METROPOLITAN ACOUSTIC ENVIRONMENTS AND USE OF VEGETATION IN NOISE CONTROL

Range of Sound Levels in the Outdoor Environment

by LEWIS S. GOODFRIEND, *Lewis S. Goodfriend & Associates, 7 Saddle Road, Cedar Knolls, N. J. 07927.*

ABSTRACT.—Current methods of measuring and rating noise in a metropolitan area are examined, including real-time spectrum analysis and sound-level integration, producing a single-number value representing the noise impact for each hour or each day. Methods of noise rating for metropolitan areas are reviewed, and the various measures from multidimensional rating methods such as the Composite Noise Rating are examined, along with the trend towards single-number rating schemes. The reliability of the various noise-measurement and evaluation methods is discussed in terms of planning needs.

THE RANGE OF OUTDOOR NOISE levels is extremely large, ranging from the tranquil quiet of the wilderness to the noisy urban environment. Some people live within 15 feet of the right-of-way of major highways, where the outdoor noise levels may be above 90 dB(A). Many suburban and suburban rural residents live along the right-of-way of major interstate highways and local freeways where even at 100 or 200 feet the sound levels approach 90 dB(A). A far larger number of people live in the rural, suburban, and urban areas more distant from the transportation systems. They are exposed to what, for most of the residents within each area, are noise environments that are quite acceptable. Even here the sound levels range from below 30 dB(A) to as high as 65 or 70 dB(A).

Some specific examples will show the nature of these noise exposures. In one remote rural farming community, the range of residual ambient sound levels across the entire acoustical frequency spectrum for a 24-hour period remained below 41 decibels (fig. 1 and fig. 2). In this same community, the intrusive or L_{10} A-weighted sound levels, the level below which 90 percent of all levels will occur, was only 43 decibels (fig. 3).

For the suburban rural environment, the residual ambient sound levels still have some indication of the flatness with frequency while the L_{10} sound levels as a function of frequency exhibit the spectrum of vehicular traffic (fig. 4).

In the urban environment, both the residual (L_{90}) and the L_{10} levels as a function of frequency show the concave bulge in the midfrequency range characteristic of road traffic (fig. 5).

Even in the urban environment the top ten percent of the levels must be the ones considered intrusive. The intrusions show up with sound levels reaching peaks as high as 90 dB(A). However, the duration is short for any given intrusion (fig. 6).

It is unfortunate that these noises cannot be described in writing because much is lost in the inability to describe all the dimensions of a sound. How can

Figure 1.—Range of summer-day residual ambient noise levels in a rural farming community.

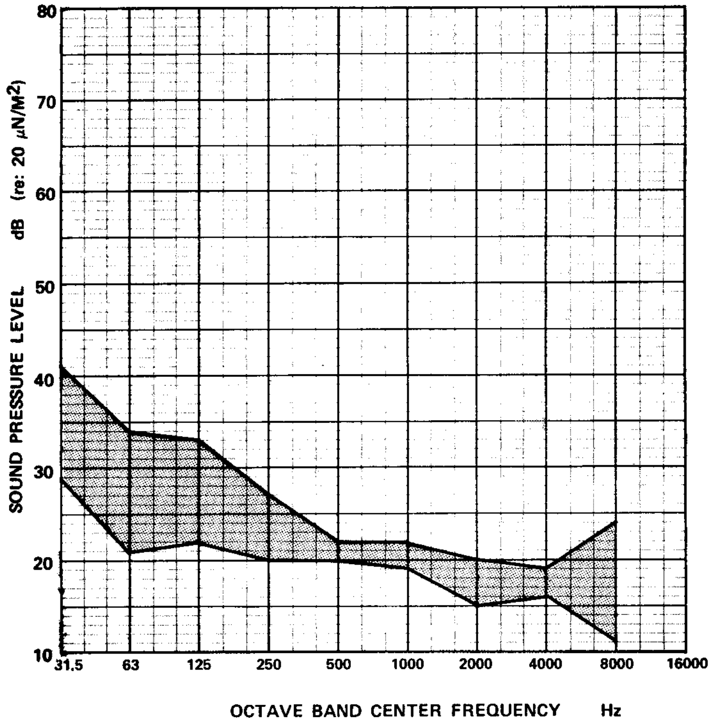


Figure 2.—Range of summer-night residual ambient noise levels in a rural farming community.

