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Volume 3-Chapter 5

NOISE IN THE ENVIRONMENT

Minnesota Environmental Quality Board
Regional Copper-Nickel Study

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Regional Copper-Nickel Study
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REGIONAL COPPER-NICKEL STUDY REPORT OUTLINE

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 2205 pounds and is abbreviated as mt. The metric ton (1000 kilograms) is roughly 10% larger (10.25%) than the common or short ton (st) of 2000 pounds. The metric ton is quite comparable to the long ton (2240 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 (10000 m^2), and is roughly equivalent to 2½ acres (actually 2.4710 acres). Thus, one square mile, which consists of 640 acres, contains some 259 hectares.

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	=	3.28 feet = 1.094 yards
1 centimeter	=	0.3937 inches
1 kilometer	=	0.621 miles
1 hectare	=	10,000 sq. meters = 2.471 acres
1 sq. meter	=	10.764 sq. feet = 1.196 sq. yards
1 sq. kilometer	=	100 hectares = 0.386 sq. miles
1 gram	=	0.037 oz. (avoir.) = 0.0322 Troy oz.
1 kilogram	=	2.205 pounds
1 metric ton	=	1000 kilograms = 0.984 long tons = 1.1025 short tons
1 m^3	=	1.308 yd^3 = 35.315 ft^3
1 liter	=	0.264 U.S. gallons
1 liter/minute	=	0.264 U.S. gallons/minute = 0.00117 acre-feet/day
1 kilometer/hour	=	0.621 miles/hour
degrees Celsius	=	(5/9)(degrees Fahrenheit -32)

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5.1 INTRODUCTION AND SUMMARY OF FINDINGS

Noise is a significant factor in determining environmental quality, especially in wilderness, recreational, and residential areas. At high enough levels, such as those to which mine workers may be exposed, there is a danger of hearing loss (see Volume 5, Chapter 2 of this report). At lower levels, man-made noise is known to have an effect on humans and wildlife, although this area needs much further study (see Volume 4, Chapter 2 of this report). In this chapter, however, the primary interest will be in describing the existing and predicted ambient sound environment for people who are not on mine property. In the first section, the existing acoustic environment of the region will be characterized. This characterization serves two main functions. First, it establishes baseline data which will make it possible in the future to determine if degradation has occured. Second it serves to determine the sensitivity of the region to new noise sources. A sound that might not even be noticed as part of the general din of a metropolitan area might be a significant intrusion in an otherwise quiet area. In the following section the predicted noise impact of copper-nickel mining development is considered in the light of the existing environment described in this section.

The results given in the first section are taken from a more extensive report (Trimbach, 1978) of a regional sound characterization study. This reference should be consulted for detailed discussions of work plans, field procedures, and a more complete discussion of results. The impact modeling work is described further in Sipson (1978). Also, see Volume 5, Chapter 9 for additional discussions of the noise impact implications of copper-nickel development.

Basically, the characterization study consisted of making sample observations in the Regional Copper-Nickel Study Area over a period of 2 years at 42 sites distributed over an area of some 500 sq mi and chosen so that all the major types of sound environments would be sampled, from wilderness to urban (Figure 1). At these sites, three types of information were collected:

1) the subjective observations of the field personnel conducting the monitoring

2) measured values of the statistical distribution of sound levels, as measured by the dBA scale

3) calibrated tape recordings from which frequency content information could be determined

Figure 1

The major results of the study were to show that the region is quiet compared with most residential areas and that a major portion of the region is, at present, very lightly impacted by man-made sounds at any level. Measurements were made in a variety of vegetation types, including jackpine, birch, aspen, black spruce, and red pine stands, as well as in clearcuts. The results indicate that L_{50} values in the region range from 24 to 32 dBA in the winter and from 25 to 36 dBA in the summer. Correspondingly, winter L_{90} values are 15 to 19 dBA and summer L_{90} values are 14 to 25 dBA. Values for L_{10} range from 31 to 45 dBA in the winter, up to 32 to 52 dBA in the summer. As expected, the dominant source of natural sound in the area is the result of wind interaction with vegetation, explaining the fact that sound levels are higher under the full foliage conditions of summer than during the winter. The relative quiet in the region makes it particularly sensitive to new sound sources.

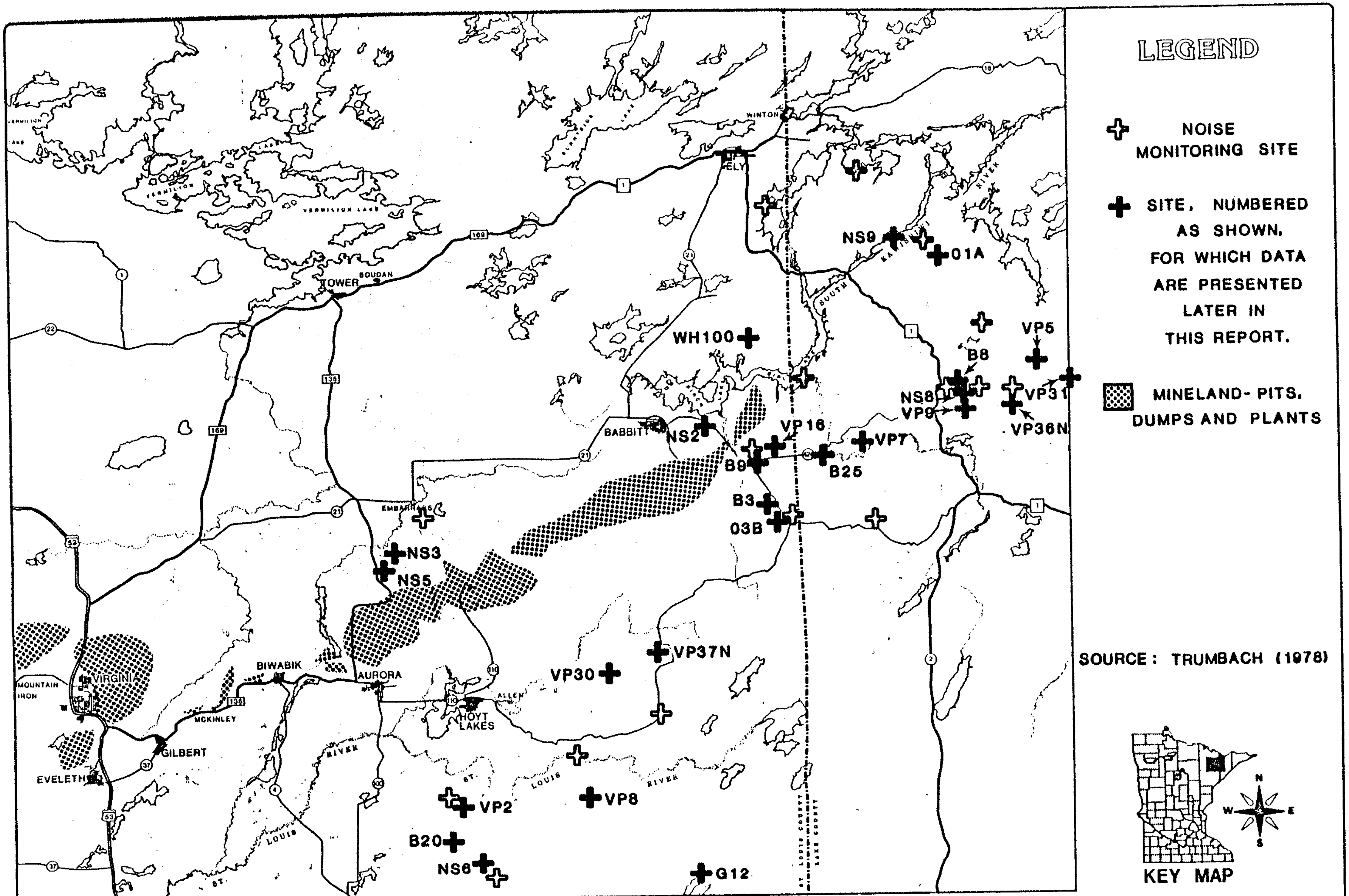


FIGURE 1

MEQB REGIONAL COPPER-NICKEL STUDY

LOCATION OF NOISE MONITORING SITES

In order to investigate the potential impacts that the development of a copper-nickel mining industry in the region might have on the local acoustical environment, a noise model was developed for use in the region. Using data on the meteorology and vegetation of the region, as well as data gathered on a variety of major sound sources likely to be present in a mining operation, the extent of the areas likely to be impacted (to various degrees) was estimated. Major mining sound sources of concern include haul trucks, sirens, and train horns. Ventilation fans are major potential sources of sound for underground mining operations. The modeling indicates that as a result of the quiet nature of the region, these potential new sources would be audible to human observers over extremely large areas. For example, an 85 ton haul truck is predicted to be audible at some time, under a variety of conditions, over areas ranging from 280 to 1800 km^2. This same truck is predicted to be audible, at least half of the time that it is operating, over areas ranging from 8 to 320 km^2. A ventilating fan is modeled as being audible over areas ranging from 480 to 940 km^2. Significant reductions in these areas can be achieved by the use of noise barriers in the mining operation, and by the selection of equipment designed to minimize the generation of noise.

It is appropriate at this point to comment briefly on the conventions used in the measurement of sound. The level of a sound in dBA has emerged over the years as being the best single number measure of the loudness of a sound. It is determined using a sound level meter which includes an A weighting filter that gives the most weight to sounds whose frequencies lie in the range 1000 Hz to 4000 Hz. One Hz (Hertz) is one cycle per second.

Sounds of very low or very high frequency are attenuated by this filter before the level is metered and thus a low frequency sound, e.g. 100 Hz, must be more powerful than one at 1000 Hz in order to have the same A weighted level. This weighting, or filtering, has been designed to make the meter's response more closely imitate the response of the human ear.

Two sounds must differ in level by at least 1 dBA in order for there to be a noticeable difference in loudness. Another useful fact is that if a sound is increased in level by 10 dBA, e.g. from 70 dBA to 80 dBA, the average human subject will perceive the sound as having become twice as loud. Figure 2, which is adapted from concepts in Architectural Acoustics by M.D. Egan (1972), may help to give the reader a better feeling of the significance of various dBA levels.

Figure 2

5.2 REGIONAL NOISE ENVIRONMENT

5.2.1 Existing Natural Sound Sources

In terms of the overall sound level, as measured in dBA, it was found that in the Study Area the dominant source of natural sound is the interaction of wind with vegetation. Second in overall importance is the sound produced by wildlife activity. Bird calls, squirrels, and insects are common daytime sources, and frogs and insects are common night-time sources. The importance of wildlife as a sound source is dependent on the season and the observer location. During the spring, territorial bird calls may be repeated quite often, and a person who is close to such a bird might experience repeated calls at a level of 50 or 60 dBA, a relatively loud sound for this region. On the other hand, during winter one might only hear a raven's call a few times per hour. Hearing more exotic forms of wildlife, such as moose or wolves, while of great interest to some persons, is not something that is frequent even in this region. Another possible source of natural sound is the motion of water, such as in a stream or waterfall. This will only affect a small area immediately adjacent to the sound source.

FIGURE 2

COMMON SOUNDS IN DECIBELS (DB)

SOME COMMON, EASILY RECOGNIZED SOUNDS ARE LISTED BELOW IN ORDER OF INCREASING SOUND INTENSITY LEVELS IN DECIBELS. THE SOUND LEVELS SHOWN FOR OCCUPIED ROOMS ARE TYPICAL GENERAL ACTIVITY LEVELS ONLY.

DECIBELS (DB)*	EXAMPLES	SUBJECTIVE EVALUATIONS
140	NEAR JET ENGINE	DEAFENING
130	THRESHOLD OF PAIN	
120	THRESHOLD OF FEELING - HARD ROCK BAND	
110	ACCELERATING MOTORCYCLE AT A FEW FEET AWAY	
100	LOUD AUTO HORN AT 10 FT AWAY	VERY LOUD
90	NOISY URBAN STREET	
	NOISY FACTORY	
80	SCHOOL CAFETERIA W/UNTREATED SURFACES	LOUD
70	STENOGRAPHIC ROOM	
60	NEAR FREEWAY AUTO TRAFFIC	MODERATE
50	AVERAGE OFFICE	
40	SOFT RADIO MUSIC IN APARTMENT	FAINT
30	AVERAGE RESIDENCE WITHOUT STEREO PLAYING	
20	AVERAGE WHISPER	VERY FAINT
10	RUSTLE OF LEAVES IN WIND	
	HUMAN BREATHING	
0	THRESHOLD OF AUDIBILITY	

CONTINUOUS EXPOSURE ABOVE HERE IS LIKELY TO DEGRADE THE HEARING OF MOST PEOPLE

RANGE OF SPEECH

*DB ARE "AVERAGE" VALUES AS MEASURED ON THE A-SCALE OF A SOUND-LEVEL METER.

ADAPTED FROM EGAN (1972)

5.2.2 Existing Anthropogenic Sound Sources

While this region should certainly be considered quiet and relatively lightly disturbed by man, acoustic evidence of man's presence is quite common. In some cases the man-made sound results in a significant increase in sound levels over those naturally occurring, while in other instances the sound might simply be detectable by the ear without significantly raising the overall sound level. In this section a basic inventory of the existing anthropogenic sound sources will be presented, while in a later section the measured characteristics of some of the more important sources will be given. First to be discussed will be the results of observations in rural areas, which constitute most of the Study Area. Following this is a discussion of the sounds observed in the urban areas.

5.2.2.1 Rural Areas: Because most of the region is rural and because urban noise has been the subject of many previous studies, most of the effort in field observations was con-centrated in the rural areas. The most commonly occurring man-made sound during the field observations was the sound of a vehicle passby, usually a car or pickup truck. The significance of these events was biased because the field measurement procedure was vehicle-based and the microphone was placed about 100 feet from a road. Had it been feasible to include sites not accessible by road, the significance of vehicles would have been reduced. Even though vehicles were the most commonly observed form of man-made sound, the remote character of the region is evident because the average number of vehicles per hour was approximately 2, and at about 25 percent of the sites no vehicles were observed during any of the measurement periods. In addition to the car-pickup truck traffic, there was also about a 25 percent mix of larger trucks, with logging related trucks being the most common. The distribution of trucks was not the same as that for the passenger vehicles. They were observed at only 25 percent of the sites. The distribution of truck traffic can be expected to shift as different areas are logged.

Next to road traffic, the most common source of artificial sound was that of air traffic. Averaged over all the sites and seasons, small planes were observed at the rate of about one per hour, while jet planes were observed at the rate of about one every three hours. Because they are more powerful sound sources and because they are airborne and thus not subject to sound absorption due to ground effects, a single aircraft would produce an intrusion that would last longer than that of a single road vehicle. Since the background levels are so low and since jet traffic at this location is at a high altitude, the sound of a jet, while not usually raising the overall sound level significantly, would remain detectable for several minutes. The lower altitude of small planes made it possible for them to raise the sound level if they passed near the site. If one considers the whole region and not just those places reachable by existing roads, air traffic is a more significant source of intrusions than is road traffic because road vehicle intrusions will only occur along a strip, centered on the roadway, whose width will depend on the vehicle type.

Less ubiquitous, but still important sources of man-made sound, are mining along the eastern end of the Mesabi Iron Range and logging activities. It was not always possible for the observer to distinguish mining sounds from logging sounds. However, most of these occurrences were probably due to mining vehicles, as will be discussed below. These sounds were observed at least once at 45 percent of the sites. At sites where these sounds were observed, they were observed with varying frequency. At 6 of the 42 total sites, these vehicle sounds were heard during 75 percent or more of the measurements while at another, which was about 20 km from the nearest mine, the sound was heard only once during 9 field measurements. For most of the sites these sounds made no significant contributions to the overall sound levels, but were simply audible and identifiable as being man-made, and can be characterized as have a "growling" or "whining" character. On calm days near a mine, these sounds could be heard continuously, while at more distant sites on windy days the sounds might only be heard occasionally--when there was a lull in the wind and/or when propagation conditions were particularly good.

Other sounds, (e.g. sirens, chainsaws, blasting, trains, and sounds from the Linde Oxygen plant, which is in the region near Babbitt) were also observed occasionally. The fact that chain saws were observed far less frequently than the sounds identified as "mining-logging" in Trimbach (1979) makes it likely that most of these were in fact mining sounds. The results of a Canadian study (Myles, et al. 1971) show that chain-saws can be heard through the forest as far as can other logging equipment, such as skidders.

5.2.2.2 Urban Areas: Limited observations were made within a regional urban area (Ely) to represent urban sound levels for the region. No unusual sources of urban sound were detected. As with most small urban areas, motor vehicles were the most significant source of sound. The problem of airport noise is minimized because the regional airport is several miles from Ely and further, it does not handle large commercial jets. Probably the most significant source of aircraft noise at Ely results from seaplane operations from Shagawa Lake just north of the town. The other urban sound sources observed were typical--people talking, radios, lawn mowers, dogs, etc.

5.2.3 dBA and Spectral Characterization of the Region

5.2.3.1 Procedures: In the previous section the subjective observations of the field observers were discussed. In this section, the results of the analysis of instrumental measurements will be discussed. There were two basic types of information obtained from the instrumentation system; level, in dBA, and frequency, in cycles per second or Hz. The level was usually determined in the field by means of a one-inch condenser microphone coupled to a sound level analyzer. The A-weighted scale was used as it most closely reflects the sensitivity of the human ear, which is the receiver of most concern in this study. The result of this measurement was a statistical distribution of the sound levels that were present during the measurement interval as described by the L_N values. The definition of the L_N values is such that the statement $L_{47} = 32$ means that the sound level that is exceeded 47 percent of the time is 32 dBA. A useful presentation of this statistical data was to plot the results on pobability paper (Burington and May, 1970). In many cases the resulting plot was close to being a straight line, which indicates that the A-weighted sound level statistics could be described as a normal or Gaussian distribution. This is fortuitous because a normal distribution is completely specified by its mean and standard deviation, making possible the summarization of all of the sound level data by two numbers. This procedure was so valuable that a statistical fit method was devised which would fit the best straight line on probability paper through the measured value for L_{10}, L_{20},...L_{90}. This method gave not only the value for the mean and standard deviation, but also a value for the standard error of estimate, $\hat{\delta}$. The parameter δ measures the root-mean-square (r.m.s.) fit of the actual data points to the best fit line; a value for δ of 1 dBA, for example, implies that approximately 68 percent of the data points fall within 1 dBA of the best fit line. This statistical fit procedure is described in detail in Trimbach (1978).

In addition to determining the statistical distribution of the overall sound levels, calibrated tape recordings were made during many of the measurements. These recordings were then frequency analyzed in the Acoustics Laboratory at Moorhead State University. In most cases the frequency content was determined in 1/3 octave bands, using a real time spectrum analyzer. In some cases the tapes were examined at higher resolution using a 1 percent bandwidth analyzer. A 1/3 octave band analysis gives more detailed information about a sound than is contained in the overall level as measured by the dBA scale. In a 1/3 octave band analysis the sound is broken up into its separate components within various frequency ranges or bands. In the range of human hearing, from 20 Hz to 20,000 Hz, there are thirty 1/3 octave bands. The analyzer then indicates the separate dBA levels for the components of the sound within these frequency ranges. A bird call, for example, might have a spectrum which peaked at a band whose center frequency was near 3000 hZ. The individual band levels may be combined, if needed, to compute the overall level in dBA.

The 1/3 octave band spectrum has a number of uses but for the purposes of this study one of the most important is its use in determining acoustic detectability. The human ear has the capability to frequency analyze. Thus a new sound is more readily detectable in the presence of an existing sound if it is at a frequency for which the band levels of the existing sound are low. The overall level, in dBA, of the sounds involved does not give enough information to determine if this is the case, while the 1/3 octave band spectrum does.

The 1/3 octave band real time analyzer proved to be a very valuable tool for this study. For example, many man-made sounds detected by the field observer did not result in a significant change in the overall dBA sound level but could be seen as a change in the sound frequency spectrum. For convenience in comparison with the dBA data, and because relatively low sound levels were observed, all the 1/3 octave band levels reported are A weighted levels. The results of a 1/3 octave analysis can best be displayed as a graph of band level vs. the corresponding bands center frequency. For this report, the maximum range of center frequencies used was from 25 Hz to 16,000 Hz; however, in many cases a smaller range of bands was used, where appropriate.

5.2.3.2 Natural Sounds:

Sound Levels

When the results of early field measurements were analyzed it became apparent, as already mentioned, that the dominant source of natural sound in this region is the interaction of wind with vegetation. Most of the time wind-generated sound not only dominated the overall A-weighted levels, but even dominated the individual A-weighted 1/3 octave band levels. There were exceptions to this, and some of them will be discussed below, but since wind-generated noise was by far the predominant natural sound, a major effort in the noise program was in characterizing this sound. There are two major factors which determine the nature of this sound. One is the type of vegetation present in the immediate vicinity of the observer and the other is the wind speed. The size of the region which is important in determining the wind-generated noise at a point is generally a circle whose radius is about 100 times the mean canopy height (Sipson, 1978). The basic philosophy of the wind-generated noise study was to monitor the sound generated in the principle regional vegetation types under a distribution of wind conditions. The results of these measurements were then analyzed to determine the statistical distribution of levels and the distribution of the sound energy with respect to frequency.

First the observed sound levels will be discussed. For the measurements where wind-generated noise dominated the A-weighted sound levels, it was found that the statistical distribution of sound levels closely followed a straight line on probability paper, indicating that the dBA level was normally distributed. In fact, the standard error of estimate, δ, resulting from the best straight line fit to L_{10}, L_{20},...L_{90} was less than 1 dBA in 95 percent of the measurements. Thus, it is reasonable to summarize the data from these measurements by using the mean or L_{50} value and the standard deviation, σ. These results, along with the standard error of estimate values, are given in Tables 1 and 2 (Trimbach 1978). From the L_{50} and σ value, the values for L_{10}, L_{20},...L_{90} can be obtained using Table 3. Also given is a formula for determining L_{eq}. The L_{eq} level of a sound is the level of a non-varying sound which would have the same intensity as the average intensity of the varying sound being measured.

