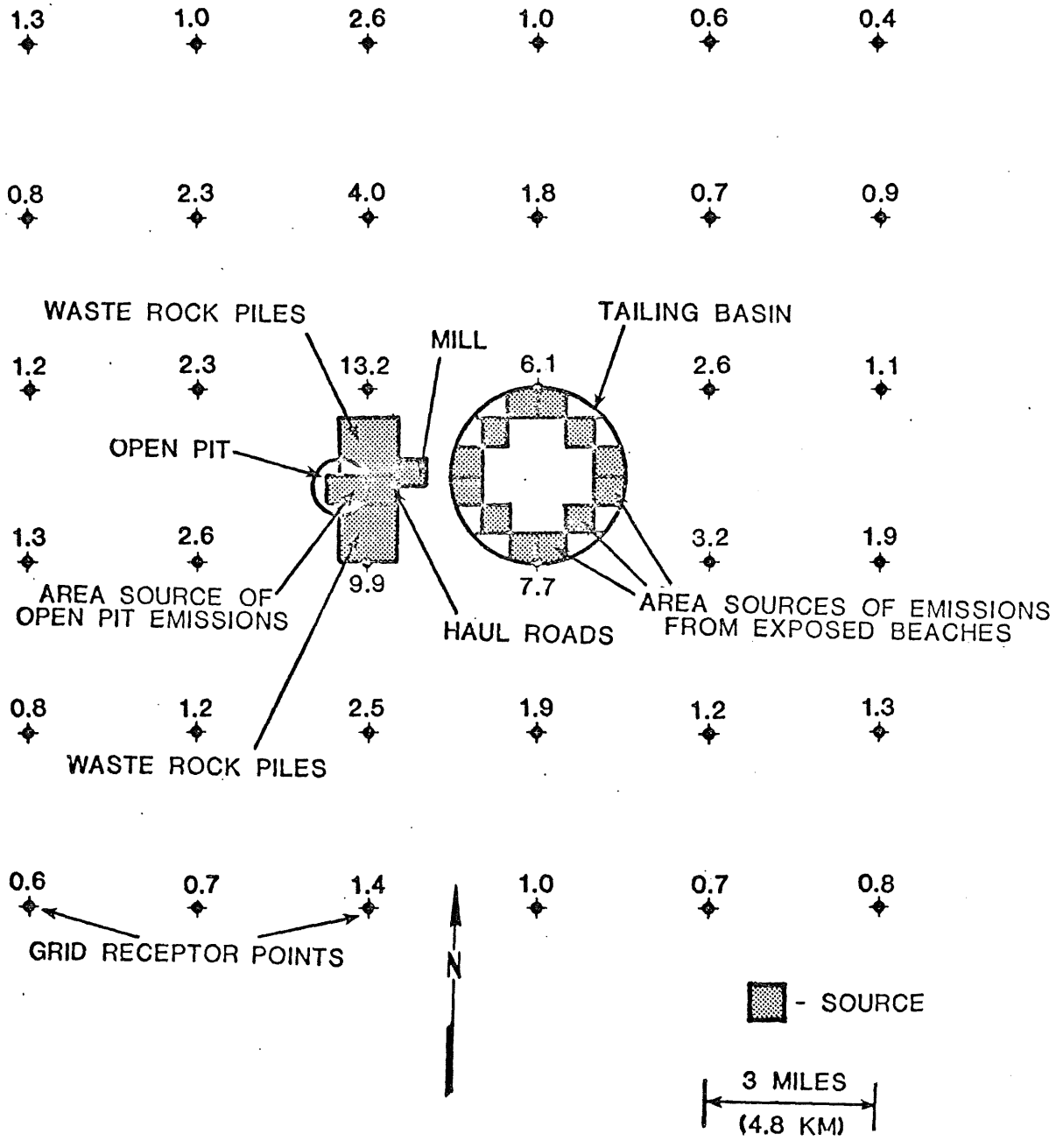
3.8.1.2 Area Sources--The following discussion of area source contributions to particulate levels is a summary of the work described in Ashbrook (1979). To allow the potential impacts from area source emissions of particulates to be addressed, a source model was generated (see section 3.6.2.2). The model consists of a large (20×10^6 mtpy) open pit mine and mill, with associated waste rock and tailing disposal areas and represents the worst case development in terms of particulate emissions. No smelter is included since this was considered in the previous section. The total emissions estimated for the model were 2,800 mtpy, midway between the 3,885 mtpy for the base case smelter model, and the 1,858 mtpy for the option 1-option 2 smelter model. Of course, in this case the sources are spread out over a large area (more than 7,000 acres) in contrast to point sources used in the smelter models.

The Climatological Dispersion Model (CDM) was used to calculate the annual geometric mean particulate concentrations resulting from these area sources. Meteorological data from International Falls was used for modeling purposes. The combined results are presented in Figure 132 on a grid system showing the location of the various source areas. The contributions from various operations are shown in Figures 133 to 137. The values shown represent concentrations due to the area sources only, and thus would be increases above the concentrations normally present in an area in the absence of copper-nickel development.