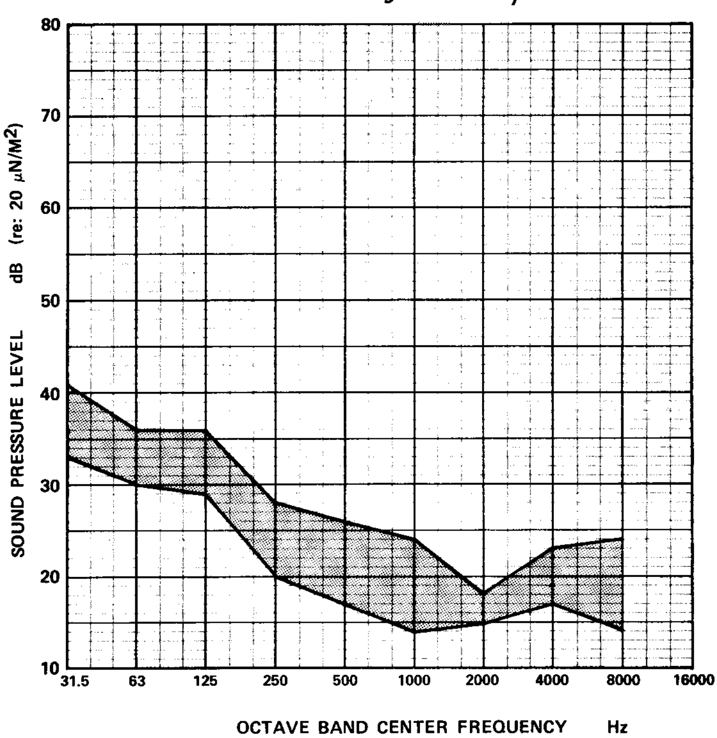


Figure 3.—Statistical distribution of summer-day noise levels in a rural farming community.

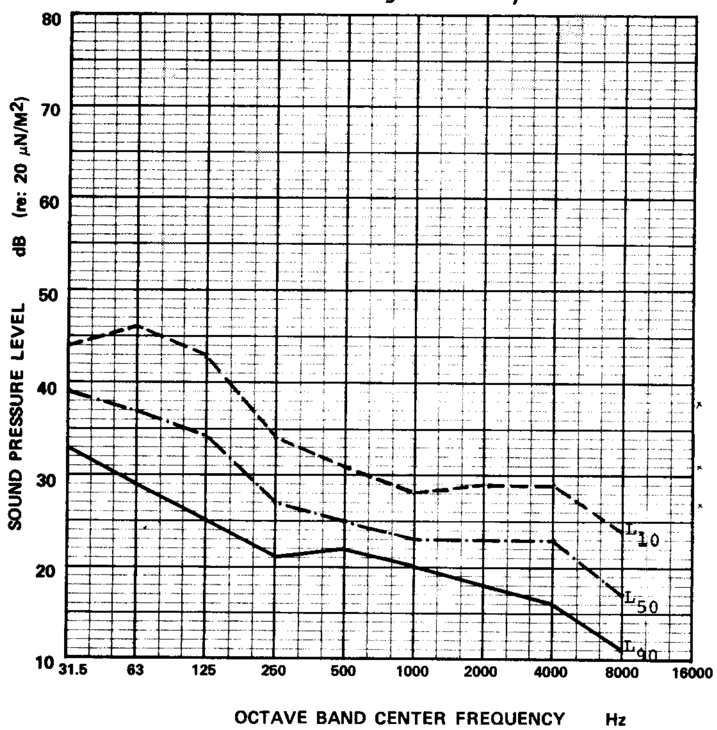


Figure 4.—Statistical distribution of summer-day noise levels in a suburban-rural community.