Tables 1 and 2

By using probability paper or probability tables, the general L_N value can be found but the standard error of estimate value is only valid for N between 10 and 90. Especially for N less than 10, the data often deviated from the straight line on probability paper due to a short term event such as a bird or a vehicle passby. In fact, for three measurements there was so much bird activity or man-made sound that the straight line was fitted only to the values of L_{90} to L_{30}. In seven measurements, artificial noise was a significant source during most of the measurement. These measurements are included here for completeness, but they were not used in the characterization of wind-generated noise.

An examination of Tables 1 and 2 show that L_{50} ranged from 13 dBA to 52 dBA (the instrumentation noise floor for these measurements was 6 dBA). This demonstrates that, compared with urban areas, the region is basically quiet. For most measurements σ was 5 dBA or less, giving a value for the range between L_{10} to L_{90} of 13 dBA or less. Thus, the sound level was relatively steady during a typical one-hour data interval. In fact, for one measurement σ was only .5, giving a value for L_{10} — L_{90} of only about 1 dBA. Within each vegetation type there is a considerable variation in the value of L_{50} as a result of the fact that, to the extent possible, measurements at each site were

Table 1. Winter Sound Level Statistics

Site No.		Results of individual measurements (dBA)						
		Jack Pine						
B-8	$\bar{X}$	13	41	31	33	30		
	σ	2.8	3.5	3.6	3.6	6.1		
	δ	.57	.39	.22	.23	.51		
B-9	$\bar{X}$	43	40	34	34	35	26**	
	σ	3.6	2.6	2.9	2.3	3.3	4.1	
	δ	.23	.37	.37	.24	.33	.42	
VP-2	$\bar{X}$	28	41	38	17			
	σ	3.5	3.3	3.6	4.5			
	δ	.39	.21	.59	.54			
		Birch						
VP-9	$\bar{X}$	20	28	32	21	34	45	
	σ	3.5	4.0	3.2	0.9	6.9	3.0	
	δ	.64	.42	.48	.31	1.21	.32	
VP-7	$\bar{X}$	32	31	43	31	37		
	σ	4.6	4.9	2.9	4.6	3.4		
	δ	.45	1.43	.37	.23	.33		
VP-8	$\bar{X}$	28	20	29	42	38	22	14
	σ	3.0	2.8	3.0	4.3	4.2	4.7	1.5
	δ	.28	.20	.28	.30	.35	.23	.24
		Black Spruce						
VP-5	$\bar{X}$	33	30	20	33	33	25	
	σ	2.8	3.8	0.5	3.4	2.8	6.8	
	δ	.20	.12	.28	.40	.43	.34	
VP-16	$\bar{X}$	31	35	33	22**	38	24**	
	σ	4.2	4.2	2.8	3.0	4.4	3.0	
	δ	.28	.54	.25	.28	.38	.51	
VP-30	$\bar{X}$	26	45	20	24*			
	σ	5.1	5.4	4.0	5.9			
	δ	.58	.34	.59	.48			
		Clear-Cut						
VP-31	X	21	25	25	23	22		
	σ	3.1	4.8	1.9	5.9	5.9		
	δ	.39	.48	.29				
03B	$\bar{X}$	28	23	31				
	σ	3.0	2.3	4.7				
	δ	.28	.48	.29				

Table 1. continued

Site No.		Results of individual measurements (dBA)			
		Spruce			
VP-36N	$\overline{X}$	30	16	46	19
	σ	3.6	3.6	3.3	5.2
	δ	.23	.23	.31	.71
B-25	$\overline{X}$	30	41	40	25
	σ	2.6	2.3	3.9	2.1
	δ	.34	.70	.65	.42
VP-37N	$\overline{X}$	27	23	25	19
	σ	4.1	3.7	5.1	3.3
	δ	.43	.57	.51	.54

$\overline{X}$ = mean = L_{50}
σ = standard deviation
δ = standard error of estimate
*data adjusted for skewing factor
**data omitted for combination of vegetation types due to presence of artificial noise

Table 2. Summer sound level statistics

Site No.		Results of Individual Measurements (dBA)				
		Jackpine				
	$\overline{X}$	33	44	32	21	
B-8	σ	4.3	3.3	2.4	2.1	
	δ	.28	.31	.36	.32	
	$\overline{X}$	34	39	36	30	43
B-9	σ	2.3	2.4	4.3	2.8	4.0
	δ	.24	.28	.57	.98	.42
	$\overline{X}$	30	34			
VP-2	σ	2.8	4.3			
	δ	.21	1.03			
		Red Pine				
	$\overline{X}$	26	43	25	41	
NS-8	σ	3.9	3.6	1.8	4.4	
	δ	1.01	.23	.34	.32	
	$\overline{X}$	31	44	26		
B-3	σ	4.4	5.7	5.6		
	δ	.38	.45	.54		
	$\overline{X}$	29	18	33		
B-20	σ	2.2	2.1	3.7		
	δ	.38	.32	.33		
		Clear-Cut				
	$\overline{X}$	23	29	27	24	
VP-31	σ	5.9	4.1	2.1	1.6	
	δ	.72	.42	.36	.30	
	$\overline{X}$	25	16			
03B	σ	3.8	3.5			
	δ	.43	.55			
	$\overline{X}$	27	30	20		
WH-100	σ	3.3	2.4			
	δ	.31	.28	.40		
		Aspen				
	$\overline{X}$	36	22	31		
01A	σ	3.6	3.2	4.5		
	δ	.52	.78	.47		
	$\overline{X}$	41	35			
NS-3	σ	4.7	5.5			
	δ	.54	.27			
	$\overline{X}$	39	20*			
G-12	σ	5.9	5.0			
	δ	.34	.41			

Table 2. continued

Site No.		Results of Individual Measurements (dBA)			
		Black Spruce			
	$\overline{X}$	25	41	23	15
VP-5	σ	4.5	4.2	4.1	1.8
	δ	.54	.28	1.00	.28
	$\overline{X}$	39	23**	22	
VP-16	σ	4.8	2.6	5.4	
	δ	.44	.42	1.73	
	$\overline{X}$	27	41		
VP-30	σ	4.0	4.7		
	δ	.42	.45		
		Birch			
	$\overline{X}$	45	52	16	
VP-9	σ	4.1	4.7	2.1	
	δ	.42	2.3	.52	
	$\overline{X}$	21**	37**	34**	
NS-2	σ	5.2	9.3	4.7	
	δ	.73	1.02	.71	
	$\overline{X}$	38	32	22	
VP-7	σ	5.9	5.5	1.6	
	δ	.26	.67	.27	
	$\overline{X}$	42	40	36	
VP-8	σ	3.8	3.7	4.2	
	δ	.12	.33	.38	
		Sapling Aspen			
	$\overline{X}$	31	37	52	19*
VP-36N	σ	5.0	2.8	2.7	3.3
	δ	.43	.20	3.2	.21
	$\overline{X}$	36	2.9		
NS-5	σ	2.8	2.3		
	δ	.62	.45		
	$\overline{X}$	40			
NS-6	σ	4.0			
	δ	.23			
		Sparse-Mixed			
	$\overline{X}$	30	27	39	
NS-9	σ	4.3	2.5	3.1	
	δ	.28	.51	.41	
	$\overline{X}$	32	26		
B-25	σ	4.2	3.8		
	δ	.61	.43		
	$\overline{X}$	34	42		
VP-37N	σ	3.8	3.3		
	δ	.43	.21		

$\overline{X}$ = mean = L_{50}
σ = standard deviation
δ = standard error of estimate
*data adjusted for skewing factor
**data omitted for combination of vegetation types due to presence of artificial noise

made over a range of wind conditions from low to high. (See Volume 4, Chapter 2 for a discussion of the various vegetation types in the Study Area, and maps of the locations of the various types.)

In order to characterize the various vegetation types, a procedure was developed to combine the statistical distributions from the individual measurements to arrive at an overall distribution for the sound levels observed within the given vegetation types. This procedure is described in Trimbach (1978). The result of this procedure is to give the distribution of levels that one might expect averaged over a full season during daylight hours, since the measurements were made between 0600 and 1800 hrs. These combined distributions can reasonably be represented as normal distributions, as the factors in Table 4 show. The combined winter Jackpine results were the most skewed, with a δ of 2.3. This was due to two very quiet measurements with L_{50} values of 13 and 17. The accuracy with which the combined distribution can be represented by a normal distribution is especially good, considering the limited number of measurements that were available from each vegetation type. Obviously, it would be desirable to have more data from each of the vegetation types. Nevertheless, the results obtained, particularly the fact that the δ values obtained were generally only about 10 percent of the σ values, seem to indicate that the procedure is valid and that these combined distributions reasonably represent the sound level statistics in these vegetation types. Because many persons are more familiar with measures of sound level distribution other than the standard deviation, the table includes values for L_{10}, L_{90}, and L_{eq} calculated from L_{50} and σ using the procedure shown in Table 3.

Table 3

Table 3. Statistical relationships.

$$
\begin{aligned}
L_{10} &= L_{50} + 1.282\,\sigma \\
L_{20} &= L_{50} + .841\,\sigma \\
L_{30} &= L_{50} + .524\,\sigma \\
L_{40} &= L_{50} + .253\,\sigma \\
L_{60} &= L_{50} - .253\,\sigma \\
L_{70} &= L_{50} - .524\,\sigma \\
L_{80} &= L_{50} - .841\,\sigma \\
L_{90} &= L_{50} - 1.282\,\sigma \\
L_{eq} &= L_{50} + \frac{\ln(10)\sigma}{20}^{2} \\
&= L_{50} + .115\sigma^{2}
\end{aligned}
$$

Table 4 gives further evidence of the relative quietness of this region. The values for L_{50} during the daytime are in the low 30s for most vegetation types, while the values for L_{90} are about 20 dBA. Even the L_{10} value is only about 50 dBA at the most, and for Clearcut sites it was only about 30 dBA. When the values given in Table 4 are compared with those found in a national sampling (EPA 1971), the most significant result is the low values for L_{90}, often called the residual sound level. For this region the L_{90} value is about 20 dBA for daylight hours, while for even quiet suburban residential areas the daylight L_{90} value is about 40 dBA. These two levels differ by a factor of approximately 4 in perceived loudness. Some seasonal variations are evident, particularly for birch stands. During the foliage season the L_{50} for birch stands went up 6 dBA, while the L_{10} went up 9 dBA. This is true in spite of the fact that the mean wind speed during the summer data period was twenty percent lower than the mean wind speed during the winter data period. Wind speed here means the regional average wind speed as measured at the airport at Hibbing. A procedure for taking wind statistics into account will be described below.

Table 4

Other vegetation types which were monitored in both seasons did not show as much variation. Also evident from Table 4 is the fact that the most powerful sources of wind-generated vegetation noise were the deciduous stands during the foliage season. The similarity of the results for birch, sapling aspen, and aspen suggested combining the data for all of these sites to give a description of the sound levels in summer deciduous vegetation, and this is the last entry in Table 4.

Table 4. Combined sound level distributions by seasons and vegetation type in dBA.

	L_{50}	σ	δ	L_{eq}	L_{10}	L_{90}	NUMBER OF DISTRIBUTIONS COMBINED
Winter Results							
Jackpine	32	10.3	2.3	44	45	19	14
Birch	30	10.0	.4	42	43	17	15
Black spruce	30	7.4	.6	36	39	21	15
Sparce	28	10.1	1.8	40	41	15	13
Clearcut	24	5.1	.5	27	31	17	8
Summer Results							
Birch	36	12.1	1.9	53	52	20	11
Sapling aspen	35	10.5	1.1	48	48	22	7
Aspen	34	10.3	1.0	46	47	21	7
Jackpine	34	6.9	.3	39	43	25	11
Sparce-mixed	33	7.0	.8	39	42	24	7
Red pine	31	9.4	.8	41	43	19	10
Black spruce	29	11.7	1.2	45	44	14	8
Clearcut	25	5.4	.5	28	32	18	9
All deciduous	34	11.2	.99	48	48	20	25

The results in Table 4 represent the statistical distribution of wind-generated noise for various vegetation types, with and without summer foliage. In obtaining these results, only data for which wind-generated noise was the dominant sound source was used. Thus, there should be a good correlation between the statistical distribution of regional wind speeds and the distribution of sound levels. In order to obtain a relationship between wind speed and sound level, it was assumed that this correlation is perfect. That is, that the sound level exceeded N percent of the time is generated by the wind speed exceeded N percent of the time.

Using this assumption, it was possible to derive a relationship between wind speed and sound level for the vegetation types considered. This procedure is discussed in Trimbach (1978) and Sipson (1978). Table 5 is based on the results of this procedure and shows the sound levels that will result from wind driven vegetation sounds for a low wind speed, 1.5 m/s, and for 7.2 m/s, a wind speed exceeded in the region less than 10 percent of the time.

Table 5 shows more clearly than Table G-4 the increase in noise generation ability resulting from summer foliage conditions, especially for deciduous vegetation.

Table 5

Sound Spectra

The discussion above summarizes the results of the study of the sound levels resulting from wind-generated noise in the region. Also important, especially in the noise impact model discussed later, is the spectral content of these sounds. For all vegetation types, the sound has a broad band character. That is, there are no pure tone components. Thus it can be well represented by a 1/3

Table 5. Expected sound levels for 1.5m/sec (3 knot) and 7.2m/sec (14 knot) winds in dBA.

VEGETATION TYPE	SL for 1.5 m/s Wind	SL for 7.2 m/s Wind
Winter		
Jack pine	21	44
Birch	19	41
Black spruce	22	38
Sparce	17	40
Clearcut	19	30
Summer		
Jack pine	29	44
Red pine	24	44
Birch	28	53
Aspen	27	49
Black spruce	21	46
Sapling aspen	28	50
Sparce-mixed	28	43
Clearcut	21	33
All-deciduous	26	50

octave band analysis. This analysis was conducted at the Acoustics Laboratory of Moorhead State University using calibrated tape recordings made in the field. The procedure used, described in detail in Trimbach (1978), was to observe the signal simultaneously on a real time analyzer which displayed the spectral content, with a measuring amplifier which displayed the dBA level, and aurally using a studio monitor loudspeaker. Using this procedure it was possible to determine which portions of a tape were dominated by wind-generated noise. In order to organize the analysis, it was decided to determine the spectral content for the sound of various vegetation types at 5 dBA intervals, i.e. 20, 25, 30, etc.

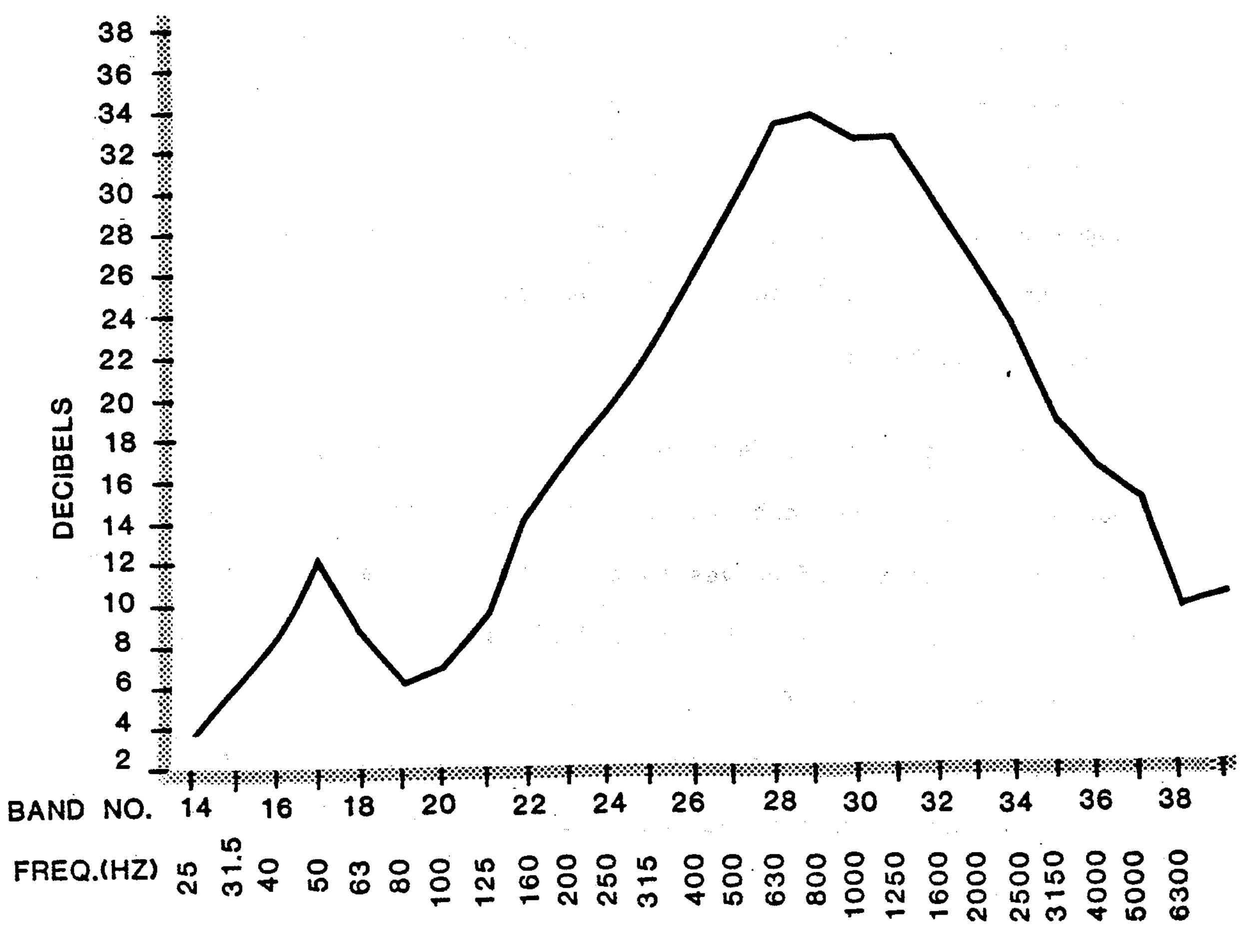
Graphs of the results of this procedure are included in Trimbach (1978). Since there are about 50 such graphs, they are not included in this summary report. Instead, a discussion of the basic nature of the spectra is given. Figure 3 shows a typical individual graph. It is a plot of the average spectral shape for winter black spruce when the sound level is 40 dBA. Basically, it can be seen that as frequency goes up the 1/3 octave band level, in dBA, rises to a peak at the 800 Hz band and then drops at higher frequencies. The small peak seen at 50 Hz in this particular graph is due to unidentified low frequency artificial sources which could have been located at a relatively great distance due to the favorable conditions for propagation at these frequencies (see the discussion of sound propagation in a later section for more on this point). These low frequency spectral components affect the overall sound level by less than .03 dBA; so it is fair to say that the sound energy for this spectrum is well represented by its distribution between 100 and 4000 Hz, which corresponds to Standard Band numbers 20 through 36. The upper cutoff frequency of 4000 Hz was chosen because it is adequate for the noise model to be discussed later and because, for measurements made at lower levels, measurement system electronic noise made it impossible to accurately determine band levels at higher frequencies. Examination of the spectral shapes for other sound levels, where black spruce vegetation noise dominated, revealed a similar shape. The only significant differences were that with higher overall dBA levels the individual band levels went up and the position of the peak was subject to a slight upward shift in frequency.

Figure 3

Taking all of these results into account the basic spectrum of wind generated noise in winter black spruce can be summarized by saying that starting from band 20, the A-weighted band levels rise essentially linearly with band number up to a peak, and above that peak they fall linearly with band number. In addition, the position of the peak shifts upward with overall sound level. Most other vegetation types showed this same pattern. The only difference was that the slopes of the two straight line portions of the spectral plots differed between vegetation types, and the position and rate of shift of the peak with sound level also differed.

In conjunction with the development of a noise model, a least squares fit procedure was developed based on the description at the beginning of this paragraph which fits a family of curves to the actual vegetation spectral plots for 25, 30, 35, 40, and 45 dBA. This procedure is described in more detail in Sipson (1978). As examples of the results obtained, Figures 4 and 5 show the results for winter black spruce and summer birch. The dots indicate the values for the 1/3 octave band levels predicted by this family of curves. The lines are drawn for convenience. The standard error of estimate between these levels and the actual data is 1.3 dBA for the summer birch and 1.5 dBA for the winter black spruce. The spectral shape for black spruce is typical of coniferous forest

FIGURE 3 AVERAGE SPECTRAL SHAPE FOR 40 DBA WINTER BLACK SPRUCE SOUNDS



while that for birch is typical of foliated deciduous forest. Even for birch, the bands above 4000 Hz contribute less than 1 dBA to the overall level. The bands below 100 Hz make a contribution of a small fraction of a dBA for all vegetation types. Immature trees, such as sparce and sapling aspen, did not exhibit as much regularity in their spectral shapes, perhaps because these classifications are less well defined than those for the mature species. Thus, the least squares fit procedure was not applied to them, although their spectra generally resembled those for birch in the corresponding season.

Figures 4 and 5

The classification of wind-generated sounds in clearcut areas presents a special problem. To what extent is the sound in a cleared area produced by wind interaction with the vegetation in the clearing itself and to what extent is it produced by the surrounding mature vegetation? This question is especially significant because most of the clearcut areas in the study region were not large, no more than one or two kilometers in diameter. In smaller clearcut areas, the sound of the surrounding vegetation was obvious. To seek an understanding of this situation, a simple analytical model was developed (Sipson, 1978). It shows that a cleared area has to be one kilometer or more in diameter in order for the sound from the surrounding vegetation to be 10 dBA less than that present in the same tree type with no clearing.