Figures 132 to 137

FIGURE 132

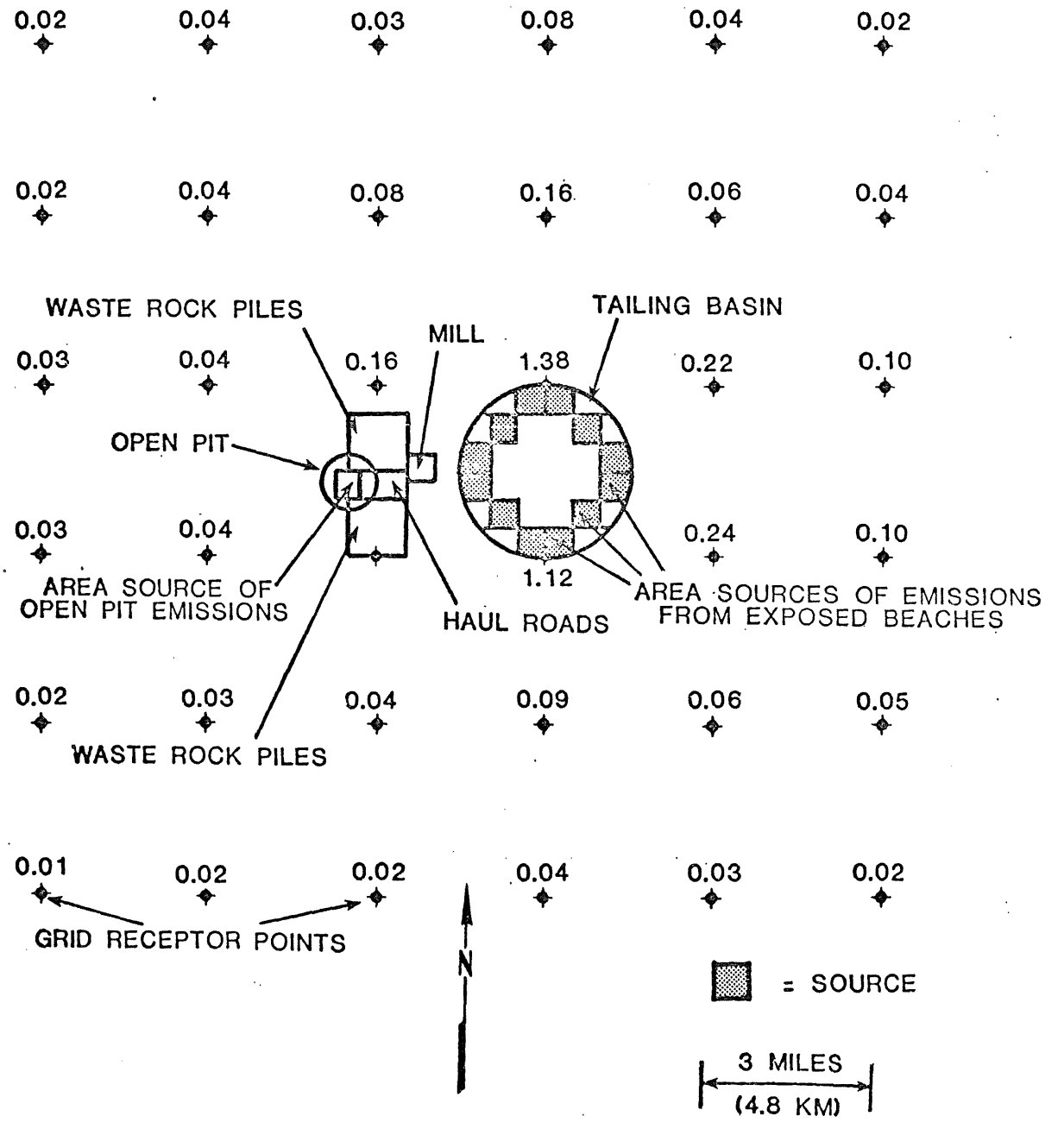
PREDICTED INCREASES IN GEOMETRIC MEAN ANNUAL TSP CONCENTRATIONS FROM ALL AREA SOURCES IN A MODEL OPEN PIT MINE AND MILL OPERATION (20 X 10^6 MTPY) (VALUES IN UG/M^3)



SOURCE : ASHBROOK (1979)

FIGURE 133

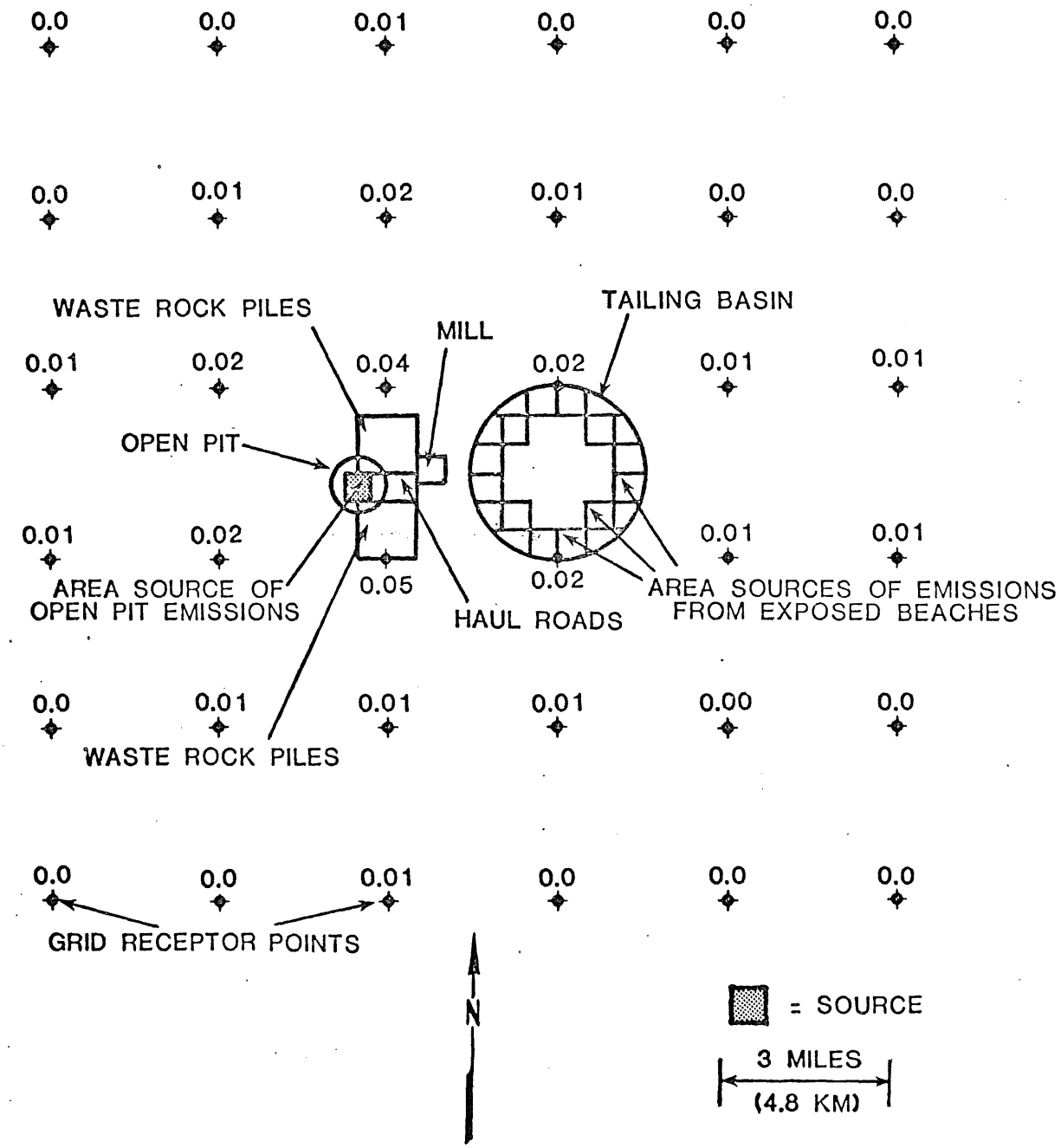
PREDICTED INCREASES IN GEOMETRIC MEAN ANNUAL TSP CONCENTRATIONS FROM TAILING BASIN SOURCES IN A MODEL OPEN PIT MINE AND MILL OPERATION (20×10^6 MPTY) (VALUES IN UG/M^3)