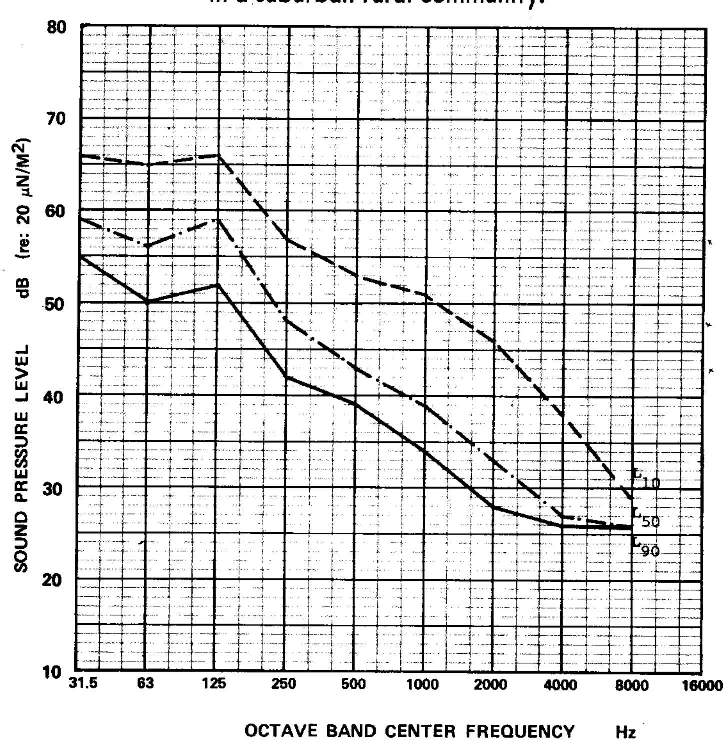


Figure 5.—Statistical distribution of summer-day noise levels in an urban community.

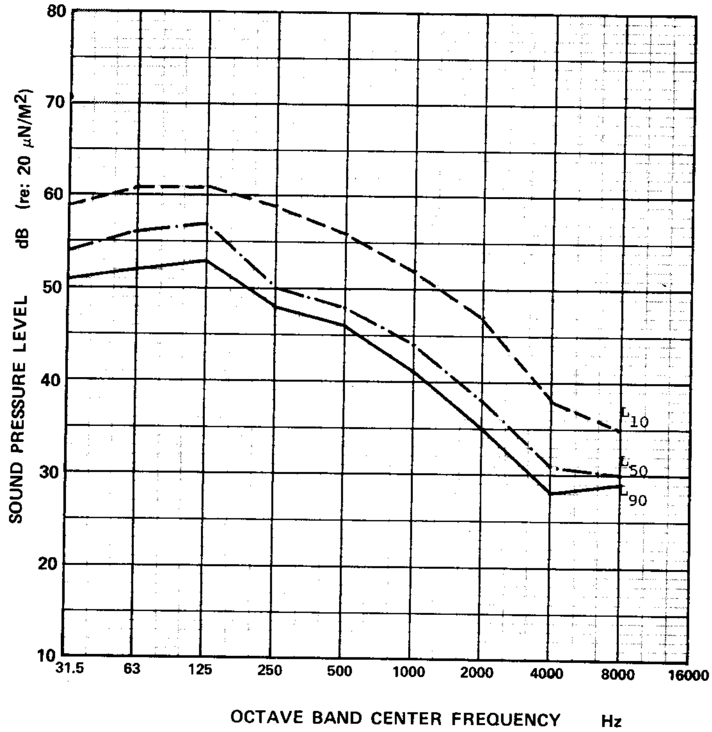
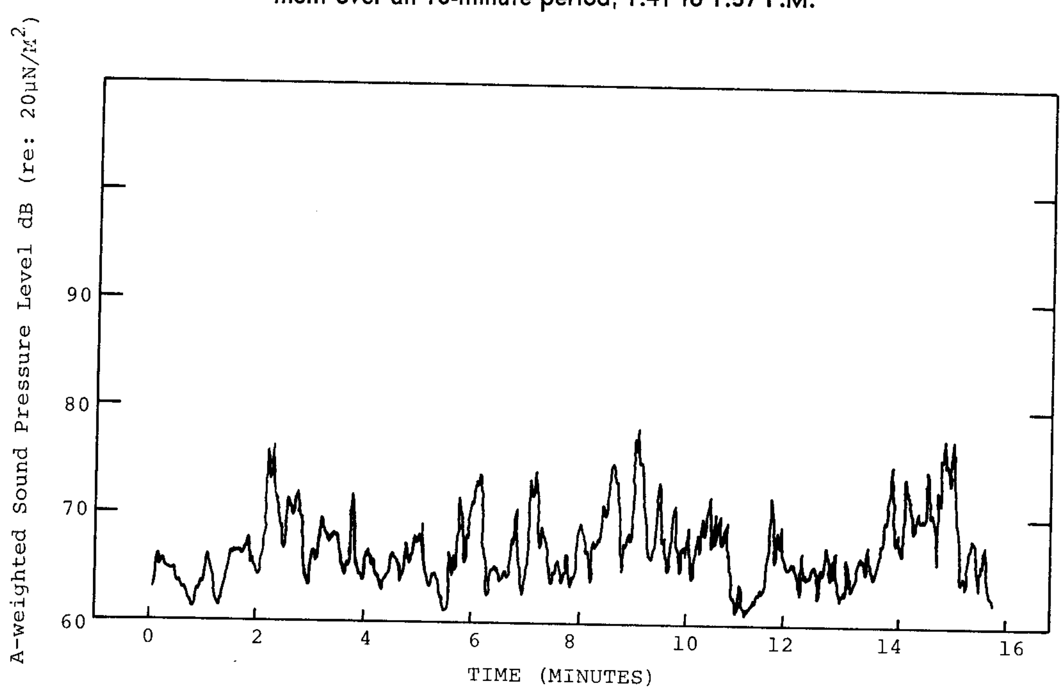