While the analysis is only approximate, it does show that the wind-generated noise observed within small clearings or on small bodies of water surrounded by a forest will be dominated by the sounds from the surrounding forest. If the cleared region is quite large and well vegetated, sounds produced within the clearing itself could dominate. Field observations in cleared areas were made difficult by problems with wind generated microphone noise due to increased

FIGURE 4 1/3 OCTAVE BAND SPECTRUM FOR WINTER BLACK SPRUCE FROM LEAST SQUARE FIT

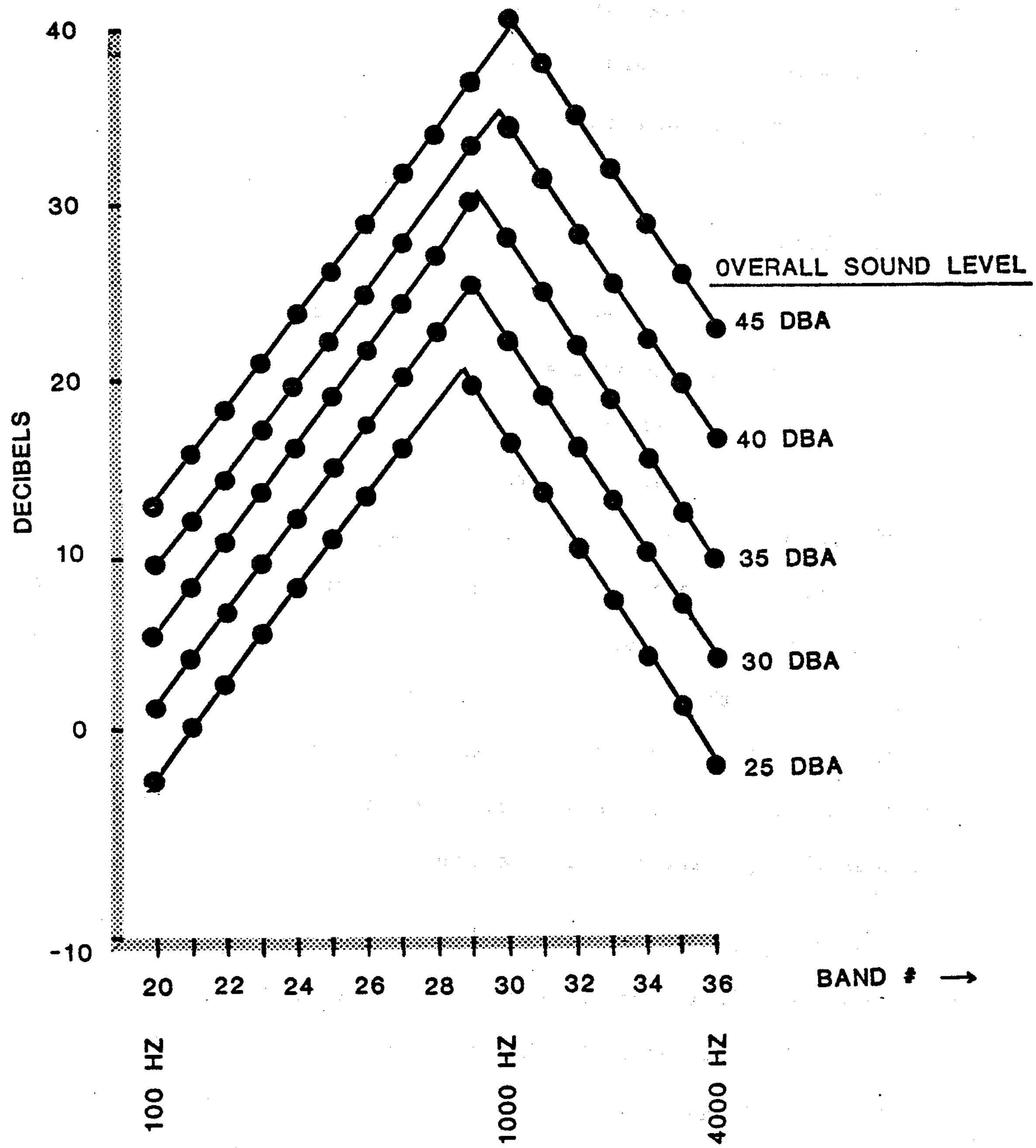
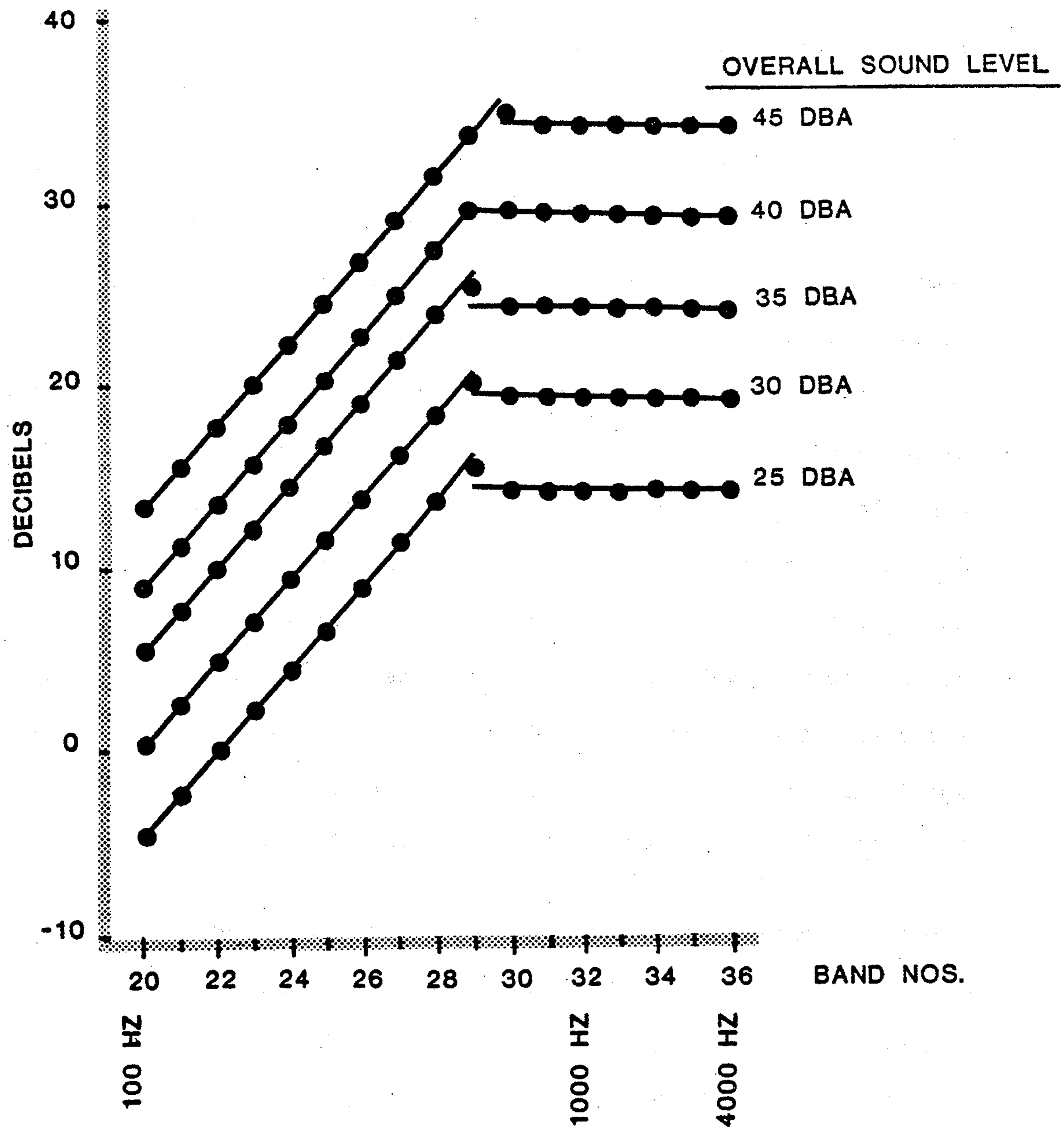


FIGURE 5 1/3 OCTAVE BAND SPECTRUM FOR SUMMER BIRCH FROM LEAST SQUARE FIT



exposure to winds and lower wind-generated sound levels. However, especially for clearings on the order of one kilometer in diameter, the conclusions of the above analysis are borne out. The spectral shape is similar to that of the surrounding vegetation type while the levels observed were reduced by an amount on the order of 10 dBA.

Other Sound Sources

Because wind-generated noise was the dominant source of natural sound, it was discussed at length. There were other sources of natural sound, however, the most significant being sounds produced by wildlife. In the winter these sounds were usually restricted to those made by occasional squirrels and ravens. The dominance of wind-generated noise was greatest in this season. In the warmer months, spring especially, bird activity increased greatly, and insects and frogs could also be heard. Under certain conditions, such as an early morning measurement on a spring day with calm winds in favorable bird habitat, it was possible to observe the effects of bird activity on the overall sound levels. However, even in this situation the effects would only be significant in L_{10} and L_{20}. The percentage of time that bird calls could actually raise the overall sound level was never as great as 50 percent. More significant than their effect on overall sound levels was their audibility and effect on the spectrum. For most species of birds the acoustic energy of their calls was predominantly above 1000 Hz, often peaking at about 3000 Hz.

Another commonly heard sound was the chatter of a squirrel. If the squirrel was close to the microphone it could influence the overall dBA level, but their activity was not as continuous as was observed for bird calls; thus, their effect would usually be seen only in L_{10}. Most of their sound energy was also above 1000 Hz. During many measurements insect sounds could be heard. Usually, they would not significantly raise the dBA level, but an individual insect buzzing near the microphone on a calm day could raise the level a few dBA. While the buzz of wing motion was the sound produced by most insects, some insects, especially crickets, are capable of producing specialized sounds. The sound produced by crickets is quite high in frequency (above 5000 Hz).

Spectral plots for some observed wildlife sounds can be found in Trimbach (1978). The general shape of these plots is a smooth background spectrum broken at one or two bands by wildlife-produced spectral components.

5.2.3.3 Man-Made Sounds: The impact of human activities upon the dBA levels and spectral shape depended strongly upon the site. In most cases only occasional events would signifi-cantly increase the dBA level. These might be vehicle passbys or a small plane passing close by (urban areas are discussed later). As was discussed previously, for most sites these events were limited to 3 or 4 per hour. Exceptions to this could be found at sites quite close to mines. For example, at one site which was about 2 km from the boundary of a mine, a calm day measurement revealed mining vehicle sounds as the dominant sound source. Figure 6 presents a 32 second average of the spectrum observed at this site. In most cases, however, when man-made sounds other than those of vehicle or airplane passbys were heard the sound did not substantially increase the overall dBA level observed. In these cases the effect of the sound could only be seen in the 1/3 octave band spectrum analysis. Figure 7 gives a spectrum where the sound of a mining vehicle could be clearly heard. The smooth background spectrum is broken by a mining vehicle tonal component at band 24 (the 250 Hz band). By summing the band levels it can be shown that this component only increases the overall dBA level by about 1 dBA. For more examples of 1/3 octave band spectra showing the presence of artificial sounds see Trimbach (1978). Figures 6 and 7 represent the two extremes of non-passby artificial sounds, ranging from dominant to simply audible.

Figures 6 and 7

The effect of vehicle and aircraft passbys depends strongly on the relative location of the observer to the path of the sound source. This is especially true for cars and trucks where an observer within 30 meters of the roadway might be exposed to peak passby levels in excess of 70 dBA, a very loud sound for this region.

Another source of man-made sounds in the region, which was occasionally observed, was the sound of railroad operations. These are powerful sources of very low frequency sounds as they are moving along, but not of pure tone components in the range 100 Hz and above. Thus, their sounds are not as intrusive as the sounds from trucks and small planes. A train horn, however, does produce strong tonal components at 250 Hz and its harmonics, and these propagate over long distances quite well. During one observation, made approximately 3 km from the nearest track, the sound of a train horn was observed at levels of up to 55 dBA. Since the fundamental component was in the 250 Hz band and thus subject to little atmospheric absorption, this sound is audible over a wide path on either side of the tracks.

5.3 MODELING PROJECTED COPPER-NICKEL NOISE SOURCES

5.3.1 General Discussion of Modeling Rationale and Procedures

The function of a noise model is to try and predict the effect that mining related noise sources will have on areas surrounding a mining development in the region. The term "effect" here refers only to the acoustic environment created by the mining development. The effects on those who work in the mine are

FIGURE 6

32 SECOND
AVERAGE SPECTRUM WHERE
MINING SOUNDS DOMINATE

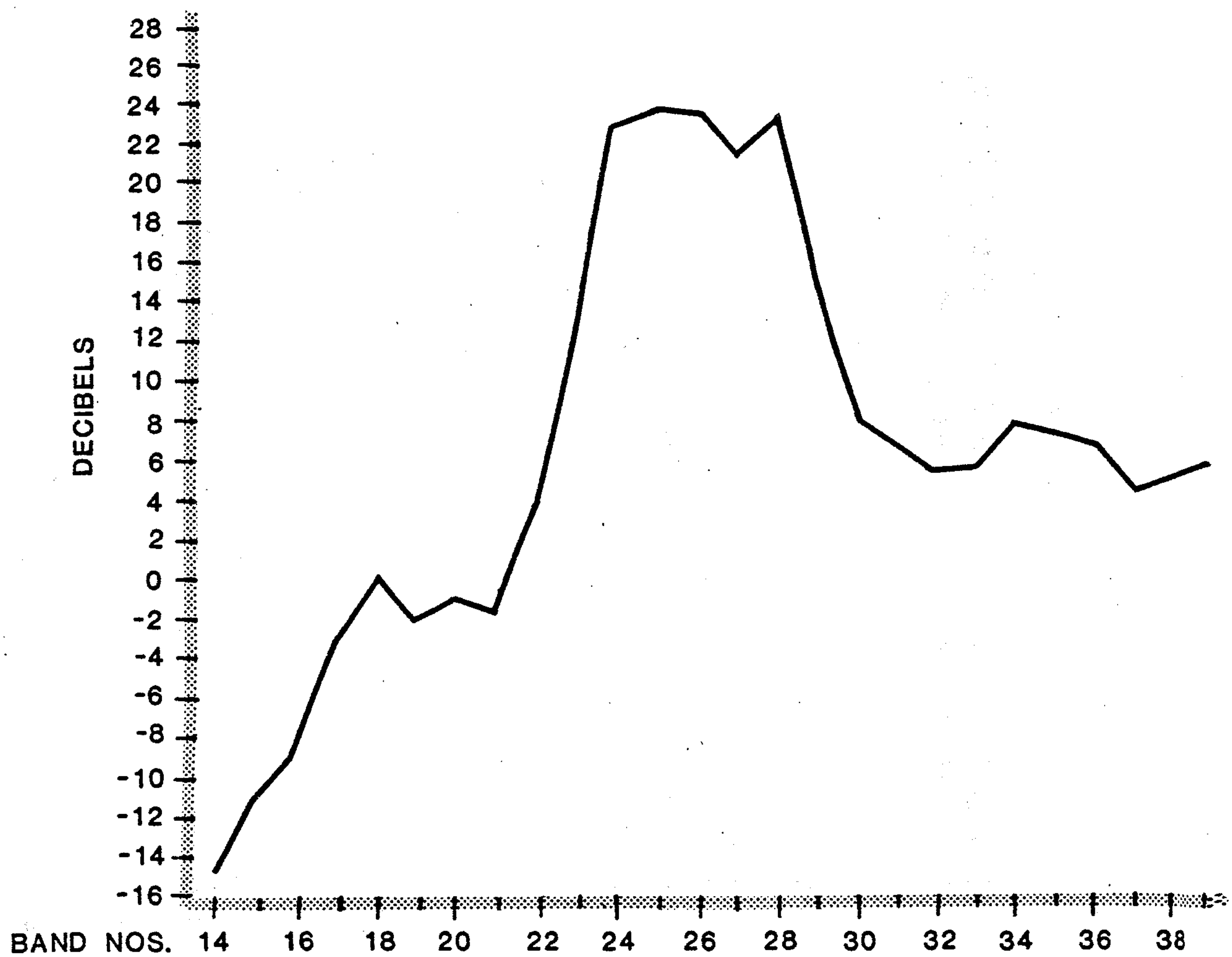
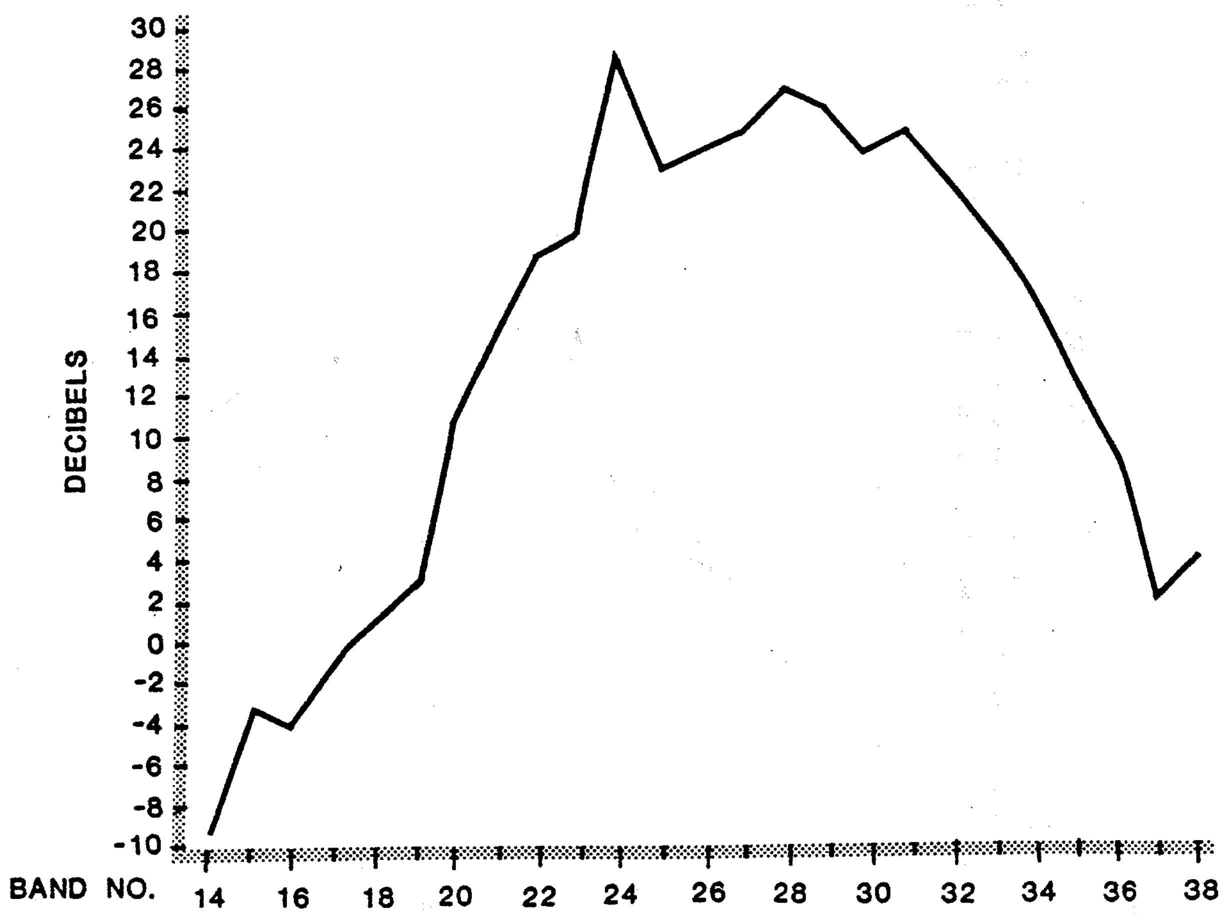


FIGURE 7

NATURAL SOUND SPECTRUM BROKEN BY MINING VEHICLE SOUNDS AT BAND 24. VEHICLE CLEARLY AUDIBLE.



controlled by OSHA regulations. Observations around the existing taconite mines in the region, discussed previously, and the results of calculations described below, show that persons off of mine property will not be subject to sounds that could be considered loud in the sense that they might cause hearing damage. They may well be a source of annoyance, however, for persons who live near the mine or those using the area for recreation. Especially sensitive will be those using the BWCA. Many of these people, especially those in paddle-only areas, find the deep sensory isolation from man's activities a major attraction of the region. Hearing the sound of mining activities, even if the sounds were not loud, might significantly reduce this sense of isolation. Taking these facts into account, it was decided to emphasize acoustic detectability in the impact model. In other words, regardless of how loud a sound is, the question to be addressed is that of how easily can it be distinguished in the presence of whatever masking sounds might be present. Since the ear is a frequency sensitive device that is capable, under some circumstances, of detecting sounds at a given frequency even when louder sounds at other frequencies are present, the model must deal not only with sound levels but also with frequency content. For this reason the model deals with sounds in 1/3 octave bands. In order to give an impression of the absolute loudness of the sounds observed, the 1/3 octave band levels are also summed to give the overall dBA values.

The starting point for the model is the 1/3 octave band spectrum levels of the source of interest, for example, a large ore-hauling truck. Typical spectra were defined using both measurements made at existing taconite mines, and other spectra described in the literature. Next, the effects of sound propagation had to be accounted for. Because the region is very quiet, sounds may remain detectable over long distances, perhaps several kilometers. Unfortunately, the precise determination of the effects of sound propagation over land for these distances is a topic where considerable research is needed since it depends on a number of parameters. Especially important are wind speed gradients, temperature and temperature gradients, relative humidity, ground cover, and terrain conditions. The complexity of this problem precluded any definitive study being completed by Copper-Nickel personnel. Instead, a brief experimental study was supplemented by a review of the existing literature. Then an "engineering decision" was made concerning the best available way to calculate sound propagation effects. Finally, using the results of the field monitoring program, the detectability of the propagated sounds in the presence of the observed background sounds in the region was modeled. A discussion of the modeling procedure with computer programs used can be found in Sipson (1978).

The propagation loss calculation that was chosen is basically a simplified version of a procedure described by D. N. Keast (1974). The reasons for the simplifications are given in Sipson (1978). Under this procedure propagation is divided into five cases: upwind, crosswind, downwind, calm-lapse, and calm-inversion. If the propagation path from the source to the receptor point is within 56 degrees of the direction from which the wind is coming, the receptor is considered to be upwind. If the propagation path is within 56 degrees of the direction toward which the wind is blowing, the receptor is considered to be downwind. If the wind is blowing and the path is neither upwind nor downwind, it is considered to be crosswind. If the wind is less than three knots it is considered calm. If there is a ground-based temperature inversion and the wind is calm, the condition is considered calm-inversion, otherwise it is considered calm-lapse.