SOURCE : ASHBROOK (1979)

FIGURE 134

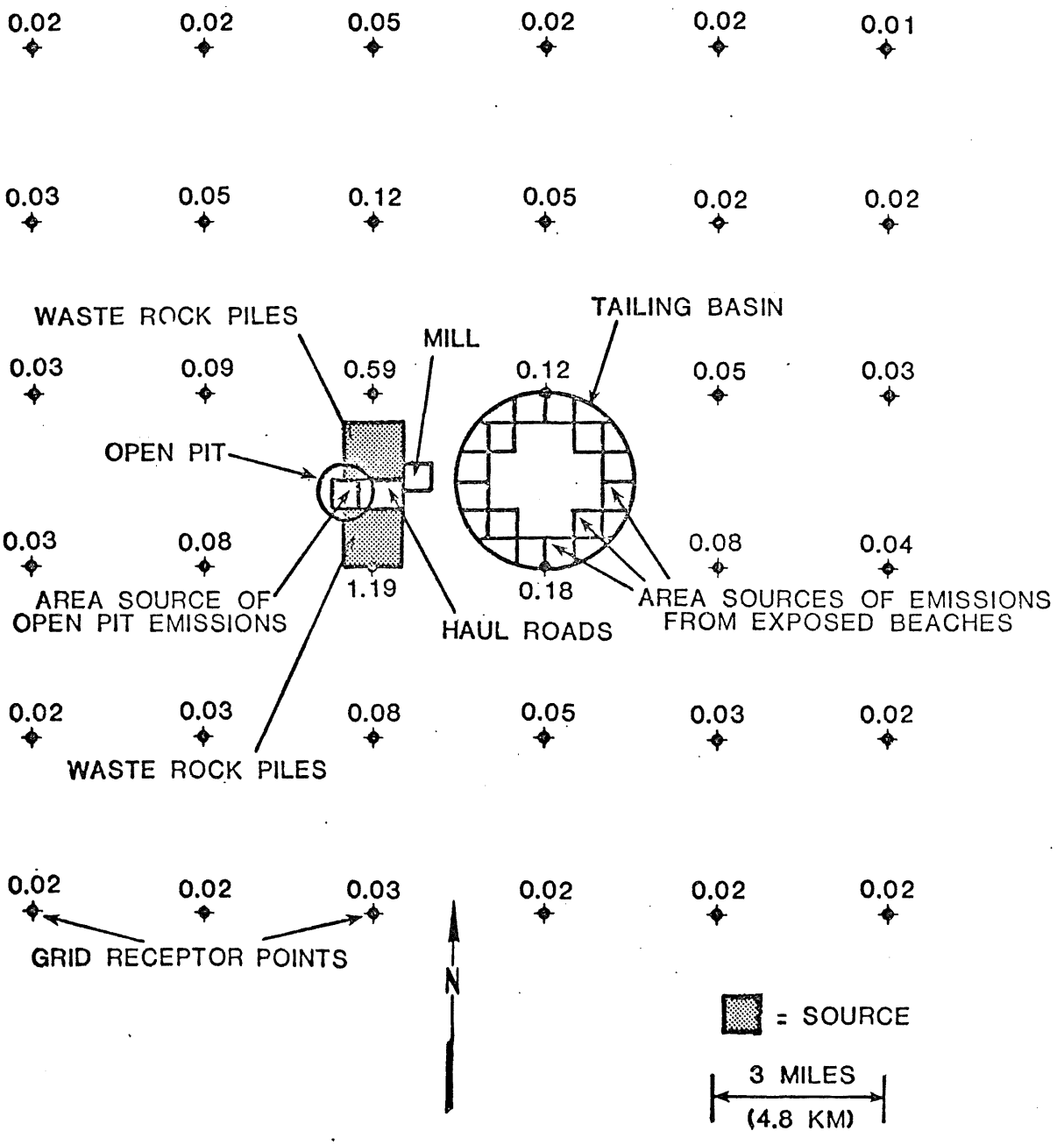
PREDICTED INCREASES IN GEOMETRIC MEAN ANNUAL TSP CONCENTRATIONS FROM BLASTING SOURCES IN A MODEL OPEN PIT MINE AND MILL OPERATION (20 X 10^6 MTPY) (VALUES IN UG/M^3)



SOURCE : ASHBROOK (1979)