Figure 6.—Time history of the daytime noise levels in a typical urban environment over an 18-minute period, 1:41 to 1:57 P.M.



the pleasant rural summer evening with crickets and peepers producing sound levels in the 40 dB(A) range be compared to the much less acceptable sound of a nearby air conditioner's air-cooled condenser, even though both spectra are rich in high frequency energy. Even more difficult to describe is the difference in the qualities of sounds made by a large heat exchange cooling tower with its water spray and splashing sounds, and the sound of the surf. The acoustical spectra may be quite similar, but one is enjoyed and the other is seldom tolerated, even at sound levels 15 to 20 decibels lower. Of course, one would not exepct to hear the sound of surf pounding the shore in an urban apartment at any sound level. It actually occurs at levels above 60 dB(A) in homes along the shore line in many beachfront communities.

There are many other groups of sounds having similar spectra and levels that range from the totally unacceptable to the pleasurable. It is clear from much of the research on the effects of noise on man that context and associative factors play major roles in the acceptability of sounds that do not interfere with speech communications or sleep. However, as background for creative activity, some high-level noise environments are considered satisfactory while low-sound-level environments containing information inimical to the listener are distracting and annoying.

Even in the residential context where routine family activity is all that is going on, certain sounds at almost any level have undesirable connotations. A new industrial plant that can just be heard, even though it is well below code requirements, would be acceptable in many communities with existing industry. It may not be accepted in a community if it were to move into an industrial zone that has not been occupied previously. The lack of acceptance, even of low-level noise in this case, obviously has social connotations.

RATING NOISE

Can we somehow rate these noise environments in terms of human acceptability? A look at some of the methods tried will indicate the success. It has been common at various times during the past 40 years to characterize noise environments by both single-number values, such as the widely used A-weighted sound level, and by the sound-pressure level in each octave band.

The A-weighted sound level was one of the earliest tools used to rate city noise. However, in the late 1940s the octave band levels were considered necessary to correctly characterize any sound. By 1970, those working in environmental noise were again almost exclusively attempting to use the A-weighted sound level for rating noise environments. Numerous schemes have been developed to measure the A-weighted sound level temporal statistics at one or more points in a community on a sampling statistics basis, and to use these statistics to define the noise climate in some way.

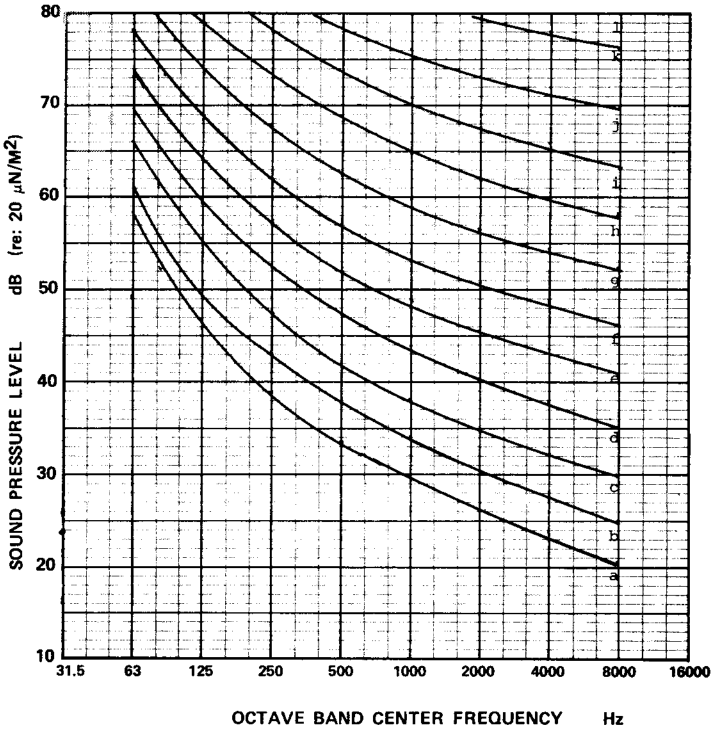
However, a close examination of the factors that influence human response will show why most proposed single-number rating schemes will fail in all but the simplest case. When rating methods are required to define the acceptability of an environment for residential use, be it one family houses, or apartments, or one or more large buildings, they often fail to consider a few susceptible individuals or people who carry on creative tasks at home, such as writers, composers, editors, and students.