For downwind and calm-inversion conditions, the propagation loss is assumed to be given by the usual inverse square law (6 dBA loss for every doubling of distance) together with atmospheric absorption, as calculated using a procedure proposed by the American National Standards Institute (Sipson, 1978). Atmospheric absorption is especially significant at higher frequencies. For example, at 20°C and 50 percent relative humidity, atmospheric absorption for a path of 1 km ranges from .2 dBA at 100 Hz to 5 dBA at 1000 Hz to 28 dBA at 4000 Hz. This absorption is linear with distance; thus at 10 km the corresponding figures are 2 dBA, 50 dBA, and 280 dBA. Thus, only low frequency sounds or the low frequency components of sounds will propagate well over distances of one or more kilometers.

If the propagation is crosswind or calm-lapse, an additional 15 dB is subtracted to account for excess attenuation due to interaction with vegetation. This is not included in the downwind or calm-inversion conditions because the downward curving propagation paths for these conditions carry them over the vegetation for most of the path. For upwind propagation, the excess attenuation is increased to 30 dBA to account for both vegetation and wind shadow effects. The model is not intended for use with sources which are within a forest canopy since this might tend to reduce wind gradient effects. Most mining related sources will operate within a substantial clearing so this will not be a problem.

Using the source spectrum levels and the above described propagation loss calculation procedure, the spectrum levels at points surrounding the source can be calculated. Whether or not this sound will be detectable by an observer at this point depends on the characteristics of human hearing and the ambient sounds present which might mask the sound. The previously described results of the regional monitoring show that the primary masking sounds are wind-generated vegetation sounds. Wildlife sounds are sporadic and are usually within high frequency bands which are subject to a large amount of atmospheric absorption. Thus, they were not considered to be important sources of masking. When the wind is not blowing, a zero wind ambient masking spectrum is assumed. This was developed by examination of spectral plots of data taken during quiet, calm conditions. If the computed band level for wind-generated noise is less than the corresponding band level assumed for zero wind ambient conditions, the zero wind ambient band level is substituted. Minimum values for the zero wind ambient band levels are those which would result in a prediction of audibility for sounds at the threshold of human hearing. Thus, the zero wind ambient spectrum used for most modeling was higher than the minimum levels observed at very quiet measurements. Artificially raising the assumed zero wind ambient spectrum further may be useful under certain circumstances, as will be discussed below. The sound level as a function of wind speed and the spectral shape as a function of sound level are modeled using the results of the monitoring study described earlier. Figure 8 gives an example of the modeled spectra for summer spruce at low, medium, and high winds.

Figure 8

Since the masking sounds are assumed to be broad band in character, the 1/3 octave band levels may be converted to equivalent masking levels using the results of psychoacoustic studies of the ability of people to detect tones in the presence of broad band masking sounds (Kryter, 1970). This conversion was done by adding the factors given in Table 6 to the 1/3 octave band levels of the masking sound. The model is thus intended for use with sources having spectra which contain important tonal components.

Table 6

The computer model compares the predicted band levels for the propagated sound, for all wind conditions, with the masking levels that are present for the

FIGURE 8

1/3 OCTAVE BAND LEVELS FOR SUMMER SPRUCE FOR 3 WIND SPEEDS

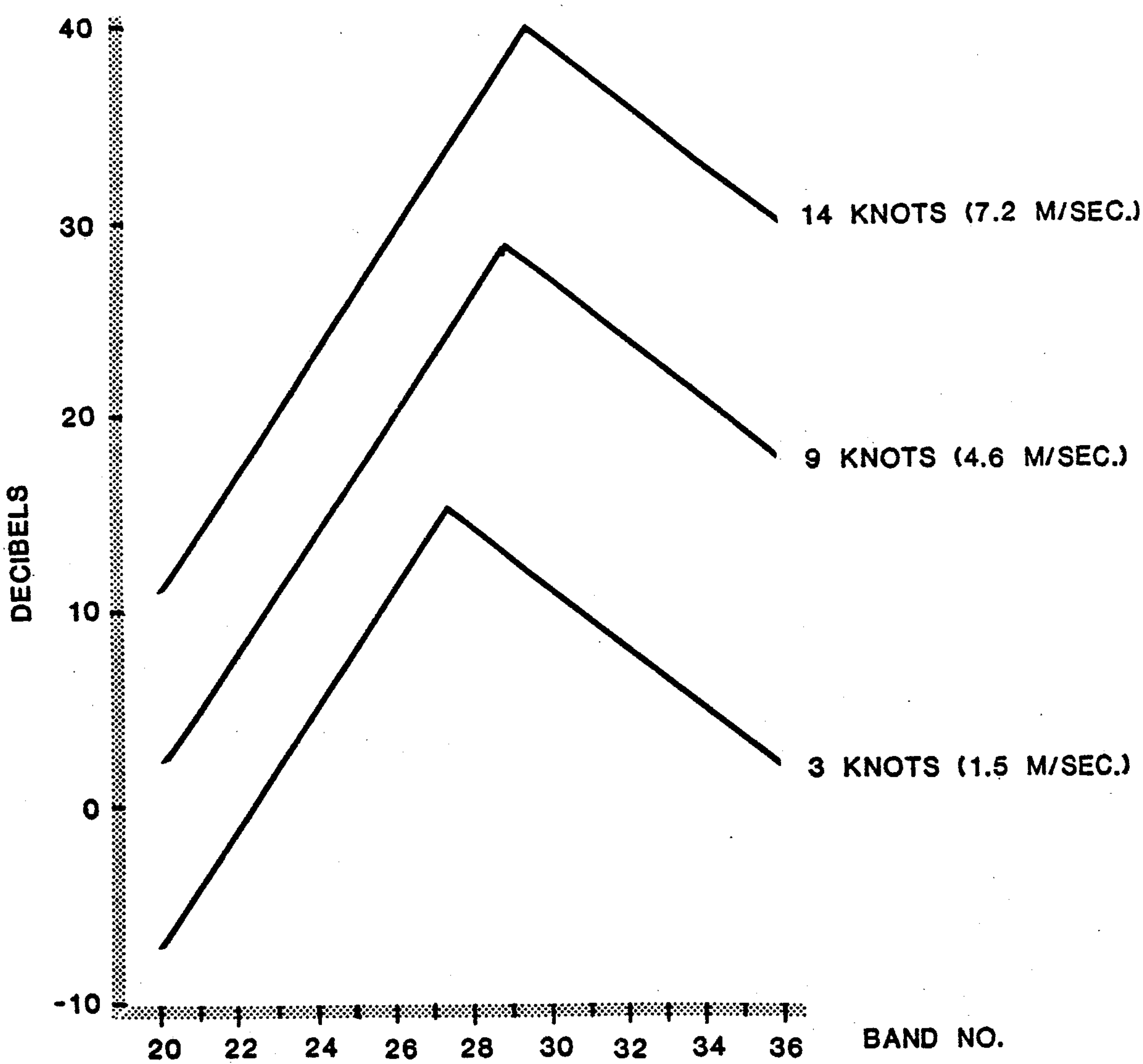


Table 6. Masking level correction factors in dBA.

BAND NUMBER	FACTOR
20	5
21	4
22	2
23	0
24	-1
25	-2
26	-3
27	-4
28	-4
29	-5
30	-5
31	-6
32	-6
33	-6
34	-6
35	-6
36	-6

corresponding wind conditions to arrive at the percentage of time that the sound will be audible at points around the source. The program then processes these results to arrive at the equal audibility contours for 0, 10, 20,...90 percent. The meaning of these contours is that persons within the 50 percent contour, for example, who are in the vegetation type assumed, will hear the source 50 percent or more of the time, during which the source is operating, with the assumed wind speed and direction statistics. If it is desired to use an impact criterion other than just audible, the program provides a user adjustable parameter which results in a prediction of impact only when the propagated levels exceed the masking levels by a specified amount, 10 dBA for example. The resulting equal percentage contours will then define the percentage of time various points will be impacted under the modified criterion.

An interesting alternative interpretation of these contours is to consider the situation from a receiver-centered point of view. The symmetry inherent in the modeled contours can be seen by noting that if, for example, the wind is from the source to the receiver, then it is upwind from the receiver to the source. Thus, if the contours are rotated by 180 degrees, they represent the locus of source locations with respect to the receiver for which there will be audibility the stated percentage of time when the receiver is in the vegetation type assumed.

Regardless of the criterion used, the model also computes the maximum overall dBA level of the propagated sound at points along the contours. This may be valuable additional information when ultimate trade-off decisions regarding mining operations are being made. It may be that a certain area is impacted ten percent of the time but that the impact results from a sound of such a low dBA level that it is not considered significant enough to restrict mining operations.

It is difficult to give a quantitative assessment of the accuracy of the computer model. The main source of limitation in accuracy lies within the method used to predict propagation losses. As is discussed in more detail in Sipson (1978), there is a great need for more theoretical and experimental research in the area of ground-to-ground sound propagation over distances of several kilometers. The method used was to include all propagation losses which seemed certain, based on existing knowledge. It is not likely that actual propagation losses will be less than those included. Thus, the actual situation will not be any worse than indicated by the model. However, based on the existing literature and limited comparisons with field data gathered around existing taconite mines, it is not considered likely by the developer of this model that the results will be found to be unrealistic. Some discussion of the comparisons with field data is included later in this report.

5.3.2 Predicted Impacts of Selected Sources

5.3.2.1 Introduction: In this section the expected impacts of various phases of mining development will be discussed. The sequence in which they will be considered will be: construction, operations, and secondary development. It will not be possible to discuss in detail every possible sound source that might be involved in these various phases. Instead, the basic goals of the impact prediction portion of the noise study were twofold. One was to develop a tool, the computer model, which can be used to evaluate the impact of any source, once its noise spectrum is known. This will prove useful when specific development plans are being evaluated where the exact nature of the proposed equipment is known.

The second goal was to use the model, together with data for a few typical sources, to develop a picture of the magnitude of the effects that might be expected, especially the size of the impacted areas. These sources were evaluated under four basic meteorological conditions: summer day, summer night, winter day, and winter night. Temperature, humidity, and wind conditions which typify these time periods were defined through consultation with other project staff. The effect of vegetation type was also considered. In this summary report, only basic results will be discussed, with more detail available in Sipson (1978). Unless otherwise stated, the results reported are based on assuming impact only when the masking levels are exceeded by 5 dBA and that the zero wind ambient levels are given by Table 7. These assumptions should represent the impact on the sensitive areas within the region. Some indication of the changes that might be made for less sensitive areas are discussed in a later section.

Table 7

5.3.2.2 Initial Site Preparation: In the early development phase of a new mining operation the sound sources will be those for initial site preparation. Any existing forest cover will have to be cleared and roadways will have to be prepared. Typical equipment used in this phase will be similar to that used in logging operations and medium-sized earth moving equipment, such as bulldozers. With regard to logging equipment, the results of a Canadian study (Myles, et al. 1971) are quite valuable. As one part of that study observers went into forest areas surrounding a logging operation to determine the distance to which they could distinguish the sounds of chain saws and skidders in the presence of the ambient sounds of the forest. They found that the distance to which this equipment was audible 50 percent of the time was the same, 2.5 km, for both devices. To compare these results with the predictions of the computer models an approximate chain saw spectrum was taken from a figure in that report. The area within

Table 7. Zero wind ambient spectrum levels in dBA. (overall level--18 dBA)

BAND NUMBER	BAND LEVEL
20	0
21	1
22	2
23	3
24	4
25	5
26	6
27	7
28	8
29	9
30	8
31	7
32	6
33	5
34	4
35	3
36	2

2.5 km of the source is 20 km^2. For the computer model this corresponds to the area within the 40 percent contour for a red pine forest and to that within the 30 percent contour for a birch forest during a summer daytime. Using this spectrum the model predicts that the mean distance to the 10 percent contour is 7 km for a red pine forest and 4.4 km for a birch forest. The authors of the study reported observations of chain saws at distances of 3.8 km but did not describe in detail the type of forest in which this observation was made. The model predicts the extreme limits of audibility to be at about 10 km for the forest types considered. Recall, however, that while the observer is assumed to be in a forested area, the model assumes that the source is operating in a substantial clearing so that the full effects of wind gradients upon sound propagation will come into play. While this assumption is reasonable for most stages of mining operations, it is not valid for a chain saw operating below the forest canopy. Thus, a shorter audibility limit, closer to the 10 percent contour value of about 5 km, is probably a more reasonable value. Audibility beyond this limit should be rare.

5.3.2.3 Full Scale Equipment: The next stage in mine development is the preparation and operation of the pit, which requires full scale mining equipment such as shovels, drills, and trucks in the 85 to 170 ton range. Blasting will also be required. Of these sources, the large trucks will be the most important source of acoustic impact. Blasting is a short duration event which will likely occur only one or two times per week. For persons who are not on mine property the chance for acoustic trauma due to blasting is remote. The audible sensation will be similar to that of thunder. The low frequency components of blasting sounds are potential sources of structural dammage, however, and this is well known and documented. Thus, mining personnel will restrict blasting to times when the meteorological conditions will result in minimum propagation of blast sounds. The blast sounds that were observed during the monitoring phase of the noise study did not seem to be particularly objectionable. Activities associated with a blast are more likely causes for significant acoustic impact, especially spotter aircraft activity and the warning siren. The reason that shovels and drills will be much less important than trucks is that these are usually electric powered and thus are not powerful sources of acoustic energy.

To evaluate the magnitude of the impact of trucks, spectral data were obtained for trucks in the 85 ton and 170 ton classes at regional taconite mines. Measurements were made for several vehicles in a number of operational modes. The results of these measurements are presented in Sipson (1978). The three spectra chosen for evaluation of the impact of these sources were: 1) the 1/3 octave band levels r.m.s. averaged during 4 seconds of level passby and subsequently r.m.s. averaged for several trucks of the same size, denoted here as the level-r.m.s. spectrum; 2) the level peak spectrum, made up of the peak 1/3 band levels observed for any vehicle during a short (1/8th sec) averaging time, denoted here as the level-peak spectrum; and 3) the r.m.s. averaged spectrum observed during a bed-lift operation. The bed-lift spectrum was included because there were particularly strong exhaust tone components during this operation, especially for the 85 ton trucks. It should be noted that the level-peak spectrum is an artificial spectrum designed to predict the maximum possibility for impact by the fleet of trucks. It was not observed at any one time for any one vehicle, and thus it will sum to a higher overall dBA level than was observed for any one truck. However, the difference between this sum and the maximum dBA level observed for any one vehicle was only two dBA and thus the overall levels which result from using this spectrum in the computer model are reasonable representatives of the peak levels that might be observed for an individual vehicle.

The predicted audibility of these spectra was investigated for several vegetation types and for both day and night conditions. Complete computer printouts for these cases are included in Sipson (1978). Results based on the level-peak spectrum should indicate the greatest range of impact possible under level operation. An audibility of ten percent, calculated using the r.m.s. spectrum, would indicate that the steady operation of the truck could be heard under ten percent of the wind conditions for that season and time of day. For the level-peak spectrum the same percentage of audibility would mean that occasional peaks from individual trucks would be audible under ten percent of the wind conditions.

First the results for 85 ton trucks will be discussed. During summer daytime conditions it was found that black spruce forests provided the least masking ability for these vehicles (i.e. impact to the greatest distance) and birch the greatest masking ability. This was true for all three spectra. Figures 9, 10, 11, and 12 show the audibility contours obtained for these two tree types for the level-peak and bed lift spectra for 85 ton trucks during summer days. Since no inversions are assumed for summer days, the greatest impact will come for downwind conditions when the wind speed is not high enough to generate substantial masking sounds. Since the wind is seldom out of the northeast, points to the southwest of the vehicle will receive the most protection and this is evident in the contour shapes. Evident also is the fact that large areas are protected by wind-generated vegetation sounds much of the time, especially for observers in birch forests. The first four lines in Table 8 make this point more apparent.

Figures 9, 10, 11, 12

MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 9

SOURCE : 85 TON TRUCK, LEVEL PEAK

WIND FILE : SUMMER DAY

TREE TYPE : SPRUCE

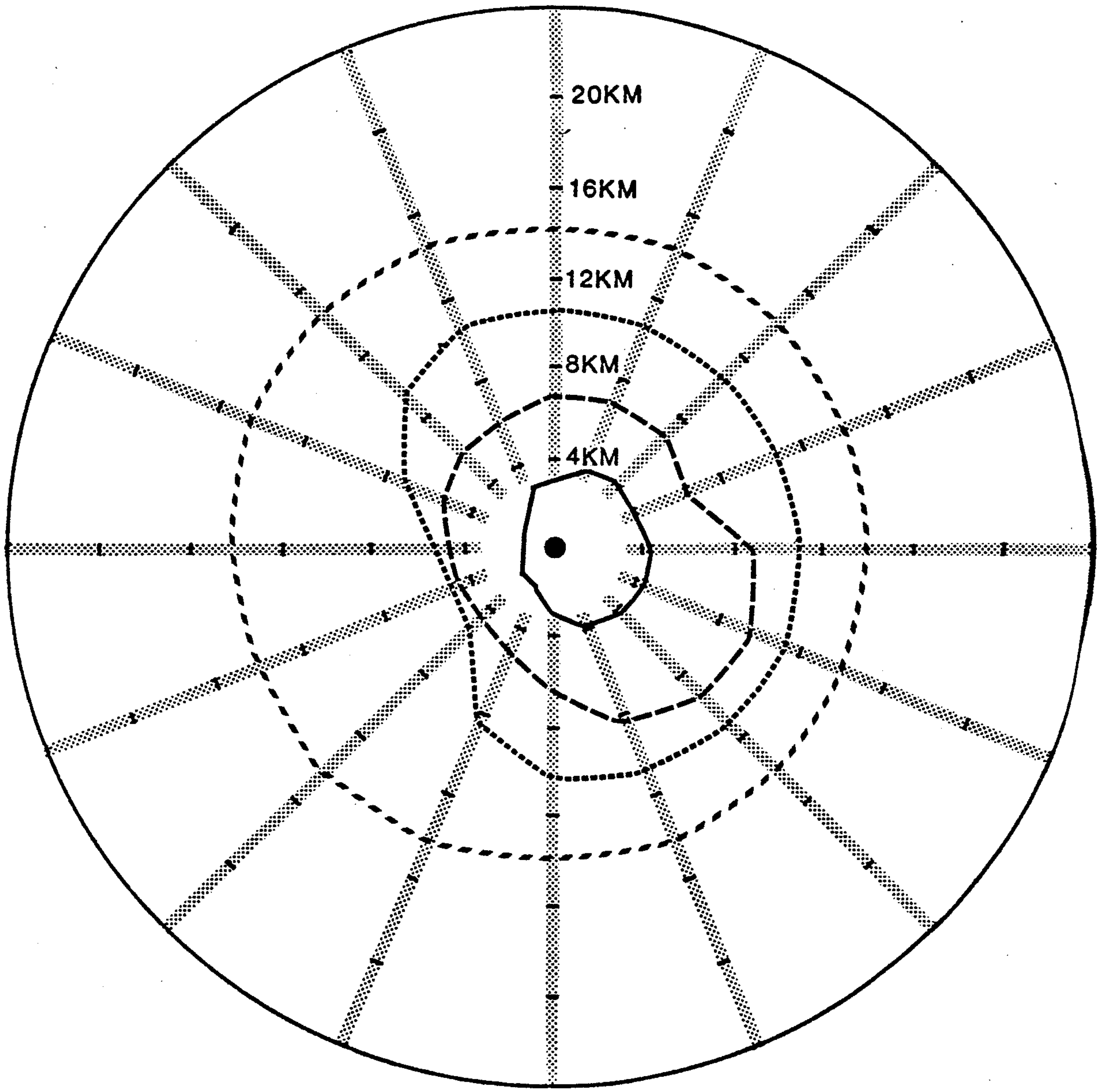
% INVERSIONS : 0

TEMP. : 20°C.