FIGURE 135

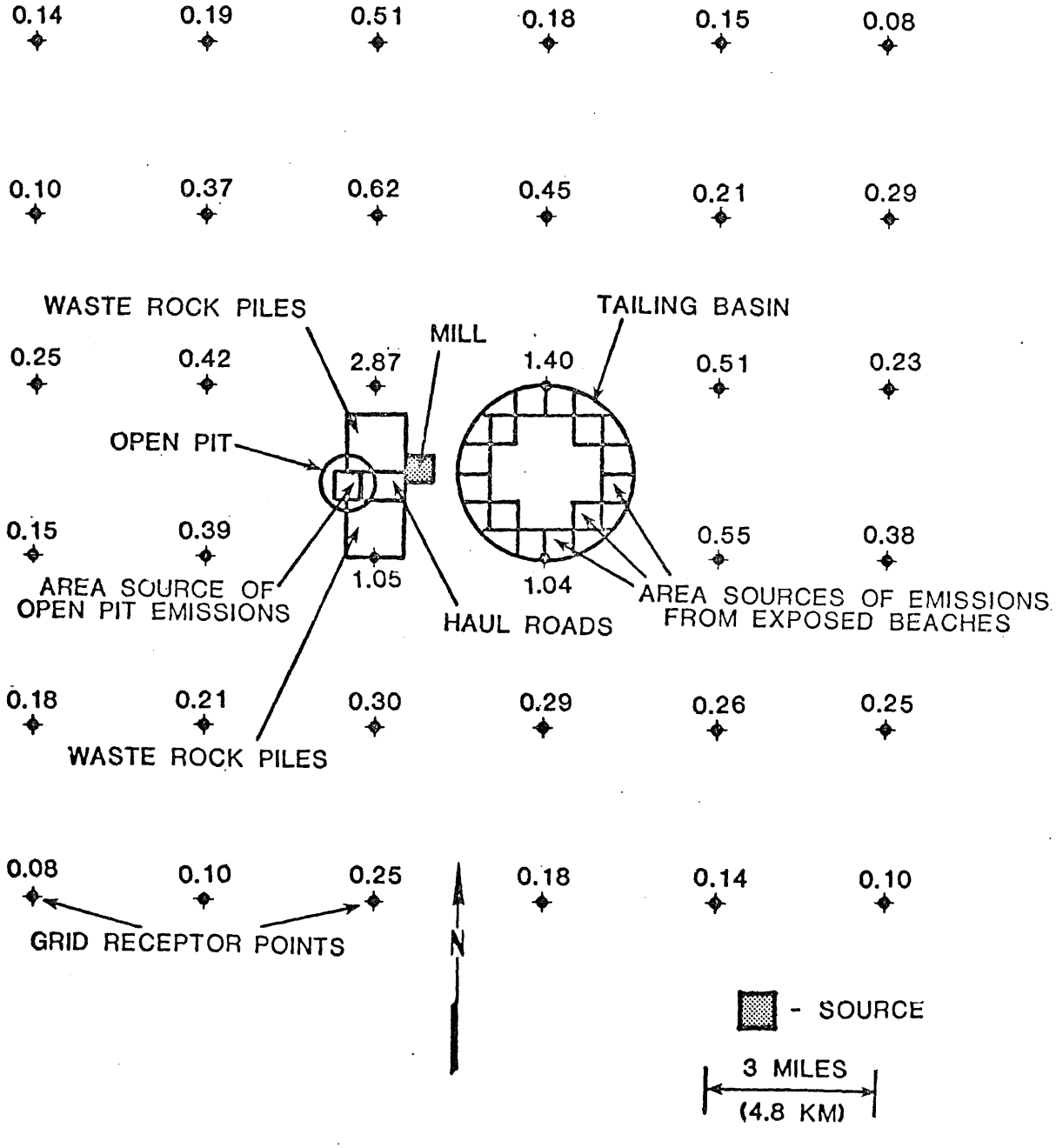
PREDICTED INCREASES IN GEOMETRIC MEAN ANNUAL TSP CONCENTRATIONS FROM WASTE ROCK PILES AND DUMPING ONTO PILES IN A MODEL OPEN PIT MINE AND MILL OPERATION (20×10^6 MTPY) (VALUES IN UG/M^3)



SOURCE : ASHBROOK (1979)

FIGURE 136

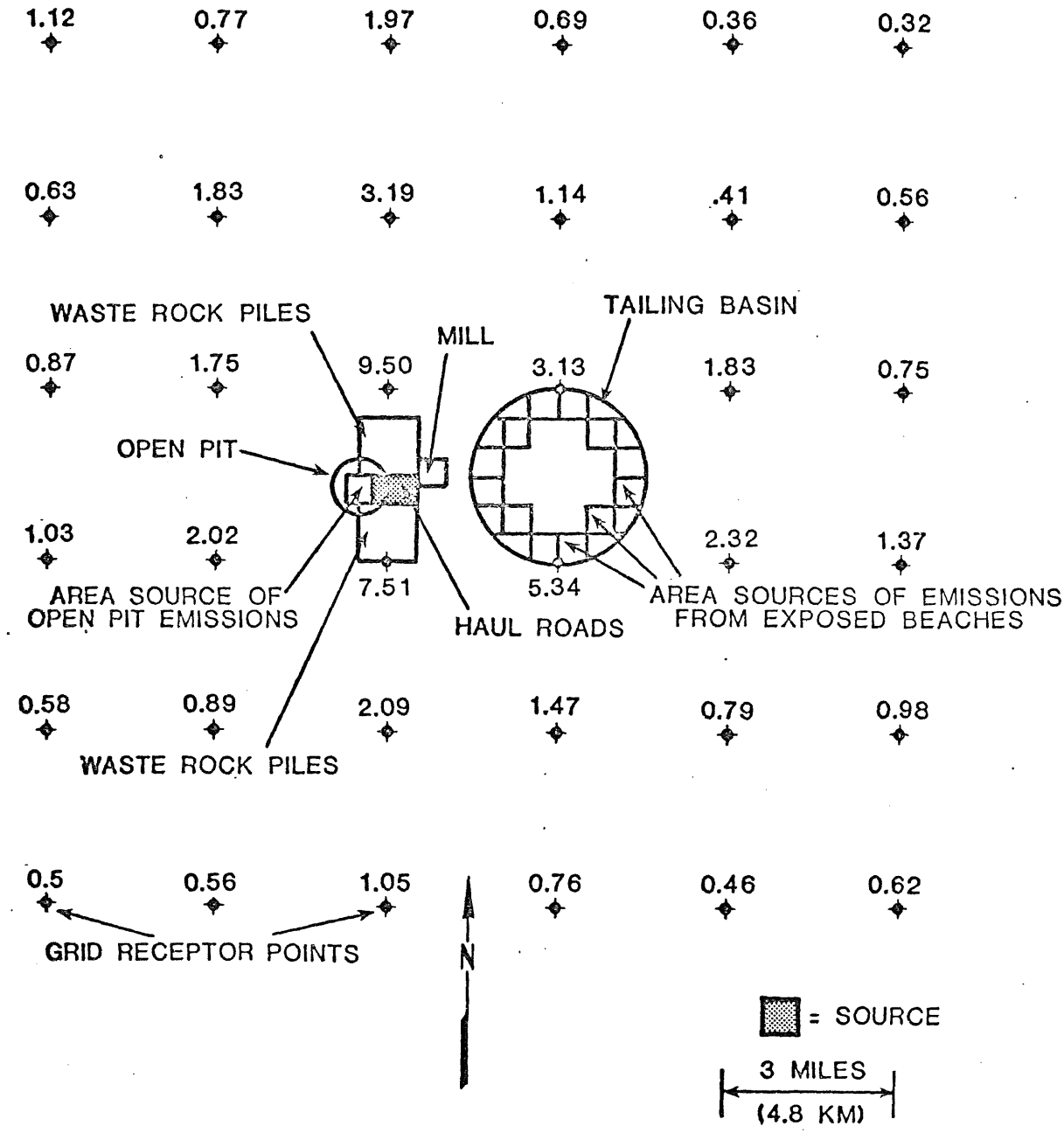
PREDICTED INCREASES IN GEOMETRIC MEAN ANNUAL TSP CONCENTRATIONS FROM ORE STORAGE, CONVEYORS, AND CRUSHING AND GRINDING SOURCES IN A MODEL OPEN PIT MINE AND MILL OPERATION (20×10^6 MTPY) (VALUES IN UG/M^3)



