CN 144

A COMPUTER MODEL FOR THE PREDICTION OF MINING NOISE IMPACTS IN NORTHEASTERN MINNESOTA

BY

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January, 1979

Prepared for the Minnesota Environmental
Quality Board, Regional Copper-Nickel Study

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INTRODUCTION TO THE REGIONAL COPPER-NICKEL STUDY

The Regional Copper-Nickel Environmental Impact Study is a comprehensive examination of the potential cumulative environmental, social, and economic impacts of copper-nickel mineral development in northeastern Minnesota. This study is being conducted for the Minnesota Legislature and state Executive Branch agencies, under the direction of the Minnesota Environmental Quality Board (MEQB) and with the funding, review, and concurrence of the Legislative Commission on Minnesota Resources.

A region along the surface contact of the Duluth Complex in St. Louis and Lake counties in northeastern Minnesota contains a major domestic resource of copper-nickel sulfide mineralization. This region has been explored by several mineral resource development companies for more than twenty years, and recently two firms, AMAX and International Nickel Company, have considered commercial operations. These exploration and mine planning activities indicate the potential establishment of a new mining and processing industry in Minnesota. In addition, these activities indicate the need for a comprehensive environmental, social, and economic analysis by the state in order to consider the cumulative regional implications of this new industry and to provide adequate information for future state policy review and development. In January, 1976, the MEQB organized and initiated the Regional Copper-Nickel Study.

The major objectives of the Regional Copper-Nickel Study are: 1) to characterize the region in its pre-copper-nickel development state; 2) to identify and describe the probable technologies which may be used to exploit the mineral resource and to convert it into salable commodities; 3) to identify and assess the impacts of primary copper-nickel development and secondary regional growth; 4) to conceptualize alternative degrees of regional copper-nickel development; and 5) to assess the cumulative environmental, social, and economic impacts of such hypothetical developments. The Regional Study is a scientific information gathering and analysis effort and will not present subjective social judgements on whether, where, when, or how copper-nickel development should or should not proceed. In addition, the Study will not make or propose state policy pertaining to copper-nickel development.

The Minnesota Environmental Quality Board is a state agency responsible for the implementation of the Minnesota Environmental Policy Act and promotes cooperation between state agencies on environmental matters. The Regional Copper-Nickel Study is an ad hoc effort of the MEQB and future regulatory and site specific environmental impact studies will most likely be the responsibility of the Minnesota Department of Natural Resources and the Minnesota Pollution Control Agency.

SECTION 1

Introduction and General Discussion

The computer models described in this report were developed as a part of a potential impact assessment for the development of copper-nickel mining in northeastern Minnesota. First to be described will be the basic assumptions of the model together with a description of how the needed input data were obtained. Following this the details of the computer program will be considered, together with a listing of the programs and user instructions.

In remote, forested, areas such as those in northeastern Minnesota, natural sounds dominate the acoustic environment. Except in the vicinty of a few point sources, the sounds of man's activities are usually limited to an occasional vehicle or aircraft passby. These statements are based on an extensive regional characterization study which is described in detail in Trimbach (1978). As a result of this study it was determined that the sounds generated by wind passing through vegetation, which was usually forest, was the only significant source of masking sound. One of the important results of this study was to quantify the level and the spectrum of this sound. These results were put into analytical form and used in the computer model to represent the masking sound present. (See section II).

On the basis of this representation of the available masking sounds, it is possible to predict whether or not the propagated sound from a distant source will be audiable. If it is audible it is considered an intrusion. An adjustable parameter is included in the computer program which allows the user to determine how easily audiable the sound must be before an impact is assessed.

To complete the modeling process, two more steps are needed. One is to model the effects of sound propagation between the source and the receiver.

The second is to determine the nature of the sound produced by the source of interest. Of these, the representation of the effects of sound propagation is the most difficult. Field observations described in Trimbach (1978) and results of the model itself showed that sounds may remain detectable over distances of several kilometers in areas as quiet as those in which the model was developed. Experimental and theoretical results which would permit the precise calculation of the effect of propagation over these distances are simply not available. Even if they were, the existing literature indicates that the amount of micrometeorological and terrain descriptive data that would be needed would require a far more massive data gathering effort than was reasonably possible.

The propagation modeling procedure that was used was developed on the basis of an extensive literature review (see Piercy, et al. 1977), together with a limited experimental study conducted in the region using a variable tone source. Probably the most significant assumption is that vegetation and wind gradient effects were represented by fixed insertion losses and not by values which were proportional to the distance traveled. The reason for this is an effect called "saturation" in the literature. For example, while the insertion loss which results from the passage of sound through vegetation increases with distances traveled for short distances, the existing experimental data shows that this loss only increases with distances to a certain point, called the saturation level. Beyond this point, no additional insertion loss in incurred as a result of increasing the path length through vegetation. A good example of this is found in Dneprovska, et al. (1963). As has been noted by others (Beranek, 1971) the insertion loss (excess attenuation) that was found by these authors was approximately the same for paths 1, 2, 3, or 4 kilometers.

Since persons within 1 kilometer of the powerful sound sources considered in this study will certainly be impacted, the minimum computation distance used was 1 km. At this distance it is assumed that saturation will have occured and thus the vegetation insertion loss used is simply a 15dB subtraction. An assumption that vegetation insertion losses will reliably give more protection than this would not seem to be justified based on the data presently available, especially the results in Dneprovska (1978). The value 15 dB is obviously an approximate figure. It is a reasonable approximation to the results of Dnsprovska (1963) that were presented as representing the average excess attenuation observed for a number of paths in undeveloped areas of Russia. It is also consistent with the saturation values used by the author of some other models (Keast).

Wind and temperature gradients are also important factors in determining the effects of sound propagation over long distances. Their effects have been the subject of considerable theoretical and experimental study. Unfortunately, to fully utilize some of the more sophisticated modeling procedures that have been developed to take these factors into account requires a knowledge of the temperature and wind speed profiles above the ground for all points along the propagation path. This would have required a much more extensive meteorological survey of the region than was possible under overall project budget limitations. Even if this information were available, the resulting computer model would have been substantially more complex and it would have required a much greater time to arrive at a statistical characterization of the impacts that might be expected on an annual basis.

As a result of these considerations, meteorological effects on propagation were taken into account using a very much simplified procedure. Meteorological conditions were divided into 5 classes 1) If, as seen from the source, the wind is coming from a direction within +/- 56.25 degree (the angle subtended by 5 points of a 16 point compass) of the direction of the sound propagation path, the propagation is considered upwind.

2) If the wind is blowing toward a direction within +/- 56.25 degrees of the direction from the source to the receiver the propagation is considered downwind.

3) If the wind is blowing, and it is neither upwind nore downwind, the propagation is considered crosswind.

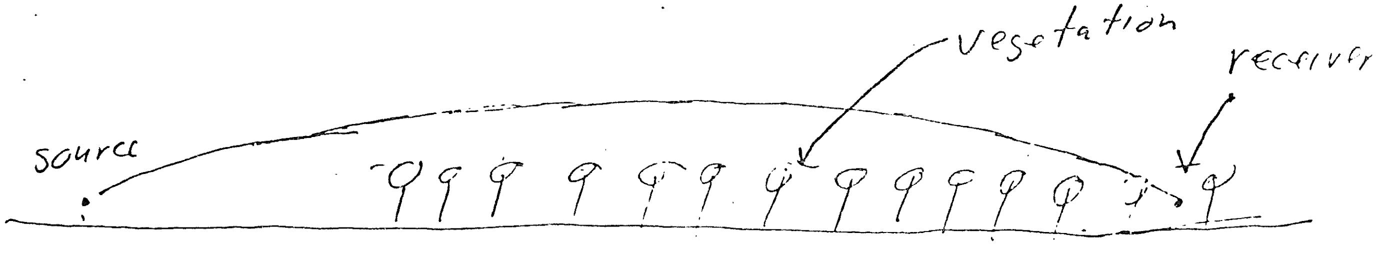
4) If the wind is less than 3knots (about .5m/sec) it is considered calm. If the wind is calm and there is a ground-based temperature inversion, the propagation is considered calm - inversion.

5) If the wind is calm and there is no ground- based temperature inversion the condition is called calm-lapse. With these conventions defined, the method of calculating propagation losses can be given.

If the propagation condition is downwind or calm - inversion, the only losses included were those due to the inverse square law and atmospheric absorption. Atmospheric absorption was modeled using a proposed standard procedure (Piercy). Over the distance considered in this study, atmospheric absorption is a very important source of attenuation. No attentuation due to vegetation was included for these conditions. The source is assumed to be operating in a large clearing and the downwind curving propagation path should carry the sound over the vegetation over most of the path. Figure 1 illustrates this point.

If the propagation condition is crosswind or calm-lapse, an additional 15 dB loss above that due to inverse square law and atmospheric absorption is included. This is to account for the surface vegetation losses described above. If the path is upwind, this excess attenuation is increased to 30 dB to account for both vegetation and wind gradient effects.

Figure 1. Propagation Downwind or During Calm - Inversions



Having decided how to treat the receiver and the path, the task of describing the source remains. Since acoustic detectability is being emphasized, both level and spectral data about the source are modeled in order to predict the received spectrum. For this reason the model was set up to deal with sound in 1/3 octave bands for the frequency range 100 Hz to 4000 Hz corresponding to standard band numbers 20 to 36. In some cases useful spectra could be obtained from literature developed for EPA studies. Spectra for on-road diesel truck and railroad locomotives were obtained in this way from (U.S. D.O.T.) and (U.S. E.P.A.). However, because of the very specialized nature of the equipment used in mining, field measurements were made at existing mines to obtain data for a few important sources, especially the large ore hauling trucks used in open pit operations. One trip was made to open pit taconite mines at Eveleth and at Hibbing in Minnesota. The results of these measurements are given in appendix 1. A second trip was made to an underground copper-nickel mine at Shebandowan, Ontario. This trip was made to observe the sound of a large, surface mounted ventilation fan. The results of this measurement are given in appendix 2. The cooperation of personnel at the Eveleth Taconite Company, the Hibbing Taconite Company, INCO's Shebandowan mine and the Ontario Ministry of the Environment office at Thunder Bay are gratefully acknowledged.

SECTION II

Characterization of Wind Generated Vegetation Sounds in Forests

Extensive field observation, described in Trimbach (1978), showed that the most important source of masking sounds in the forested areas of northeastern Minnesota are the sounds that result from wind passing through the trees. Other sources of natural sounds, particularly those of wildlife, were sporadic and generally at a frequency where atmospheric absorption was great enough to reduce propagated sound components below the level of audibility even at points relatively close to the source. Thus the computer model for the prediction of audibility included only wind generated sounds for masking. Masking levels for calm wind conditions are considered separately. In order to represent these sounds in the computer model it is necessary to characterize them analytically and this section describes the procedure used to do this. First to be discussed will be the dependence of sound level on wind speed. Following this the spectral distribution of the sound energy is considered. The procedure used to obtain a relationship between wind speed and sound level in dBA is discussed in Trimbach (1978). It is included here for completeness.

During the field observations, the statistical distribution of sound levels was observed during serveral one hour observation periods in each of several forest types. As discussed in Trimbach (1978) it was found that when L10, L20...L90 were plotted on probability paper, the result was very nearly a straight line for observations where wind generated sounds dominated. This indicates that, at least during the one hour observation periods, the sound level distribution follows a Gaussion or normal statistical distribution. Since a normal distribution is completely characterized by its mean and standard deviation, this fact means that the data for each one hour measurement could be reduced to two numbers, the mean, L50, and the standard deviation σ.

To accomplish this reduction, a least squares fit procedure was developed to determine the best straight line fit on probability paper to the points L10, L20...L90. This procedure is described in appendix A. The result of this procedure was the determination of L50, σ and δ. Here δ is the standard error of estimate which is the standard deviation of the scatter of the actual data points from the corresponding values determined from the best fit straight line. A small value for δ indicates that the straight line gives a good representation of the data. Since δ was usually less than 1 dB the fit can be considered good.

Next it is necessary to combine the results of the individual one hour measurements to arrive at the overall distribution of sound levels during each of two seasonal conditions, foliage and no foliage. Since the field observation times were chosen to cover a complete range of wind conditions, from low to high, the resulting combined distribution should describe the sound level statistics during the daylight hours for each of the two seasonal conditions, (all observations were during daytime).

Using a histogram technique, described in Trimbach (1978), the results of the individual measurements were combined to give overall values for L10, L20...L90. It was found that these values again fall very nearly on a straight line on probability paper, indicating that the seasonal sound level statistics could also be represented by a normal distribution. Using the least squares fit procedure, seasonal values for L50 and σ were determined and these values, taken from Trimbach (1978) are given in Table 1. Despite the fact that the number of individual one hour measurements combined was only of the order of 10, the standard error of estimate values are low enough to show that a normal distribution provides a good representation of the sound level statistics during the two seasons. The values for Leq, L10, and L90 given are those

Table 1. 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

calculated from L50 and σ using the method of appendix A. A good indication of the quietness of the region is given by the low values for L90. On the other hand, the values for L10 show that, under windy conditions, wind generated sounds in forests can provide a substantial amount of masking.

The results in Table 1 give the wind generated sound level statistics for the period of time covered by the fiels observations and thus reflect the wind statistics during that time. In order to determine the sound levels which might be found during other time periods, a direct relationship between sound level and wind speed was derived using a statistical procedure. Using data from a regional airport, the wind speed distributions for the field monitoring periods with foliage and no foliage were found. While, at any given time, the wind speed at this airport and that at a given field observation point may differ, it is assumed that the seasonal wind statistics at any field point are the same as those at the airport. For this region this assumption is reasonable. However, for other areas, such as near mountains or an ocean, this assumption might not be good and it would then be necessary to directly monitor the winds at each measurement site, not an easy task in forested areas.

To derive the relationship between wind speed and sound level used in the model define Wn to be the wind speed exceeded N% of the time. Using values of Wn determined from the airport data it is found that, for N between 10 and 90, a plot of Wn on probability paper was essentially a straight line. Thus the least squares fit procedure of appendix 3 can be used to determine, for each of the data seasons, the values for W50 and σ_W which characterize the wind speed statistical distribution. As in appendix 3, let t_n be the number of standard deviations from the mean of a normal distribution corresponding to sampled values found to be exceeded N% of the time. Then the fact that the wind speed and sound level statistics are normal makes the following two equations valid (t is a time variable).

1. $W(t) = W_{50} + \sigma_w t_{N(t)}$

2. $L(t) = L50 + \sigma_s t_{M(t)}$

If the wind speed and sound level statistics were uncorrelated, ther would be no relationship between N(t) and M(t). However, since L_N describes the statistical distribution of wind generated sounds (some data adjustment was needed in a few cases where non wind generated sounds were significant, see Trimbach (1978)) it can be assumed that, for example, a sound level of L_{30} would occur when the wind was at a speed corresponding to W_{30}. In terms of the variables of equation 1 and 2 this means that N(t) = M(t). Using this fact, equation 1 and 2 can be combined to obtain the desired relationship.

3. $$L(t) = L_{50} + \sigma_s \frac{(W(t) - W_{50})}{\sigma_w}$$

$$= A1\ W(t) + A2$$

$$A1 = \sigma_s / \sigma_w$$

$$A2 = L_{50} - \frac{\sigma_s}{\sigma_w} W_{50}$$

Since the relationship has been derived based on statistical model developed for data only between the 90th and the 10th percentiles, it should only be used for wind speeds between W_{90} and W_{10}, between 3 and 14 knots for this region. It certainly is not valid for a wind speed of 0, it may be valid for higher wind speeds but this has not been tested. For wind speed in knots and sound levels in dBA, the values for A1 and A2 for several vegetation types are given in Table 2.

The above discussion of the derivation of the relationship between wind generated

TABLE 2

Values for A1 and A2

	A1	A2
Winter		
Jackpine	2.05	15.03
Birch	1.99	13.51
Black Spruce	1.47	17.79
Spruce	2.01	11.34
Clearcut	1.02	15.59
Summer		
Jackpine	1.33	25.19
Red Pine	1.81	18.99
Birch	2.33	20.54
Aspen	1.98	20.84
Black Spruce	2.25	14.05
Sapling Aspen	2.02	21.59
Spruce-Mixed	1.35	24.06
Clearcut	1.04	18.10
All Deciduous	2.16	19.69

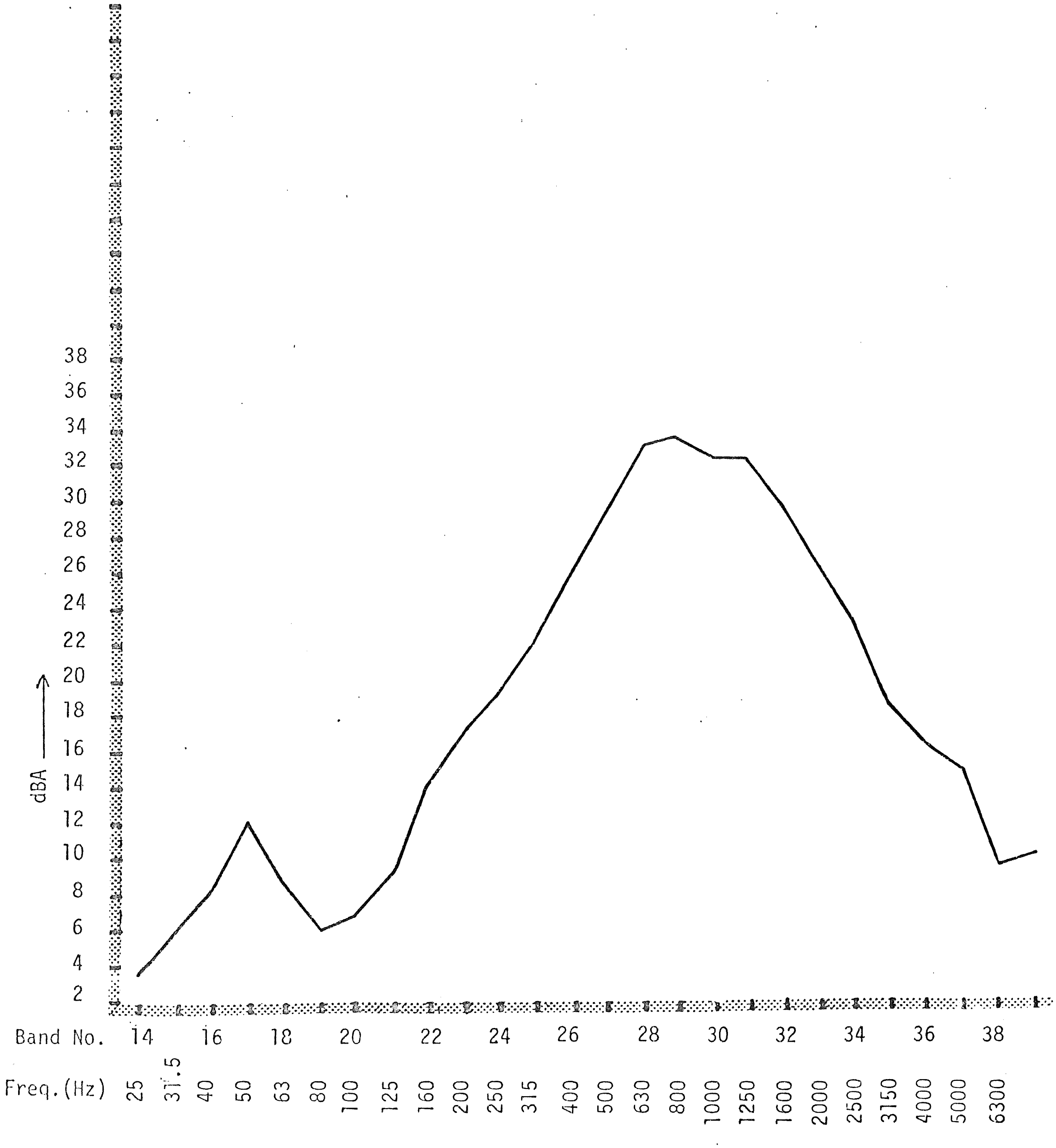
sound level and wind speed only indicates the procedure used for the benefit of those whose interest is in the modeling procedure. Numerical details and a discussion of field measurement procedures can be found in Trimbach.

Next to be discussed is the spectral distribution of the sound energy. From tape recordings made in the field the spectral content of the wind generated sound was determined in 1/3 octave bands using a real time analyzer at the acoustic laboratory of Moorhead State University. This instrument was calibrated to correct for tape recorder frequency response characteristics and yielded an A weighted 1/3 octave band spectrum. Using data from several different sites within each vegetation type the average spectral shape for the sound from the various vegetation types was determined at 5 dBA levels, i.e. 20, 25, 30 dBA etc. The results of this procedure are included in Trimbach (1978). Figure 1, 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 falls above that frequency. The small peak at 50 Hz which presents in this particular graph is due to unidentified low frequency sound sources which could have been located at a relatively great distance due to the low atmospheric absorption at these frequency.

Consideration of the spectra of mining noise sources shows that an adequate model can be developed using band 20 (the 100Hz band) as the lower cut-off frequency. Because of the high degree of atmospheric absorption at high frequencies, the upper cut-off frequency can be set at band 36 (the 4000Hz band). Further, most of the energy of wind generated sounds lies between these bands. Within this range, an examination of the spectral plots such as fig.1, shows a general shape which can be characterized as a linear rise of band level with

Fig 1

Average Spectral Shape for 40 dBA
Winter Black Spruce Sounds



band numbers above this. Within a given species of tree it is found that the slopes of these two straight line segments do not vary with sound level. However, the position of the peak does shift upward with the sound level to a varying degree. To quantify these observations, a least square fit procedure was developed which fits a family of curves based on this description to the actual vegetation spectral plots for 25, 30, 35, 40 and 45 dBA. This was done using a computer program which allowed the rate of shift of the position of the peak with level to be adjusted on a trial and error basis to arrive at a fit which gave the smallest value to the standard error of estimate.