A look at some of the more widely used current methods of rating noise environments should show the nature of the problem and the reason why and how each particular scheme fails—and they do fail.

Composite Noise Rating

This first appeared in 1954 in the Air Force's Handbook of Acoustic Noise

Figure 7.—Level rank curves for use in rating residential noise environments. The spectrum to be rated is drawn on the chart and the letter in the highest zone between the curves is assigned as the level rank. The level rank is adjusted according to table I to obtain the Composite Noise Rating or CNR.



Control and was later revised in a paper by Stevens, Rosenblith, and Bolt *(1955)*, and by Harris *(1957)*. The basic idea is to compare the spectrum and levels of a noise with a set of octave band contours labelled with lower case letters (fig. 7). The highest contour penetrated is called the *level rank* for the noise. The level rank is then changed one rank (the equivalent of a five-decibel step) for each of a series of adjustments related to season, time of day, ambient levels, duration, and character of the noise.

The resulting adjusted level rank is given a capital letter designation called the *Composite Noise Rating* (CNR). Use of the curves (fig. 7) allows an estimate based on experience to be made of the nature of community response by comparing the CNR to a table or curve of predicted response (fig. 8). The method is quite good, although it is claimed by Bishop *(1967)* to be less sensitive than it might be because of the five-decibel steps used. However, it has proved most effective where the correct data are supplied, particularly the duration of the intruding noises. Major drawbacks in using the CNR were the need for octave band spectra at several places in the community, along with duration information. This method was later adapted for an aviation noise response-prediction scheme jointly by the military and FAA *(1964)* for a land-use planning evaluation scheme for use around airports.

Community Noise Equivalent Level

This was developed by Wyle Laboratories *(1971)* for application to the airport noise monitoring problem. When

Table 1.—Correction numbers to be applied to noise level rank to yield Composite Noise Rating

Influencing factor	Correction number
1. Background noise:	
Type of neighborhood:	
Very quiet suburban	+1
Suburban	0
Residential urban	—1
Urban near industry	—2
Near heavy industry	—3
2. Temporal and seasonal factors:	
a. Daytime only	—1
Nighttime	0
b. Repetitiveness	
Source operates 20% of time in an 8-hour period	—1
Source operates 10% of time in an 8-hour period	—2
Source operates 2% of time in an 8-hour period	—3
c. Winter	—1
Summer	0
3. Character of the noise:	
a. Spectrum character:	
Continuous spectrum	0
Pure tone	+1
b. Peak factor:	
Smooth time character	0
Impulsive	+1
4. Previous exposure:	
None	0
Some	—1

Figure 8.—The predicted response of a community uniformly exposed to noise levels plotted on the level rank curves and adjusted according to table 1.