SOURCE : ASHBROOK (1979)

FIGURE 137

PREDICTED INCREASES IN GEOMETRIC MEAN ANNUAL TSP CONCENTRATIONS FROM HAUL ROADS IN A MODEL OPEN PIT MINE AND MILL OPERATION (20 X 10^6 MTPY) (VALUES IN UG/M^3)



SOURCE : ASHBROOK (1979)

The greatest overall concentration increase predicted, 13.2 ug/m^3, occurred just under 1 km north of the northern waste rock pile. This was the only receptor site with an increase greater than a background level of roughly 10 ug/m^3. Combining a background level of 10 ug/m^3 with the greatest estimated increase of 13.2 ug/m^3 gives an estimated level of about 23 ug/m^3. This value is less than half of both the primary (75 ug/m^3) and secondary (60 ug/m^3) annual ambient standards.

Annual average concentrations can be statistically converted into 24-hour averages (Larson 1971). Although this conversion method has drawbacks, it is appropriate for use here to estimate whether this mine-mill model would likely meet the 24-hour PSD requirements. It can be seen directly from the figure that none of the receptor sites exceed the annual average increment of 19 ug/m^3 permitted for Class II regions; however, 4 sites exceed the permitted increment of 5 ug/m^3 for a Class I area. Application of Larson's method of converting annual averages shows that to meet the 24-hour PSD increments, the annual average increments may not exceed 9.6 ug/m^3 for Class II areas or 2.6 ug/m^3 for Class I areas. Using criteria for Class II areas, 2 receptor sites would be expected to exceed the 24-hour PSD increment; however, these sites are virtually on the premises of the mine-mill development. Using criteria for Class I areas, 6 of the 36 receptor sites would be expected to exceed the 24-hour PSD increment.

As has been the finding throughout this impact analysis discussion, the air quality standards that will be the most difficult to meet are the 24-hour PSD increments. According to this modeling study of dust sources from a large mine-mill development, Class II 24-hour PSD increments may be exceeded in the close proximity to the mine and mill areas (i.e. within 1 km or less), while Class I 24-hour PSD increments may be exceeded up to 10 km away from the operation in

some directions. If such a development were not allowed to use up the entire PSD increment, an even larger area may exceed the Class I increment.

Although the CDM estimates are somewhat crude, they do indicate the relative importance of different sources of dust from potential mine-mill operations and highlight where additional control efforts would be most beneficial. A more detailed analysis, similar to that done in the case of SO_2 impacts, is not warranted here due to the crude nature of the emission estimates. Nevertheless, the basic problem is clear; it is expected that it will be difficult for an open pit operation located within some 10-15 km of a Class I area to meet the 24-hour PSD requirements. Extremely good dust control measures would be needed, particularly on haul roads.

In the case of an underground operation, the picture is greatly improved, though concentrations in excess of the Class I increment may still occur within a few kilometers of the operation. The elimination of dust from blasting in the pit, as well as the great reduction in the amount of haulage and storage of waste rock and significant (almost 50%) reduction in tailing material greatly reduces the emissions in this case. Reasonable dust control measures should allow the Class I increment to be met beyond the immediate ($1/2$-1 km) vicinity of the operation.

The TSP implications of siting a smelter at the location of the model mine-mill complex must be briefly discussed. The situation is rather similar to that for the smelter alone. The Class II 24-hour PSD increment may be exceeded within a few kilometers of the operation, depending on the degree of fugitive dust control that is used. The facility would have to be some distance (possibly 20-30 km for the base case smelter) from Class I areas to avoid exceeding the 24-hour increment. However, the ambient air quality standards do not appear to be

threatened by a common-site facility unless it is adjacent to other major particulate sources.

3.8.2 Particulate Deposition

Annual deposition rates for the two smelter models were calculated for the hypothetical smelter site south of Babbitt. Table 85 presents the resulting rates in kg/ha/yr for the various receptor sites in the model. For comparison, the table presents the predicted 1977 and 1985 rates due to local point sources in the emissions inventory. Finally, data is given on the total projected 1985 rates as a result of expected local point sources plus the smelter models.

Table 85

As expected, the rates for the option 1-option 2 model are half those for the base case model at all receptors corresponding to the differing emissions rate. The highest deposition rate for the base case smelter (4.8 kg/ha/yr) occurs, as expected at the closest receptor site, Dunka River. This is followed by rates of 2.0 and 1.6 kg/ha/yr at Babbitt and Unnamed Creek, respectively. Rates at most of the intermediate sites range from .1 to .6 kg/ha/yr, with a few values below .1 kg/ha/yr at remote sites.

The predictions for the base case model with the deposition from local point sources in 1985 indicate the smelter would have a significant impact on the closer receptor points. The Dunka River site increases from 4.7 kg/ha/yr without a smelter to 9.5 kg/ha/yr with the base case smelter, an increase of 102%. This drops to a 51% increase for the option 1-option 2 smelter model, but this is still a large change. The base case smelter increases the predicted 1985 deposition rates by 56% at Babbitt and 50% at Unnamed Creek.

Table 85. Predicted particulate loading rates for model smelters with and without contributions from other Regional Point Sources (kg/ha/yr).