To program these results, they must be put in the form of equations. In describing these equations, the variables used in the computer program will be used for ease of comparison. Let K be the standard band number minus 20, i. e. K = 0 corresponding to band number 20, K = 16 corresponding to band 36. Let P1 be the value of K for which the peak occurs when the sound level, S1, is 35 dBA. Then, if S2 is the number of band numbers that the peak has shifted when the sound level is different than 35,

4. $$S2 = \tfrac{1}{2}\,[1 - \mathrm{SGN}\,(S1 - 35)]\,(S1 - 35)\,B1 + \tfrac{1}{2}\,[1 + \mathrm{SGN}\,(S1 - 35)]\,(S1 - 35)\,B2$$

here SGN $(x) = -1$ if $x < 0$, $= 1$ if $x > 0$, $= 0$ of $x = 0$. It can be seen that this formula gives a shift of B1 band numbers per dB below 35 dBA and B2 band numbers per dB above 35 dBA. The use of two different shift rates was found to give an improved fit to the actual data. Next let W(S1, K) be the A weighted level in band K for a wind generated sound where overall level is S1. Let E1 and E2 be the slope and intercept of the straight line segment which represents the spectrum shape below the peak (P1) and E3 and E4 by the corresponding quantities above the peak. Then

5. $$W(S1, K) = (E1\,y + E2)\,\tfrac{1}{2}\,[1 - \mathrm{SGN}\,(y - P1)] + (E3\,y + E4)\,\tfrac{1}{2}\,[1 - \mathrm{SGN}\,(y - P1)] + S1 - 35$$

where y = K -S2. The parameter P1, B1, B2, E1, E2, E3, and E4 are the results of the least squares fit procedures.

Figures 2 and 3 show the results of this procedure for winter black spruce and summer birch. The actual band levels are indicated by the data, the straight lines are drawn to indicate how the procedure works. The black spruce results are typical of those for coniferuous forests while those for birch are typical of foliated deciduous forests. The standard error of estimate between these values and the actual data is 1.3 dBA for summer birch and 1.5 dBA for winter spruce so this procedure gives a reasonably good fit to the data. Values for the best fit parameter for the forest types modeled can be found in Appendix B. The immature types, spruce and sapling aspen, did not exhibit as much regularity in their spectral shapes and thus were not modeled. In general, however, their spectra resembled those for birch in the corresponding season.

Fig. 2

1/3 Octave Band Spectrum for
Winter Black Spruce
from Least Square Fit

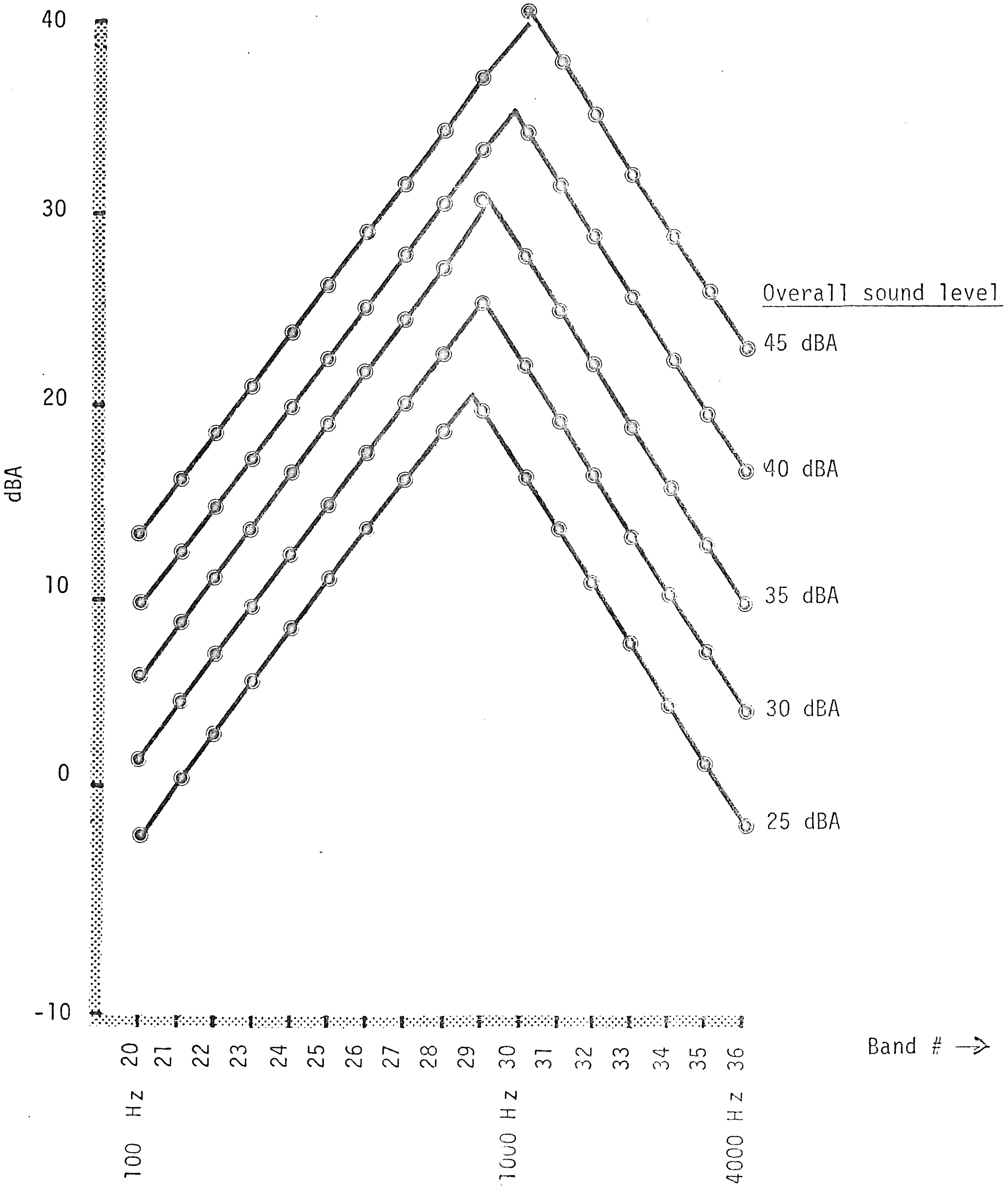
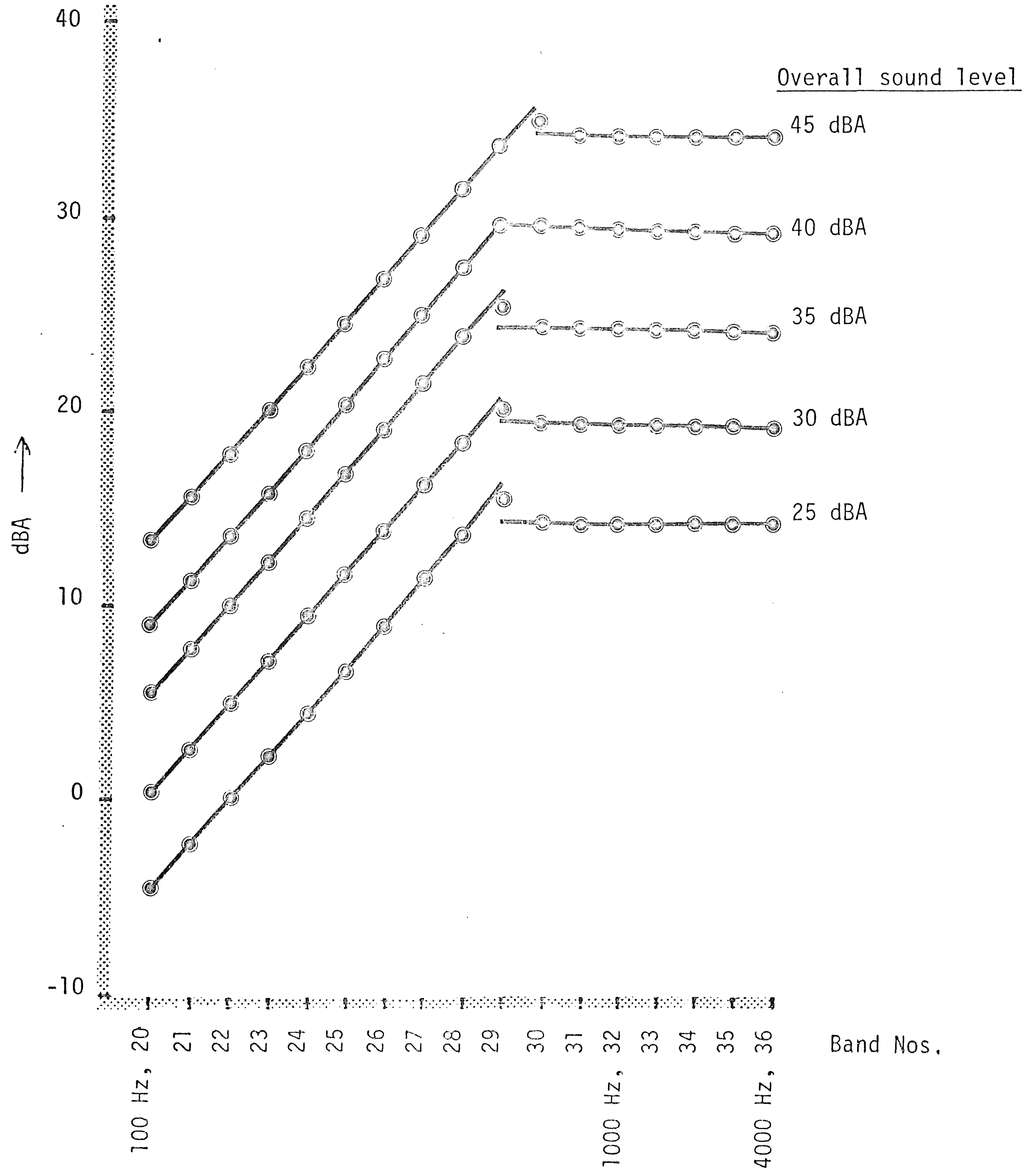


Figure 3
1/3 Octave Band Spectrum for
Summer Birch
from Least Square Fit



SECTION III

Description of PROP, the Single Source Model

The basic function of this computer model is to predict the percentage of time that a given sound source will be audible in the region surrounding a source with a known spectrum. This section provides a description of the function of the various sections of the program. The line numbers refer to those in the listing of PROP given in appendix 4. The programming language is BASIC.

The first computational section is lines 499-560. This section calculates the rate of atmospheric absorption based on a proposed standard procedure. The input data required for this section are the temperature, relative humidity and barometric pressure, T, P, H, which are entered by lines 151 and 332. The output of this section is A1(K). Here, as throughout the program, K is a 1/3 octave band number variable, K = 0, denotes standard band number 20 which corresponds to a center frequency of 100Hz and K ranges up to K = 16 which denotes standard band number 36 with a center frequency of 4000Hz. Line 540 performs a conversion from the value of K to the corresponding center frequency. The significance of A1(K) is that 8.69 A1(K) is the atmospheric attenuation rate, in dB/meter, at the frequency corresponding to the value of K.

The next computation section is line 605 through 680. In this section and in the following sections, I is a direction variable based upon a 16 point compass. I = 1 corresponds to North, I = 2 corresponds to NNE,..., 16 corresponds to NNW. The input required for this section is U1 (I) which is entered via lines 2, 164, 165, 167, 176. U1(0) is the percent of time the wind is calm while, for I = 1 to 16, U1(I) is the percent of time the wind is from direction I. The output of this section is U(I), D(I), C(I). U(I) is the percent of time that direction I is upwind for sound propagation (see section I), C(I) and D(I) are the percentages for crosswind and downwind.

The next section is lines 700-720 which calculates the 1/3 octave band levels as a function of distance from the source, D2(R,K). R is in units of 500 meters while K is as described above. The input to this section is S(K), the A weighted 1/3 octave band levels for the source being considered. These levels are measured in the far field of the source but are corrected by the inverse square law to equivalent one meter levels before being entered. S(K) is entered through lines 3, 164, 165, 168, 177. The basic computation is in line 700 where the input levels are diminished by the losses resulting from the inverse square law and atmospheric absorption. Lines 730-770 sum the band levels determined in the previous section to determine D1(R), which is the overall A weighted sound level, during downwind conditions, at the distance R. Lines 800-825 determine the band levels for crosswind and upwind conditions.

Lines 1000-1045 compute the masking levels for conditions when there is a wind present. The basic result is W(L,K), the masking level in band K which is exceeded 10L% of the time that the wind is blowing. L runs from 1 to 10, corresponding to 10-100%. One of the inputs to this section is W1(L) which gives the statistical distribution of wind speeds for the time period being considered. W1(3), for example, is the wind speed that is exceeded 30% of the time that the wind is blowing. Note that this only refers to times when the wind is blowing. Calm wind (less than 3 knots) are dealt with separately. Thus the wind speed statistics must be computed only within the subclass of non-calm winds. W1(10) is always entered as

3 knots. Line 1005 computes the wind generated sound level corresponding to the particular wind speed. Lines 1010-1026 computes the 1/3 octave band masking levels corresponding to the particular wind speed percentile level being considered. The conversion from 1/3 octave band level to masking level is accomplished through the addition of the masking correction factors, M(K), which are discussed in appendix 6. The M(K), are entered through lines 150 and 300. The parameters A1, A2, B1, B2, E1, E2, E3, E4, and P1 are entered through lines 1, 164, 165, 166, and 175.

Before the function of line 1030 can be understood, the concept of the zero wind ambient levels must be introduced. While the program models the masking effects of wind generated noise, some provisions obviously must be made to deal with the situation of calm winds. In this program, this is done through the use of B(K), called here the zero wind ambient levels. These should reflect the residual levels present under calm conditions. The field measurements described in Trimbach (1978) show that these levels can be very low in northeastern Minnesota. In fact, if these levels were used, the subsequent section of this program which determines whether a propagated sound is audible or not would give unreasonable results, predicting audibility for sounds below the threshold of human hearing. Thus the band levels used for modeling in wilderness areas were adjusted upward from the actual minimum band levels observed. In Sipson (1978) the utility of entering higher zero wind ambient levels is considered. Lines 1030 and 1035 perform the function of substituting the zero wind masking levels for the wind generated masking levels in any band where the zero wind levels are higher. Obviously the program could give absurd results if this substitution were not made.

Steps 1100-1210 determine the precentages of time that the propagated sound will be audible as a function of distance from the source for downwind, crosswind, and upwind conditions. Audibility is predicted when any propagated sound band level exceeds the corresponding masking by the user adjustable amount K3. Theoretically K3 = 0 would correspond to predicting audibility at the limit of audibility. In using the model, however, this parameter was set at 5 dB as a minimum value. This value gave results that were in reasonable agreement with available experimental data. As discussed in Sipson (1978) this parameter can be set higher to arrive at a less stringent criteria. The results of this section are D3(R), C3(R), and U3(R) which are the percentages of time that the propagated sound will be audible at the distance R for downwind, crosswind, and upwind propagation.

Lines 1250-1305 compute the percentages of time that the sound will be audible under calm conditions. Z4(R) is the percentage of time that the sound will be audible at distance R for calm-inversion conditions, Z3(R) is for calm-lapse conditions. Lines 1500-1525 compute A(R, I), the percentage of time that the sound will be audible at a distance R along the direction I. Lines 1550-1560 make use of the unused direction index I = 0 to make the first column of the audibility matrix, A, equal to the distance which the corresponding row corresponds to. This is convient in the event that the entire audibility matrix, A(R,I), is printed out.

Lines 1600-1645 perform a linear interpolation on the values of A(R,I) along each direction I to determine the points where decile precentage level crossings occur. The output of this section is K(I,L). K(12, 8), for example, is the distance from the origin, in units of 100 meters, to the crossing of the 80% audibility contour along the direction WSW. The search for these crossing is only within the computation range, which is from 1 to 40 kilometers. If a given percentile crossing along some direction would occur outside of this range a value of zero is returned. For a weak source, for example, the 90% contour may fall within 1 km and this K(I,9) would be returned as zero. Because of the manner in which the audibility computation is made, no attempt is made to compute a 100% contour within which the progated sound could be heard 100% of the time. This K(I,10) is always zero.

Lines 1650-1675 determine K1(I,L) which is the maximum (downwind or calm inversion) A weighted level at a distance from the source equal to K(I,L). This allows an assessment of the maximum sound level that might be expected at points along the equal audibility contour determined in the previous section. Lines 1680-1685 calculate G(L), the total area in km^2 within the equal audibility contour labeled by L.

Lines 1699-1737 are the printout lines. 1710-1715 print out the equal audibility contour matrix. Lines 1720-1725 print out the maximum levels expected along these contours. Lines 1730-1737 print out the affected areas within the equal audibility contours.

SECTION IV

Description of MPROP, the Multiple Source Model

The basic modeling procedures for MPROP are the same as those for PROP, However in this case the audibility percentage refers to the % of time that at least one of several sources will be audible. The model should be especially useful for modeling multiple pit mines or for determining the incremental impact from opening a second mine near an existing one.

Lines 499-560 are exactly the same as in PROP. They compute the atmospheric attenuation coefficients. Lines 700-730 compute L(J, R, K), the level for downwind conditions for source J, at distance R, in band K. The variable K and R have the same significance as in PROP, J labels the various sources. The spectra for the various sources are read from a data file by lines 107-131, 134-138. Lines 1000-1045 compute the masking levels exactly as in PROP.

Lines 1090-1195 determine R1(J), R2(J), which are the distances to which source J can be heard under, respectively, calm inversion and calm lapse conditions. Lines 1200-1315 determine R3(D, J, L). Here D is an index of propagation condition, D = 0 corresponds to downwinds, 1 corresponds to crosswind, and 2 corresponds to upwind. For example R3(1, 2, 8) is the distance to which source number 2 can be heard under crosswind conditions 80% of the time.

Lines 2000-2270 compute A(R, M) which is the percent of time that at least one of the sources can be heard at a distance R along direction M. Here R is in units of 500 meters and M is the clockwise angle from north measured in units of 10°. X1(J), Y1(J) are the x and y components of the vector between source J and the observation point. R(J) is the distance between source J and the observation point and I(J) is the direction between source J and the observation point. Here I ranges 1 to 16 and is as described in the discussion of PROP. The branch at line 2100 is put in to save computer time and is valid only if none of the sources is more than 5 km. from the origin. This allows modeling sources up to 10 km apart. To model situations with sources more than 5km from the origin change line 2100 to read "IF R < 61 THEN 2130". Line 2210 determines the propagation index D(J) for source J when the wind is from direction I. For example if the wind is from the west (I = 5) while the direction between the source and the observation is north (I(J) = 1) then the propagation condition is crosswind (D(J) =1). Thus F1(1, 5) = 1, as can be seen from line 201. The basic computation of this section is to sum the contributions to the percent audibility from the 16 possible wind directions, calm lapse and calm inversion conditions.

Lines 2795-2870 interpolate the results of the previous section to search, along each of the 36 directional rays, for crossing of audibility contours at 10% intervals. These are printed out as they are found. A typical line of print-out might be 60, 5.13, 4. This would signify that a 60% contour crossing was located 5.13 km. from the origin along a directional ray 40° east of north.

SECTION V

User Instruction

In this section the details of how the program are actually run will be discussed. To run either program, three binary coded data files are needed. They are TREE, WIND, and SOURCE. For each tree type considered the file TREE must contain, in this order, the values for A1, A2, B1, B2, E1, E2, E3, E4, and P1. The data is read from this file after the pointer has been correctly positioned by a SET command. The file used in developing Sipson (1978) is given in Appendix 5.

The binary file WIND contains the statistical inforamation about the wind speed and direction characteristics for the time period being modeled. For each time period there is a set of 28 numbers. The first 11 of this set are, in this order, the wind speeds exceeded, 0, 10, 20,....100 percent of the time when it is blowing. The wind speed exceeded to 0 percent of the time is not used in the program but is put in for programing convenience. The next 17 numbers describe wind directional characteristics. They are U1(0) ....U1(16). U1(0) is the percent of time the wind is calm, U1(1) is the percent of time the wind is from the north, U1(2) is the percent of time the wind is from the NNE etc. The data files used in developing Sipson (1978) are given in Appendix 5.

The file SOURCE contains the spectra for the source to be modeled. These are sets of 17 numbers which begin with band 20 (K = 0) and ending with band 36 (K = 16). The values entered are the A weighted 1/3 octave band levels, converted by the inverse square law to equivalent 1 meter levels. The SOURCE file used in developing Sipson (1978) is included in Appendix 5.

To run PROP make it the primary file, making TREE, WIND, and SOURCE secondary files. Next adjust the data in line 332 and 333 as required. The 4 items in 332 are, respectively, the temperature in Kelvins, the ratio of the barometric pressure to P_o(Po = 1.01×10^5 N:M^{-2}), the relative humidity, and the percent of calm conditions that are inversions for acoustic propagation. The data value in line 333 is the number of decibles by which a propagated sound band level must exceed the masking level in that band in order that an impact be predicted. Be certain that the zero wind ambient spectrum in line 305 is the one desired. Next start the run. When requested by the computer, enter the tree number, wind number and source number, which are needed to obtain the appropriate information out of the files.

The results of a typical run are included here. The output consists of two matrices of numbers and a line of numbers. The first matrix of numbers locates the audibility contours. In it, the first row (of zeros) is not significant and is simply an artifact of programming convience. From left to right, the column corresponds to 0%, 10%, 20%....100%. The last column will always consist of zero and is not significant. The rows corresponds to directions, from 1 to 16. For example the entry in row 5, column 3 is 258. This means that along direction 5 (east) there is a crossing of the 20% contour 25.8 km from the origin.

The matrix on the second page of output gives the maximum A weighted levels that will be observed along the contour described by the first matrix. For example row 5, column 3 is 18.8. Thus at 25.8 km from the origin along direction 5 (see above) the maximum A weighted level will be 18.8 dB. This level results from only absorption and the inverse square law. The final row of output gives the area, in km^2, contained within the various audibility contours.