RELATIVE HUMIDITY : 65%

EXCEEDENCE PARAMETER : 5 DBA

SCALE : 1 DIVISION-4 KM



LEGEND: % AUDIBILITY

50% ———— 20% – – – – 10% ········ 0% - - - - -

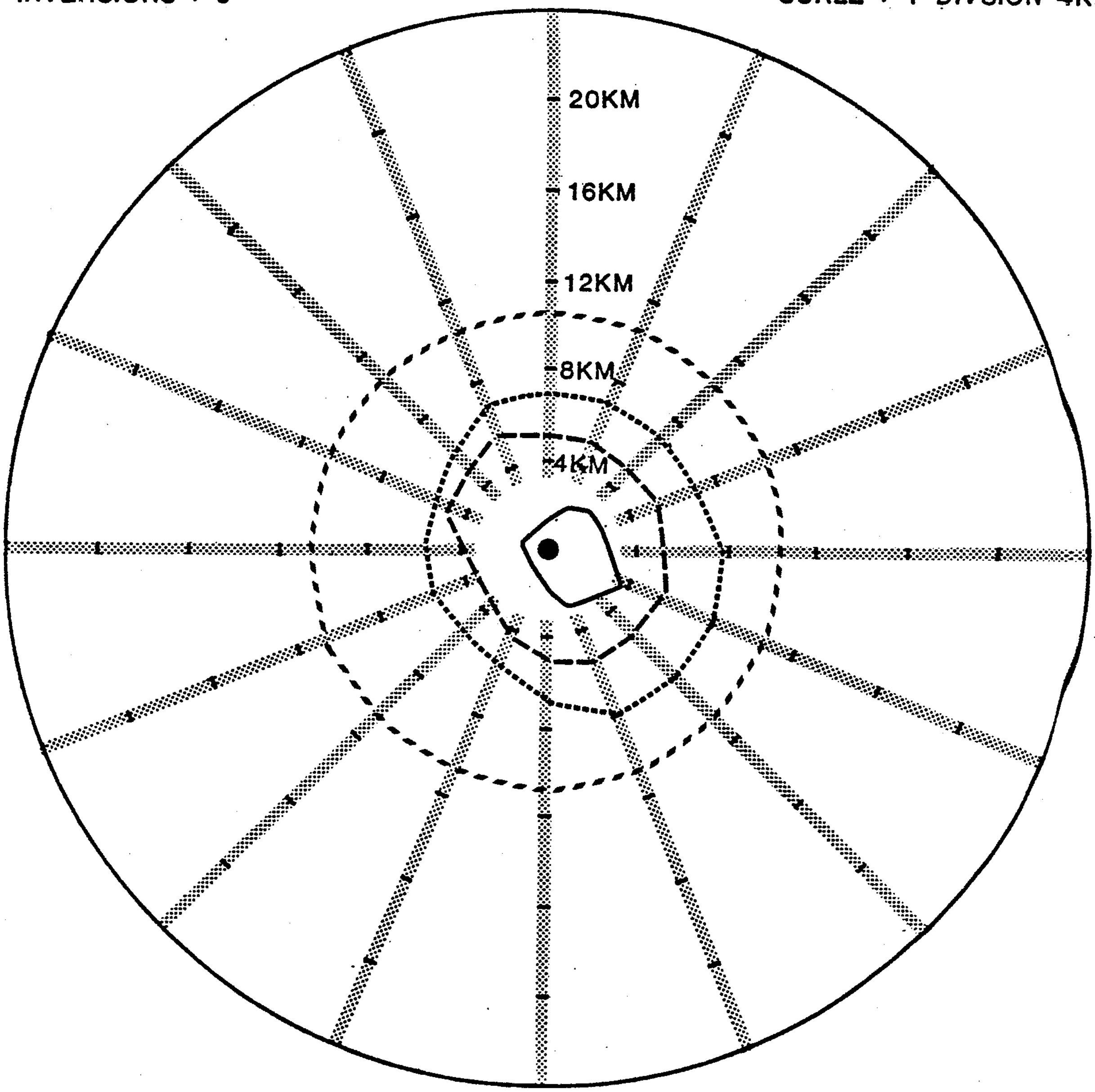
● SOURCE LOCATION

MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 10

SOURCE : 85 TON TRUCK, LEVEL PEAK
WIND FILE : SUMMER DAY
TREE TYPE : BIRCH
% INVERSIONS : 0

TEMP. : 20° C.
RELATIVE HUMIDITY : 65%
EXCEEDENCE PARAMETER : 5DBA
SCALE : 1 DIVSION-4KM



LEGEND: % AUDIBILITY

50% —— 20% - - - 10% ······ 0% - - -

● SOURCE LOCATION

MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 11

SOURCE : 85 TON TRUCK-BED LIFT

WIND FILE : SUMMER DAY

TREE TYPE : SPRUCE

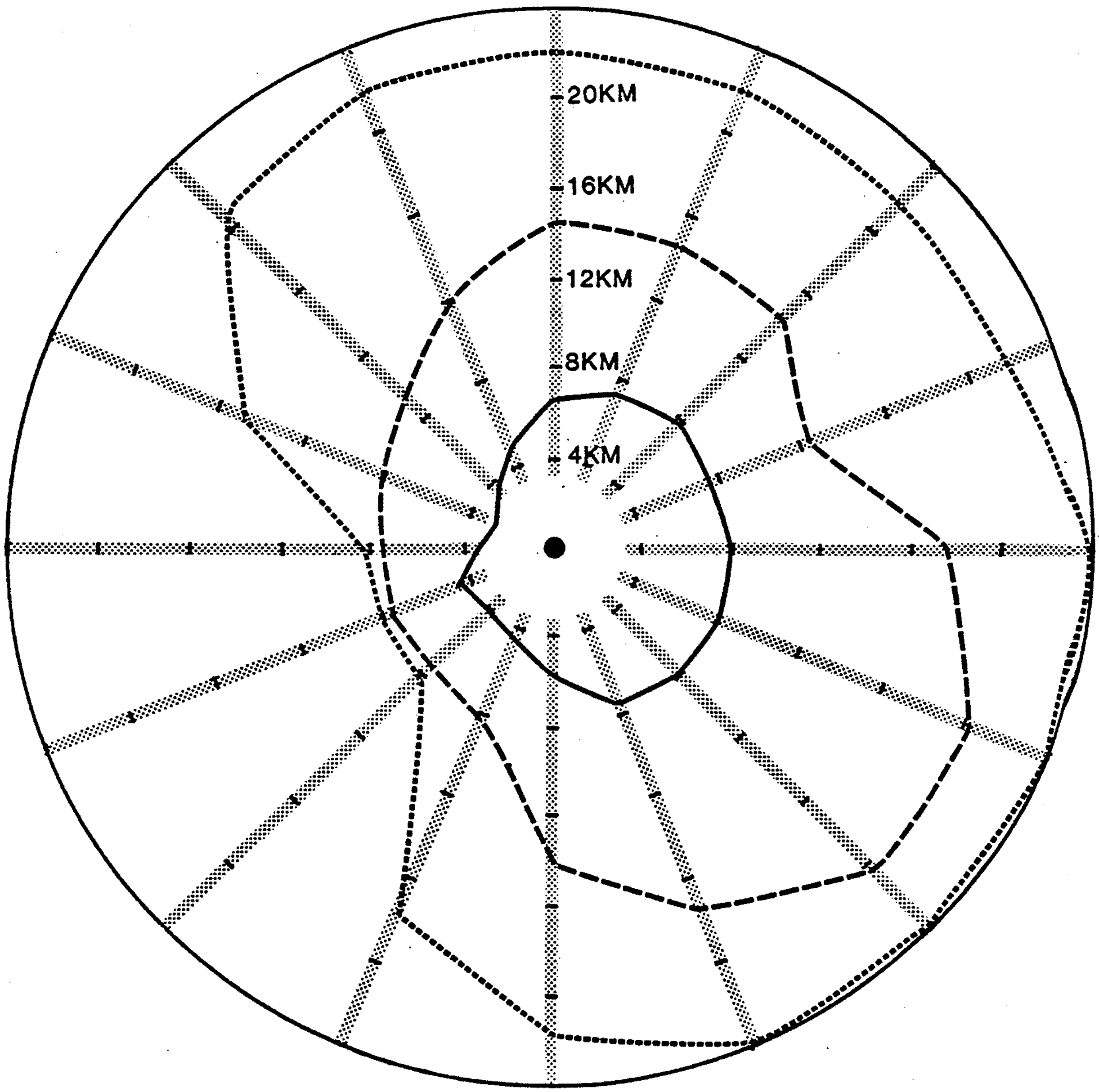
% INVERSIONS : 0

TEMP. : 20°C.

RELATIVE HUMIDITY : 65%

EXCEEDENCE PARAMETER : 5 DBA

SCALE : 1 DIVISION- 4 KM



LEGEND: % AUDIBILITY

50% ———— 20% – – – – 10% ·········· 0% - - - - -

● SOURCE LOCATION

MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 12

SOURCE : 85 TON TRUCK BED LIFT

WIND FILE : SUMMER DAY

TREE TYPE : BIRCH

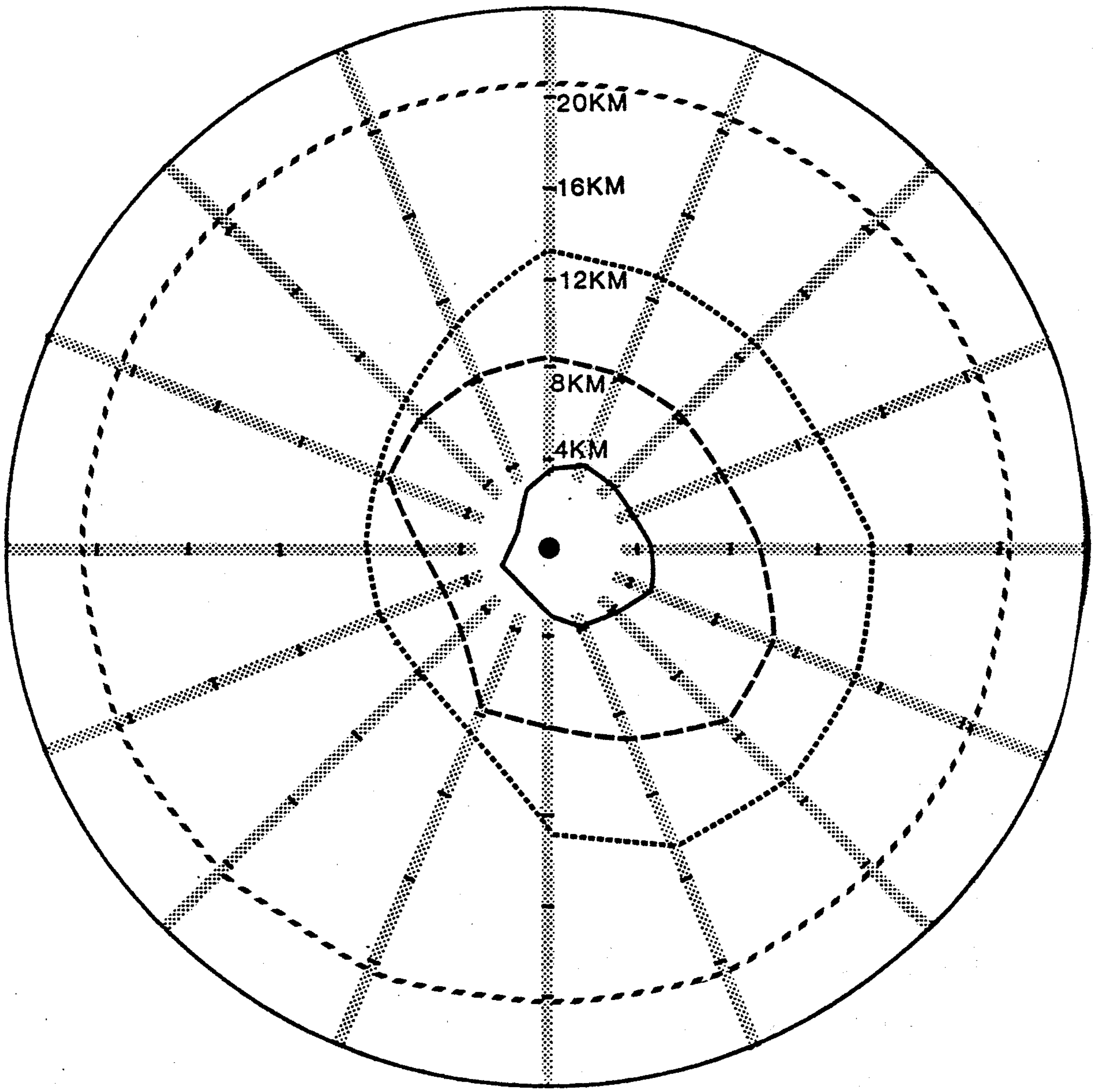
% INVERSIONS : 0

TEMP. : 20° C.

RELATIVE HUMIDITY : 65%

EXCEEDENCE PARAMETER : 5 DBA

SCALE : 1 DIVISION-4 KM



LEGEND: % AUDIBILITY

50% ———— 20% – – – – 10% .... 0% - - - -

● SOURCE LOCATION

The area within the 10 percent contour is about 1/2 of the area within the 0 percent contour for birch forests while spruce forests show considerably less masking ability.

The predicted extreme limits of audibility (0% contour) are quite great, especially for the bed lift spectrum for an observer in a spruce forest where the model predicts possible audibility to 24 km. Probably the most significant contributing factor to this large extreme range is the fact that this region is so quiet. The sound that is being detected at 24 km for the bed lift spectrum is only 11 dBA in overall level; however, it is detectable because it is primarily concentrated in a tonal component within the 125 Hz band and the masking level in this band under the lightest wind condition is only 6 dBA.

The corresponding results for winter days are similar; these are shown by Figures 13, 14, 15, 16, and lines 5 through 8 of Table 8.

Again, it is seen that a large fraction of the area within the limits of audibility is protected more than 90 percent of the time. In comparing the contours with the corresponding summer contours the predominance of northwesterly winds in winter is clear.

Figures 13, 14, 15, 16

Table 8

For nighttime conditions there is less wind to generate masking sounds (especially for summer nights) and there is a greater chance for temperature inversions to be present. The contrast with daytime conditions is not large during winter because winter nights are relatively windy but summer nights are calm over 40 percent of the time and this has a significant influence on audibility. The contour shapes for winter nights are similar to those for winter days

MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 13

SOURCE : 85 TON TRUCK, LEVEL PEAK

WIND FILE : WINTER DAY

TREE TYPE : SPRUCE

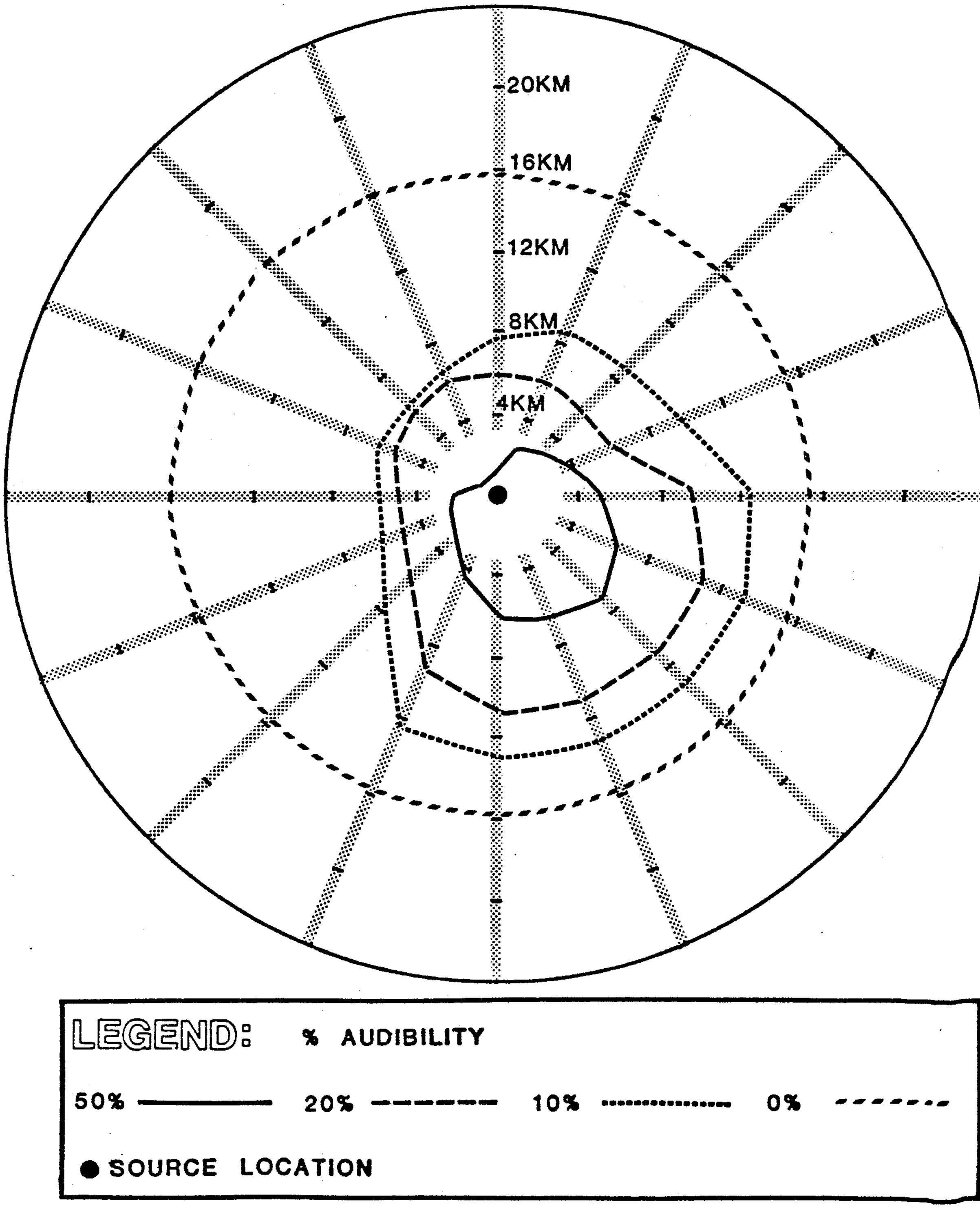
% INVERSIONS : 0

TEMP. : -13^{0}C.