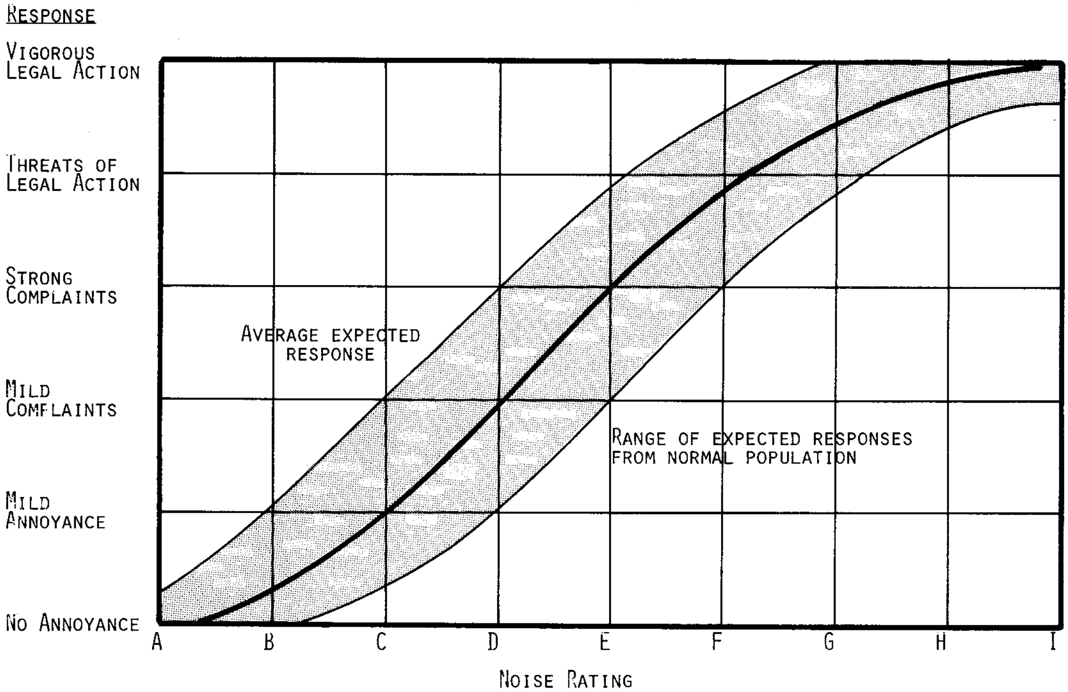
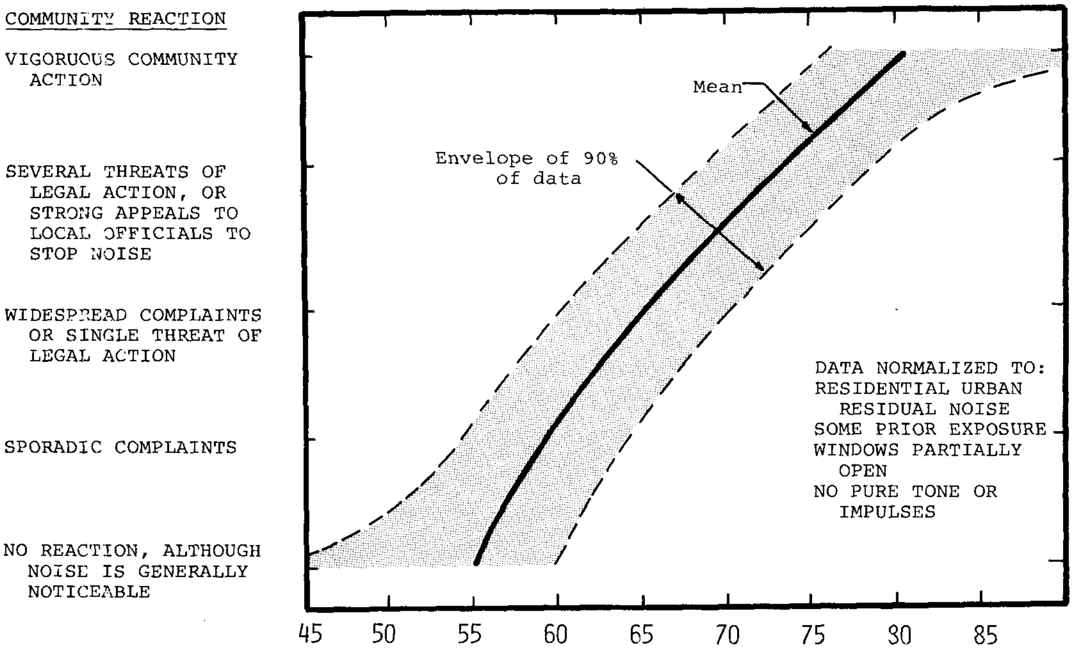


Figure 9.—The predicted response of a community may be obtained from the energy equivalent sound level in three periods—day, evening and night—using the equation shown below the figure. The figure shows the predicted response after adjustment according to table 1.



$$CNEL = 10 \, Log \left(\frac{1}{m+n+l}\right) \left[\sum_{i=1}^{m} Antilog \, (DL_{10}/10)_i + 3 \sum_{i=1}^{n} Antilog \, (EL_{10}/10)_i + 10 \sum_{i=1}^{l} Antilog \, (NL_{10}/10)_i \right]$$

Where m, n, and l are the number of intrusive noise level values for day, evening, and night-time sampling periods, respectively.

examining the problem of using a single number to describe the noise impact on a community from any kind of source, they found that the CNEL could be used as the evaluator of the physical exposure of members of the community. The CNEL is essentially the average of the hourly energy averaged A-weighted sound levels in three periods; day, evening, and night. This may be computed from the data by using the hourly L_{eq} (fig. 9).