The multiple source program, MPROP, makes use of the same data files as does PROP. To run it, make it the primary file and make TREE, WIND, and SOURCE secondary files. Type RUN or RNH and repond to the questions asked (see included example run). The output consists of three columns of numbers. The first is the contour precentage, the second is the crossing distance in km. and the third is the direction angle from north, in degrees divided by 10. For example from the included run it can be seen that there are three crossings of the 40% contour along the direction 10° east of north. One at 5.16 km and two others very close together, at 4.00 km. In the example run included, only the results for the first two directions are included, the complete output contains the results for 20° to 350°.

```
RNH
TREE NUMBER, WIND NUMBER, SOURCE NUMBER
? 4,2,33
PROGRAM-PROP
 THE SOURCE SPECTRUM IS
 0  0  0  0  134  0  0  128  0  125  0  0  0  0  0  0  0
THE ZERO WIND AMBIENT LEVELS ARE
 0  1  2  3  4  5  6  7  8  9  8  7  6  5  4  3  2
THE WIND ROSE IS
 11.6125  .5925  .9  1.35  2.025  1.275  2.3625  3.7125  6.4125  9.45
 5.5125  5.0625  4.725  5.475  7.425  14.175  12.6
THE WIND SPEED PERCENTILE LEVELS ARE
 14.1  12.5  11.2  9.7  8.6  7.5  6.7  5.6  4.6  3
 THE WIND GENERATED NOISE SPECTRUM IS DESCRIBED BY
A1              A2              B1              B2
 2.254           14.028          .11             .06
E1              E2              E3              E4
 3.07109         2.17849        -1.54731         43.6354
P1= 9
T               P               H               Z
 293             1               65              0
THE EXCEEDENCE PARAMETER IS 5 DB
 AUDIBILITY CONTOURS
 0  0  0  0  0  0  0  0  0  0  0

 315  283.  237.  226.  198.  175.  123.  101.  73.8  42.   0

 315  284.  238.  226.  201.  182.  154.  122.  91.9  43.3  0

 315  283.  237.  226.  201.  184.  170.  150.  120.  54.5  0

 315  282.  230.  226.  199.  183.  168.  138.  110.  52.3  0

 315  286.  258.  228.  216.  194.  176.  139.  108.  50.4  0

 315  289.  267.  236.  226.  200.  180.  137.  100.  43.7  0

 315  288.  265.  229.  220.  195.  166.  110.  84.  42.5  0

 315  286.  257.  228.  215.  183.  138.  104.  80.3  42.1  0

 315  283.  236.  226.  197.  170.  122.  100.  73.5  41.9  0

 315  256.  227.  199.  179.  151.  114.  94.  72.9  41.9  0

 315  228.  202.  183.  168.  138.  113.  100.  73.5  41.9  0

 315  228.  203.  184.  170.  150.  121.  103.  74.8  42.1  0

 315  229.  216.  184.  167.  125.  107.  88.7  70.1  41.6  0

 315  238.  226.  193.  155.  113.  100.  83.8  62.6  41.3  0

 315  268.  228.  215.  180.  125.  104.  86.3  63.9  41.4  0

 315  282.  230.  225.  193.  153.  110.  89.6  70.6  41.6  0
```

```
CORRESPONDING A WEIGHTED MAX LEVELS
 0  0  0  0  0  0  0  0  0  0  0

 11.1  15.4  21.8  23.3  27.4  30.8  39.4  43.4  49.   57.4  0

 11.1  15.3  21.6  23.2  27.   29.8  34.1  39.6  45.2  57.  0

 11.1  15.3  21.8  23.3  27.   29.5  31.7  34.8  39.8  53.7  0

 11.1  15.5  22.8  23.4  27.3  29.7  32.   36.7  41.8  54.3  0

 11.1  14.9  18.8  23.   24.7  28.   30.7  36.6  42.   54.8  0

 11.1  14.6  17.5  21.9  23.3  27.1  30.1  36.9  43.5  56.8  0

 11.1  14.8  17.8  22.9  24.2  27.8  32.3  41.7  46.8  57.2  0

 11.1  15.   19.   23.1  24.9  29.7  36.8  42.9  47.6  57.3  0

 11.1  15.4  21.9  23.3  27.6  31.7  39.5  43.6  49.1  57.4  0

 11.1  19.   23.2  27.3  30.2  34.6  41.   44.8  49.2  57.4  0

 11.1  23.1  26.8  29.7  31.9  36.7  41.2  43.6  49.1  57.4  0

 11.1  23.   26.6  29.5  31.7  34.8  39.8  43.1  48.8  57.4  0

 11.1  22.9  24.8  29.4  32.1  39.1  42.2  45.8  49.8  57.5  0

 11.1  21.6  23.3  28.2  34.   41.1  43.6  46.8  51.6  57.6  0

 11.1  17.4  23.   24.8  30.1  39.   42.9  46.3  51.3  57.6  0

 11.1  15.6  22.8  23.4  28.2  34.3  41.7  45.6  49.7  57.5  0

AFFECTED AREAS
 3.04E+3  2.22E+3  1.70E+3  1.42E+3  1.15E+3  840.  581.  375.  219.  59.7

RUN COMPLETE.
```

```
RNH
TREE NUMBER,WIND NUMBER
? 6,2
HOW MANY SOURCES
? 2
INPUT X( 0 )        Y( 0 )      SOURCE FILE NUMBER
? 2,2,3
INPUT X( 1 )        Y( 1 )      SOURCE FILE NUMBER
? -2,-2,3
PROGRAM MPROP
THERE ARE 2 SOURCES
THEIR X COORDINATES ARE, THEIR Y COORDINATES ARE
       2                       2
      -2                      -2
THEIR SPECTRA ARE
 90  87  97  101  91  98  100  95  99  99  99  98  101  96  93  92  91
 90  87  97  101  91  98  100  95  99  99  99  98  101  96  93  92  91
THE WIND ROSE IS
 11.6125  .5925  .9  1.35  2.025  1.275  2.3625  3.7125  6.4125  9.45
 5.5125  5.0625  4.725  5.475  7.425  14.175  12.6
 THE ZERO WIND AMBIENT LEVELS ARE
 0  1  2  3  4  5  6  7  8  9  8  7  6  5  4  3  2
W1( 1 )= 14.1
W1( 2 )= 12.5
W1( 3 )= 11.2
W1( 4 )= 9.7
W1( 5 )= 8.6
W1( 6 )= 7.5
W1( 7 )= 6.7
W1( 8 )= 5.6
W1( 9 )= 4.6
W1( 10 )= 3
THE WIND GENERATED NOISE SPECTRUM IS DESCRIBED BY
A1              A2              B1              B2
 2.331           20.517          0               .1
E1              E2              E3              E4              P1
 2.28747         5.47778         -.05567         25.1851          9
T= 293 P= 1 H= 65
Z= 0 K3= 5
 THE AUDIBILITY CONTOURS ARE
 60   1.35  0
 50   2.06  0
 40   3.49  0
 30   6.14  0
 20   6.79  0
 10   8.26  0
 0   12.5  0
 60   1.39  1
 50   2.22  1
 40   4.  1
 40   4.  1
 40   5.16  1
 30   6.71  1
 20   7.31  1
 10   8.84  1
 0   12.5  1
```

REFERENCES

Beranek, L.L. 1971. Noise and Vibration Control, McGraw Hill, New York.

Dneprovska, I.A., V.K.Iofe, and F.I. Levitas. 1963. "On the attenuation of Sound as it Propagates through the Atmosphere". Soviet Phys.-Acoustics, vol. 8. pp.235-239.

Keast, D.N. 1974. Development of a procedure for predicting industrial sites. Bolt, Beranek and Newman report No. 2897. Sept.

Piercy, J.E. private communications.

Sipson, R.F. 1978. Noise in the Environment, Regional Copper-Nickel Study Report, Volume 3, chapter 5.

Trimbach, J.T. 1978. A Noise Monitoring Study for the Regional Copper-Nickel Study, Minnesota Pollution Control Agency Report.

U.S. Environmental Protection Agency. 1975 (Dec.) Background Document for Railroad Noise Emission Standards, EPA-55019-76-005.

U.S. Deptartment of Transportation Report # DOT-TST-75-109 Truck Noise IV-13 Identifying the Source of Noise on a Heavy Duty Diesel Truck.

For an extensive bibliography of noise propagation literature see J.E. Piercy, T.F.W. Embleton and L.C. Sutherland "Review of Noise Propagation in the Atmosphere" Journal of tha acoustical society of America Vol 61. #6 June 1977.

Appendix 1

ORE HAULING TRUCK SOURCE LEVELS

The purpose of these measurements was to determine reasonable values for mining noise source spectrum levels that could be used in developing a mining noise model, it was not to determine exact levels for the particular equipment observed. Thus measurement procedures were used that could easily be carries out without interfering with mining operations. Some of the limitations of these procedures will be discussed below but in terms of predicting noise impact, these procedures probably slightly underestimate the potential for noise impact. The primary emphasis was placed on observation of the large truck used, 85 tons at Eveleth and 170 tons at Hibbing.

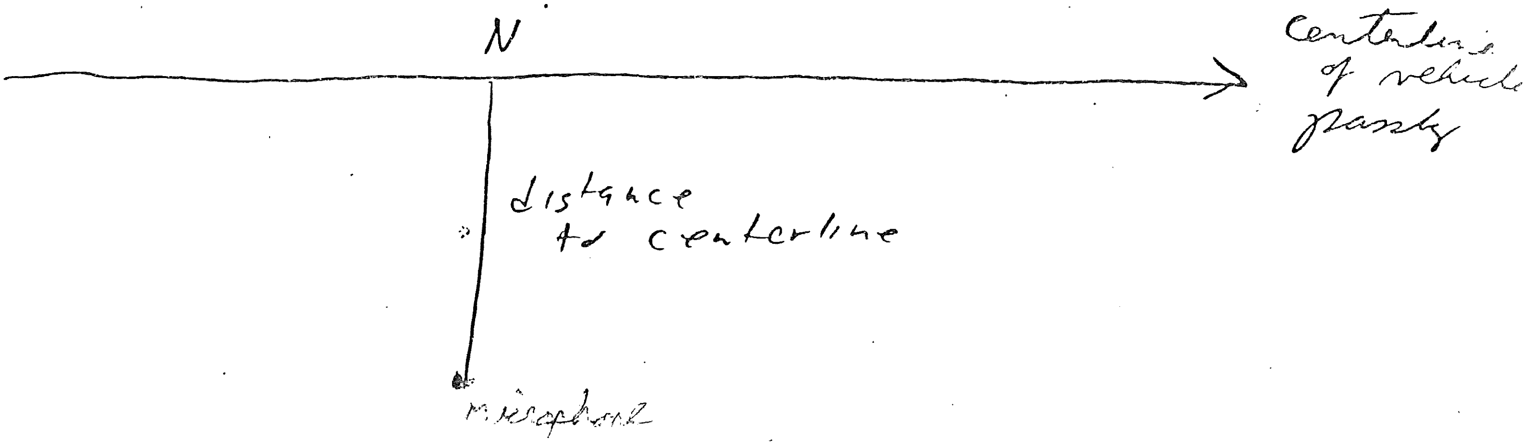
The acoustic output of these sources depend on the operating conditions and the direction from which they are observed. As mentioned above, the needs of this particular study did not warrant a complete study of the influence of these factors. Listed observations were made during five typical operating conditions.

I. Loaded - moving up the maximum grade
II. empty - moving down the maximum grade
III. loaded - level, constant speed passby
IV. empty - level, constant speed passby
V. during the bed lift or dump operation

Observation for condition I-IV were made by placing a microphone 4 ft off the ground at a known distance from the centerline of vehicle passby. The distance chosen varied between 50 and 100 ft. A calibrated tape recording was then made of the output from this microphone for subsequent analysis in the laboratory. If the sound output of the vehicle was strictly nondirectional, the maximum levels would be observed when the vehicle was nearest to the microphone, point N in figure 1. In fact, however, vehicle sound radiation is somewhat directional, particularly in its spectral characteristics. Sound coming directly from the engine and cooling systems are most easily heard before the vehicle reaches N while exhaust tones tend to be directed toward the rear of the vehicle and are thus loudest after the vehicle has passed N. Thus, for example, when the level of an exhaust tone component reaches its peak level the distance from the microphone to the vehicle will be somewhat greater than the distance from the microphone to the centerline. In the analysis of the tapes, however, it was assumed that the distance from the microphone to the vehicle was always equal to the distance from the microphone to the centerline. The effect of this is to underestimate the true levels of some spectral components radiated from the rear of the vehicle.

The primary instrument for the analysis of the tapes was a General Radio 1/3 octave real time spectrum analyzer. The instrument will provide rms averaged band levels for standard band numbers 14-43 (25Hz ———> 20Hz) as well as overall linear and A weighted levels. The individual band attuenuaters were adjusted to compensate for the tape recorder's frequency response characteristics as well as to result in the output being A weighted band levels. Band 43 was not used because the tape recorder frequency response did not extend into this band. For each of the operating conditions both rms average and peak band levels were determined. The rms average levels were arrived at by rms averaging the band levels over the loudest 4 seconds of the passby and then rms averaging these band levels over all of the passbys observed. This method does give some averaging over the direction between the source and the microphone since the vehicle may have moved as much as 100 ft during 4 seconds. Assuming, as dicussed above, that all data was taken at the pass-by distance the resulting values were inverse square law corrected to give the equivalent levels that would have been observed at

Fig 1: Monitoring of Mining Vehicle Passby.



100 ft. These levels can then be used as typical operating levels for the model.

In addition to these average levels some data was taken using a 1/8th second averaging time to determine the peak levels reached in certain bands that appeared dominant for the given operating condition. Particular emphasis was placed on determining peak levels for bands below band 30(1000Hz) since the higher bands will be strongly subjected to molecular absorption for observers well off of mine property.

Observations of operating condition V, raising the box for a dump, were made at a know distance from the trucks at a fixed directional orientation. Safty considerations ruled out observations at a variety of directional orientations without interrupting mining operations. For this condition the rms average values were obtained by averaging the signal during the lift for 8 seconds and then rms averaging the resulting band levels over the number of lifts observed.

Results of the analysis (all levels quoted are 100 ft equivalent levels).

1) 85 ton trucks - loaded - up an 8% grade

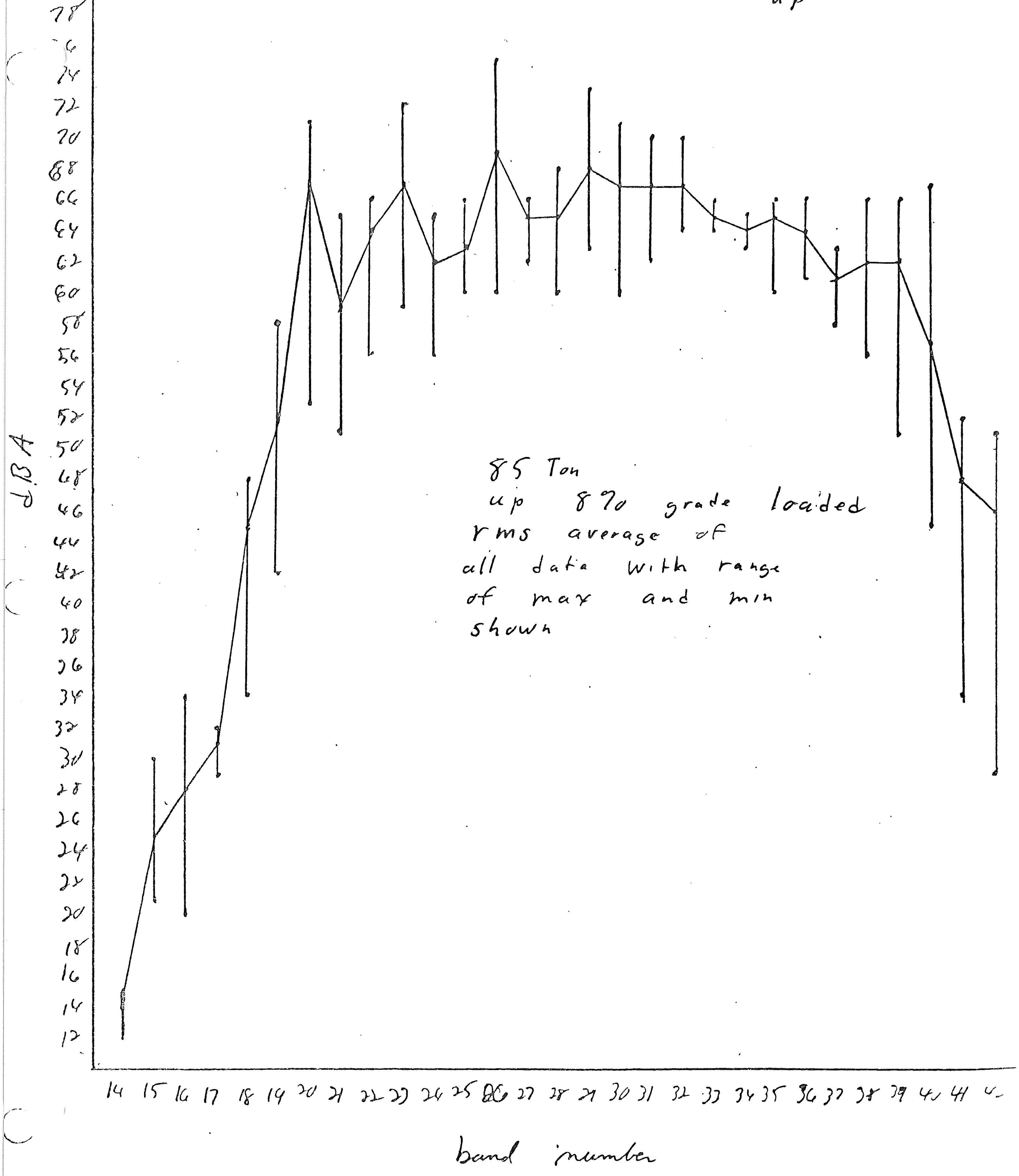
The results obtained from the observation of five passbys are shown in Figure 2. Below band 30, peak band levels were observed in bands 20, 23, and 26. The overall linear (dBL) and A weighted levels (dBA) observed were as follows:

	dBL	dBA
peak	91	81
rms	88	79
min	87	76

2) 85 ton trucks - empty - down an 8% grade. Figure 3.

Fig 2

MIA
up

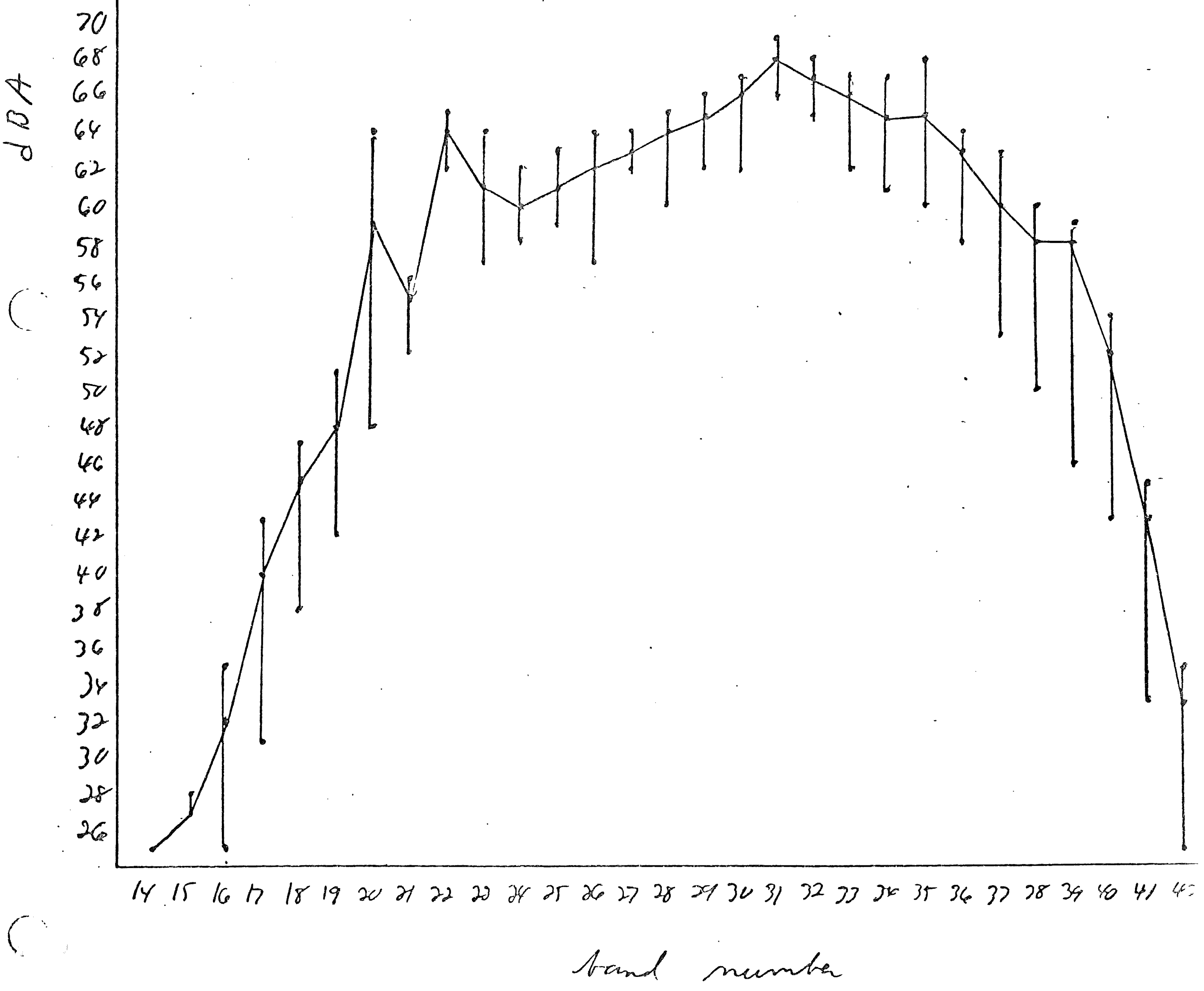


85 Ton
up 8% grade loaded
rms average of
all data with range
of max and min
shown

Fig 3

MIA

85 Ton
down 8% grade empty
rms average of all
data with range of
each band shown



The exhaust tone peaks are not as evident as for the uphill case. The overall levels were:

	dBL	dBA
peak	84	78
rms	83	76
min	82	74

3) 85 ton trucks - level operation.