RECEPTOR			SMELTER MODELS ALONE		LOCAL SOURCES IN REGION WITHOUT COPPER-NICKEL		LOCAL SOURCES PLUS SMELTER MODELS, 1985	
Map No.	Comp. Code	Name	Base Case Model	Option 1-Option 2 Model	1977 Regional Baseline	1985 Projection	With Base Case Model	With Option 1-Option 2 Model
1	301	Little Johnson Lake	.11	.051	1.9	1.2	1.3	1.2
2	106	Little Vermillion Lake	.11	.053	2.2	1.3	1.4	1.4
3	104	Birch lake Dam	.20	.098	2.0	1.0	1.2	1.1
4	103	Saganaga Lake	.07	.033	1.6	.6	.7	.6
5	105	Vermillion Lake	.21	.10	3.3	2.8	3.0	2.9
6	102	Shagawa R.W.	.32	.16	2.9	2.1	2.4	2.2
7	214	Ely H.S.	.40	.20	3.2	2.0	2.4	2.2
8	224	Fernberg Rd.	.24	.12	2.6	1.2	1.5	1.4
9	219	Tower-Sudan	.27	.13	4.0	4.0	4.3	4.1
10	206	Bear Island R.W.	.63	.31	3.7	2.7	3.3	3.0
11	201	Kawishiwi Lab W.	.63	.31	3.6	2.0	2.6	2.3
12	202	Keeley Creek W.	.56	.27	3.9	2.1	2.7	2.4
13	107	August Creek	.43	.21	4.0	2.1	2.5	2.3
14	101	Isabella Watershed	.32	.16	3.8	1.8	2.1	1.9
15	212	NW of Virginia	.12	.060	9.3	6.9	7.0	7.0
16	207	Embarrass R.W.	.51	.25	6.7	6.6	7.1	6.8
17	215	Babbitt	2.0	.98	4.3	3.6	5.6	4.5
18	204	Unnamed Creek W.	1.6	.76	4.5	3.2	4.8	4.0
19	223	Env. Learning Center	.76	.37	5.3	2.8	3.5	3.2
20	225	Parkville	.11	.054	23	7.9	14	14
21	221	Erie Office	.29	.14	16	20	20	20
22	208	Dunka Road	.91	.45	7.9	8.2	9.2	8.7
23	205	Dunka River W.	4.8	2.4	5.3	4.7	9.5	7.1
24	203	Stony River W.	.78	.380	6.2	3.1	3.9	3.5
25	217	NW of Eveleth	.09	.044	8.9	7.6	7.6	7.6
26	218	NE of Eveleth	.12	.058	7.1	6.8	6.8	6.8
27	213	Hoyt Lakes G.C.	.24	.11	8.1	8.6	8.9	8.8
28	209	St. Louis River W.	.40	.20	6.3	5.7	6.1	5.9
29	210	Waterhen Creek W.	.14	.069	5.2	5.0	5.2	5.1
30	211	Whiteface River W.	.17	.082	5.7	5.2	5.4	5.3
31	222	Toimi	.40	.19	5.8	4.4	4.8	4.6
32	220	Whiteface	.09	.044	4.9	4.4	4.5	4.5
33	226	Tower	.14	.070	4.2	3.4	3.6	3.5

Other more distant sites in areas expected to be impacted by local settlement and industry other than copper-nickel are predicted to receive minimal impacts. For example, the high levels predicted to occur in 1985 at Erie are not expected to increase due to the base case smelter. The site northwest of Virginia shows a 1-2% increase, and the Dunka Road site shows a 12% increase. Increases at remote sites are relatively large, due to the low values predicted without copper-nickel development. Fernberg shows a 25% increase in 1985 deposition rates due to the base case smelter, with 17% at Isabella Watershed and 20% at Birch Lake Dam. These percentages, of course, decrease with the option1-option 2 smelter model.

No actual total particulate deposition data was collected in the region to provide a basis for comparison. However, as discussed earlier, the real interest is in the deposition rates of certain elemental constituents of the particulates which may accumulate in the soils and vegetation and cause environmental impacts. As in the previous section, it is assumed for modeling purposes that the particulates have the composition of the concentrate fed to the smelter, and that the above bulk deposition rates may be converted to elemental loading rates. These rates can in turn be compared to measured loading rates found in the region by the analysis of bulk deposition samples.

The annual elemental loading rates predicted for the modeled constituents in the concentrate using this procedure are shown in Table 86 for selected receptor sites. The table also shows average measured rates for the region based on bulk deposition data (see section 3.5.2.2). As in the case of ambient concentration estimates, the predicted elemental deposition rates should be read as order of magnitude estimates only.

Table 86

Table 86. Predicted annual elemental loading rates at selected receptors for the base case smelter sited south of Babbitt, with regional measured values for comparison (all values in gm/ha/yr).

ELEMENT	MEASURED RATES[a] (without Cu-Ni development) IN THE REGION	BASE CASE SMELTER LOADINGS AT SELECTED SITES[g] Dunka River Watershed Receptor[b]	Kawishiwi Lab Receptor[c]	Saganaga Lake Receptor[d]
Si	NA[f]	350	46	5.1
Al	846	87	11	1.3
Mg	-11,000[e]	74	9.7	1.1
Ca	-11,300	55	7.2	.80
Na	- 3,500	19	2.5	.27
K	- 3,500	3.8	.50	.056
Ti	NA	4.8	.63	.070
P	280	.48	.063	.0070
Mn	NA	1.4	.19	.021
Cr	NA	1.9	.25	.028
B	NA	1.5	.19	.022
Ba	NA	.62	.081	.009
Sr	NA	.24	.031	.0034
V	NA	.41	.054	.0059
Th	NA	.014	.0018	.0002
Zr	NA	.12	.016	.0017
S	4,800	1,200	160	18
Cu	11	660	87	9.6
Ni	-14	130	17	1.8
Fe(total)	1,100	1,600	200	23
Co	NA	6.3	.83	.092
Zn	57	5.5	.71	.079
Pb	77	.29	.038	.0042
As	-11	.15	.019	.0021
Hg	NA	.00084	.00011	.000012
Mo	NA	.13	.018	.0019
Cd	3	.19	.025	.0027

[a]Based on bulk deposition data, 1977-78 (Thingvold et al. 1978).
[b]Values assume a bulk loading rate of 4.8 kg/ha/yr.
[c]Values assume a bulk loading rate of .63 kg/ha/yr.
[d]Values assume a bulk loading rate of .070 kg/ha/yr.
[e]- indicates a "less than" value.
[f]NA = element not analyzed.
[g]Several significant figures are shown for calculational purposes only. The values should be read as order-of-magnitude deposition rate estimates. Smelter particulates here are assumed to have the composition of the concentrate fed to the smelter.

The deposition results, as expected, show the potential for greatly increased deposition rates for copper and nickel. Within 5-10 km of the smelter the rates may be 1 to 2 orders of magnitude greater than those found in the region (on the average) during the 1977-78 sampling period. Even in the most remote parts of the region, increased deposition may be comparable to existing levels. The added deposition of sulfur (as sulfide) and iron may be comparable to background loadings close to the smelter. Other constituents, notably zinc, lead, and calcium, do not appear to pose the potential for major increases. There are no measured values of mercury or cobalt for comparison, but cobalt deposition may be expected to increase since there are presently no known significant sources of cobalt emissions in the region.