The CNEL is then adjusted in the same way that the Composite Noise Rating was obtained and is normalized to the following conditions:

- Residential urban residual noise.
- Some prior exposure.
- Windows partially open.
- No pure tones or impulses.

These data may then be compared to table or chart to evaluate the probable community response (fig. 9).

ISO Draft Recommendation No. 1996

This suggests a method of measurement of noise, corrections to the measured level, and a means of using this corrected or rating sound level, for comparison with a community noise criterion *(ISO 1970)*. The community noise criterion considers various environmental acceptability factors.

The ISO draft recommends that noise should be measured by using a precision sound-level meter set at the A-weighting network and "fast" response. If the noise varies with time (as is the usual case for most nonindustrial environments), the rating is based on the energy equivalent level, L_{eq}. L_{eq} is defined as the "energy mean" of the noise, and for sampled data may be represented as a continuous, unvarying signal resulting in the same total energy each hour, or each day, as produced by the actual noise being measured.

The ISO recommendation suggests adding values to L_{eq} dependent upon the character of the noise and its duration, which results in a better estimate of the community's response to the noise. The resulting value is termed the "rating sound level", L_r.

The "rating sound level" might be considered the A-weighted sound level of a steady noise that does not contain any tonal or impulsive characteristics and produces the same community response. Hammering and riveting, it is suggested, are impulsive characteristics and require that +5 dB(A) be added to the rating sound level.

Two other methods for rating noise have been widely used. These are the Effective Perceived Noise Level in EPNdB, and the Noise Pollution Level.

Effective Perceived Noise Level

This is an extension of the aircraft noise rating method based on the noisiness curves developed by Kryter *(1959)* and applied by him to a broader noise-evaluation technique. It is basically a duration adjusted perceived noise level. It requires the use of the octave band spectra as input. The noise in question is evaluated on a band-by-band basis, using curves or a chart of noy — for noisiness — values for the level in each band. A summing scheme similar to that developed by S. S. Stevens *(1961)* in his loudness computation method, yields a summed noisiness value which may then be converted into the perceived noise level in PNdB. Adjustment for duration and pure tone content are made, and the result is the Effective Perceived Level.

Noise Pollution Level

This appears, at first glance, to have the right balance of the factors of level and duration to provide useful measure of noise impact. It was developed by D. W. Robinson *(1969)* who carried out a thorough analysis of a number of noise-rating methods and proposed that annoyance was related both to the total distribution of energy through the day — i.e., the exposure of the individual to the noise — and to a factor governed by the variation of level. He defined the Noise Pollution Level NPL $= L_{eq} + 2.56\sigma$ where σ is the standard deviation of the measured signal, assuming its distribution of levels as gaussian. This appears to be handy and rank orders numerous environments reasonably well.

However, the scale turns out to be somewhat compressed. Wyle Laboratories *(1971)* found that busy downtown areas had NPL values only slightly higher than suburban residential areas, judged by the public to be considerably less noisy. The strange result derives from the fact that downtown, the standard deviation is rather small — it is continuously noisy — although the L_{eq} is high, but out in the suburbs L_{eq} is low, but the standard deviation is high, as neighbors' cars and delivery vehicles come and go, and the sounds of children at play add to the range of σ. Finally, since community noise is not gaussian, the standard deviation has little or no meaning here.

Department of Housing and Urban Development Noise Criteria

The United States Department of Housing and Urban Development (HUD) has set acceptability criteria for new housing. The external noise standards are:

Category	*Standard*	*Environment*
Clearly acceptable	Does not exceed 45 dB(A) more than 30 minutes per 24 hours.	The noise exposure is such that both the indoor and outdoor environments are pleasant.
Discretionary: normally acceptable	Does not exceed 65 dB(A) more than 8 hours per 24 hours.	The noise exposure is great enough to be of some concern, but common building construction will make the indoor environment acceptable, even for sleeping quarters, and the outdoor environment will be reasonably pleasant for recreation and play.
Discretionary: normally unacceptable	Exceeds 65 dB(A) 8 hours per 24 hours; loud repetitive sounds on-site.	The noise exposure is significantly more severe so that unusual and costly building constructions are necessary to ensure some tranquility indoors, and barriers must be erected between the site and prominent noise sources to make the outdoor environment more tolerable.
Clearly unacceptable	Exceeds 80 dB(A) 60 minutes per 24 hours; Exceeds 75 dB(A) 8 hours per 24 hours.	The noise exposure at the site is so severe that the construction costs to make the indoor environment acceptable would be prohibitive and the outdoor environment would still be intolerable.