The variations observed between individual passby were small enough that. it was decided to combine the results for conditions III and IV into a single characterization for level operations, loaded or unloaded. (The rms average dBA and dBL were the same for both cases). The results are shown in Figure 4. The rms average band levels are very close to those obtained for downhill operation, however, the downhill band levels were subject to greater peaks. The overall levels were:

	dBL	dBA
peak	86	78
rms	83	76
min	80	74

4) 85 ton trucks - bed lift

The results are shown in Figure 5. Note the maximum in the rms average levels observed in bands 21 and 23. These are pure exhaust tone components. This was verified using narrow band analysis (a General Radio 1% bandwidth analyzer). During this mode of operation strong pure tone components were observed at around 115Hz (peak level 79dBA), 100Hz (peak level 77dBA) and around 230Hz (peak level 66dBA). These were all measured in the fast response mode. The observed overall levels for this mode were:

Fig 4

MIB

Level operation
85 Ton

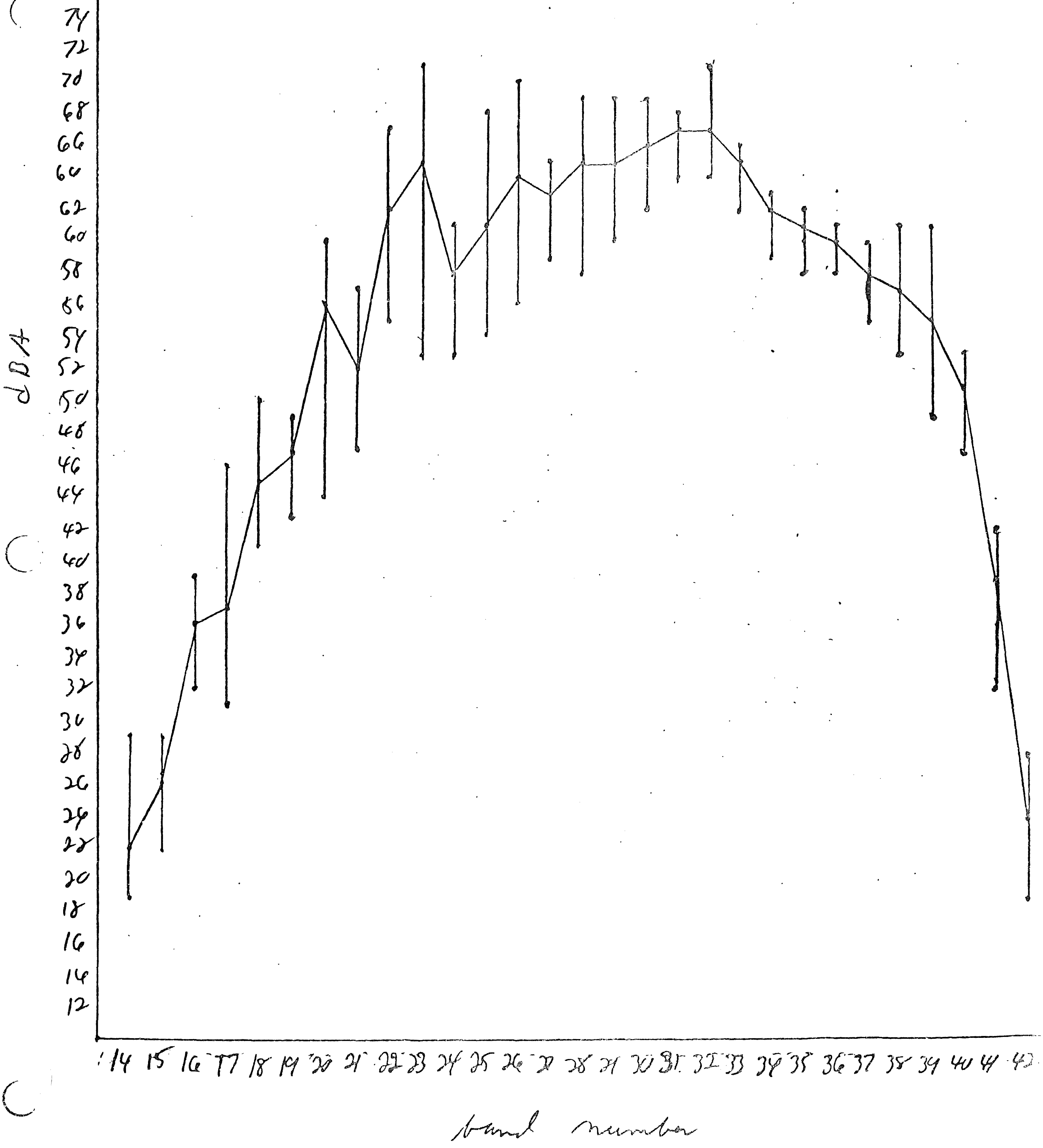
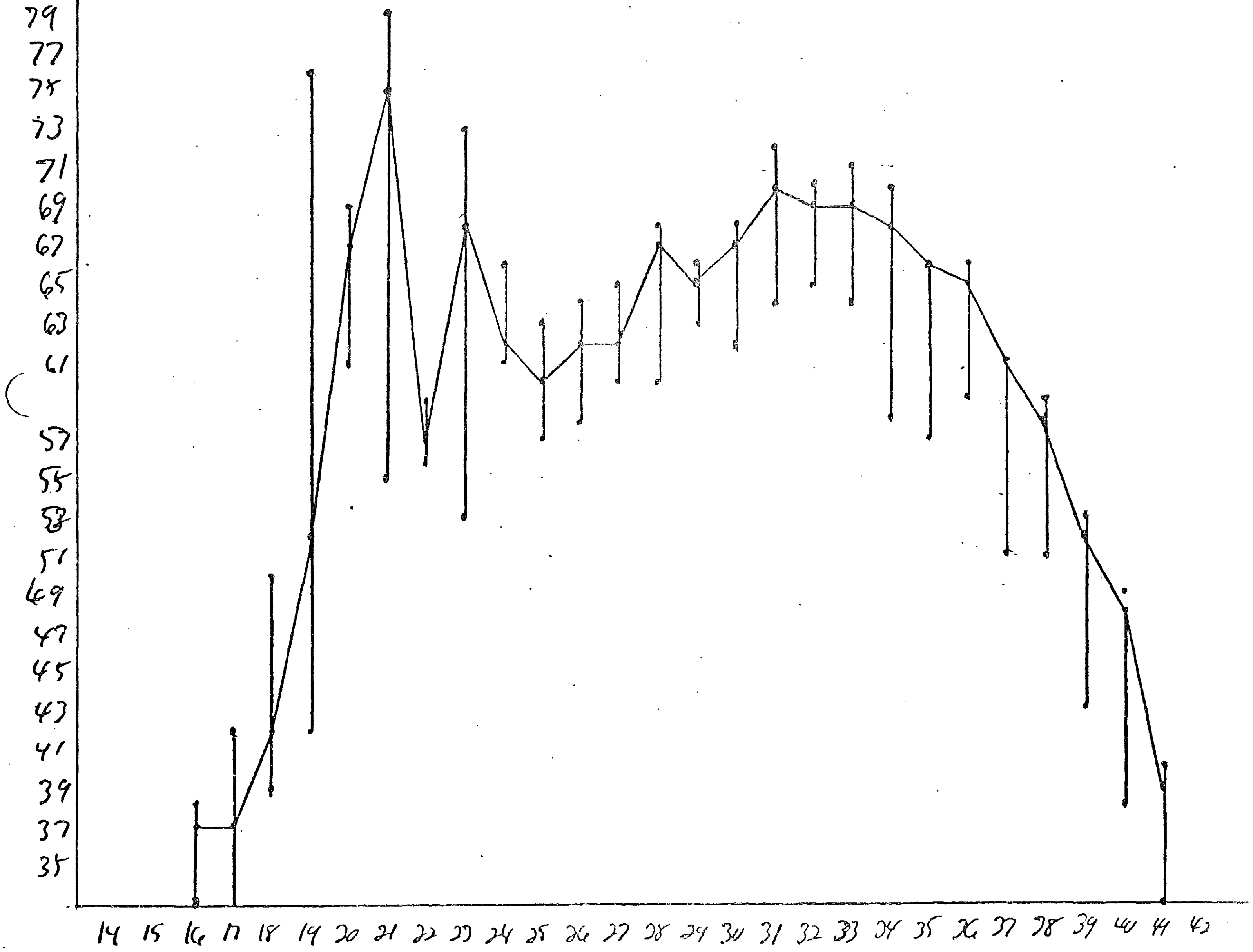


Fig 5

M I B

85 Ton bed lift
rms determined from 8 sec runs
max and min from some 1/8th sec
data



	dBL	dBA
peak	97	81
rms average	92	80
min	86	78

5) 170 ton trucks - up 5% grade

The results are shown in Figure 6. 1% analysis was used to locate some important pure tone components where band levels reached a peak. (Of course these components can move around in frequency with changing engine speed). Within band 27 pure tone components as high as 84 dBA were observed, within band 23 a pure tone peak level of 83 dBA was observed and within band 21 a pure tone component peak of 76 dBA was observed. The overall level resuls were:

	dBL	dBA
peak	96	90
rms average	91	85
min	88	81

6) 170 ton trucks - down 5% grade

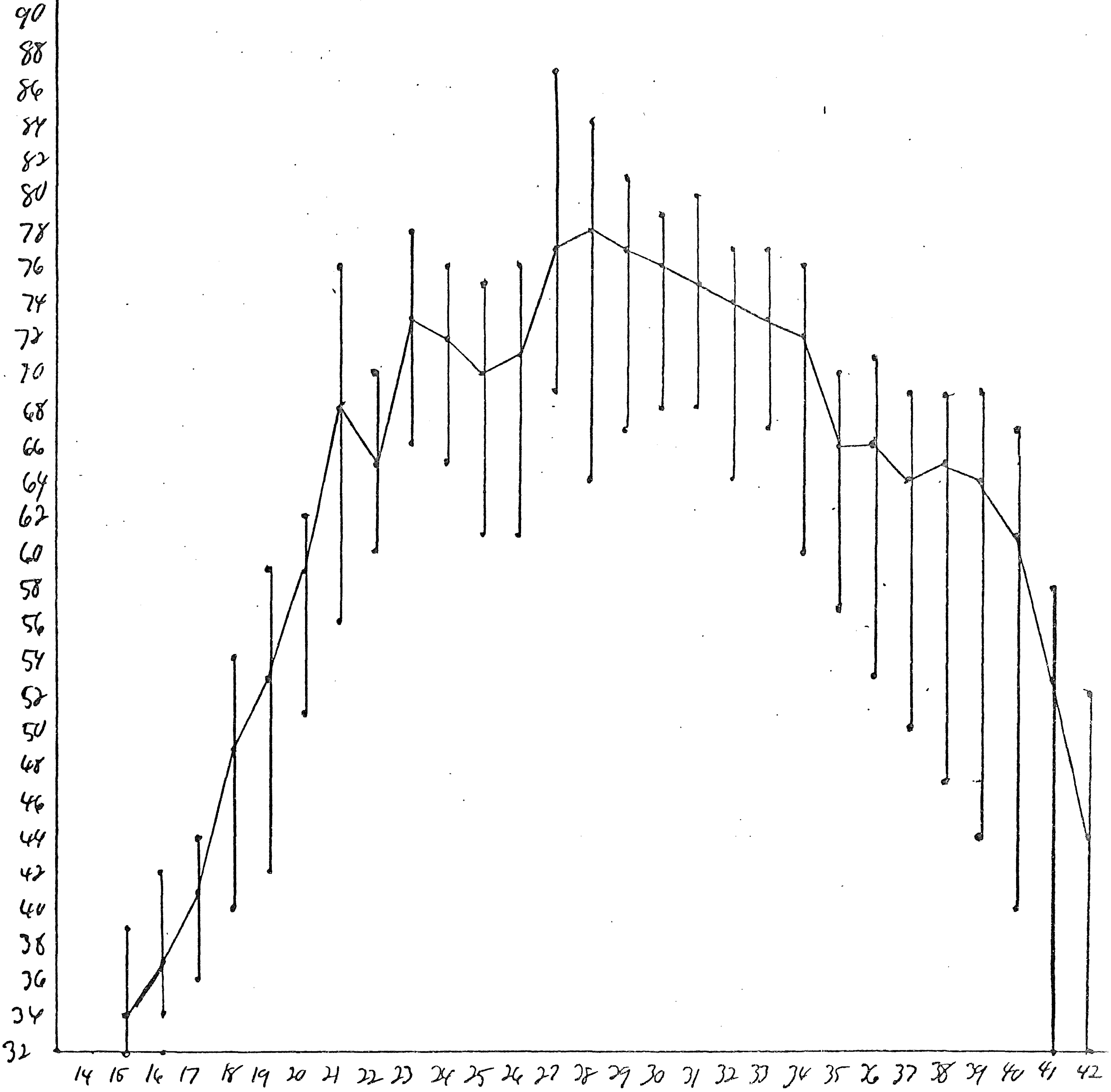
The band results are shown in Figure 7. Note the peak levels observed in band 23. This is due to an exhaust pure tone component. Using the 1% analyzer pure tone component levels as high as 90 dBA were observed in this band. The overall level results were:

	dBL	dBA
peak	102	91
rms average	97	88
min	94	86

Largely as a result of the strong component in band 23, these levels are higher than the uphill levels.

Tape M2A fig 6

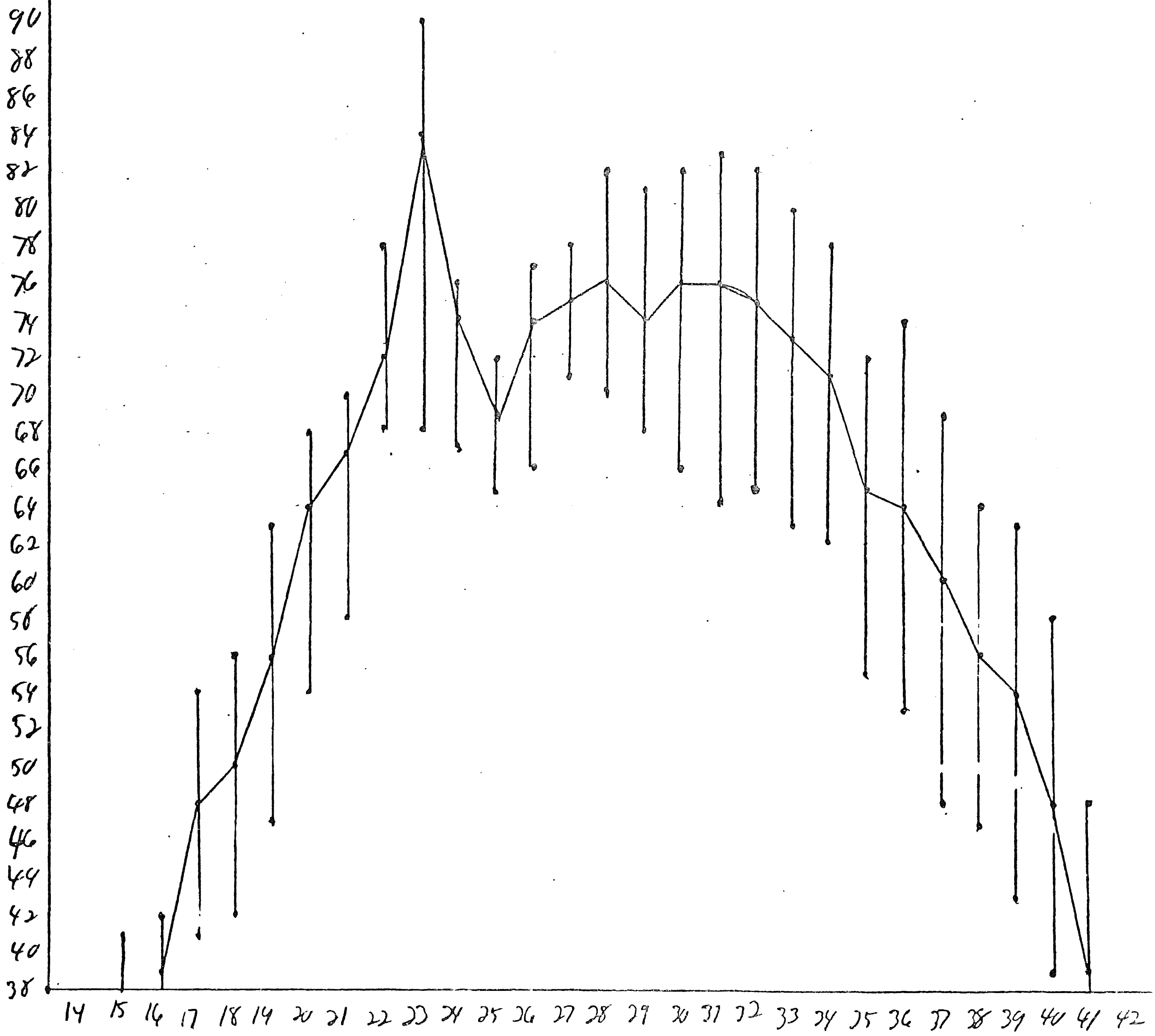
170 Ton trucks uphill
rms and range of each band



Tape M2A Fig 7

170 ton trucks downhill

rms average and range of each band



7) 170 ton truck - full - level passby

The band level results are shown in Figure 8. Here again, exhaust component peaks are evident in bands 23 and 24. The overall results are

	dBL	dBA
peak	101	91
rms average	96	88
min	95	87

8) 170 ton - empty - level passby

The band level are shown in Figure 9. The overall results are

	dBL	dBA
peak	93	88
rms average	89	83
min	88	81

9) 170 ton dump Figure 10

These observations were made while the trucks were dumping ore into a belt which was covered by a building. Approximately the rear 10% of the truck was within the opening into the building. This may well have reduced the exhaust tone component from what might have been observed under more ideal isolated conditions. None the less, as with the 85 ton trucks, the dump mode is seen to bring out the exhaust tone components, especially in band 23. The overall level results were:

	dBL	dBA
peak	98	88
rms average	90	82
min	86	80

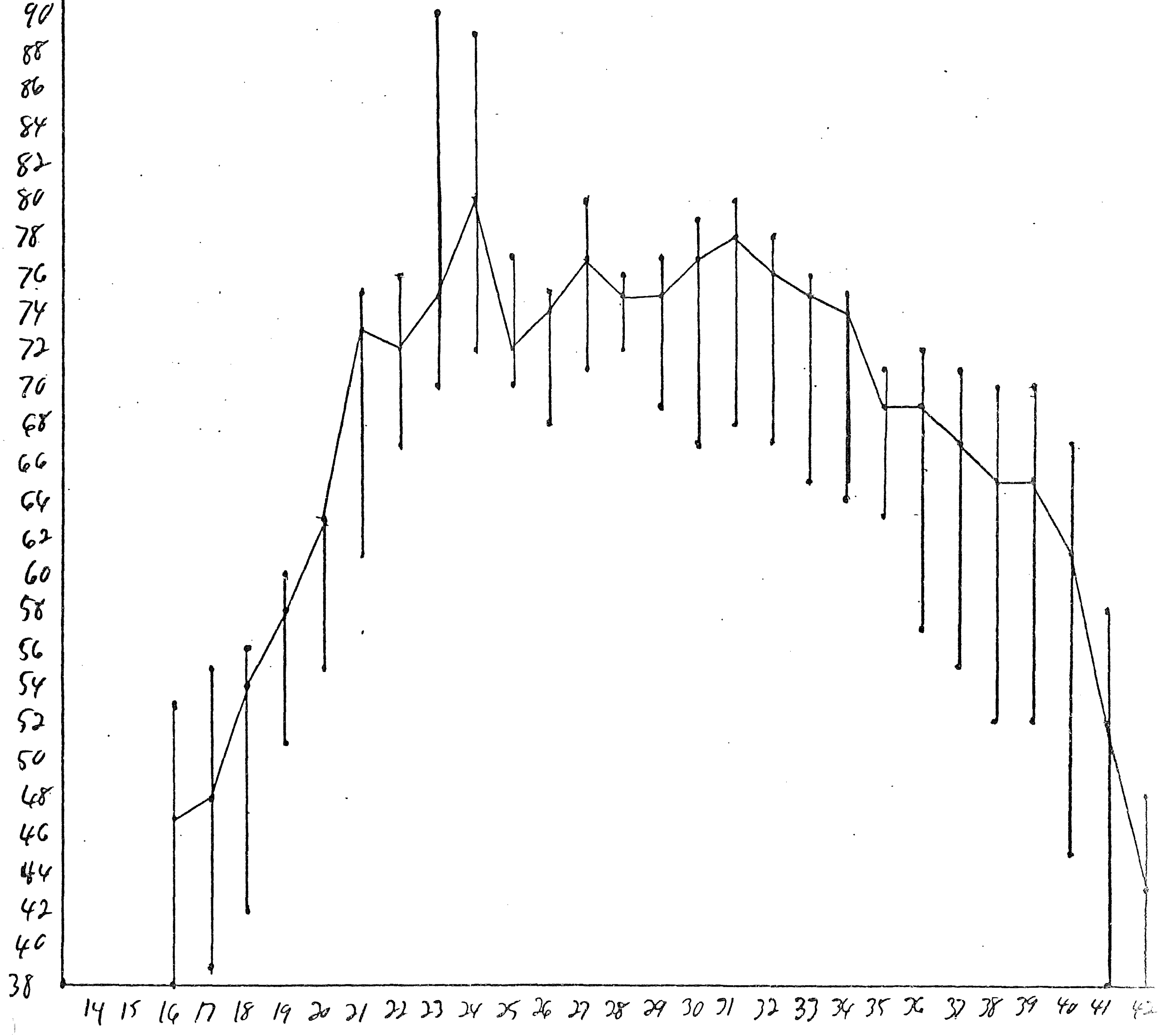
As a check on the assumption that the trucks are the dominant noise source the sound from a bulldozer operating in a rock pile was recorded and analyzed. The average spectrum levels are shown in Figure 11. Comparison