RELATIVE HUMIDITY : 80%

EXCEEDENCE PARAMETER : 5 DBA

SCALE : DIVISION-4 KM

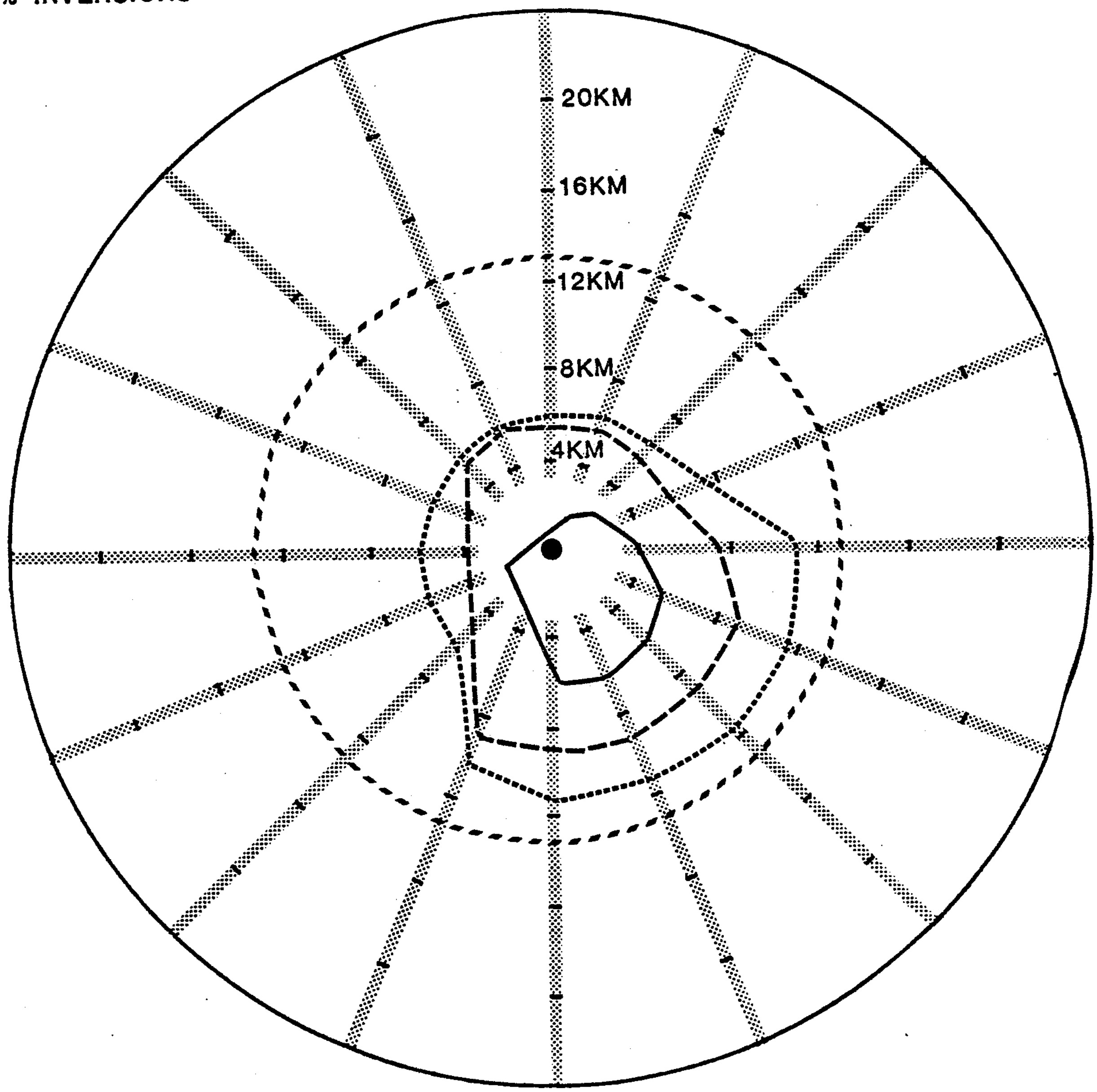


MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 14

SOURCE : 85 TON TRUCK, LEVEL PEAK
WIND FILE : WINTER DAY
TREE TYPE : BIRCH
% INVERSIONS : 0

TEMP. : -13°C.
RELATIVE HUMIDITY : 80%
EXCEEDENCE PARAMETER : 5 DBA
SCALE : 1 DIVISION-4 KM



LEGEND: % AUDIBILITY

50% —— 20% – – – 10% ······· 0% - - - -

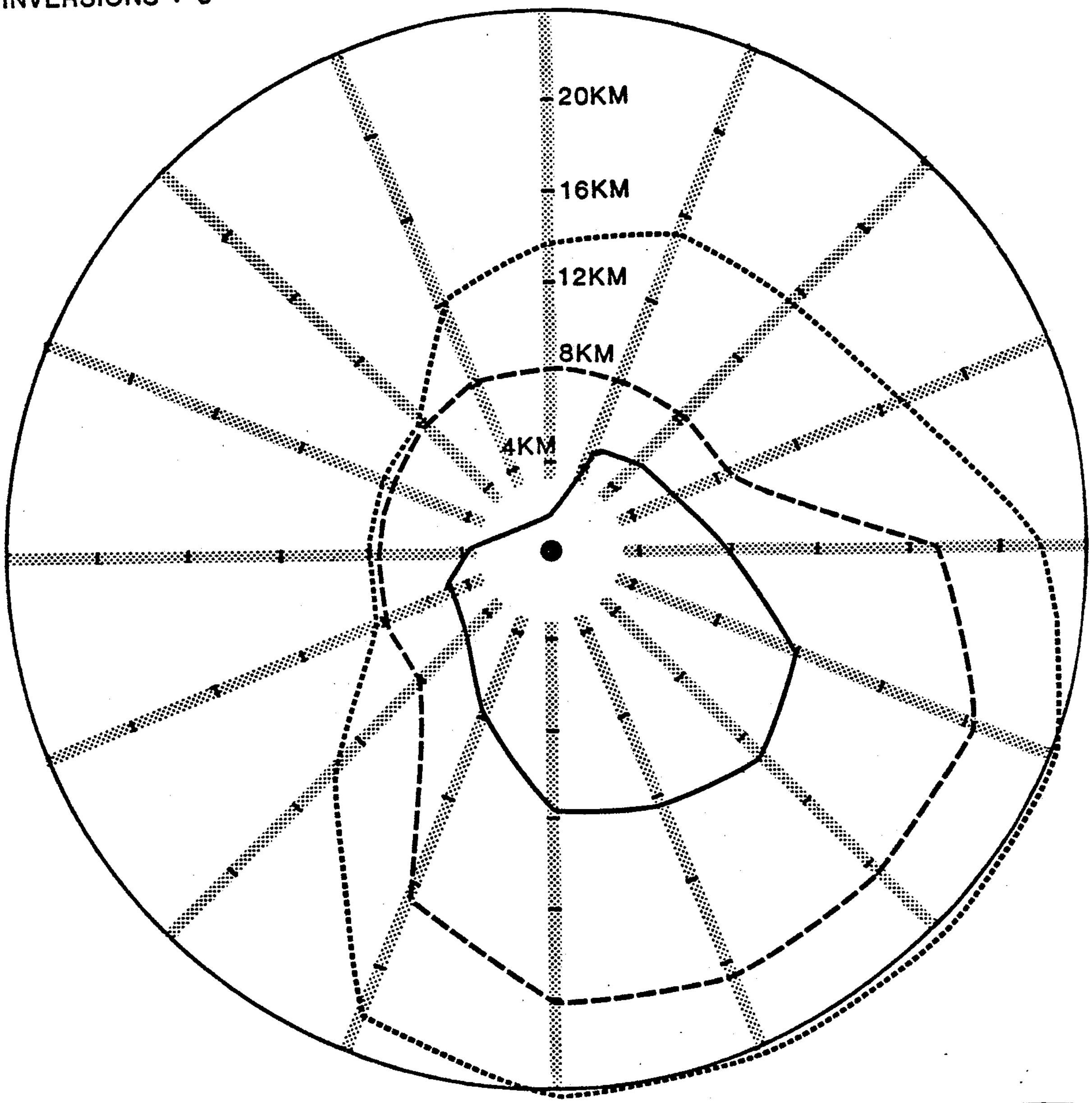
● SOURCE LOCATION

MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 15

SOURCE : 85 TON TRUCK BED LIFT
WIND FILE : WINTER DAY
TREE TYPE : SPRUCE
% INVERSIONS : 0

TEMP. : -13^{0} C.
RELATIVE HUMIDITY : 80%
EXCEEDENCE PARAMETER : 5 DBA
SCALE : 1 DIVISION-4 KM



LEGEND: % AUDIBILITY

50% ———— 20% — — — 10% ········ 0% - - - - -

● SOURCE LOCATION

MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 16

SOURCE : 85 TON TRUCK BED LIFT

WIND FILE : WINTER DAY

TREE TYPE : BIRCH

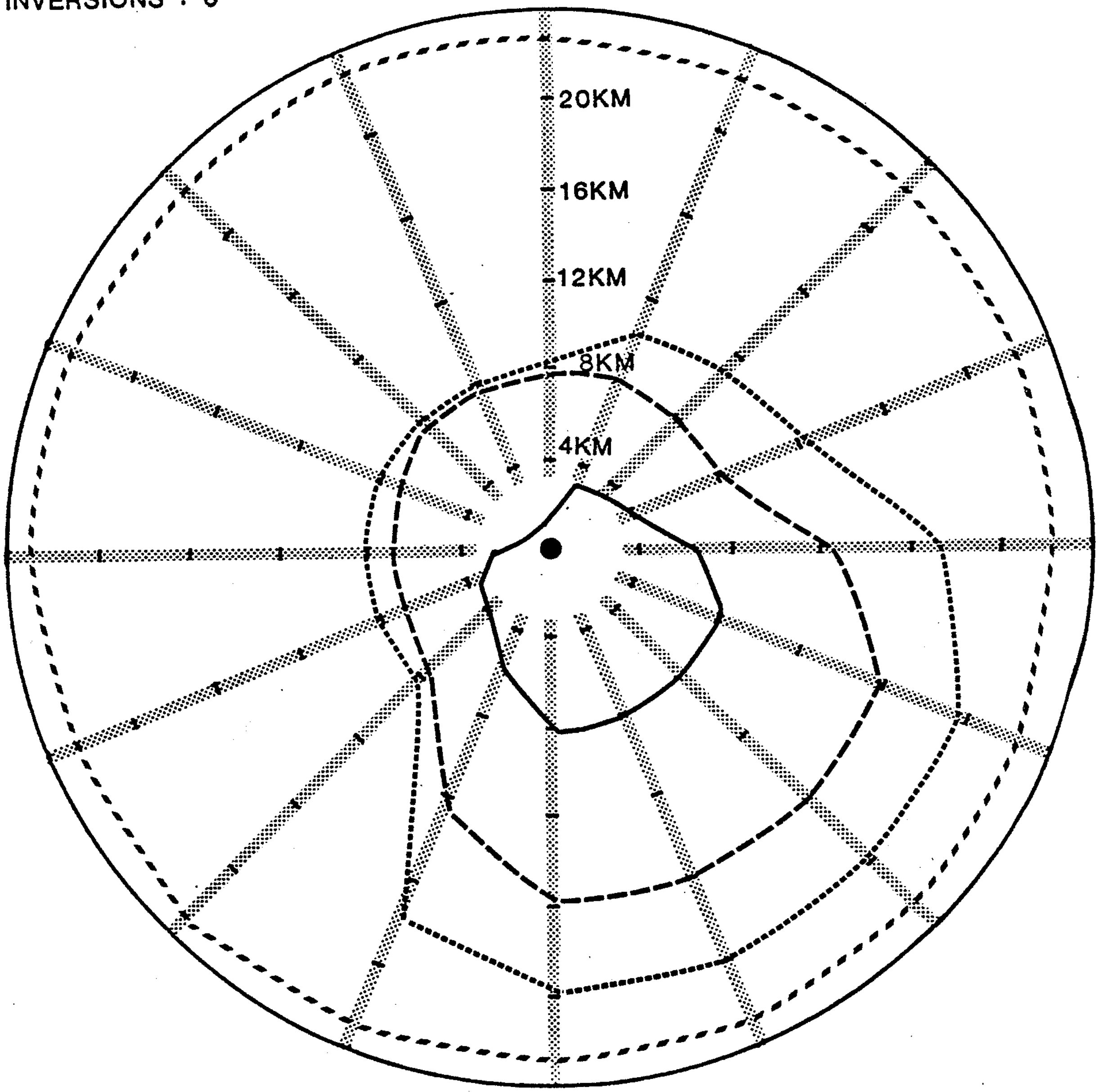
% INVERSIONS : 0

TEMP. : -13° C.

RELATIVE HUMIDITY : 80%

EXCEEDENCE PARAMETER : 5DBA

SCALE : 1 DIVISION-4 KM



LEGEND: % AUDIBILITY

50% ———— 20% — — — — 10% ··········· 0% - - - - -

● SOURCE LOCATION

Table 8. Affected areas within contours for ore hauling trucks in km^2.

SPECTRUM TYPE[a]	TREE TYPE	TIME PERIOD[b]	TRUCK SIZE (ton)	CONTOUR 0%	10%	20%	30%	40%	50%
I	Spruce	S.D.	85	560	260	130	78	52	29
I	Birch	S.D.	85	340	130	75	45	21	8
II	Spruce	S.D.	85	1800	1200	530	230	160	110
II	Birch	S.D.	85	1200	430	200	130	67	30
I	Spruce	W.D.	85	690	280	180	120	75	47
I	Birch	W.D.	85	520	200	130	76	46	33
II	Spruce	W.D.	85	1800	900	510	380	220	160
II	Birch	W.D.	85	1600	530	340	210	110	71
I	Spruce	W.N.	85	780	750	490	220	140	90
I	Birch	W.N.	85	780	750	360	150	93	53
II	Spruce	W.N.	85	1800	1800	1600	770	500	320
II	Birch	W.N.	85	1800	1800	1200	470	300	170
I	Spruce	S.D.	170	2800	1800	1200	850	680	450
I	Spruce	W.D.	170	4100	2300	1700	1300	910	710
III	Spruce	S.D.	85	280	110	51	28	19	9
III	Spruce	S.D.	170	1400	910	410	200	130	80
III	Spruce	W.D.	85	310	110	66	42	24	15
III	Spruce	W.D.	170	1400	710	470	300	190	130

a I = level-peak
II = bed lift
III = level-r.m.s.

b S.D. = summer day
W.D. = winter day
W.N. = winter night

with the exception that the 10 percent contour moves out to merge with the 0 percent contour as a result of calm inversion conditions. The affected areas are given by lines 9 through 12 of Table 8.

For summer nights the 0, 10, 20, 30, and 40 percent contours merge as a result of the large fraction of calm inversion conditions (all nighttime calm conditions were assumed to be inversion for acoustic propagation). Thus, for this condition the area impacted can be well represented by the area within the 0 percent contour. For the level-peak spectrum this is 740 km^2 while for the bed lift spectrum it is 2100 km^2 corresponding to audibility out to 25 km. At 25 km the maximum sound level resulting from a bed lift is only 11 dBA. At 20 km it is 14 dBA, while persons at 10 km are subject to 24 dBA.

If larger trucks are used the impact will be greater. As an example of this, the results for 170 ton trucks using the level-peak spectrum are presented for summer and winter days in a spruce forest in Figures 17 and 18. In comparing with the 85 ton results, note the change of scale. The bed lift spectrum results are not presented here because the spectra obtained for these trucks for this operation indicated a smaller area of impact than was obtained for level operation. The affected areas are given in lines 13 and 14 of Table 8.

Figures 17 and 18

In comparing these results with the corresponding results for 85 ton trucks, a large increase in impacted areas is seen. The increase over the results obtained for the 85 ton bed lift operation is not as great; however, it should be noted that the bed lift operation accounts for a small fraction of the duty cycle and thus the comparison for level operation is very important. For summer nights the model predicts a maximum distance of impact of 35 km, with the peak

MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 17

SOURCE : 170 TON TRUCK, LEVEL PEAK

WIND FILE : SUMMER DAY

TREE TYPE : SPRUCE

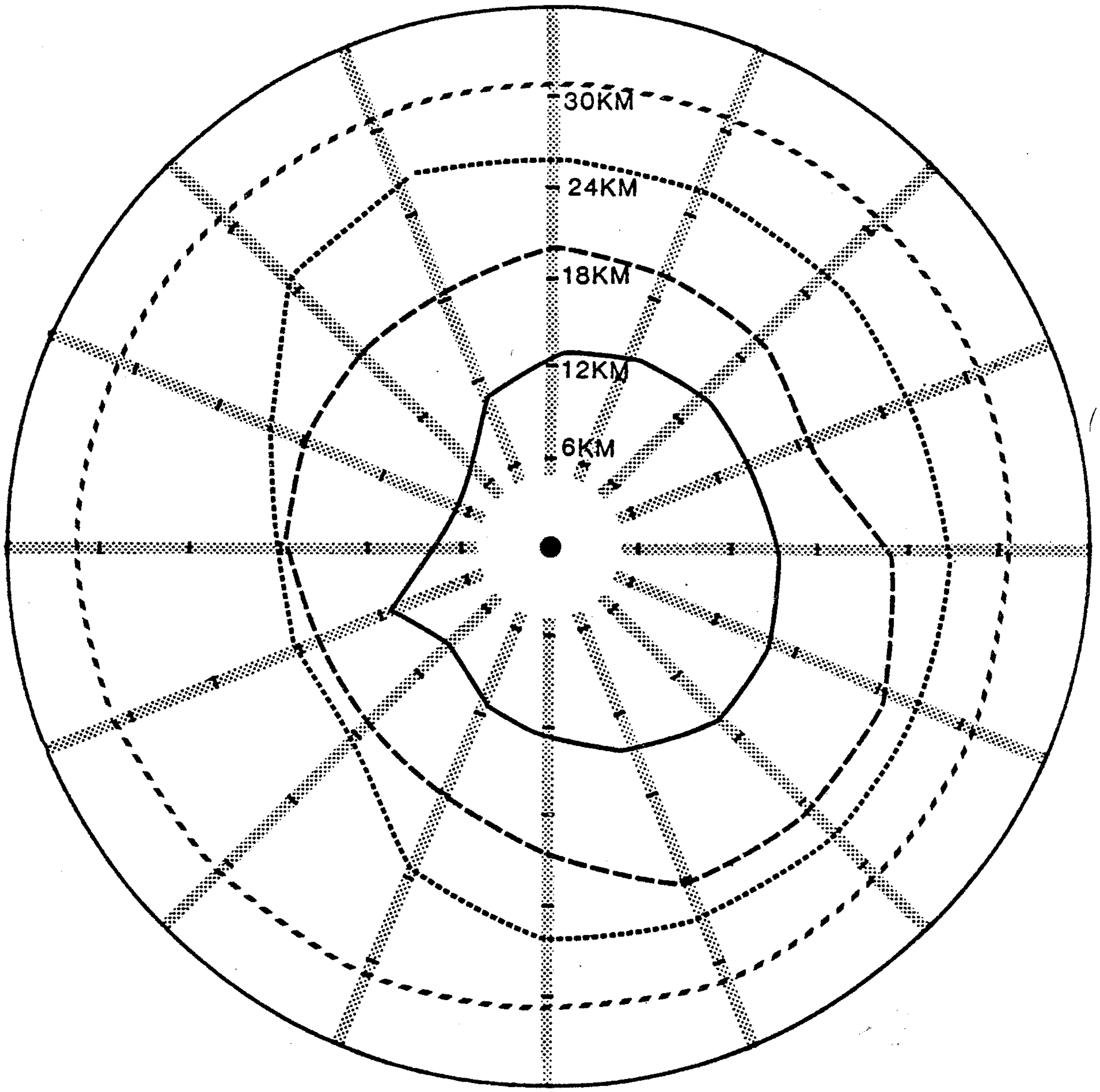
% INVERSIONS : 0

TEMP. : 20°C.

RELATIVE HUMIDITY : 65%

EXCEEDENCE PARAMETER : 5 DBA

SCALE : 1 DIVISON-6 KM



LEGEND: % AUDIBILITY

50% ———— 20% – – – – 10% ············ 0% - - - - -

● SOURCE LOCATION

MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 18

SOURCE : 170 TON TRUCK, LEVEL PEAK

WIND FILE : WINTER DAY

TREE TYPE : SPRUCE

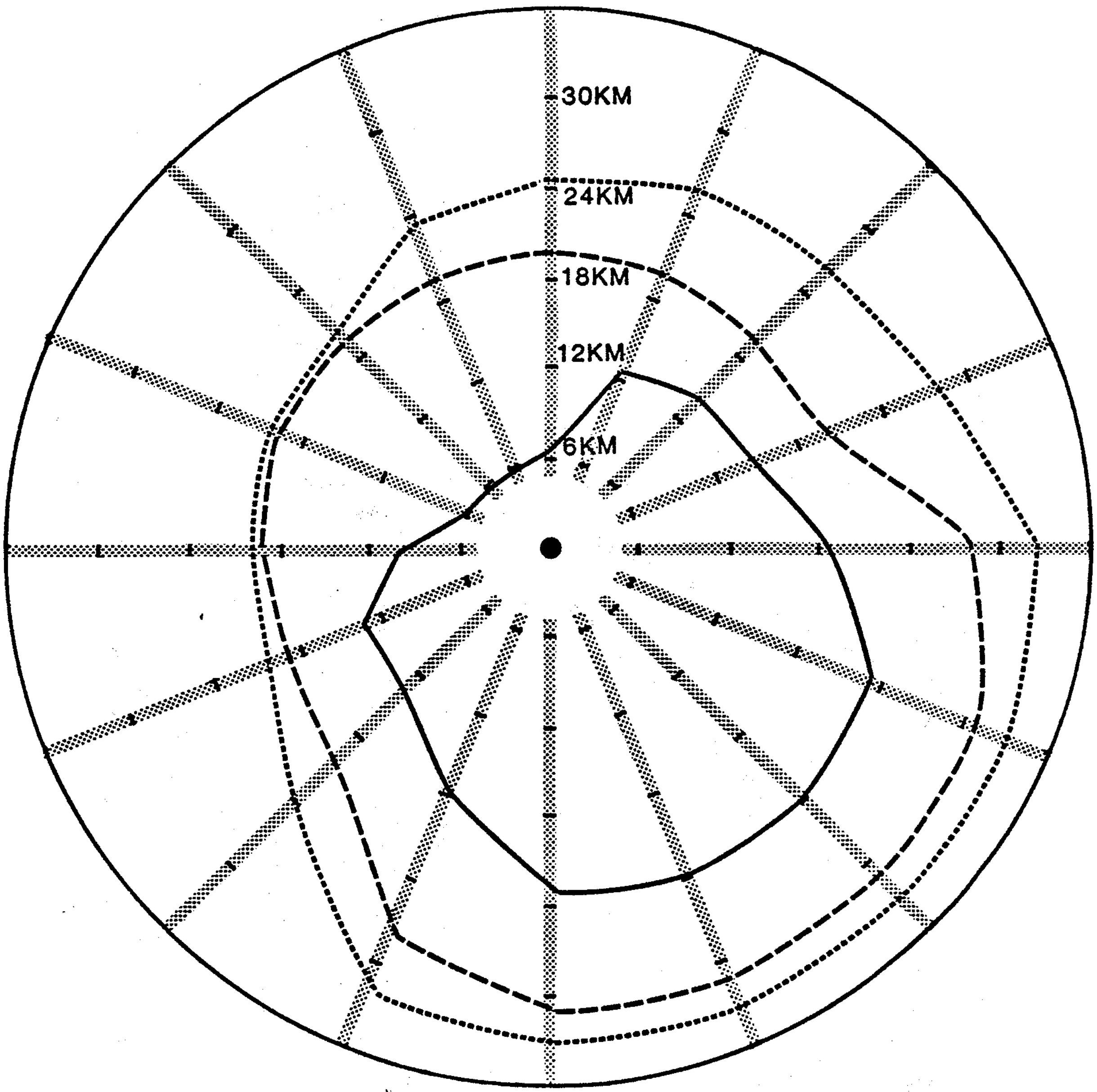
% INVERSIONS : 100

TEMP. : 20°C.

RELATIVE HUMIDITY : 65%

EXCEEDENCE PARAMETER : 5 DBA

SCALE : 1 DIVISION-6 KM



LEGEND: % AUDIBILITY

50% ———— 20% – – – – 10% ········ 0% - - - - -

● SOURCE LOCATION

level at this distance being 10 dBA. Even at a distance of 20 km, peak levels of 25 dBA will be encountered. Thus, the 170 ton trucks give the greatest noise impact of any of the mining sources encountered.

For any further stages of an open pit mining operation the large ore-hauling trucks will continue to be the limiting factor for noise impact since they are powerful acoustic sources and are an important part of the operation. Even if there is an on-site refinery, the trucks will be the dominant noise source for persons not on mining property since they are operating in the open as opposed to in-plant sources which are subject to a substantial transmission loss due to building walls.

The above results for audibility under level operation were obtained using the level-peak spectrum. Results obtained using the level-r.m.s. spectrum will indicate the percentage of time that the steady operation of the trucks can be heard. The contour shapes are similar to those for the level-peak spectrum, so only the affected areas will be reported here. For spruce trees during summer and winter days, the results are given in lines 15 through 18 of Table 8.

Comparison with the corresponding results for the level-peak spectrum shows that of the area within a given contour as determined by the peak spectrum, less than half of it is close enough so that the steady operation of the truck can be heard for the same percentage of time. Areas between the two contours will be subject to audibility only under high speed or high acceleration conditions. The frequency with which these occur will depend on the number of trucks, their condition, and upon driver operating habits, among other things. The bed lift spectrum for 85 ton trucks is essentially a peak spectrum in that the primary cause for increased audibility is the exhaust tone component, which is especially strong during this operation. This component remains strong for the duration of the bed lift, on the order of 10 seconds each time a truck dumps its load.

An auxiliary noise source associated with truck operations is the backup warning horn required by OSHA regulation. These horns must be loud enough to be heard while the truck is operating and are of an intermittent nature. Thus, they are capable of being a source of annoyance when they are audible. The computer model was run using the spectrum measured for the backup warning device on a 170 ton truck. The results showed a larger variation in the maximum distance of audibility than was found for trucks and other sources with substantial low frequency content. This is due to the increased importance of atmospheric absorption for this signal. The extreme range of audibility ranged from 5 to 10 km. Under standard summer night conditions, the device is audible to 8 km with a level at this distance of 7 dBA. Under the same conditions the level at 5 km is 22 dBA, which would be very noticeable on a calm night. While these levels are not as great as those produced by the truck itself, the nature of the sound will make it an extra source of annoyance for those within about 5 km of the mine.

As another example of a noise source which might be used in a mining operation, the audibility of a warning siren was modeled. A complete set of computer runs was made with the spectrum adjusted so as to represent a siren with a 100 ft sound level of 105 dBA. For summer and winter days in spruce forests, the affected areas were nearly equal and are shown in Table 9 along with the result for a 115 dBA siren. During a calm summer night with inversion conditions, the affected area is double that shown in Table 9 with the extreme limit of audibility at 17 km for a 115 dBA siren. For this siren the level at 10 km is 35 dBA, a prominent sound under quiet conditions.

Table 9

Table 9. Affected areas within contours, warning siren, spruce forest, daytime (in km^2).

	0%	10%	20%	30%	40%	50%
105 dB Siren	310	240	210	160	120	90
115 db Siren	480	390	340	270	210	160

If an underground mine is developed, the overall noise impact will be substantially reduced because most of the operations will be enclosed. Observations made at such a mine at Shebandowan, Ontario, indicated that the most likely sources for acoustic annoyance are the tonal components present in the sound of large ventilating fans needed for this type of mine. This conclusion is made on the basis of subjective observations by Copper-Nickel personnel and also on the basis of citizen complaints reported by personnel of the mine and the Ontario Ministry of the Environment. In order to determine the impact that might be expected from this type of fan, the spectrum of the fan at Shebandowan was measured at a point protected by a noise barrier and at a point not protected by a barrier. Since much of the sound from this fan was of a broad-band "rushing" character which was not a source of annoyance, the spectrum used for input to the model was only the first three harmonics of the tonal components present as determined using a one percent bandwidth wave analyzer. Details regarding this measurement are given in Sipson (1978). The fan had 16 blades, each 84 inches in diameter, and was driven at 870 rpm by a 250-HP motor. Such a fan would typically operate 24 hours a day, 7 days a week.

The summer day and winter day, with and without barrier results are presented in Table 10 and 11 for the forest types giving the greatest and the least masking.