Day-Night Level

The L_{dn} is equivalent to the $L_{eq_{24}}$ with a 10 dB weighting applied to the equivalent level during the nighttime hours. The L_{dn} is defined as follows:

$$L_{dn} = 10 \log \frac{1}{24} [15 (10^{Ld/10} + 9 (10^{Ln/10})]$$

$L_d = L_{eq}$ for the daytime hours (0700 to 2200)

$L_n = L_{eq}$ for the nighttime hours (2200 to 0700)

The 10 decibel weighting was derived from several considerations: prior use of a nighttime weighting in other descriptors, and a normal difference in daytime and nighttime levels of 10 decibels. Descriptors such as CNR, NEF, NCNEL all use a weighting on the order of 10 decibels to adjust noise produced during the night to produce a more severe reaction on their response scales. The correction in these rating schemes, as well as L_{dn}, is designed to protect persons from possible sleep interference.

The assumption that equivalent sound levels for daytime and nighttime usually differ may be a valid one for urban and suburban communities, but in a rural suburban or rural community, this is rarely the case. Sound levels in rural areas are determined by distant events since local activity is low. Local activity causes the difference in daytime and nighttime levels, and an area lacking this activity will experience very little change from day to night with perhaps an increase at night due to insects. It is in this case that the usefullness of L_{dn} as a descriptor of impact is limited. A noise source may operate solely during the day, at levels comparable to the daytime ambient of, say, 45 dB(A); and a similar level at night of 45 dB(A) may be produced by insects, resulting in an L_{dn} of 55. However, the EPA literature indicates that this level produces activity interference outdoors. Clearly the noise source is not causing the high L_{dn}, which indicates that care must be used whenever L_{dn} is used as a criterion.

DISCUSSION

Mathematical modelling techniques have proved useful in predicting the noise of a wide variety of projected facilities. Among the more widely used noise models are those for:

- Power-plant fans
- Cooling towers
- Air discharge and valve noise
- Highway traffic noise
- Railroad noise
- Aircraft

These models and some specially designed proprietary models for power plants and construction sites may be combined with analytical techniques to produce large-scale environmental models. Many models have been developed or modified for computer use. Others make use of nomographs, tables, and charts.

There are many situations where monitoring cannot identify which of multiple noise sources is the major contributor. Also, where changes to industrial plants are to be made or new transportation or industrial facilities are to be built, mathematical modelling of acoustical properties is a useful and reliable predictive technique.

We have shown that the range of outdoor noise levels is great, ranging from less than 30 to more than 90 dB(A). The methods that are close to actual field conditions for rating the acceptability of these various environments include factors that account for the social and geographic situation as well as the spectrum duration and the level of noise. No rating system is completely successful in rating environmental noise because it is difficult to characterize or quantify some of the factors that influence acceptability.

The final rating of environmental noise is always its acceptance or rejection by the community.

LITERATURE CITED

Bishop, D. E., and R. D. Horonjeff.
1967. PROCEDURES FOR DEVELOPING NOISE EXPOSURE FORECAST AREAS FOR AIRCRAFT FLIGHT OPERATIONS. FAA-DS-67-11.

Harris, Cyril M. (editor).
1957. HANDBOOK OF NOISE CONTROL, CHAPTER 36. McGraw-Hill, New York.

International Standards Organization (ISO).
1970. NOISE ASSESSMENT WITH RESPECT TO COMMUNITY RESPONSE. Acoust. Soc. Am. R1996.

Kryter, K. D.
1959. SCALING HUMAN REACTIONS TO THE SOUND FROM AIRCRAFT. J. Acoust. Soc. Am. 31: 1415-1429.

Robinson, D. W.
1969. THE CONCEPT OF NOISE POLLUTION LEVEL. NPL Aero Rep. AC38. Natl. Phys. Lab., Aerodyn. Div., Teddington, England.

Stevens, S. S.
1961. PROCEDURE FOR CALCULATING LOUDNESS: MARK VI. J. Acoust. Soc. Am. 33: 1577-1585.

Stevens, K. N., W. A. Rosenblith, and R. H. Bolt.
1955. A COMMUNITY'S REACTION TO NOISE: CAN IT BE FORECAST? Noise Control 1: 63-71.

Wyle Laboratories.
1971. COMMUNITY NOISE. U.S. Environ. Protect. Agency. 100 p.