Tape M2B Full-level passby

rms average and peak band levels

170 ton

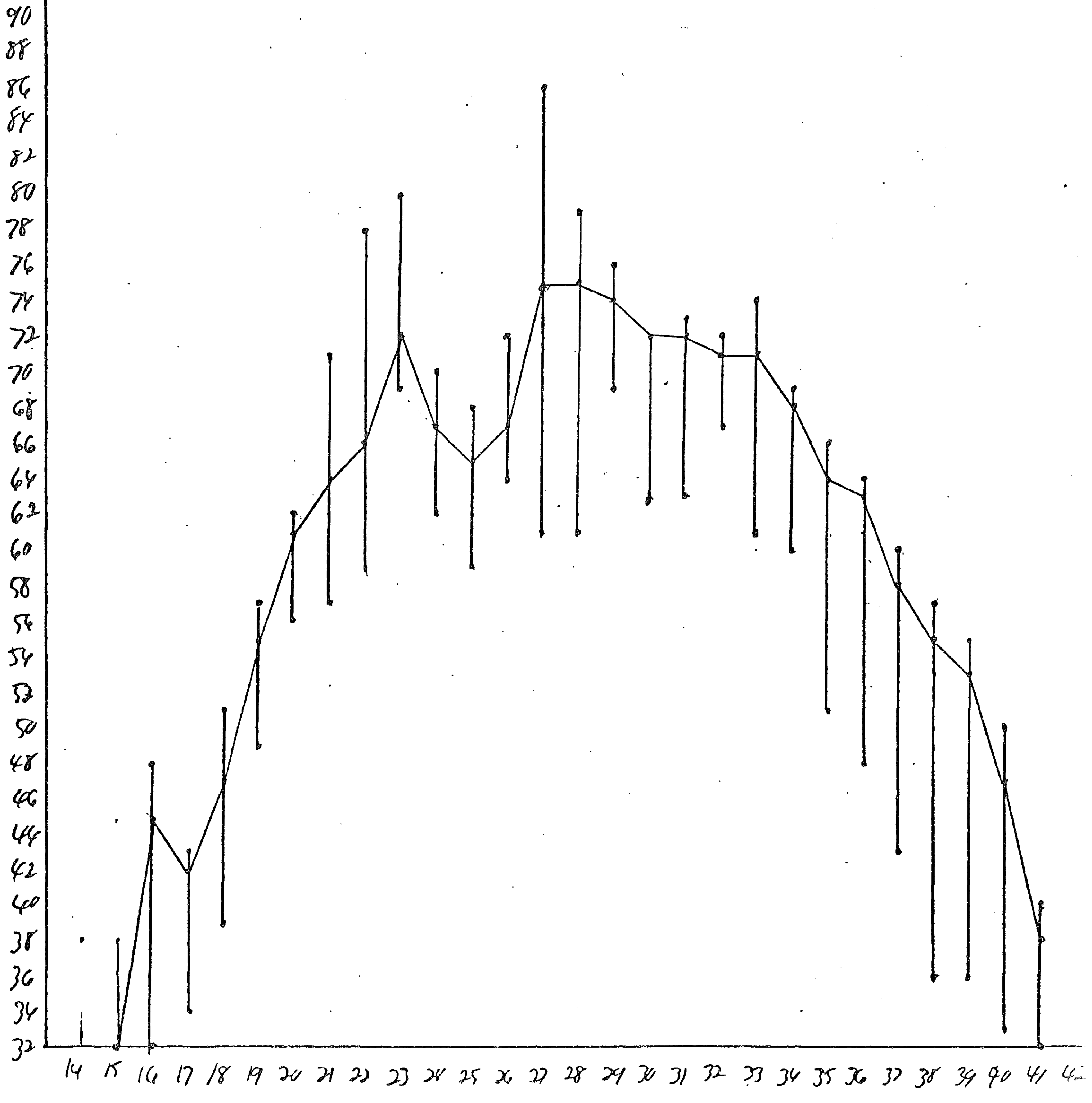
Fig 8



Empty - level passby

170 Ton

Fig 9



170 Ton dump Fig 10

rms avg and range of each band

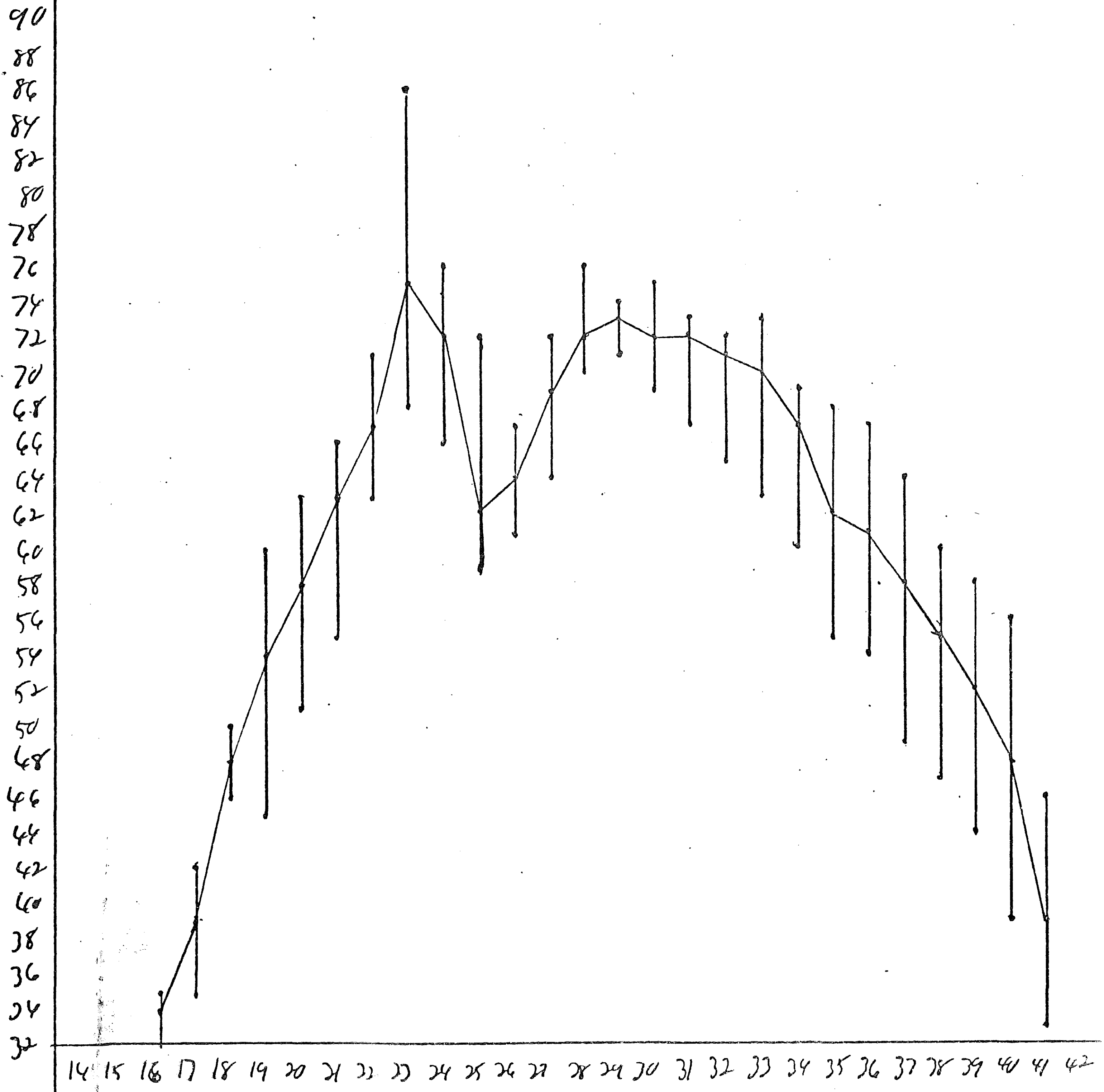


Fig 11

dozer


78
76
74
72
70
68
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
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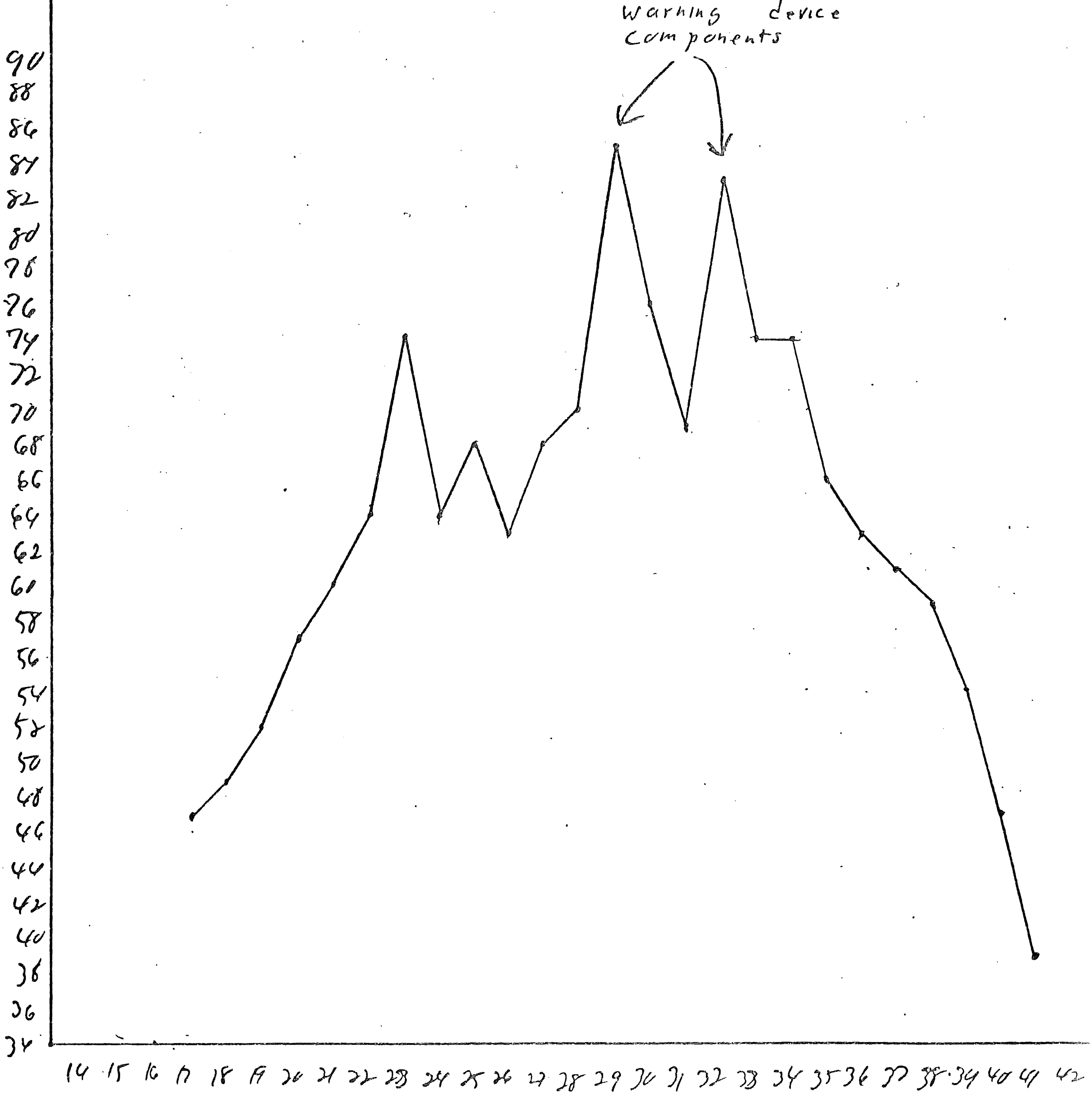
41

of this spectrum with that for 85 ton trucks in various operational modes shows that, except for an exhaust component at band 18 and some tread squeek between bands 31 and 33, the levels for the trucks are higher than those for the dozer.

Discussion with personnel of Eleveth Taconite revealed that there had been some complaints regarding the sound of truck backup warning horns. The sound of one of these horns was recorded at Hibbing and it was found to produce 85 dBA in band 29 and 83 dBA in band 32. Figure 12 shows a spectrum for a 170 ton truck backup with its warning device on. These band levels are higher than the levels for the corresponding bands that result from 170 ton truck sounds in any operational mode observed. Thus these devices may well be quite audible off of mining property under some circumstances.

170 Tow truck backing up with warning device

Fig 12



Appendix 2

MEASUREMENTS OF FAN NOISE AT SHEBANDOWAN MINE

The measurements made were to provide some information about: 1) the characteristics and power of the source; 2) the effectiveness of the barrier now in place; and 3) the levels observed at cottages across the lake that result from the fan. The results of these measurements are discussed below.

1) To obtain some information about source power and characteristics, measurements were made on the side of the fan that was not covered by the barrier. In order to be in the far field, the measurements were made at 100 feet from the fan center and, to account for standing waves that result from the barrier, two different measurement locations were used; locations 1 and 2 on the attached figure (Figure 1). At location 1 the sound level was a maximum for a 100 foot distance and at location 2 it was a minimum. The calibrated tape recordings made at these locations have been analyzed at the Acoustics Laboratory of Moorhead University to obtain a complete 1/3 octave band spectrum and to obtain the narrow band levels of the primary tonal components.

The A weighted 1/3 octave band levels were determined using a General Radio 1921 1/3 octave real time spectrum analyzer. This instrument was calibrated using the calibration tone recorded on the tape in the field and, since the sound was stationary, a 32 second averaging time was used. (For those not familar with the standard band numbers, a table in included, Table 1). The sound of the fan included a broad band "rushing" sound plus a steady tonal component. Both of these can be seen in the 1/3 octave plots (Figures 2 & 3).

measurement location diagram
For Fan at Shilbendowan

figure 1

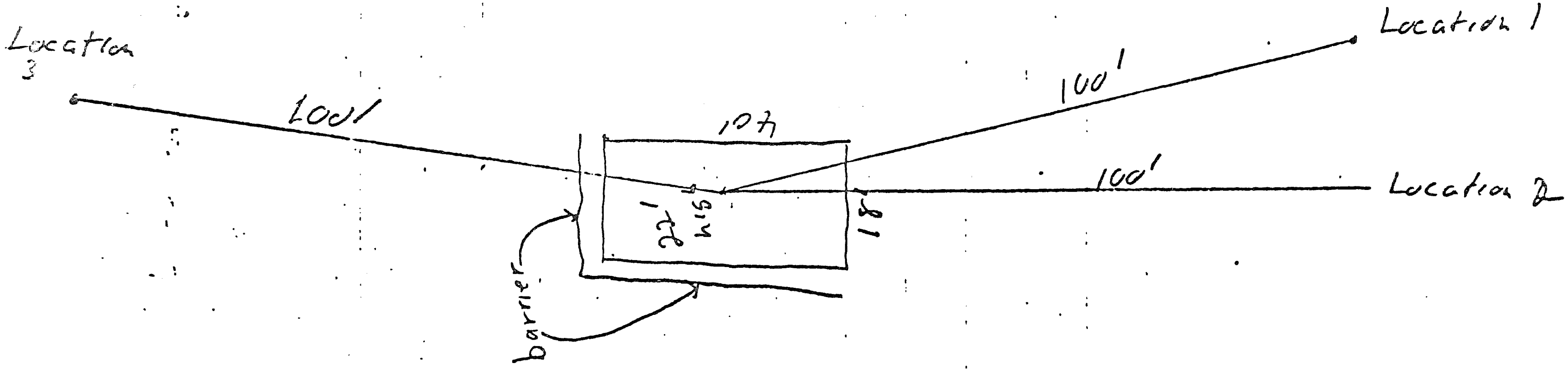


TABLE 1. Standard band numbers.

Band #	Center Frequency	Band #	Center Frequency
14	25	29	800
15	32	30	1000
16	40	31	1250
17	50	32	1600
18	64	33	2000
19	80	34	2500
20	100	35	3200
21	125	36	4000
22	160	37	5000
23	200	38	6400
24	250	39	8000
25	320	40	10,000
26	400	41	12,500
27	500	42	16,000
28	640		

Band number = 10 log (center frequency)

Shebandowan Mine Tapes
100 ft 1st Location

32 sec
A weighted 1/3 octave band levels

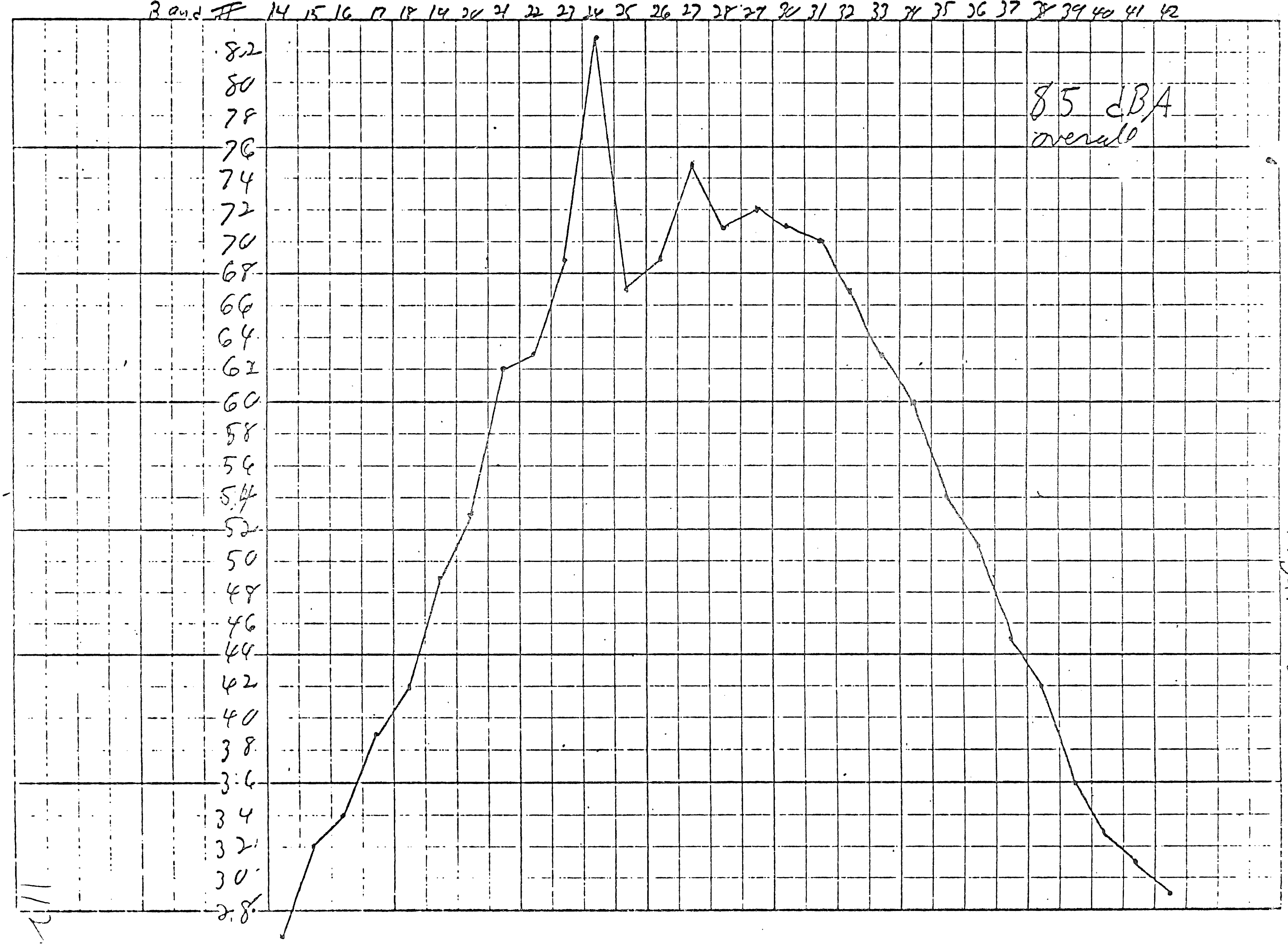


Figure 2

100 ft 2nd Location

A weighted 1/3 octave band levels

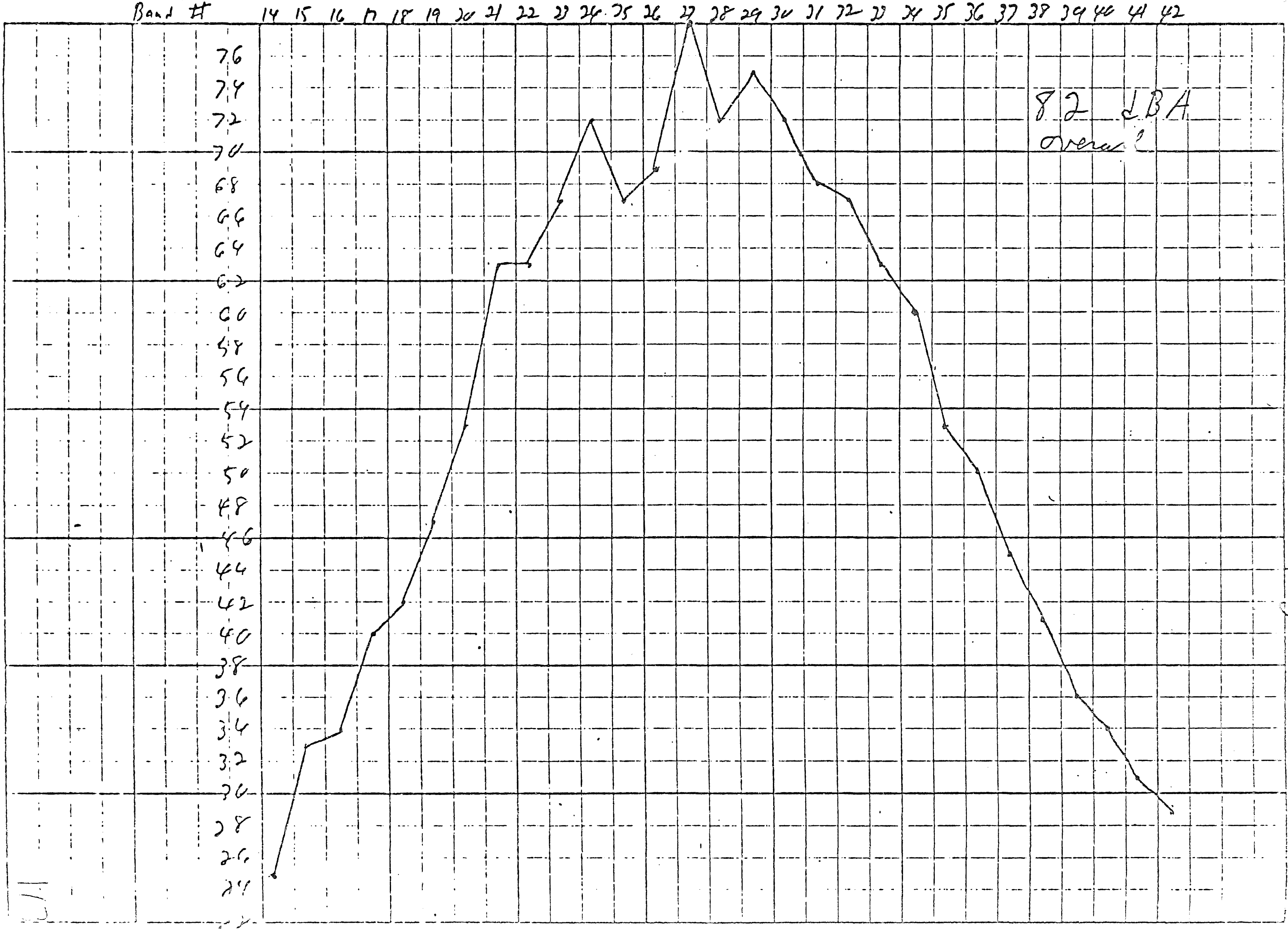


Figure 3

The broad band component is evident from bands 14 through 42 while the fundamental, 2nd harmonic and 3rd harmonic stand out in bands 24, 27, and 29, respectively. On comparing the graphs for locations 1 and 2, the effects of the standing waves can be seen. The only bands which change by more than 1 dB between the two locations are the tonal component bands.