The above results are subject to the same uncertainties that were discussed earlier for the estimates of ambient concentrations of elemental constituents. In particular, estimates for the volatile constituents, especially mercury, lead, and arsenic, should be carefully evaluated in the light of more detailed data should a specific operation be proposed. These constituents may have deposition rates as much as 1 to 2 orders of magnitude higher than those shown, if they are concentrated in the strong SO_2 gas streams and escape removal by SO_2 control devices.

3.8.3 Mineral Fibers

As discussed in section 3.6.2.3, a conversion factor of 10^9-10^{10} fibers/gram of dry tailing and concentrate was determined as characterizing the materials which act as potential fiber emissions sources. The ambient TSP data given earlier for the smelter can be converted directly into potential ambient fiber concentrations using this factor. Using a worst case conversion factor of 10^{10} fibers/gram of

particulates, Figure 138 indicates the resulting concentrations predicted along the combined plume centerline for the base case smelter model. The fugitive contribution shown in the figure essentially represents the values for the option 1-option 2 model. It must be stressed that this prediction asssumes that the fibers will behave exactly like the gross particulates in dispersing in the atmosphere, so that the conversion factor of 10^{10} fibers/gram remains constant at all distances.

Figure 138

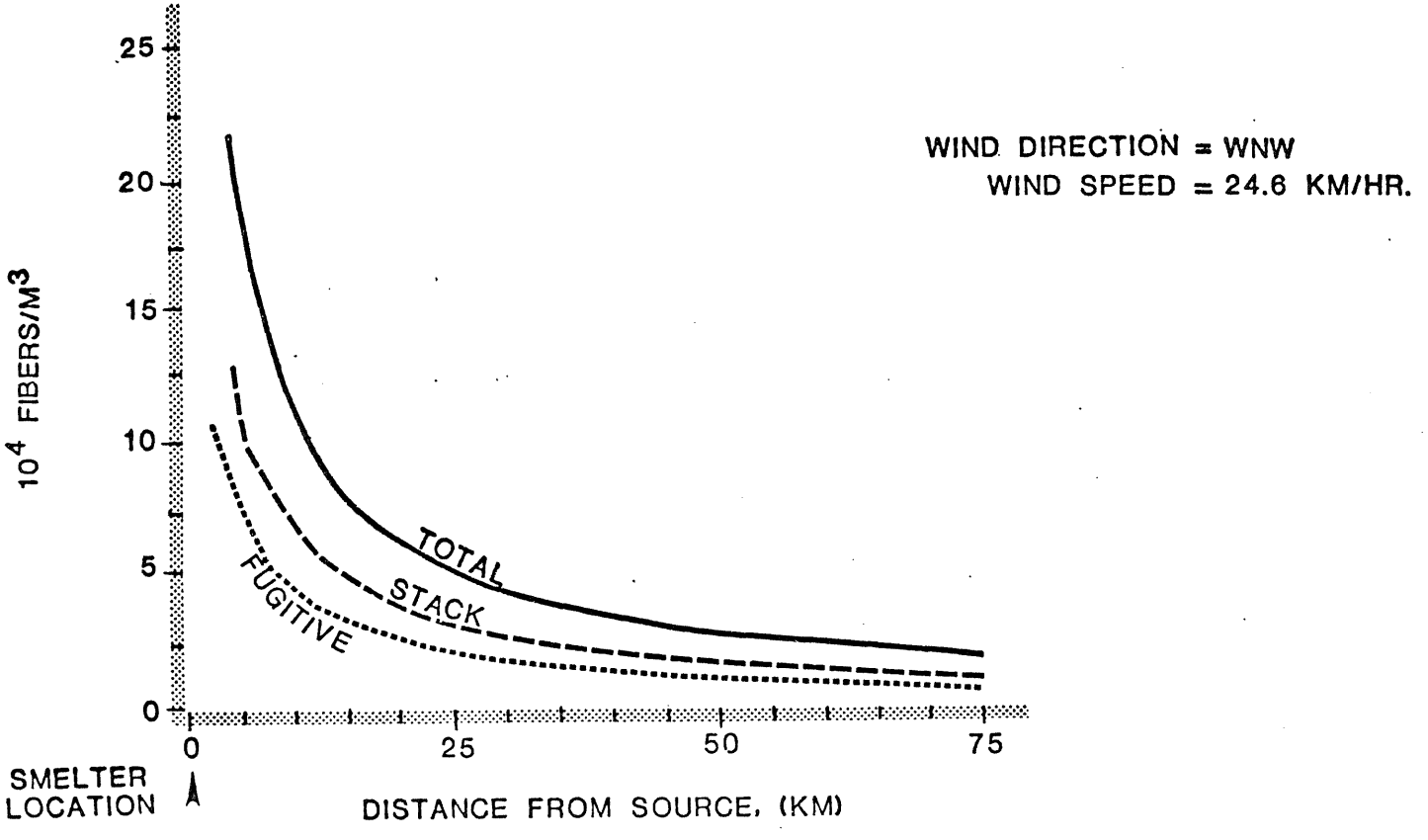
With the worst case assumptions made here, fiber concentrations in the range of 100,000-200,000 are predicted within 5 to 10 km of the smelter. These values can be compared to present concentrations in the region ranging from 10,000 to 40,000 fibers/m^3, and concentrations of 200,000 to 400,000 measured in 1974-75 around the Reserve taconite processing plant in Silver Bay (see section 3.5.3). This indicates the potential for a smelter to generate fiber concentrations in the immediate vicinity of the plant which may be an order of magnitude above ambient levels, and comparable to those found in the past in Silver Bay. Correspondingly, it must be pointed out that if the more optimistic figure of 10^9 fibers per gram of particulates is used, the maximum concentrations become comparable to ambient levels. Beyond 15 to 25 km from the site, concentrations drop to existing ambient levels, and possibly far below in both model cases.

In the case of the tailing basin, the results of the CDM analysis discussed earlier may be used, taking only the tailing basin contribution to particulates. Figure 139 shows the resulting predicted annual average fiber concentrations, again assuming a worst case conversion of 10^{10} fibers per gram of dust emitted. The same qualifications made with regard to the smelter predictions apply here.