Table 10, 11

The shapes of the contours are similar to those for the corresponding season and tree type for trucks. These results show that, without the barrier, a fan of this size can affect an area slightly larger than that affected by an 85 ton truck in level operation but not nearly as large as that affected by 85 ton bed lifts or by 170 ton trucks in level operation. Also evident is the value of the approximately 10 dBA drop in level of the tonal components which was achieved by

Table 10. Affected areas within contours; ventilating fan, spruce forest (in km^2).

	0%	10%	20%	30%	40%	50%
Summer day - no barrier	640	360	210	150	100	60
Summer day - with barrier	220	100	50	32	20	9
Winter day - no barrier	940	460	350	230	150	110
Winter day - with barrier	310	120	72	45	28	17

Table 11. Affected areas within contours; ventilating fan, birch forest (in km^2).

	0%	10%	20%	30%	40%	50%
Summer day - no barrier	480	230	160	100	50	26
Summer day - with barrier	150	55	37	20	7	3
Winter day - no barrier	780	400	290	170	120	90
Winter day - with barrier	250	85	56	32	18	13

the simple solid wall barrier. The maximum predicted audibility distances were 18 km without the barrier and 10 km with the barrier; however, the levels at these distances were only 7 dBA.

5.3.2.4 Secondary Development Sources: Transportation systems are the most likely sources of additional noise impact due to secondary development. Two examples considered here are over-the-road diesel trucks and trains. Both of these will be particularly important in the case of underground mining, where they may be more significant than any mining operation sources. Spectra for these sources were obtained from existing literature (see Sipson (1978) for details). The spectra chosen were those for maximum output operating conditions and thus should represent the greatest impact possible.

For trucks, the results obtained were quite similar to those obtained for an 85 ton ore hauling truck using the level-peak spectrum. For summer daytime conditions in spruce and birch forests, the affected areas are given by Table 12.

Table 12

These values are very close to those for the level-peak spectrum given in Table 8. Recall, however, that the percentages given refer to the percent of time that the propagation and masking conditions are such that the source could be heard if it was operating. While it is likely that, at any given time, there will be at least one ore hauling truck operating in a level mode and situated so that there is no shielding effect from the pit; the same cannot be said of the diesel trucks being considered here. These trucks will most likely only be involved in occasional deliveries of equipment and supplies.

Suppose, for example, that a diesel truck was operating at the source position ten percent of the time. Then in terms of the actual percentages of time that

Table 12. Affected areas within contours; diesel truck, summer days (in km^2).

	0%	10%	20%	30%	40%	50%
Spruce	600	320	150	100	67	38
Birch	340	160	110	67	31	16

such a truck would be audible, the 10 percent contour from the model computation would become the 1 percent contour of actual time audible, the 20 percent contour the 2 percent, the 30 percent the 3 percent, etc. The position of the 0 percent contour, which describes the limits of audibility, would be unchanged. Thus, while the area subject to some impact is the same as that for 85 ton trucks in level operation, duty cycle considerations indicate that the percentage of time that there will be impacts due to diesel trucks will be much less than that for the ore-hauling trucks.

Another source considered in this secondary development section, although it should perhaps be considered as a primary source since it is essential to a mining operation, is the sound of railroad operations. There are many sound producing aspects of railroad operations, only two of which are considered here. These are the sound of a locomotive operating under load and the sound of the horn.

First to be considered will be the locomotive sound. Spectral information for this type of source was obtained from EPA (1975). Using a narrow band spectrum presented in this reference, it can be seen that the sound from this source contains many closely-spaced tonal components. None of these can be considered particularly dominant in the frequency range of the model (100 to 4000 Hz). Consequently, in contrast to trucks where dominant exhaust tone components are present, the sound of a locomotive has more of a continuous spectrum, "broad band" characteristic to the ear. This will make it harder to distinguish in the presence of broad band masking sounds, such as those from wind driven vegetation. To take this into account, at least in an approximate way, the audibility criterion in the model was adjusted so that audibility was predicted when the 1/3 octave band level of the source exceeded the masking level for that band by 10 dBA, rather than the 5 dBA used for the other sources. With this modification the affected areas for a summer day are those in Table 13.

Table 13

The maximum impacted distance is 19 km with a maximum sound level at this point of 18 dBA. As with the diesel trucks, the number of operations per day must be taken into account to determine the actual percentage of time that this sound will be audible. The other sound of railroad operations considered here is that of the horn. This sound is designed to be especially detectable since it is a warning device. The spectrum for such a horn was observed during the field observations. This spectrum was used in the model with the level adjusted so that the equivalent 100 ft level would be 105 dBA, the average result reported by EPA (1975). With the audibility criterion returned to 5 dBA, the model results for a summer day are given in Table 14.

Table 14

The maximum predicted range of audibility is 30 km, with the level at this range being 11 dBA. The 90 percent contour is at 4 km. Thus, these horns represent a significant source of intrusions, especially in the quiet environments of the Study Area.

5.3.2.5 Validity of the Model: An ideal procedure for determining the validity of the computer model would be to operate a known source at a fixed location in the center of a large clearing. Observations would then be made at a large number of points surrounding the source over an extended time period, and these would be compared with the predicted results from the model. While the time to conduct this type of evaluation was not available, the results of the field monitoring described in detail in Trimbach (1978) can be used to determine if

Table 13. Affected areas within contours; summer day, locomotive (in km^2).

	0%	10%	20%	30%	40%	50%
Spruce forest	1100	780	340	120	75	50

Table 14. Affected areas within contours; summer day, train horn (in km^2).

	0%	10%	20%	30%	40%	50%
Spruce forest	3000	2200	1700	1400	1100	840

the model is reasonable. This is possible because many observations were made in the vicinity of two active taconite mining operations, Erie's Dunka Pit and the Reserve Mining Company Pit, which were only a few miles apart.

During the period of time that the field observations were being made, both mines were primarily using trucks in the 85 ton class. Since the field observations were made during daytime, the most important modeling results are those shown by Figures 9 through 16. These figures show that the model predicts rare observations of bed lift operations as far as 20 km from the mine while at points within 4 km of the mines, particularly to the southeast, even the level operation of the trucks should be commonly heard. These predictions seem to be borne out by the observations described in Trimbach (1978). At one location about 2 km southeast of Erie's Dunka Pit, mining noise was observed during each of 8 1-hour observation periods which covered a wide range of wind speeds. At points situated about 5 km from the mines, mining noise audibility was reported during about 50 percent of the observation periods. (There were not enough separate observations made to allow a more precise statistical statement.) Finally, the most distant points where observations of mining noise were reported were 20 km from the nearest mine. While it is not possible to be absolutely certain of the source, these sounds did have a level and a spectrum the same as that predicted for a bed lift operation observed at this distance.

Thus, it would appear from the results of the field monitoring study that, at least for 85 ton trucks, the model gives a reasonable representation of the actual situation.

5.3.2.6 Multiple-Source Model: A second computer program was developed to model the impact that would result if two or more sources were operating at positions separated by several kilometers. If the source separation is so large that none of the contours for the separate sources determined by the single-source model overlap, the single-source model results are all that is needed. However, if the single-source contours do overlap, the single source model results may not be simply combined because the audibility statistics of the separate sources are not independent. The multiple source model described in detail in Sipson (1978) was designed to correctly combine the audibility statistics to predict the percent of time that at least one of the sources will be audible. For mining noise impact the primary value of this model will be in its ability to predict the increase in impacted areas that will result from the development of a second mining operation in the vicinity of an existing one.

Suppose, for example, that a second operation is developed 5.5 km southwest of an existing operation. Further suppose that both are using 85 ton trucks. To determine the increase in impacted areas that would result from this situation, two runs were made using the multiple-source model with the 85-ton level-peak spectrum for the source. For the first run only one source was entered. It was positioned at a point 2 km north and 2 km east of the origin of the coordinate system. The results of this run are shown in Figure 19 with the position of the source marked with an X. Aside from slight details, which are artifacts of the different iteration processes used in the two programs, these contours are the same as those shown in Figure 9 which were obtained for the same situation using the single source model. This is as it should be, since the same basic assumptions regarding propagation and audibility are used in both programs.

Figure 19

Next, the model was run with the second source included at a point 2 km south and 2 km west of the origin of coordinates, giving a source separation of approximately 5.5 km. The results of this run are shown in Figure 20. By

MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 19

SOURCE : 85 TON TRUCK, AT 2.2 KM LEVEL PEAK SPECTRUM

WIND FILE : SUMMER DAY

TREE TYPE : BIRCH FOREST

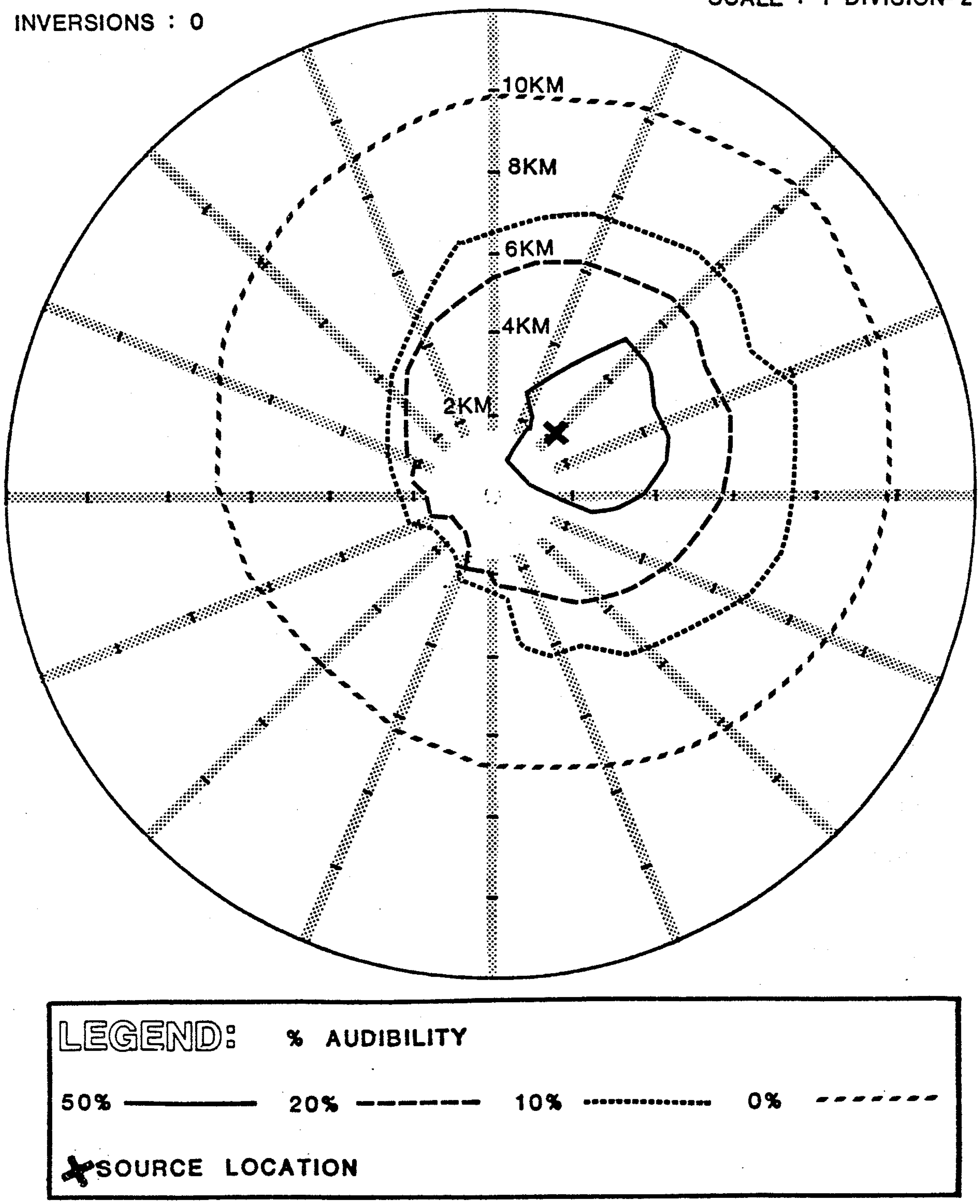
% INVERSIONS : 0

TEMP. : 20 C.

RELATIVE HUMIDITY : 65%

EXCEEDENCE PARAMETER : 5 DBA

SCALE : 1 DIVISION- 2 KM



comparing this figure with the previous one, the increase in impact which results from the second operation can be seen. It is interesting to note that while the area within the 50 percent contour essentially doubles for this particular situation, the fractional increase in area within the 0 percent contour is not as great. In fact it is only 35 percent greater. For the particular example chosen, there were only two sources and they both had the same spectrum. The model, however, is set up to handle up to six sources at different locations, each of which may have a different spectrum. Thus, it is flexible enough to deal with a large number of development scenarios.

Figure 20

5.3.2.7 Regional Perspective: In order to put the above results into a regional perspective, Figure 21 is included. From Figure 17 it can be seen that the predicted limit of audibility for 170 ton trucks for the level-peak spectrum is 30 km during summer daytime for observers in spruce forests. A circle of this diameter is drawn in Figure 21 centered on the position marked by ★. Also shown is the 50 percent contour. Recall that these results were obtained assuming only natural masking sounds, thus the inclusion of Ely and Hoyt Lakes within the 0 percent contour is not significant. Audibility, however, can be expected in Babbitt for this example. This will be better seen from the discussion of results in section 5.3.3. Figure 23 of this section is based on a criterion which is reasonable for describing audibility in quiet residential areas. Babbitt is included in the affected area calculated based on this criterion.

Figure 21

For this particular location there is no significant impact on the BWCA. However, if the mine location is shifted to the point marked X on this figure, it can be seen that a substantial portion of the BWCA will be affected. The

MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 20

SOURCE : 2 TRUCKS AT 2,2 AND -2, -2 KM. BOTH HAD LEVEL PEAK SPECTRA - 85 TON TRUCKS

WIND FILE : SUMMER DAY

TREE TYPE : BIRCH FOREST

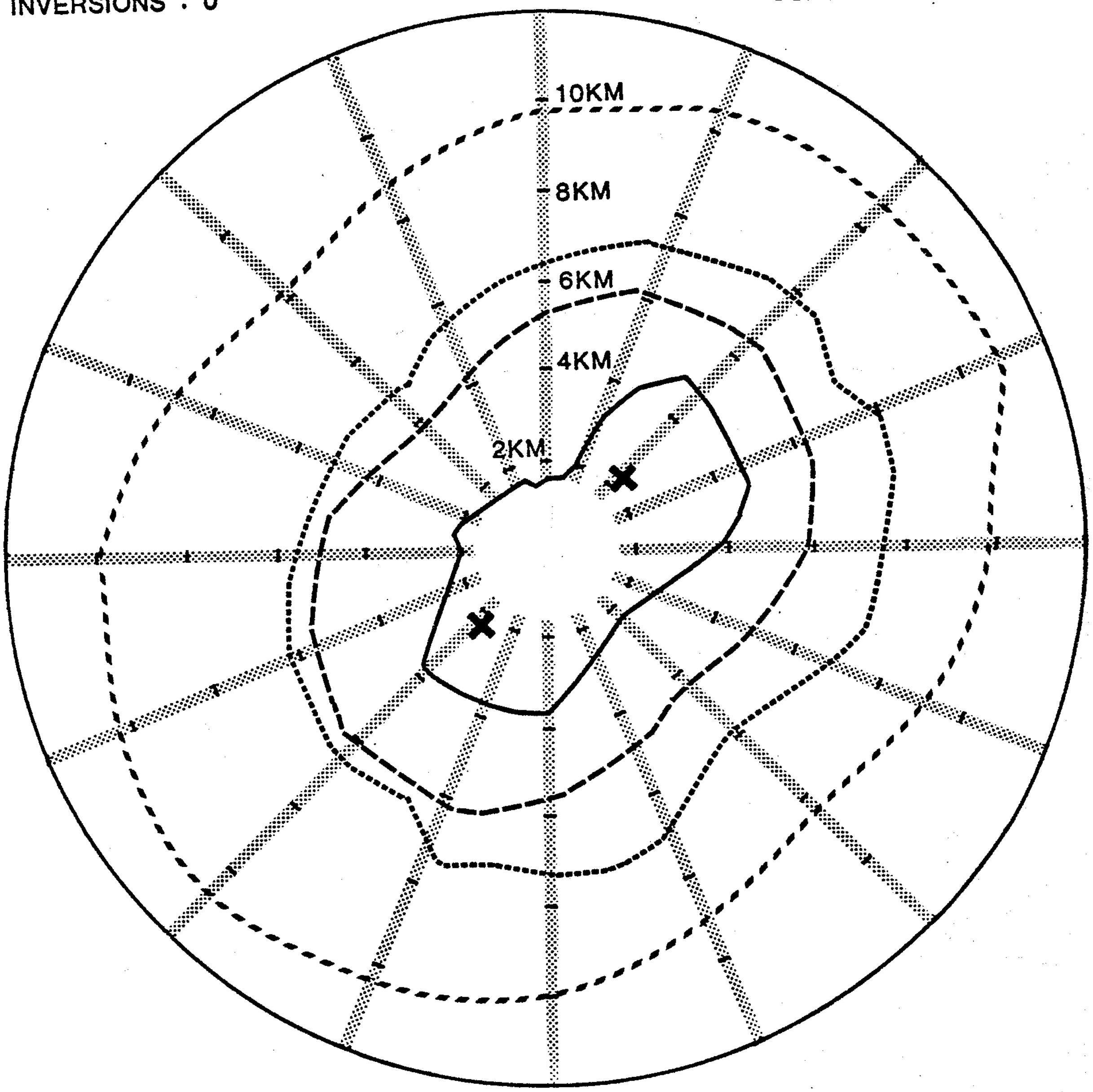
% INVERSIONS : 0

TEMP. : 20^{0} C.

RELATIVE HUMIDITY : 65%

EXCEEDENCE PARAMETER : 5 DBA

SCALE : 1 DIVISION-2 KM



LEGEND: % AUDIBILITY

50% ———— 20% — — — — 10% ·········· 0% - - - - - -

✖ SOURCE LOCATION

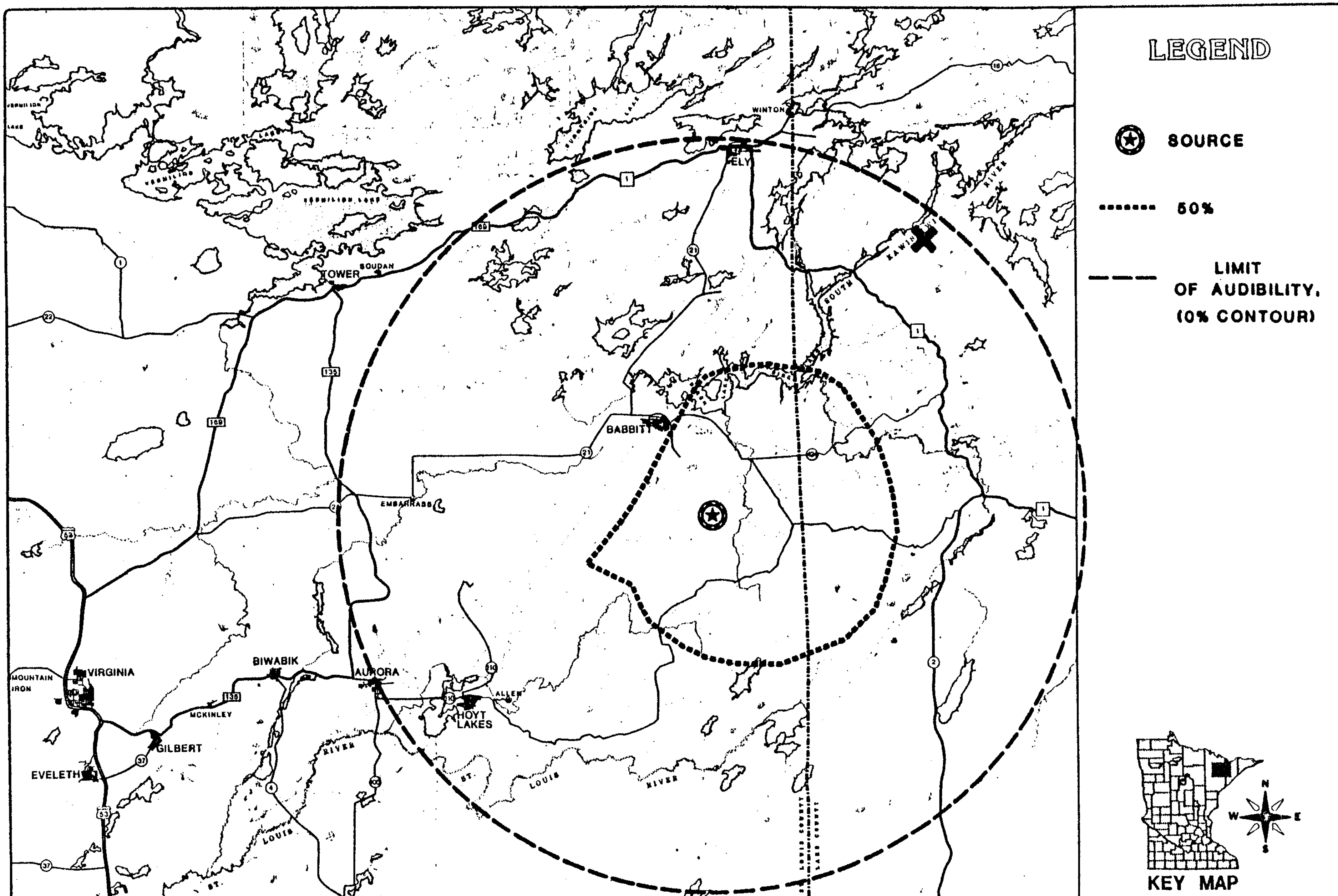


FIGURE 21 MEQB REGIONAL COPPER-NICKEL STUDY

NOISE CONTOURS FOR A 170 TON TRUCK- LEVEL PEAK SPECTRUM implications of such changes in the noise environment are further discussed in Volume 5, Chapter 9, Outdoor Recreation.