To learn more about the tonal components, the data was also analyzed using a 1 percent bandwidth filter (General Radio 1568-A). Since the levels tended to fluctuate, the narrow band levels were statistically analyzed using a Metrisonic 602. Also, the frequency of the components was measured using a Berkley/Beckman digital frequency counter. The frequency of the tone was found to be quite constant with the measured results being between 239.1 and 239.3Hz. In fact this small variation in speeds may be due to speed inaccuracies of the tape recorders. The measured narrow band levels for the fundamental, 2nd, and 3rd harmonics are as follows:
(all A weighted)

<u>1st location</u>

fundamental	82±1	ANSI
2nd harmonic	70±2	Slow Response
3rd harmonic	69±1	

<u>2nd location</u>

fundamental	60±2	ANSI
2nd harmonic	75±1	Slow Response
3rd harmonic	74±1	

To within 1 dB, the sum of these components for location 1 is 82 dBA, while at the second location it is 79 dBA. Comparing these values with the overall dBA values leads to the conclusion that the sound level that would be present if these components were missing would be 79 or 80 dBA. Most of this "other" sound is broad band with a small contribution from higher harmonics.

The source of this tonal component is the blade passing frequency of the fan. The fan has 16 blades and runs at 870 rpm. This results in 870 x 16/60 = 232 blade passings per second. Since the measured frequency was 239 Hz, it would appear that the fan was rotating slightly faster than its nominal rate of 870 rpm, more like 896 rpm. It is likely that this tonal component was increased when the blade pitch angle was changed.

2) Effect of Barrier

To learn something of the effect of the barrier that has been constructed on two sides, a location 3 was chosen on one of the sides with a barrier. The 1/3 octave band levels at this location are plotted on an attached graph (Figure 4). The first and second harmonics of the tonal component are still evident, but the overall level is reduced by more than 10 dB. As before the tonal components were measured using a 1 percent bandwidth and the results were:

fundamental	68±1	ANSI
2nd harmonic	62±1	Slow REsponse
3rd harmonic	49±2	A weighted

The sum of these three components is 69 dBA which is 10 or more dB lower than the sum of these components as determined on the side with no barrier.

3) Levels as Determined on the Other Side of the Lake

To learn something of the levels experienced by cottage owners, measurements were made at the end of route 586 approximately 3 km over water from the source. Measurements were made in the early afternoon when there was a light wind present and after dark when the winds were calm. The afternoon measurements were made at two locations, one at the end of the road approximately 100 yards from the shore and one about 50 feet from the shore. The evening measurement was made 50 feet from the shore. In all cases the sound of the fan could be heard. In the evening it was the dominant sound.

Shebandowan Mine
100 ft other side of barrier

A weighted 1/3 octave band levels

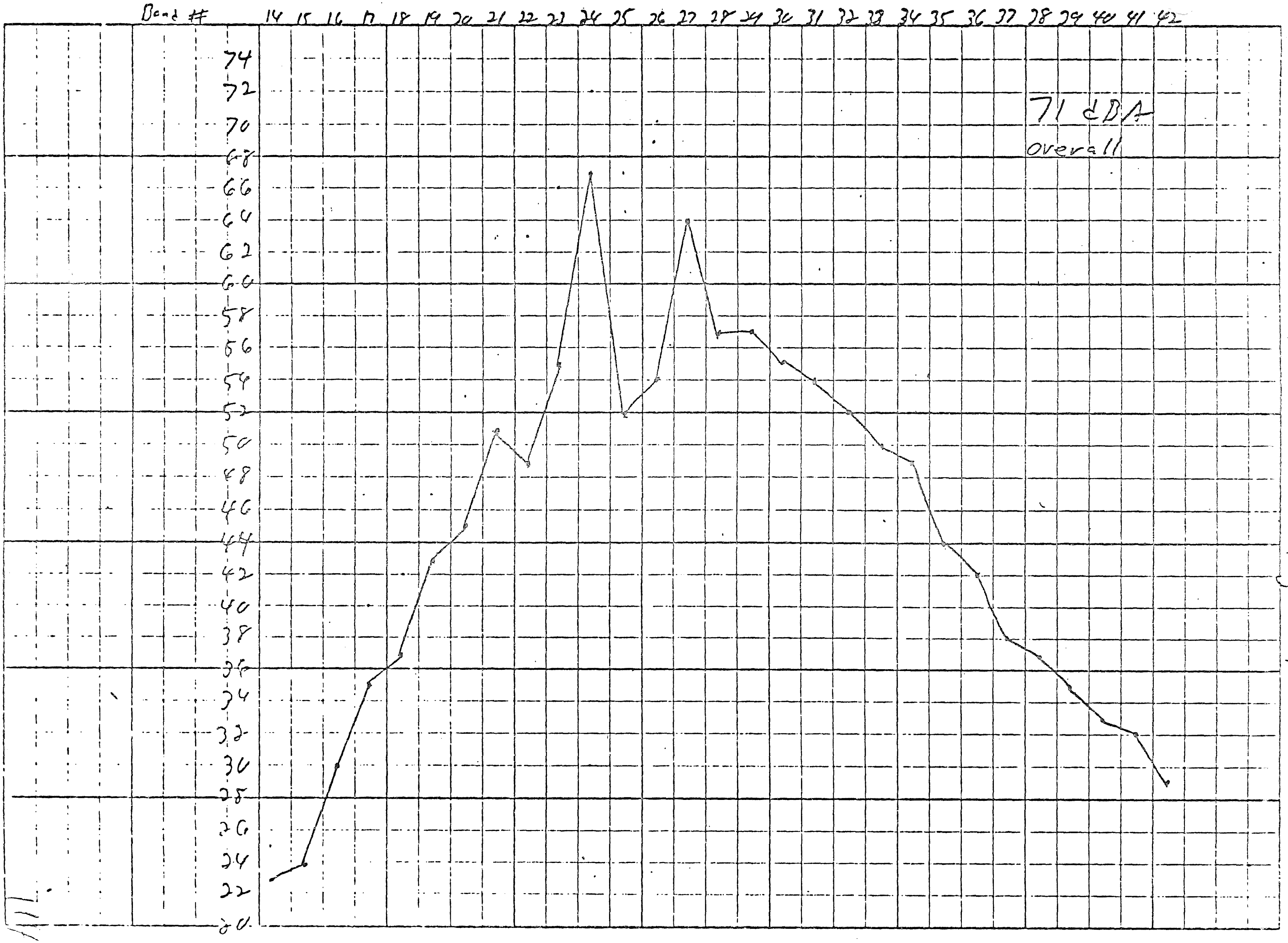


figure 4

11

The results of 1/3 octave band analysis of tapes made in the afternoon are attached (Figures 5 & 6). While wind in the trees, squirrels, and planes have their effect, one can see evidence of the tonal components in bands 24 and 27. To learn more of these tonal components, the 1 percent filter and Metrosonic analyzer were used to establish the statistics for the levels observed during the 10 minute data periods. The results of this analysis are as follows:

<u>100 yards back</u>

	L_{10}	L_{20}	L_{30}	L_{40}	L_{50}	L_{60}	L_{70}	L_{80}	L_{90}
fundamental -	15	14	13	12	11	10	9	7	5
2nd harmonic -	16	15	14	13	12	11	11	10	8

<u>Near shore</u>

	L_{10}	L_{20}	L_{30}	L_{40}	L_{50}	L_{60}	L_{70}	L_{80}	L_{90}
fundamental -	24	20	18	17	16	15	14	13	11
2nd harmonic -	18	17	15	14	13	12	11	9	7

What this means, for example, is that the fundamental, near shore, exceeded 18 dBA 30 percent of the time. These results show that the level of the tonal components is quite unsteady. To establish the backgound noise levels in a 1 percent bandwidth the filter was tuned up 1/6 of an octave above the fundamental and 2nd harmonic frequencies (to 268 Hz and 539Hz, respectively). The analysis was then repeated. The results of this measurement, called background levels here (assuming a reasonable smooth background spectrum), are as follows:

Background Levels--
<u>100 yards from shore</u>

at 268 Hz L_{10}=5 L_{50}=-2 L_{90}=-6
at 539 Hz L_{10}=9 L_{50}=4 L_{90}=1

Figure 5

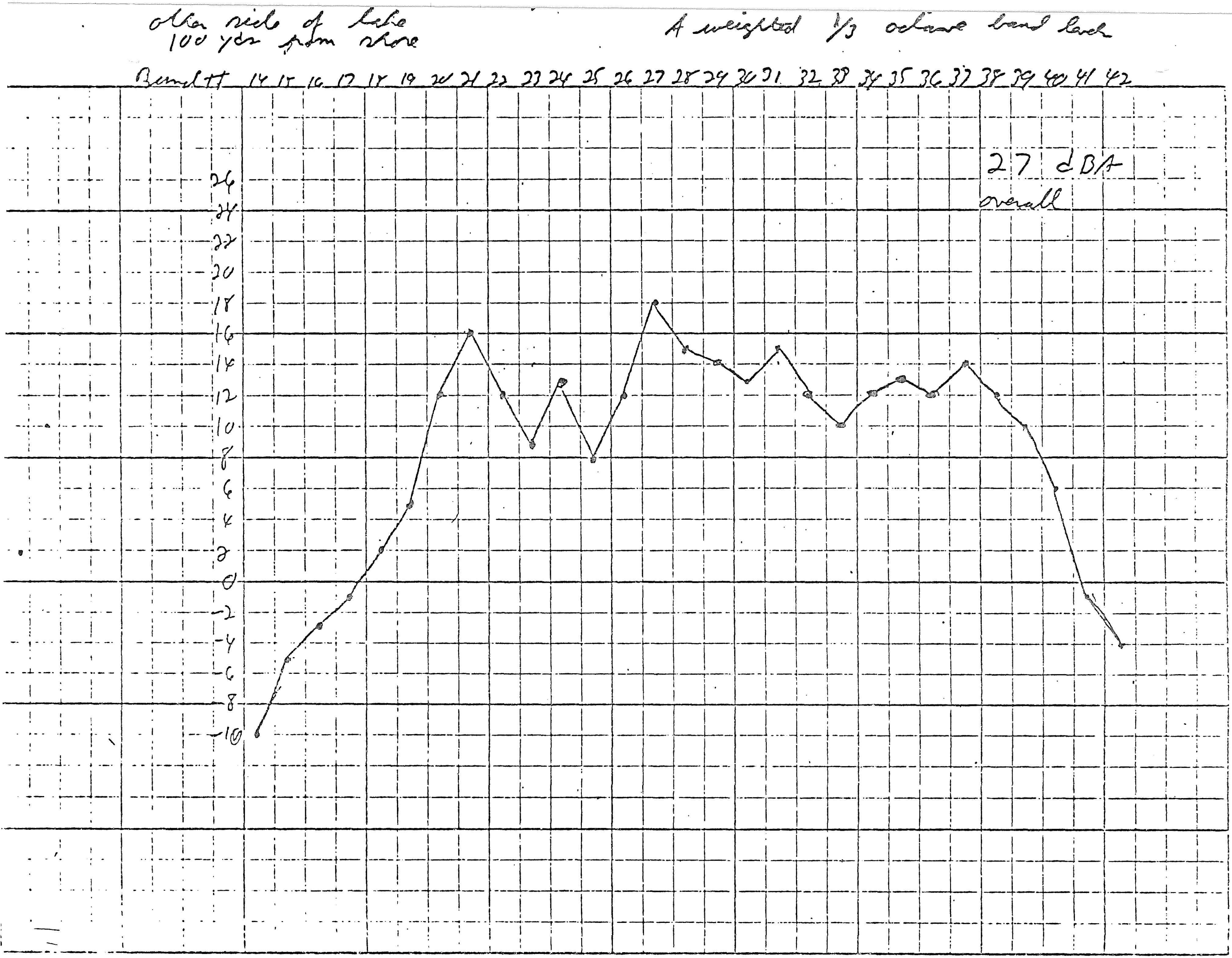
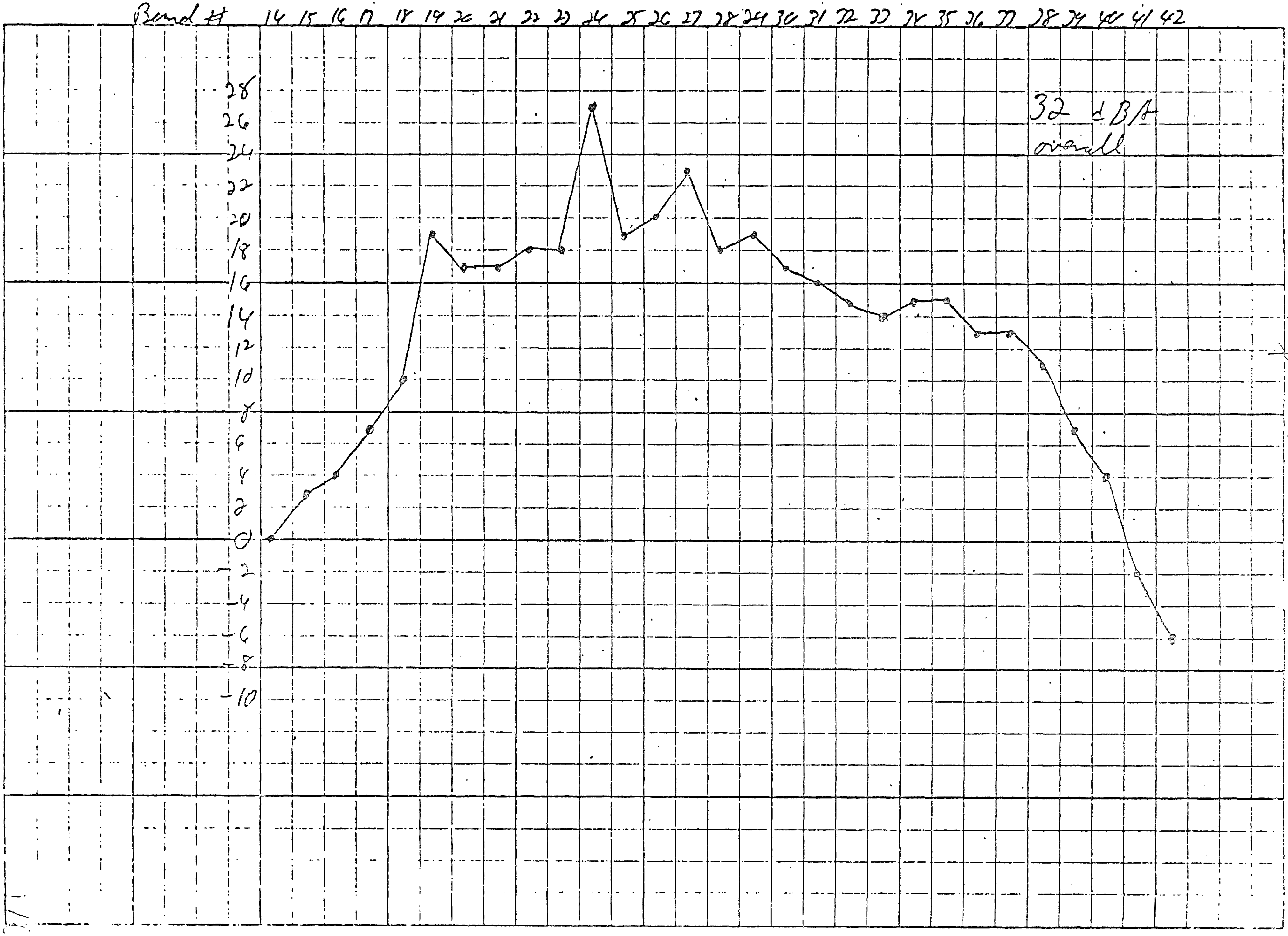

other side of lake
100 yds from shore
A weighted 1/3 octave band levels
Band #
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
27 dBA
overall

Figure 6

other side of lake
near shore

A weighted 1/3 octave band levels



Near shore

at 268 Hz $L_{10}=13$ $L_{50}=7$ $L_{90}=2$
at 539 Hz $L_{10}=13$ $L_{50}=5$ $L_{90}=2$

From these it can be seen that the background levels should not have had a great influence on the measured tonal component levels except perhaps for L_{80} and L_{90} for the 2nd harmonic near shore. For the evening measurement the wind was down and the tonal components were up so, again the measured results are well above background. The results are:

Evening--near lake

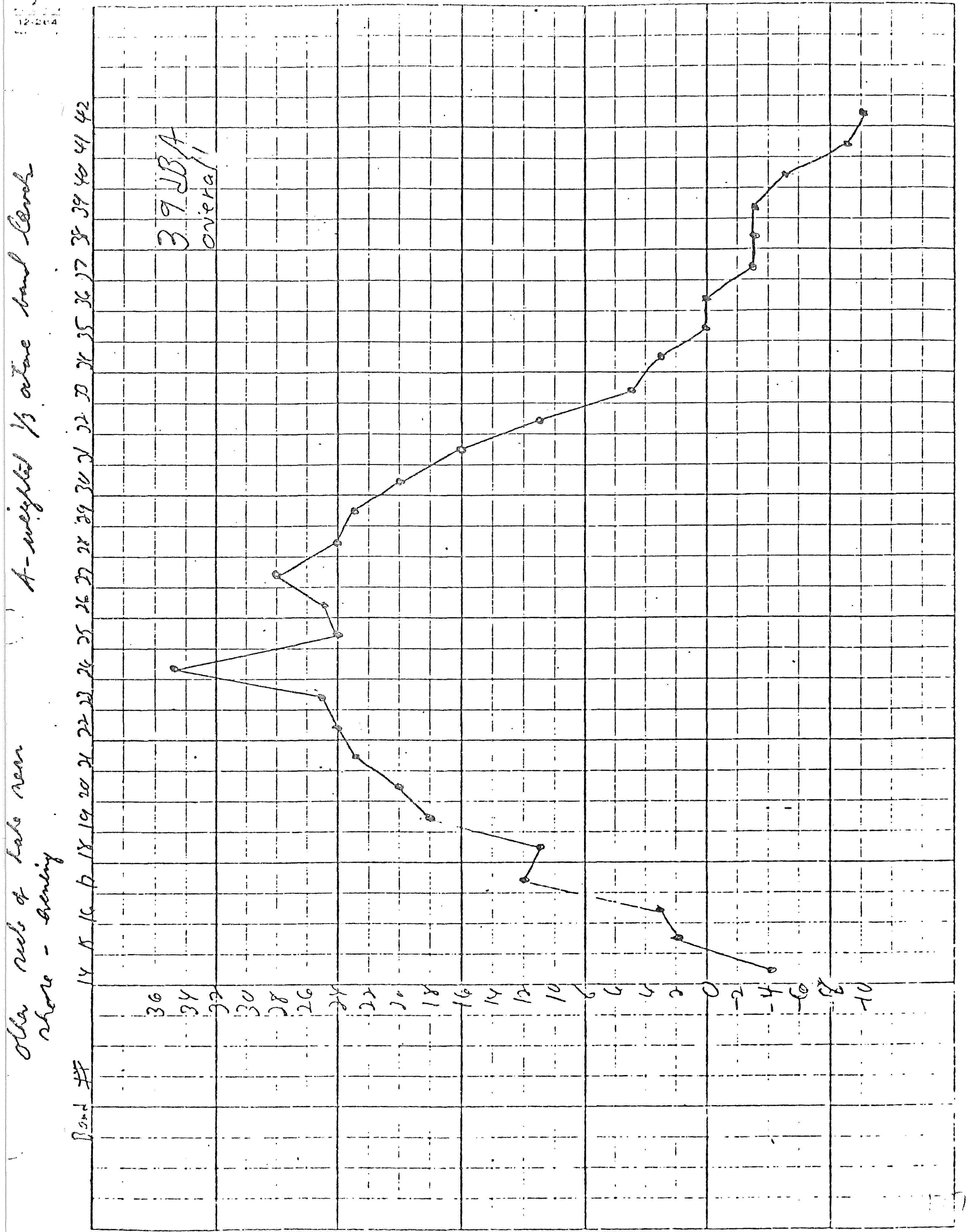
	L_{10}	L_{20}	L_{30}	L_{40}	L_{50}	L_{60}	L_{70}	L_{80}	L_{90}
fundamental -	33	31	29	28	27	26	24	22	19
2nd harmonic -	26	24	23	22	21	20	19	17	14

In interpreting these results, it should be noted that the statistics of the levels of the fundamental and 2nd harmonic appear to be quite independent. That is, when a peak level of one of them is observed, the other is not necessarily at a peak. This could be seen by watching the real time analyzer. Comparing the evening and daytime near the lake levels shows that the tonal components propagated approximately 10 dB better on this particular evening than they did in the afternoon. It is probable that, during a strong midsummer evening temperature inversion over the lake, still higher levels would be observed. A 1/3 octave plot for a 32 sec. data interval is also included (Figure 7), and the tonal components are again evident.