FIGURE 138

PREDICTED STACK AND FUGITIVE CONTRIBUTIONS TO 24-HOUR MINERAL FIBER CONCENTRATIONS* ALONG A COMBINED PLUME CENTERLINE FOR THE BASE CASE SMELTER MODEL. (MODIFIED GAUSSIAN MODEL)

(BASED ON METEOROLOGY DATA FOR NOVEMBER 6, 1976)



*PREDICTIONS REPRESENT WORST CASE ASSUMPTIONS USING 10^4 FIBERS PER GRAM OF DRY PARTICULATES. DATA INDICATES A RANGE OF 10^3-10^4 FIBER/GRAM. MODEL ASSUMES FIBERS IN THE ATMOSPHERE DISPERSE THE SAME AS TOTAL PARTICULATES (SEE TEXT).

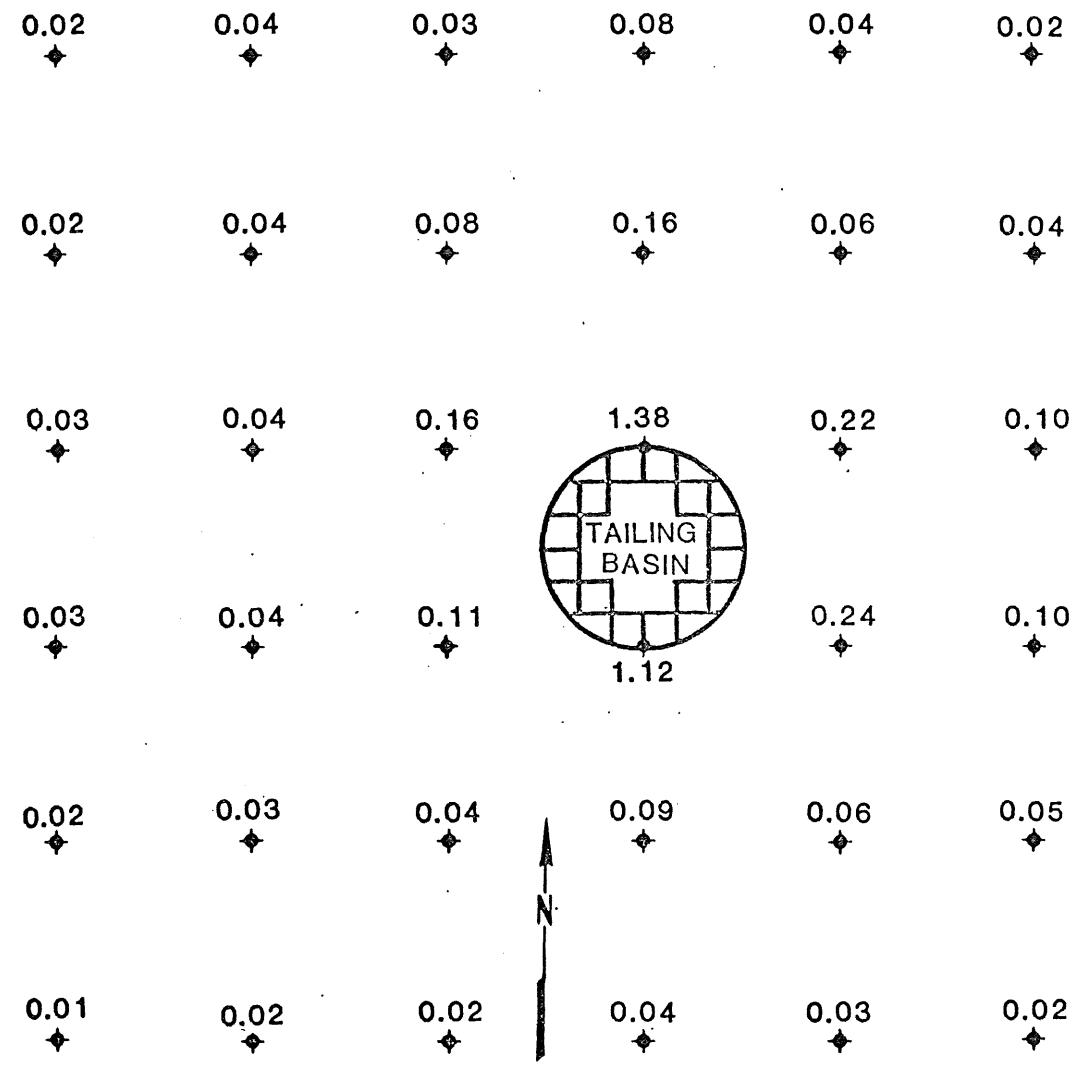
The results indicate that concentrations immediately adjacent to the source areas (1 km or less) may fall in the range of existing ambient concentrations. Otherwise the predicted values are well below present levels.

Figure 139

The conclusions from this analysis indicate the potential for major increases of ambient fiber concentrations in the area immediately surrounding a smelter due to dryer and fugitive dust. However, the nature of the source emission estimates used indicate that available technology is capable of reducing these emissions from 1 to 2 orders of magnitude if the potential problem is recognized and resolved. This should prevent significant increases in fibers concentrations. However, the analysis performed here has required modeling assumptions which cannot be verified by actual laboratory or field data, particularly the constancy of the fiber-to-weight conversion factor with particle injection and also with distance from the source. As such, these estimates simply serve to highlight areas requiring further investigation. The site specific considerations for a smelter (and tailing basin) must clearly address this question in the light of more detailed data. In any event, in the context of potential human health concerns, fiber concentrations should be monitored in the vicinity of any new operation to confirm or modify the results of modeled predictions and to verify the continued effectiveness of planned control measures.

FIGURE 139

PREDICTED INCREASES IN GEOMETRIC MEAN ANNUAL AMBIENT MINERAL FIBER CONCENTRATIONS* FROM TAILING BASIN EMISSIONS FOR A MODEL OPERATION (20 X 10^6 MTPY) (ALL VALUES REPRESENT 10^4 FIBERS/M^3)



*PREDICTIONS REPRESENT WORST CASE ASSUMPTIONS OF 10^{10} FIBERS PER GRAM. DATA INDICATES A RANGE OF 10^9 - 10^{10} FIBERS/GRAMS. THE MODEL ASSUMES TSP CONCENTRATIONS MAY BE CONVERTED DIRECTLY TO FIBER CONCENTRATIONS WITH THE ABOVE CONVERSION FACTOR

SOURCE : ASHBROOK (1979)

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