5.3.3 Alternate Criteria

The criteria used in obtaining the results described above are very sensitive. An impact is defined as occurring when any tonal component of propagated sound slightly exceeds (by 5 dBA) the minimum level necessary for audibility. The assumed zero wind ambient levels are so low that an impact is predicted, at relatively great distances from the source, even when the received sound level might be quite low, on the order of 10 dBA in some cases. While these criteria might be desirable in accessing the impact on sensitive areas, it is likely that it will be decided that many areas in the region do not require this level of protection. While completely different modeling procedures could be developed using criteria based on other measures of impact, such as L_{eq}, L_{10}, or any of a large number of other existing measures of community noise impact, the computer model developed is flexible enough to permit some modification of criteria that may be useful for less sensitive areas. Two possibilities will be discussed here together with examples which show the changes in the impacted areas which result.

One possible change is to increase the amount by which a propagated sound band level must exceed the masking level for that band in order for an impact to occur. In obtaining the previously described results, this was set at 5 dBA. This is probably the minimum reasonable value. If this parameter is increased to 15 dBA the propagated sound would have to be much more intrusive before an impact occurred. The intrusive sound, while perhaps not being describable as "loud," would certainy then be very noticeable. With this simple modification in the computer program, runs were made using the 170 ton truck level-peak spectrum as the source. The results for spruce forest during a summer daytime condition are given in Figure 22 and Table 15.

Figure 22

Table 15

Notice that this procedure moves all contours closer to the source when compared with those of Figure 17 and the areas in Table 8, line 13. Of course, the impacts are much more significant. Assuming that the sound propagates as modeled, it would be quite difficult not to notice the sound of the source during the time percentages for which an impact is assessed.

A second possible modification would be to increase the assumed zero wind ambient levels. This might be done for two reasons. One would be to increase it artificially above the actual zero wind ambient levels. This would have the effect of setting up a spectral "fence" below which an impact would not be assessed even if a propagated source band level exceeded the masking level by more than the criterion established. The second reason would be if the masking spectrum was actually higher, such as in a populated area.

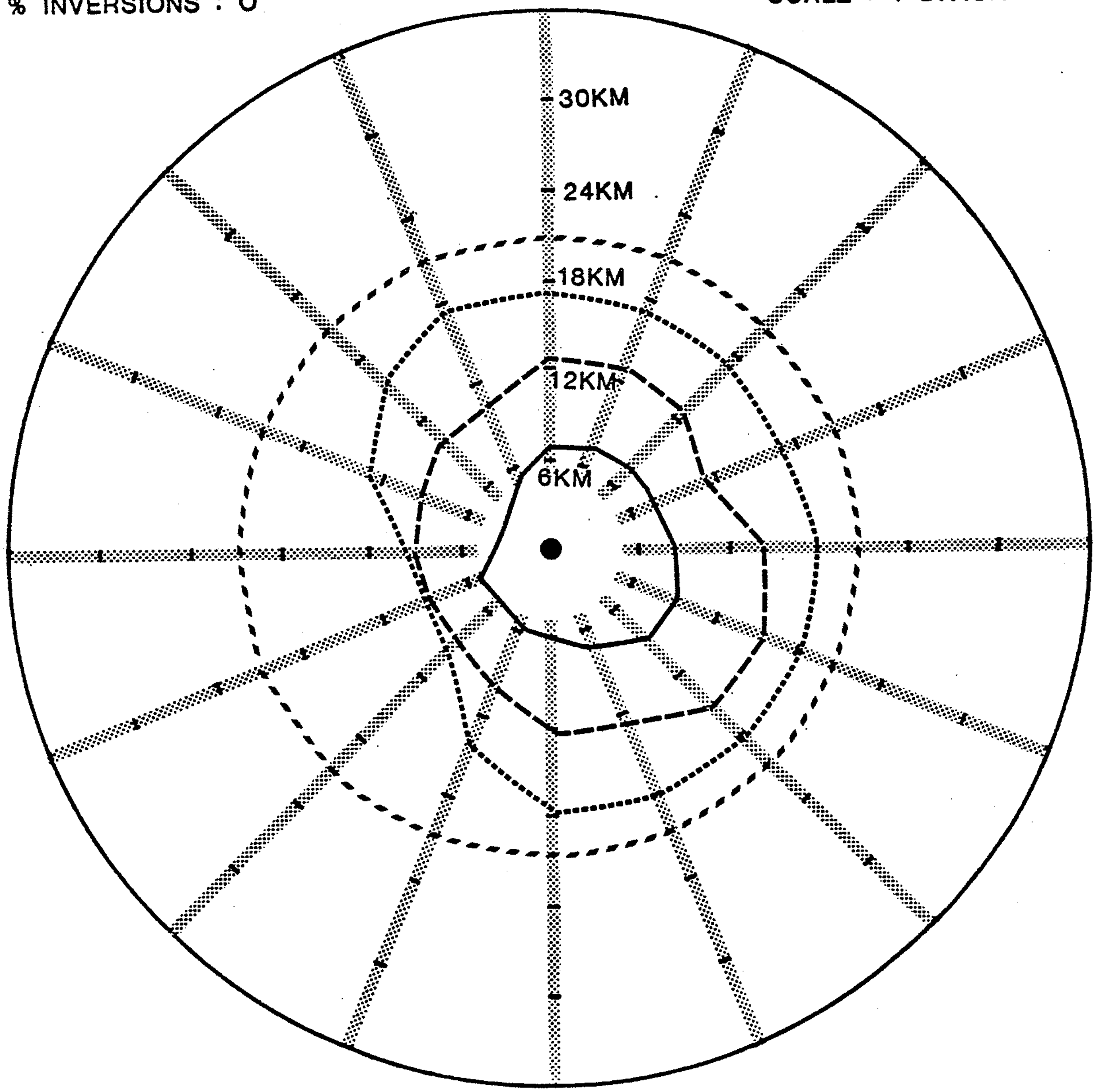
As an example of the first possibility suppose the zero wind ambient levels entered into the computer model were arbitrarily set at 20 dBA for each band, and the exceedence criterion was left at 5 dBA as in the previous runs, the minimum 1/3 octave band levels for which an impact would be assessed are those in Table 16. These are obtained using Table 6. While even these levels are low by ordinary community noise standards, tonal components at these levels may still be a cause for citizen concern in quiet environments. Based on inverse square law and atmospheric absorption losses only, propagated tonal components from the ventilating fan at Shebandowan, Ontario, should have been only 32 dBA

MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 22

SOURCE : 170 TON TRUCK, LEVEL PEAK
WIND FILE : SUMMER DAY
TREE TYPE : SPRUCE
% INVERSIONS : O

TEMP. : 20° C.
RELATIVE HUMIDITY : 65%
EXCEEDENCE PARAMETER : 15 DBA
SCALE : 1 DIVISION- 6 KM



LEGEND: % AUDIBILITY

50% ———— 20% – – – – 10% ········· 0% - - - - -

● SOURCE LOCATION

Table 15. Affected areas within contours; alternate criteria study (in km^2)(see text).

	0%	10%	20%	30%	40%	50%
170 Ton Level-Peak	1300	730	420	270	200	120

in band 24 at the locations of the most distant citizens who complained about the sound before the barrier was constructed. Since these people were living at summer cottages this would seem to indicate that levels much above those of Table 16 might result in complaints from some residents of rural areas.

Table 16

An interesting comparison is to remove the A-weighting from revised zero wind ambient spectrum being considered here. These results are shown in Table 17. Comparing these band levels with Figure 15 of EPA (1971) shows that this spectrum is one that might describe the residual sound spectrum for a quiet residential area. Thus, the 0 percent contour obtained using the revised zero wind ambient spectrum being considered would describe the limits to which intrusions might be expected in quiet residential areas. The positions of the other contours would only be valid in suburban areas to the extent that wind driven vegetation sounds were the primary cause of masking.

Table 17

A computer run for which the zero wind ambient band levels were increased to 20 dBA as discussed above was made using a 170 ton level-peak spectrum for summer day conditions. The results are shown by Figure 23 and Table 18.

Figure 23

Table 18

It can be seen by comparison with Figure 17 that in addition to reducing the impacted areas, this substantial increase in the minimum levels before impact is assessed results in a change of contour shapes. The reason for this can be seen

Table 16. Minimum band levels for impact-revised zero wind ambient levels.

BAND NUMBER	BAND LEVEL, dBA
20	30
21	29
22	27
23	25
24	24
25	23
26	22
27	21
28	20
29	20
30	20
31	19
32	19
33	19
34	19
35	19
36	19

Table 17. Equivalent dBL* levels for a spectrum with a constant 20 dBA band level.

BAND NUMBER	dBL LEVEL
20	39
21	36
23	31
24	28
26	25
27	23
29	21
30	20
32	19
33	19
35	19
36	19

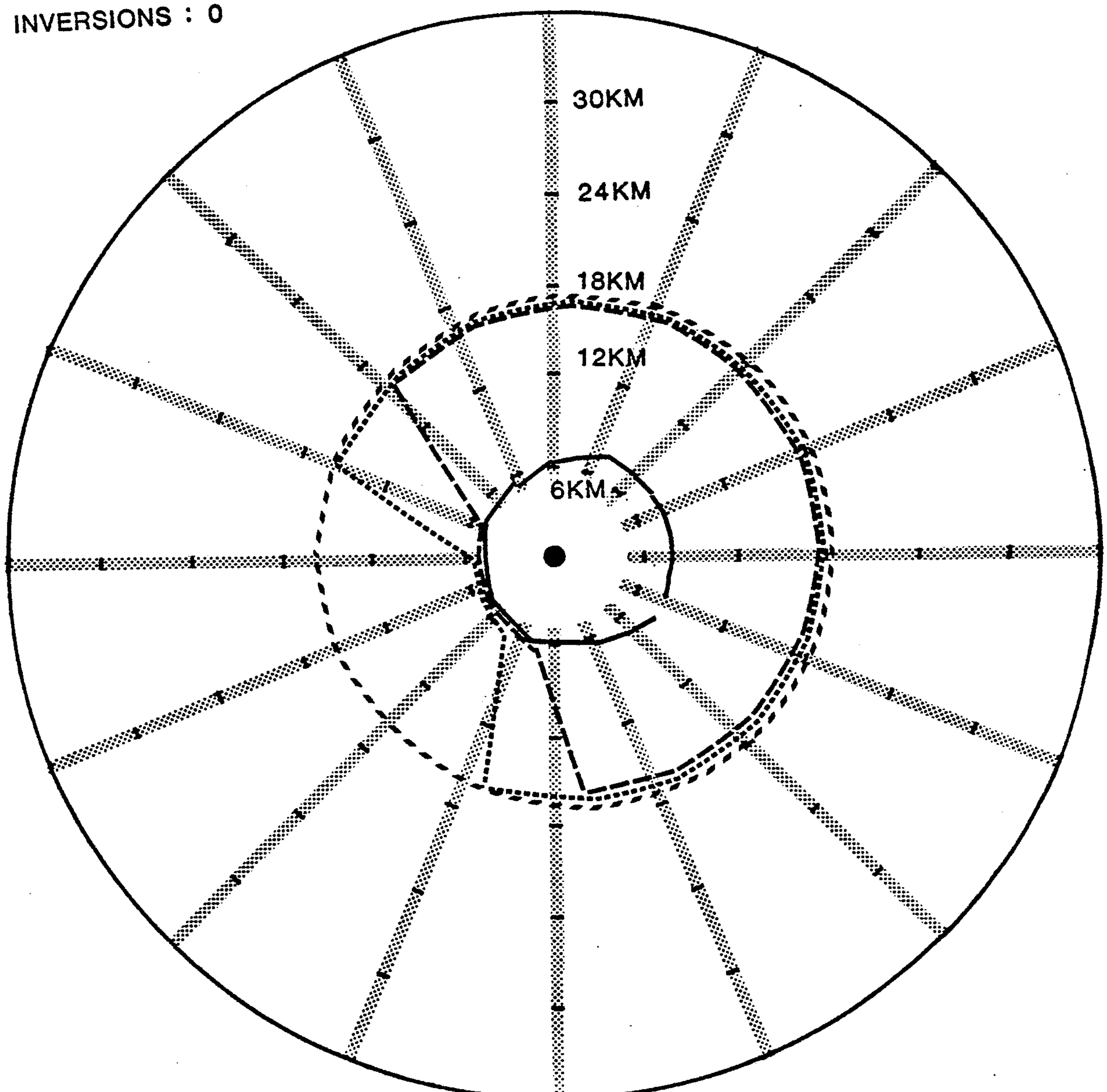
*dBL = decibels linear (not A-weighted)

MODELED AUDIBILITY CONTOURS FOR NOISE SOURCE

FIGURE 23

SOURCE :170 TON TRUCK, LEVEL PEAK
WIND FILE : SUMMER DAY
TREE TYPE : SPRUCE
% INVERSIONS : 0

TEMP. : 20 C.
RELATIVE HUMIDITY : 65%
EXCEEDENCE PARAMETER : 15 DBA
SCALE : 1 DIVISION- 6 KM



LEGEND: % AUDIBILITY

50% ———— 20% – – – – 10% ········· 0% - - - - -

● SOURCE LOCATION

Table 18. Affected areas within contours, revised criterion (in km^2)(see text).

	0%	10%	20%	30%	40%	50%
170 Ton Level-Peak	780	630	540	260	120	120

from Figure 8. From this figure it can be seen that except for a band of frequencies around 1000 Hz (band 30), the wind-generated masking levels are less than the assumed zero wind ambient levels most of the time. Since the program substitutes the zero wind ambient levels if they are higher, most of the time the levels for impact are those given by Table 17. The main effect of the wind in the model then comes during the occurrence of crosswind and upwind conditions which result in additional attenuation. If the increase in the assumed zero wind ambient levels had been more modest, wind generated masking would have remained more important and the inner contours would have been subject to little or no change, while the outer contours would have been moved in.

Neither of the particular revisions considered in this section should be considered a recommendation for any particular part of the Study Area. Instead, they should be considered as examples of the types of modifications that might be useful for non-wilderness land use areas. The amount of modification desirable will have to be adjusted to fit the land use. Unfortunately, these criteria will depend on difficult "quality of life" decisions unless it is decided to allow this quiet environment to be degraded to the levels found in urban areas which are governed by existing State of Minnesota standards. There is a great need for research into criteria which can be used for various nonurban land uses. The criterion used for the impact assessment described in the previous sections of this report is essentially a nondegradation criterion.

5.4. MEANS OF REDUCING IMPACT

The three basic means of controlling any noise problem are to control the source, the path, and the receiver. Since persons not on mine property cannot reasonably be expected to use any form of hearing protection, only controls on the first two items are possible. Path control would include the use of barriers or enclosures and would be especially valuable for fixed equipment. If the source can be totally enclosed, a very large amount of reduction is possible. For example, if an underground mine ventilating fan is installed underground with only an air intake at the surface, the problem of fan noise can be significantly reduced. At the Shebandowan mine there were some fans installed in this manner and they were not significant noise sources. For sources which are fixed but which cannot be totally enclosed, noise barriers can be helpful. The previously discussed results for a surface mounted ventilating fan with and without a barrier show this. By using barriers and enclosures it should be possible to have an operating underground mine with no significant impact beyond 5 km. Except for the previously mentioned fan, this was essentially true of the Shebandowan mine.

With wide-ranging surface equipment, such as the trucks in an open pit mine, effective barriers and enclosures of a practical size are not possible. If the distance between a source and a barrier is large compared to the height of the barrier, wind and temperature gradient effects will carry the sound over the barrier. This leaves source control as the only possible means of control for this type of equipment.

The type of source control needed to reduce off-mine-property impact is somewhat different than that needed for OSHA noise reduction. It is primarily the low frequency tonal components which result in impacts at points several kilometers from the mine. This is because atmospheric absorption has relatively little effect on low frequency tonal components. To illustrate this fact Figure 24 is presented. It shows the distance to which pure tones at various frequencies must travel before they are reduced to 10 dBA as a function of the equivalent 1-meter levels of the source. These results are based on inverse square law and atmospheric absorption. The difference between the 1-meter levels and the 100-

ft levels is 30 dBA. Thus, a 1-meter level of 70 dBA is equivalent to a 100-ft level of 40 dBA.

Figure 24

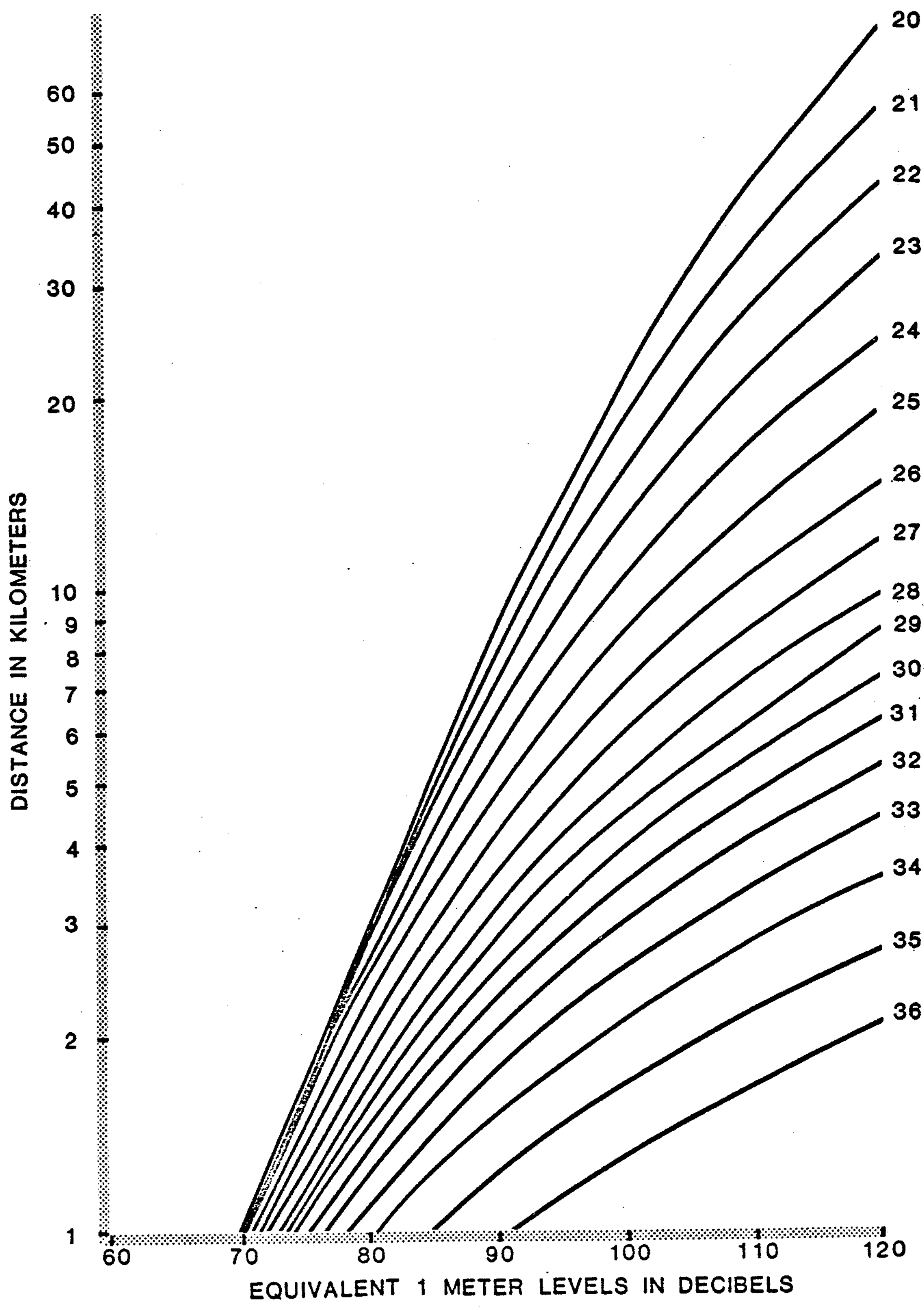
The importance of low frequency components is clearly shown by Figure 24. A tone at 4000 Hz (band 36) with a 1-meter level of 100 dBA is reduced to 10 dBA in less than 1.5 km while the same source level for a tone at 100 Hz (band 20) has to travel 21 km to obtain the same reduction. Thus, for the large ore hauling trucks, for example, the greatest range of impact will result from low frequency exhaust tone components. It may be possible to modify these vehicles to reduce these low frequency components if operations near sensitive areas are being considered. Using Figure 24 it can be seen that if a tonal component at 200 Hz can be reduced from a 1-meter level of 120 dBA to a 1-meter level of 100 dBA, the distance to which the propagated sound will remain above 10 dBA is reduced from 32 km to 16 km. This would reduce the impacted area by a factor of 4.

If source controls are not practical, alternate equipment choices could be considered. For example, based on the particular equipment observed in developing the spectra for 85 and 170 ton trucks used in the model calculation, the range of impact of 170 ton trucks was much greater than that of 85 ton trucks, with the exception of the bed lift operation. Since the tonal components of two trucks are not likely to coincide due to differences in operating conditions which will usually exist, the range of detectability of two 85 ton trucks will not be significantly greater than that for either of them. This is especially true if the level-peak spectrum is used, since an increase above the level-peak spectrum level for one truck would then result only if the sound of both vehicles reached a simultaneous peak for tonal components at nearly the same

FIGURE 24

STANDARD SUMMER NIGHT.

DISTANCE TO WHICH TONE WITHIN VARIOUS BANDS MUST TRAVEL BEFORE THEY ARE REDUCED TO 10 DBA



frequency. Thus, based on the particular equipment observed, an operation using 85 ton trucks would result in significantly less noise impact than one using 170 ton trucks.

Another possible procedure to reduce impacts would be to restrict the time of operation of the equipment. For an underground mine, for example, associated delivery truck and railroad operations will be significant sources of noise intrusions. To the extent possible, it would be desirable to limit the operation of these sources during sensitive summer nighttime conditions. During summer afternoons calm conditions and temperature inversions are unlikely. Thus, scheduling operations during these times favors the presence of wind-generated masking sounds and unfavorable propagation conditions which will greatly reduce the impacted areas. Similar time restrictions for the ore hauling trucks of an open pit operation, while possible, would have to be considered in the light of a substantial economic impact which would result from having very expensive equipment stand idle. Such limitations may be necessary, however, if maximum protection is to be given to sensitive areas, such as the BWCA.

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