It is interesting to compare the observed levels of the tonal components with those that would be predicted by the inverse square law. Unfortunately, to do this accurately would have required a detailed study of the directionality properties of the fan as a sound source which would have taken a long time and would have been quite difficult because of the fan's location near

12-204

Figure 7



PRELIMINARY DRAFT SUBJECT TO MAJOR REVISION DO NOT QUOTE a steep dropoff. However, to give a rough idea, one may use as 100 foot levels those observed on the other side of the barrier. This is 68 dBA for the fundamental and 62 dBA for the 2nd harmonic. The inverse square law drop in going from 100 feet to 3 km is 40 dB. Thus, the inverse square law prediction arrived at by this method is:

28 dBA fundamental } inverse square from beyond barrier levels
22 dBA 2nd harmonic

As can be seen, these values are quite comparable to the evening L_{50} values. Discussions with mining personnel indicated that complaints had been received from cottage owners on Middle Shebandowan Lake, a distance of 6 km from the mine, mostly over water. On the night when the above observations were made, it was not possible to hear the mine from this distance (observations made at the shore of Young Bay), but a gas station owner who was talked to said that he had been able to hear it a few times during the summer. If, under inversion conditions, the inverse square law held out to this distance the predicted levels would be about 22 dBA for the fundamental and 16 dBA for the 2nd harmonic, which would definitely be audible on a quiet night. Before the barrier was constructed these levels would have been 10 dB higher.

While the prime concern of the trip was to study the effect of the fan noise, other mining related noises were quite evident during the evening measurement, especially truck noises. To illustrate this, two 1/3 octave Plots of momentary peaks in truck noises are included (Figures 8 & 9).

Other side of radio - evening
illustrating truck noise

A-weighted 1/3 octave band levels

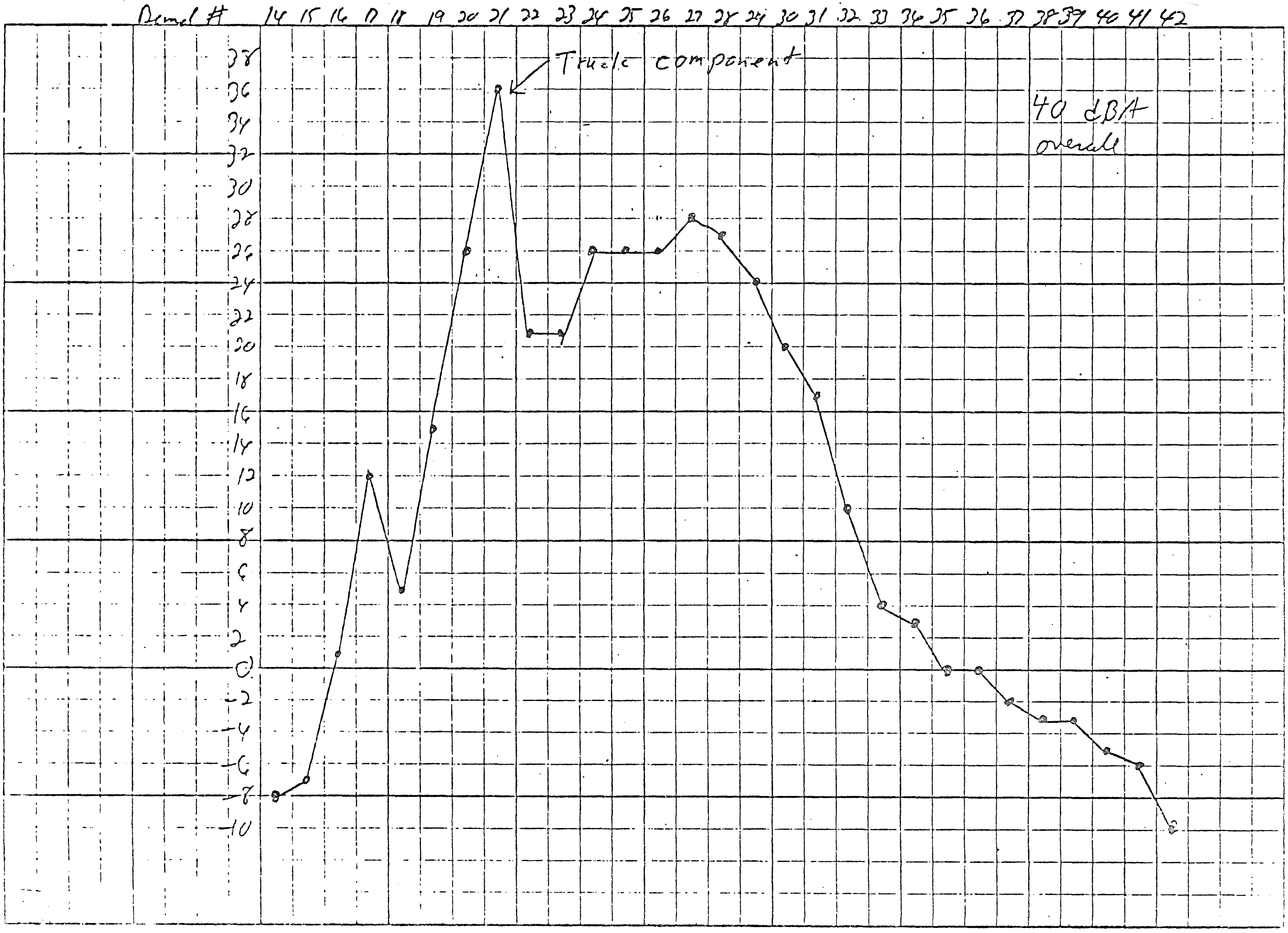
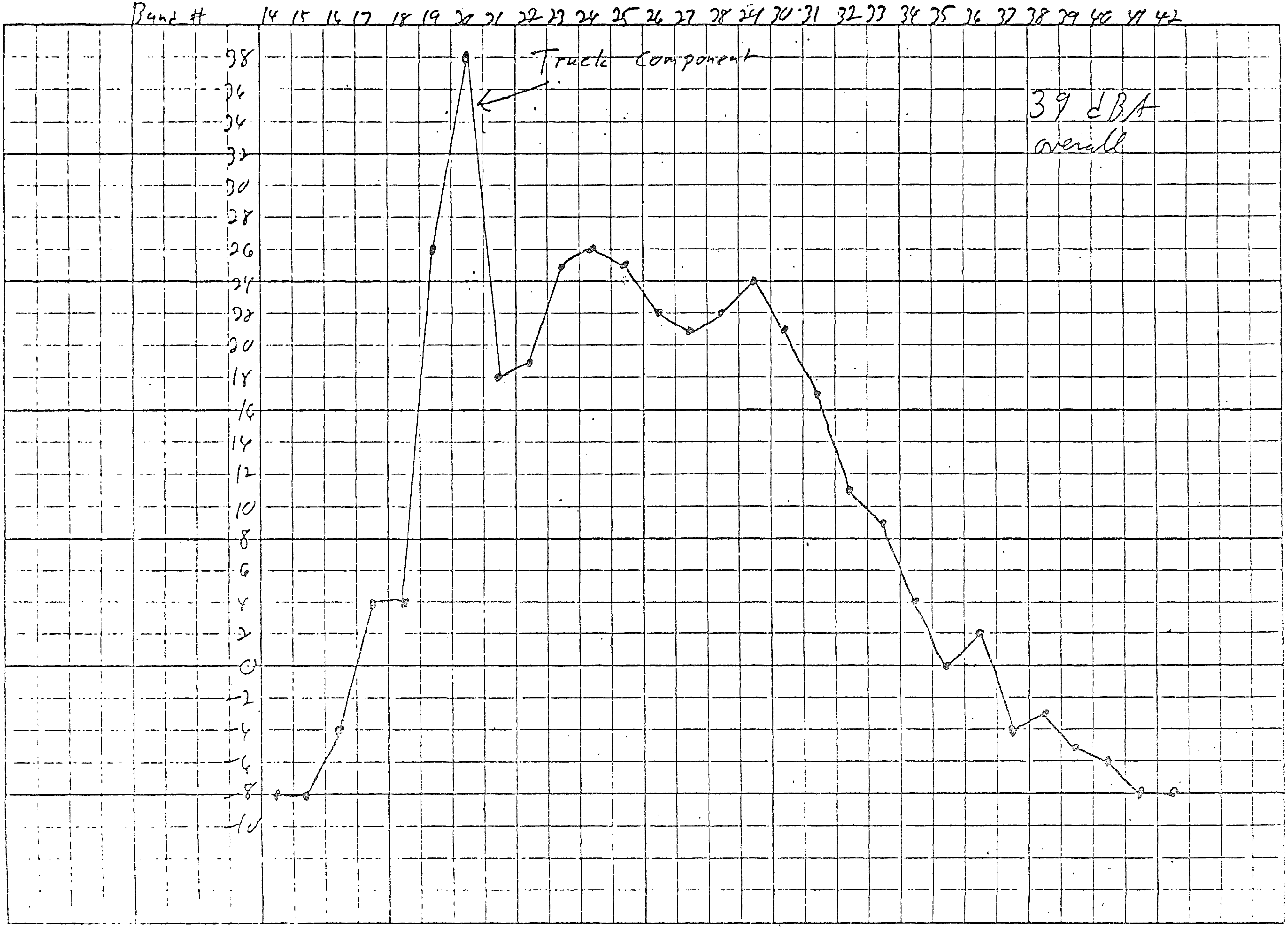


figure 8

other side of lake - evening
illustrating truck noises

A-weighted 1/3 octave band levels



39 dBA
overall

Figure 9

NOTES TAKEN IN CONVERSATION WITH FRANK WOTT-INCO VENTILATION ENGINEER

The shaft has two fans, only one of which is in use at this time. The other presently serves as a backup. They are Joy model 84-50-870. They have a 50 inch hub, the fans are 84 inches in diameter and they are designed to operate at 870 rpm. They have 16 blades and are driven by a 250 H.P. motor. The blade pitch angle is adjustable to control loading.

The pitch angle used to be 43° giving 225,000 CFM of flow. When underground operations expanded, the pitch angle was changed to 53° which appears to load the motor to its full capacity. Before the pitch change, only one complaint was recieved concerning the fan noise, since the change there have been more. Frank Wott's readings indicated that the pitch angle change raised the levels at the shoreline by 2 dB. To try to reduce the levels they erected a barrier out of 3/4 inch plywood which stands about 3 or 4 feet from the unit, covers two sides, and is just large enough to shield the unit from view. INCO measurements indicated a drop of levels at their shoreline (which is about 50 feet lower in elevation than the fan) of about 10 dBA.

Appendix 3

Normally Distributed Sound Level Statistics

If a plot of the values of L_N on probability paper appears to be a straight line it is resonable to assume that the sound level statistics can be well represented by a Gaussion or normal statistical model. If the sound level statistics were exactly normal the points would lie exactly on a straight line where slope and intercept would be determined by the mean, L_{50}, value and the standard deviation σ. In this section a procedure will be described which determines the best straight line fit to the actual data points together with a measure of how good the fit is. The procedure works directly with L_N, which is the form of the output of some sound level statistical analyzers.

To make the discussion specific, suppose that the decile percentiles are the data, i.e. L_{10}, L_{20}, up to L_{90}. Let σ be the standard deviation of the Gaussian model which is to be fit to this data and L_{50} be the mean. Note that the best fit model value of L_{50} may not exactly equal the data value. From statistical tables, the number of standard deviations from the mean that corresponds to a given percentile level for normal statistics can be found. Calling this t_N one has

$t_{10} = 1.282$, $t_{20} = .841$, $t_{30} = .524$, $t_{40} = .253$

From the symetric nature of normal statistics, $t_N = -t_{(100 - N)}$. If the data statistics are normal, a plot of L_N vs t_N would be a straight line. The slope of this line would be σ and the $t_N = 0 (N = 50)$ intercept would be L_{50}. This relationship may be expresses as

1. $L_N = L_{50} + \sigma t_N$

The fitting procedure used for much of the field data analysis was to use standard linear least square fit theory to find the best straight line fit to the pairs of values (L_N, t_N).

The slope of the resulting line is the best fit value of σ, the intercept is the best fit value of L_{50}, and is denoted here by $\tilde{L}_{50}$. The correlation coefficient, r, which results from this is a measure of how well the straight line fits the data points on probability paper. More convient than r is the standard error of estimates, denoted here by δ. Standard theory gives

2. $\delta = \sqrt{1 - r^2} \quad \sigma'$

where $\sigma'$is the standard deviation of the set of numbers formed by the data values of L_N used in the fitting procedure. The significance of δ is that it is the r.m.s. deviation of the actual data points from the values predicted by the best straight line.

It should be noted that this procedure gives equal weight to each L_N value, regardless of N. Thus the value for $\tilde{L}_{50}$ and σ determined by this method will in general, differ from the mean and the standard deviation computed by standard methods.

Appendix 4

Computer Listings of PROP and MPROP

```
1 FILE #1="TREE"
2 FILE #2="WIND"
3 FILE #3="SOURCE"
95 BASE 0
100 DIM B(16),A(80,16),F(16),V1(32),U1(16),V(32),U(16),C(16),D(16)
105 DIM D2(80,16),S(16),D1(80),C2(80,16),U2(80,16),W1(10),W(10,16)
110 DIM M(16),D3(80),C3(80),U3(80),Z3(80),Z4(80),A1(16)
115 DIM K(16,10),K1(16,10)
116 DIM G(9)
150 MAT READ M,B
151 READ T,P,H,Z,K3
164 PRINT "TREE NUMBER, WIND NUMBER, SOURCE NUMBER"
165 INPUT Q1,Q2,Q3
166 SET #1,9*Q1+1
167 SET #2,28*Q2+1
168 SET #3,17*Q3+1
175 READ #1, A1,A2,B1,B2,E1,E2,E3,E4,P1
176 MAT READ #2,W1,U1
177 MAT READ #3,S
300 DATA 5,4,2,0,-1,-2,-3,-4,-4,-5,-5,-6,-6,-6,-6,-6,-6
305 DATA 0,1,2,3,4,5,6,7,8,9,8,7,6,5,4,3,2
332 DATA 260,1,80,0
333 DATA 5
399 PRINT"PROGRAM-PROP"
400 PRINT" THE SOURCE SPECTRUM IS"
401 PRINTS(0);S(1);S(2);S(3);S(4);S(5);S(6);S(7);S(8);
402 PRINT S(9);S(10);S(11);S(12);S(13);S(14);S(15);S(16)
403 PRINT"THE ZERO WIND AMBIENT LEVELS ARE"
404 PRINT B(0);B(1);B(2);B(3);B(4);B(5);B(6);B(7);B(8);B(9);B(10);
405PRINT B(11);B(12);B(13);B(14);B(15);B(16)
406 PRINT"THE WIND ROSE IS"
407 PRINT U1(0);U1(1);U1(2);U1(3);U1(4);U1(5);U1(6);U1(7);U1(8);
408 PRINT U1(9);U1(10);U1(11);U1(12);U1(13);U1(14);U1(15);U1(16)
410 PRINT "THE WIND SPEED PERCENTILE LEVELS ARE"
411 FOR L=1 TO 10
412 PRINT W1(L);
413 NEXT L
414 PRINT
415 PRINT" THE WIND GENERATED NOISE SPECTRUM IS DESCRIBED BY"
416 PRINT"A1","A2","B1","B2"
417 PRINT A1,A2,B1,B2
418 PRINT"E1","E2","E3","E4"
419 PRINT E1,E2,E3,E4
420 PRINT"P1=";P1
421 PRINT "T","P","H","Z"
422 PRINT T,P,H,Z
423 PRINT"THE EXCEEDENCE PARAMETER IS";K3;"DB"
499 LET T1=273.16
500 LET G=10.79856*(1-(T1/T))-5.02808*LGT(T/T1)-2.2195983
501 LET G=G+1.50474E-4*(1-10^(-8.29692*((T/T1)-1)))
```

```
502 LET G=G+0.42873E-3*(10^(4.76955*(1-(T1/T)))-1)
503 LET G=10^G
504 LET H=H*G/P
505 LET T=T/293
510 LET F1=P*(24+4.41E4*H*(.05+H)/(.391+H))
515 LET F2=P*T^(-.5)*(9+350*H*EXP(-6.142*(T^(-1/3)-1)))
520 LET C1=1.84E-11*P^(-1)*T^(-.5)
525 LET C2=T^(-5/2)*1.278E-2*EXP(-7.642/T)
530 LET C3=T^(-5/2)*.1068*EXP(-11.44/T)
535 FOR K=0 TO 16
540 LET F(K)=10^((K+20)/10)
545 NEXT K
550 FOR K=0 TO 16
555 LET A1(K)=F(K)^2*(C1+C2/(F1+F(K)^2/F1)+C3/(F2+F(K)^2/F2))
560 NEXT K
605 FOR I=1 TO 16
610 LET V1(I)=U1(I)
615 NEXT I
620 FOR I=17 TO 32
625 LET V1(I)=U1(I-16)
630 NEXT I
635 LET V(1)=V1(15)+V1(16)+V1(1)+V1(2)+V1(3)
640 LET V(2)=V1(16)+V1(1)+V1(2)+V1(3)+V1(4)
645 FOR I=3 TO 30
650 LET V(I)=V1(I-2)+V1(I-1)+V1(I)+V1(I+1)+V1(I+2)
655 NEXT I
660 FOR I=1 TO 16
665 LET U(I)=V(I)
670 LET D(I)=V(I+8)
675 LET C(I)=100-D(I)-U(I)-U1(0)
680 NEXT I
700 FOR R=2 TO 80
705 FOR K=0 TO 16
710 LET D2(R,K)=S(K)-20*LGT(500*R)-8.69*A1(K)*500*R
715 NEXT K
720 NEXT R
730 FOR R=2 TO 80
735 LET D1(R)=0
740 NEXT R
745 FOR R=2 TO 80
750 FOR K=0 TO 16
755 LET D1(R)=10^(D2(R,K)/10)+D1(R)
760 NEXT K
765 LET D1(R)=10*LGT(D1(R))
770 NEXT R
800 FOR R=2 TO 80
805 FOR K=0 TO 16
810 LET C2(R,K)=D2(R,K)-15
815 LET U2(R,K)=D2(R,K)-30
820 NEXT K
```

```
825 NEXT R
1000 FOR L=1 TO 10
1005 LET S1=A1*W1(L)+A2
1010 LET S2=.5*(1-SGN(S1-35))*(S1-35)*B1+.5*(1+SGN(S1-35))*(S1-35)*B2
1015 FOR K=0 TO 16
1020 LET Y=K-S2
1025 LET W(L,K)=(E1*Y+E2)*.5*(1-SGN(Y-P1))+(E3*Y+E4)*.5*(1+SGN(Y-P1))
1026 LET W(L,K)=W(L,K)+S1-35+M(K)
1030 IF W(L,K)>B(K)+M(K) THEN 1040
1035 LET W(L,K)=B(K)+M(K)
1040 NEXT K
1045 NEXT L
1100 FOR R=2 TO 80
1105 LET Q1=Q2=Q3=10
1110 FOR K=0 TO 16
1115 FOR L=1 TO 10
1120 IF U2(R,K)>W(L,K)+K3 THEN 1145
1125 IF C2(R,K)>W(L,K)+K3 THEN 1160
1130 IF D2(R,K)>W(L,K)+K3 THEN 1175
1140 GOTO 1185
1145 IF L>Q1 THEN 1125
1150 LET Q1=L
1155 GOTO 1125
1160 IF L>Q2 THEN 1130
1165 LET Q2=L
1170 GOTO 1130
1175 IF L>Q3 THEN 1185
1180 LET Q3=L
1185 NEXT L
1190 NEXT K
1195 LET D3(R)=100-10*Q3
1200 LET C3(R)=100-10*Q2
1205 LET U3(R)=100-10*Q1
1210 NEXT R
1250 FOR R=2 TO 80
1255 LET Z3(R)=Z4(R)=0
1260 FOR K=0 TO 16
1265 IF C2(R,K)>B(K)+M(K)+K3 THEN 1285
1270 IF D2(R,K)>B(K)+M(K)+K3 THEN 1295
1280 GOTO 1300
1285 LET Z3(R)=100
1290 GOTO 1270
1295 LET Z4(R)=100
1300 NEXT K
1305 NEXT R
1500 FOR R=2 TO 80
1505 FOR I=1 TO 16
1510 LET A(R,I)=U(I)*U3(R)+D(I)*D3(R)+C(I)*C3(R)+Z*U1(0)*Z4(R)
1515 LET A(R,I)=(A(R,I)+(1-Z)*U1(0)*Z3(R))/100
1520 NEXT I
```

```
1525 NEXT R
1550 FOR R=2 TO 80
1555 LET A(R,0)=5*R
1560 NEXT R
1600 FOR L=0 TO 10
1601 FOR I=1 TO 16
1602 LET K(I,L)=0
1603 NEXT I
1604 NEXT L
1605 FOR I=1 TO 16
1610 LET L=INT(A(2,I)/10)
1615 FOR R=3 TO 80
1620 IF A(R,I)>10*L THEN 1640
1621 IF A(R,I)=A(R-1,I) THEN 1627
1625 LET K(I,L)=((A(R-1,I)-10*L)/(A(R-1,I)-A(R,I))+R-1)*5
1626 GOTO 1630
1627 LET K(I,L)=(R-1)*5
1630 LET L1=INT(A(R,I)/10)
1631 IF L-L1=1 THEN 1634
1632 LET L=L-1
1633 GOTO 1620
1634 LET L=L1
1640 NEXT R
1645 NEXT I
1650 FOR I=1 TO 16
1655 FOR L=0 TO 10
1660 LET X=INT(K(I,L)/5)
1661 LET Q=K(I,L)/5
1662 LET Q1=Q-X
1665 LET K1(I,L)=(1-Q1)*D1(X)+Q1*D1(X+1)
1670 NEXT L
1675 NEXT I
1680 FOR L=0 TO 9
1681 LET G(L)=K(16,L)*K(1,L)*.3826/200
1682 FOR I=1 TO 15
1683 LET G(L)=G(L)+K(I,L)*K(I+1,L)*.3826/200
1684 NEXT I
1685 NEXT L
1699 SETDIGITS 3
1710 PRINT " AUDIBILITY CONTOURS"
1715 MAT PRINT K;
1716 FOR J=0 TO 12
1717 PRINT
1718 NEXT J
1720 PRINT " CORRESPONDING A WEIGHTED MAX LEVELS"
1725 MAT PRINT K1;
1730 PRINT "AFFECTED AREAS"
1735 FOR L=0 TO 9
1736 PRINT G(L);
1737 NEXT L
```

```
99 BASE 0
100 DIM B(16),A(60,35),F(16),U(16),L(5,60,16),S(5,16),W1(10)
101 DIM W(10,16),M(16),A1(16),R1(5),R2(5),R3(2,5,9),D(5),I(5)
102 DIM X(5),Y(5),X1(5),Y1(5),R(5),F1(16,16)
105 FILE #1="TREE"
106 FILE #2="WIND"
107 FILE #3="SOURCE"
110 PRINT "TREE NUMBER,WIND NUMBER"
111 INPUT Q1,Q2
115 PRINT "HOW MANY SOURCES"
116 INPUT N
117 LET N=N-1
120 FOR I=0 TO N
130 PRINT "INPUT X(";I;")       Y(";I;")      SOURCE FILE NUMBER"
131 INPUT X(I),Y(I),Q
132 LET X(I)=X(I)*2
133 LET Y(I)=Y(I)*2
134 SET#3,17*Q+1
135 FOR J=0 TO 16
136 READ#3,S(I,J)
137 NEXT J
138 NEXT I
150 SET#1,9*Q1+1
151 SET#2,28*Q2+1
152 READ#1,A1,A2,B1,B2,E1,E2,E3,E4,P1
153 MAT READ#2,W1,U
155 MAT READ F1,M,B
156 READ T,P,H,Z,K3
199 LET P3=3.14159
200 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
201 DATA 0,2,2,2,1,1,1,0,0,0,0,0,1,1,1,2,2
202 DATA 0,2,2,2,2,1,1,1,0,0,0,0,0,1,1,1,2
203 DATA 0,2,2,2,2,2,1,1,1,0,0,0,0,0,1,1,1
204 DATA 0,1,2,2,2,2,2,1,1,1,0,0,0,0,0,1,1
205 DATA 0,1,1,2,2,2,2,2,1,1,1,0,0,0,0,0,1
206 DATA 0,1,1,1,2,2,2,2,2,1,1,1,0,0,0,0,0
207 DATA 0,0,1,1,1,2,2,2,2,2,1,1,1,0,0,0,0
208 DATA 0,0,0,1,1,1,2,2,2,2,2,1,1,1,0,0,0
209 DATA 0,0,0,0,1,1,1,2,2,2,2,2,1,1,1,0,0
210 DATA 0,0,0,0,0,1,1,1,2,2,2,2,2,1,1,1,0
211 DATA 0,0,0,0,0,0,1,1,1,2,2,2,2,2,1,1,1
212 DATA 0,1,0,0,0,0,0,1,1,1,2,2,2,2,2,1,1
213 DATA 0,1,1,0,0,0,0,0,1,1,1,2,2,2,2,2,1
214 DATA 0,1,1,1,0,0,0,0,0,1,1,1,2,2,2,2,2
215 DATA 0,2,1,1,1,0,0,0,0,0,1,1,1,2,2,2,2
216 DATA 0,2,2,1,1,1,0,0,0,0,0,1,1,1,2,2,2
217 DATA 5,4,2,0,-1,-2,-3,-4,-4,-5,-5,-6,-6,-6,-6,-6,-6
220 DATA 0,1,2,3,4,5,6,7,8,9,8,7,6,5,4,3,2
300 PRINT"PROGRAM MPROP"
301 PRINT"THERE ARE";N+1;"SOURCES"
```

```
302 PRINT"THEIR X COORDINATES ARE, THEIR Y COORDINATES ARE"
303 FOR J=0 TO N
304 PRINT "        ";X(J)/2;"                        ";Y(J)/2
305 NEXT J
306 PRINT "THEIR SPECTRA ARE"
307 FOR J=0 TO N
308 PRINT S(J,0);S(J,1);S(J,2);S(J,3);S(J,4);S(J,5);S(J,6);S(J,7);
309 PRINT S(J,8);S(J,9);S(J,10);S(J,11);S(J,12);S(J,13);S(J,14);
310 PRINT S(J,15);S(J,16)
311 NEXT J
312 PRINT"THE WIND ROSE IS"
313 PRINT U(0);U(1);U(2);U(3);U(4);U(5);U(6);U(7);U(8);U(9);
314 PRINT U(10);U(11);U(12);U(13);U(14);U(15);U(16)
315 PRINT" THE ZERO WIND AMBIENT LEVELS ARE"
316 PRINT B(0);B(1);B(2);B(3);B(4);B(5);B(6);B(7);B(8);B(9);
317 PRINT B(10);B(11);B(12);B(13);B(14);B(15);B(16)
318 FOR L=1 TO 10
319 PRINT "W1(";L;")=";W1(L)
320 NEXT L
321 PRINT"THE WIND GENERATED NOISE SPECTRUM IS DESCRIBED BY"
322 PRINT "A1","A2","B1","B2"
323 PRINT A1,A2,B1,B2
324 PRINT "E1","E2","E3","E4","P1"
325 PRINT E1,E2,E3,E4,P1
326 PRINT "T=";T;"P=";P;"H=";H
327 PRINT "Z=";Z;"K3=";K3
332 DATA 93,1,65,0
333 DATA 5
499  LET T1=273.16
500 LET G=10.79856*(1-(T1/T))-5.02808*LGT(T/T1)-2.2195983
501  LET G=G+1.5047E-4*(1-10^(-8.29692*((T/T1)-1)))
502 LET G=G+0.4287E-3*(10^(4.76955*(1-(T1/T)))-1)
503 LET G=10^G
504 LET H=H*G/P
505 LET T=T/293
510 LET F1=P*(24+4.41E4*H*(.05+H)/(.391+H))
515 LET F2=P*T^(-.5)*(9+350*H*EXP(-6.142*(T^(-1/3)-1)))
520 LET C1=1.84E-11*P^(-1)*T^(-.5)
525 LET C2=T^(-5/2)*1.278E-2*EXP(-7.642/T)
530 LET C3=T^(-5/2)*.1068*EXP(-11.44/T)
535 FOR K=0 TO 16
540 LET F(K)=10^((K+20)/10)
545 NEXT K
550 FOR K=0 TO 16
555 LET A1(K)=F(K)^2*(C1+C2/(F1+F(K)^2/F1)+C3/(F2+F(K)^2/F2))
560 NEXT K
700 FOR J=0 TO N
705 FOR R=1 TO 60
710 FOR K=0 TO 16
715 LET L(J,R,K)=S(J,K)-20*LGT(500*R)-8.69*A1(K)*500*R
```

```
720 NEXT [illegible]
725 NEXT R
730 NEXT J
1000 FOR L=1 TO 10
1005 LET S1=A1*W1(L)+A2
1010 LET S2=.5*(1-SGN(S1-35))*(S1-35)*B1+.5*(1+SGN(S1-35))*(S1-35)*B2
1015 FOR K=0 TO 16
1020 LET Y=K-S2
1025 LET W(L,K)=(E1*Y+E2)*.5*(1-SGN(Y-P1))+(E3*Y+E4)*.5*(1+SGN(Y-P1))
1026 LET W(L,K)=W(L,K)+S1-35+M(K)
1030 IF W(L,K)>B(K)+M(K) THEN 1040
1035 LET W(L,K)=B(K)+M(K)
1040 NEXT K
1045 NEXT L
1090 FOR D=0 TO 2
1091 FOR J=0 TO N
1092 FOR L=0 TO 9
1093 LET R3(D,J,L)=0
1094 NEXT L
1095 NEXT J
1096 NEXT D
1100 FOR J=0 TO N
1105 FOR R=1 TO 60
1110 FOR K=0 TO 16
1115 LET Q=SGN(L(J,R,K)-15 -B(K)-K3)
1120 IF Q>0 THEN 1140
1125 NEXT K
1130 LET R2(J)=R-.5
1135 GOTO 1155
1140 NEXT R
1145 LET R2(J)=R1(J)=60
1150 GOTO 1200
1155 FOR R=R TO 60
1160 FOR K=0 TO 16
1165 LET Q=SGN(L(J,R,K)-B(K)-M(K)-K3)
1170 IF Q>0 THEN 1190
1175 NEXT K
1180 LET R1(J)=R-.5
1185 GOTO 1200
1190 NEXT R
1195 LET R1(J)=60
1200 FOR D=0 TO 2
1205 LET R=1
1210 FOR L=1 TO 10
1215 FOR K=0 TO 16
1220 LET Q=SGN(L(J,R,K)-15*D-W(L,K)-K3)
1225 IF Q>0 THEN 1245
1230 NEXT K
1235 NEXT L
1240 GOTO 1310
```

```
1245 FOR R=1 TO 60
1250 FOR K=0 TO 16
1255 LET Q=SGN(L(J,R,K)-15*D-W(L,K)-K3)
1260 IFQ>0 THEN 1290
1265 NEXT K
1270 LET R3(D,J,10-L)=R-.5
1275 LET L=L+1
1280 IF L>10 GOTO 1310
1290 NEXT R
1295 FOR L=L TO 10
1300 LET R3(D,J,10-L)=60
1305 NEXT L
1310 NEXT D
1315 NEXT J
2000 MAT A=ZER
2005 FOR M=0 TO 35
2010 FOR R=1 TO 60
2015 LET X=R*SIN(M*P3/18)
2020 LET Y=R*COS(M*P3/18)
2025 FOR J=0 TO N
2030 LET X1(J)=X-X(J)
2035 LET Y1(J)=Y-Y(J)
2040 LET R(J)=(X1(J)^2+Y1(J)^2)^.5
2045 NEXT J
2050 LET Q1=Q2=0
2055 FOR J=0 TO N
2060 LET Q1=MIN(Q1,R(J)-R1(J))
2065 LET Q2=MIN(Q2,R(J)-R2(J))
2070 NEXT J
2075 IF Q1>=0 THEN 2260
2080 LET Q1=1
2085 IF Q2>=0 THEN 2095
2090 LET Q2=1
2095 LET A(R,M)=Z*U(0)*Q1+(1-Z)*U(0)*Q2
2100 IF R<30 THEN 2130
2105 LET I1=INT(M*16/36+1.5)
2106 IF I1<17 THEN 2110
2107 LET I1=1
2110 FOR J=0 TO N
2115 LET I(J)=I1
2120 NEXT J
2125 GOTO 2200
2130 FOR J=0 TO N
2135 IF X1(J)=0 THEN 2160
2140 LET T3=-ATN(Y1(J)/X1(J))
2145 LET I(J)=.5*(1+SGN(X1(J)))*(5+(180*T3+11.25*P3)/(22.5*P3))
2150 LET I(J)=I(J)+.5*(1- SGN(X1(J)))*(13+(180*T3+11.25*P3)/(22.5*P3))
2155 GOTO 2165
2160 LET I(J)=.5*(1+SGN(Y1(J)))+.5*(1-SGN(Y1(J)))*9+.01
2165 LET I(J)=INT(I(J))
```

```
2166 IF I(J)<17 THEN 2170
2167 LET I(J)=1
2170 NEXT J
2200 FOR I=1 TO 16
2205 FOR J=0 TO N
2210 LET D(J)=F1(I(J),I)
2211 IF R(J)>=1 THEN 2215
2212 LET D(J)=0
2215 NEXT J
2220 FOR L=9 TO 0 STEP -1
2225 FOR J=0 TO N
2230 LET Q=SGN(R3(D(J),J,L)-R(J))
2235 IF Q>0 THEN 2255
2240 NEXT J
2245 NEXT L
2250 GOTO 2260
2255 LET A(R,M)=A(R,M)+U(I)*L/10
2260 NEXT I
2265 NEXT R
2270 NEXT M
2795 PRINT" THE AUDIBILITY CONTOURS ARE"
2799 SETDIGITS 3
2800 FOR M=0 TO 35
2805 LET L=INT(A(1,M)/10)
2810 FOR R=2 TO 60
2811 IF A(R,M)>0 THEN 2815
2812 PRINT 0;R/2;M
2813 GOTO 2870
2815 LET I=INT(A(R,M)/10)
2820 IF I<L THEN 2835
2825 IF I>L THEN 2850
2830 IF I=L THEN 2865
2835 LET R1=R-1+(A(R-1,M)-10*L)/(A(R-1,M)-A(R,M))
2840 PRINT 10*L;R1/2;M
2845 GOTO 2860
2850 LET R1=R-1+(10*I-A(R-1,M))/(A(R,M)-A(R-1,M))
2855 PRINT 10*I;R1/2;M
2860 IF (L-I)^2=1 THEN 2864
2861 LET L=L+SGN(I-L)
2862 GOTO2811
2864 LET L=I
2865 NEXT R
2870 NEXT M
3000 END
```

Appendix 5 Data Files

Source Spectra on file
(bands 20 - 36)

\# 0, R.M.S. average spectrum for
180 ton truck in level operation
93, 103, 102, 105, 110, 102, 104, 107, 105
105, 107, 108, 106, 105, 104, 99, 99

\#1, 1/8th sec peak spectrum for
180 ton truck in level operation
93, 105, 106, 120, 119, 107, 105, 110, 106, 107
109, 110, 108, 106, 105, 101, [illegible]

\#2, R.M.S. average spectrum for 85
ton truck in level operation
86, 82, 92, 95, 88, 94, 93, 95, 95
96, 97, 97, 95, 92, 91, 90

\#3, 1/8 th sec peak spectrum for 85
ton truck in level operation
90, 87, 97, 101, 91, 98, 100, 95, 99 [illegible]
99, 98, 101, 96, 95, 92, 93

\#4, R.M.S. average spectrum for [illegible]
lift - 180 ton truck
88, 93, 97, 102, 92, 94, 99, 102, 103
102, 102, 101, 100, 97, 92

\#5 backup warning device
0, 0, 0, 0, 0, 0, 0, 0, 0, 115, 0, 0, 113, 0, 0, 0, 0

\#6, Shebandowan fan - pure tone
components - no barrier
0, 0, 0, 0, 109, 0, 0, 103, 0, 102, [illegible]

\#7, Shebandowan fan - pure tone
components - with barrier
0, 0, 0, 0, 98, 0, 0, 92, 0, 79, 0, 0, 0, 0, 0, 0, 0

\#8, approximate chain saw spectrum
0, 94, 0, 0, 91, 0, 0, 101, 0, 0, 104
0, 0, 99, 0, 0, 95

\#9, 180 ton truck spectrum #0 modified
by R.F. Sipson for sensitivity
analysis
93, 103, 102, 105, 105, 102, 104, 107, [illegible]
105, 107, 108, 106, 105, 104, 99, 99

\#10, 85 ton truck spectrum #2 modified
by R.F. Sipson for sensivity
analysis
86, 82, 90, 90, 88, 91, 94, 93, 95, 95, 96, 97
97, 95, 92, 91, 90

Source spectra - continued

#11, Siren spectrum - 105 dB at 100 ft
0, 0, 0, 0, 0, 0, 0, 0,135, 0, 0, 125, 0, 0, 0, 0, 0

#12, 85 ton truck - bed lift
97, 105, 87, 98, 90, 92, 92, 97
95, 97, 100, 99, 99, 98, 96, 95

#13, Dozer on rock pile
77, 84, 85, 86, 85, 82, 87, 92, 93
95, 97, 101, 102, 102, 98, 94, 92

Spectra 14 - 30 are for sensitivity analysis

#14, 100,0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

#15, 0, 100,0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

#30, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,100

31, Diesel road truck
80, 96, 98, 93, 106, 99, 97, 99, 100,
99, 100, 101, 98, 97, 96, 94, 92

#32, Locomotive
104, 106, 103, 97, 99, 104, 104, 106, 108
107, 107, 105, 105, 105, 105

#33, Locomotive horn
0, 0, 0, 0, 134, 0, 0, 128, 0, 125, 0, 0, 0, 0, 0, 0, 0

Wind file W(0) - W(10), U(0) - U(16)

0, Winter day
W) 30, 144, 133, 117, 10.5, 9.5, 8.6
7.3, 6.1, 4.7, 3

U) 14.9497, 16.2, 1.125, .45, 7875, 1.5
.675, 1.125, 1.9125, 4.575, 3.4875, 2.25
2.925, 3.3, 6.075, 23.4, 21.2625

1, Winter night

W) 30, 14.1, 11.8, 10.3, 9.3, 7.9, 7.1, 6.1, 5.2, 3.8, 3

U) 16.0375, 10.65, .675, -45, 1.675, 1.8
1.2375, .5625, 1.35, 5.25, 5.5125, 1.9125,
1.575, 1.8, 8.775, 16.425, 24.4125

Wind

2, Summer day
W), 30, 14.1, 12.5, 11.2, 9.7, 8.6, 7.5, 7.6, 5.6, 4.6, 3

U), 11.6125, .5925, .9, 1.35, 2.025, 1.275, 2.3625
3.7125, 6.4125, 9.45, 5.5125, 5.0625, 4.725
5.475,7.425, 14.175, 12.6

3, Summer night
W), 30, 11.4, 9.4, 7.7, 6.9, 5.7, 5.2, 4.6, 4.0, 3.6, 3

U), 42.925, 4.65, .5625, 0, .3375, 1.275
3.375, 4.8375, 5.85, 5.25, 5.175, 2.925, 3.375
2.475, 4.8375, 4.8375, 7.3128

Tree File
A1, A2, B1, B2, E1, E2, E3, E4, P1

0 Winter Jackpine
2.0518, 16.0045, .05, .06, 3.12776
3.07229, -2.30164, 47.4052, 8

1 Winter Spruce
1.4745, 17.7864, .06, .1, 2.6543
5.88875, -3.09386, 59.1787, 9

2 White Birch
1.9918, 13.5065, .14, 0, 2.19837
8.70695, -2.08642, 44.9303, 8

3 Summer Jackpine
1.329, 25.173, .24, .03, 3.54186
-.564873, -.917298, 34.4013, 8

4 Summer Spruce
2.254, 14.028, .11, .06
3.07109, 2.17849, -1.54731, 43.6354, 9

5 Summer Red Pine
1.811, 18.967, .12, .05, 3.16946
2.49801, -1.12113, 36.6113, 8

6 Summer Birch
2.331, 20.517, 0, .1, 2.28747
5.47778, -.05567, 25.1851, 9

7 Summer Aspen
1.985, 20.815, .24, .12, 2.43768
3.60353, -.322687, 28.874, 9

8 Summer Conifer
1.798, 19.389, .2, .03, 3.11396
1.31702, -1.21554, 39.1856, 9

9 Summer Decdious
2.158, 20.666, .1, .1, 2.3832
4.77107, -.173316, 26.9799, 9

10 All Winter
1.839, 15.4318, .1, .04, 2.61431
6.4363, -2.60211, 53.3446, 9

Appendix 6

Conversions of 1/3 octave Band Level to Masking level

The so called "critical ratio" (Kryter 1970 page 6) is the ratio of the intensity of a pure tone to the intensity per cycle, or spectrum level, of a broad band noise which masks it. Thus a pure tone component will be just audible in the presence of a broad band noise if

1. Intensity of tone = (critical ratio) x (Spectrum level of noise).

The spectrum level of a broad band noise is determined from the corresponding 1/3 octave band level by

2. Spectrum level = $\dfrac{\text{1/3 octave band intensity}}{\text{corresponding 1/3 octave bandwidth}}$

Combining 1 and 2 and converting to decibles gives

3. dB level of just Audible Tone = $10 \times \log \left(\dfrac{\text{critical ratio}}{\text{1/3 octave B.W.}}\right)$

   + 1/3 octave Band dB level

The first term on the right hand side of this equation is called here the masking level correction factor. Using Hawkin's and Steven's data, as reported in Kryter (1970), to determine the critical ratio to the nearest 10 Hz, the following table is arrived at

Reference — Kryter. 1970. _The Effects of Noise on Man_, Academic Press.

BAND NUMBER	CENTER FREQUENCY	1/3 OCTAVE BANDWIDTH	CRITICAL RATIO	MASKING LEVEL CORRECTION FACTOR
20	100 HZ	23 HZ	80 HZ	5
21	125	29	70	4
22	160	37	60	2
23	200	46	50	0
24	250	58	50	-1
25	315	72	50	-2
26	400	92	50	-3
27	500	115	50	-4
28	630	145	60	-4
29	800	184	60	-5
30	1000	230	70	-5
31	1250	288	70	-6
32	1600	368	90	-6
33	2000	460	110	-6
34	2500	575	150	-6
35	3150	725	200	-6
36	4000	920	240	-6