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CHAPTERS VII + VIII

Guidelines for Preparing Environmental Impact Statements on Noise

Committee on Hearing, Bioacoustics and Biomechanics

Assembly of Behavioral and Social Sciences

The National Research Council

VII. QUANTIFICATION OF THE ENVIRONMENTAL IMPACT OF NOISE

A. General

The impact of a noise environment on people regularly experiencing that environment is the degree to which the noise interferes with various activities such as speech, sleep, listening to radio and TV, thus, the peaceful pursuit of normal activities, and the degree to which it may impair health, through, for example, the inducement of hearing loss. The impact of a particular noise environment is a function of both sound level and the size of the population experiencing a particular value of sound level. One method for describing the noise impact of an action requiring the preparation of a noise impact report is to tabulate the number of people regularly experiencing various sound levels as described in Chapter IV.

Sound levels produced by sources being considered in an environmental assessment will generally vary with distance from the source, sometimes over a large geographic area. As a consequence, people occupying different geographic areas will experience different sound levels. It is desirable to derive a single number which represents quantitatively the integrated effect of "impact" of the action on the total population experiencing the different sound levels. This single number quantification is defined below as the sound level weighted population, LWP. Sound level weighted population, together with the tabulations of populations experiencing sound levels of a specified value, constitute the minimum quantification of environmental impact of noise recommended in these guidelines. A useful second descriptor of noise impact is the noise impact index, NII, which is formed by the ratio of sound level-weighted population to the total population.

In some high level noise environments people will be exposed regularly to average sound levels in excess of 75 decibels. In these environments special consideration should be given to the potential for noise-induced loss of hearing. A measure is defined below, the population weighted hearing loss, PHL, which provides a measure of the average hearing loss that might be expected for the population under consideration.

B. Sound Level Weighted Population

Sound level weighted population is a single number representation of the significance of a noise environment to the exposed population. Several assumptions are made in this method of analysis:

1) Intensity of human response is one of several consequences of average sound level, depending upon the response mode of interest (annoyance, speech interference, hearing loss).
2) The impact of high noise levels on a small number of people is equivalent to the impact of lower noise levels on a larger number of people in an overall evaluation. Thus the properties of intensity (level of sound) and extensity (number of people affected by the sound) can be combined mathematically.
3) On the basis of these two assumptions one can ascribe differing numerical degrees of impact to different segments of the population of concern, depending on the average sound level.

These concepts have been embodied into a descriptive term called the fractional impact method. In this method, the "fractional impact" is the product of a sound level weighting value and the increment of population exposed to a specified sound level. Summing the "fractional impacts" over the entire population provides the sound level weighted population, LWP. That is:

$$LWP = \int P(L_{dn}) \cdot W(L_{dn}) \; d(L_{dn}) \qquad \text{VII-1}$$

where $P(L_{dn})$ is the population distribution function, $W(L_{dn})$ is the day-night average sound level weighting function characterizing the severity of the impact as a function of sound level described below, and $d(L_{dn})$ is the differential change in day-night average sound level.

It is usually not necessary to use the integral form to compute LWP. Sufficient accuracy is usually obtained by taking average values of the weighting function between equal decibel increments, up to 5 decibels in size, and replacing the integrals by summations of successive increments in average sound level. See the example given below.

C. Noise Impact Index

Noise Impact Index, NII, is a useful concept for comparing the relative impact of one noise environment with that of another. It is defined as the sound level weighted population divided by the total population under consideration:

$$NII = \frac{LWP}{P_{Total}} = \frac{\int P(L_{dn}) \cdot W(L_{dn}) \; d(L_{dn})}{\int P(L_{dn}) \; d(L_{dn})}$$

where the functions are the same as described above in Section B.

D. Population Weighted Loss of Hearing

The population weighted loss of hearing, PLH, is a single number representation of the potential loss of hearing, i.e., the average change in hearing threshold level in decibels that would be expected from a population experiencing the various day-night average sound levels in excess of 75 decibels. This quantity is formed by the ratio of sound level-weighted population to total population (experiencing day-night average sound levels in excess of 75 decibels).

Similar to NII, PHL is computed in decibels as:

$$PHL = \frac{\int_{75}^{x} P(L_{dn})\ H(L_{dn})\ d(L_{dn})}{\int_{75}^{x} P(L_{dn})\ d(L_{dn})}$$

where $H(L_{dn})$ is the loss of hearing weighting function described below, $P(L_{dn})$ is the population distribution functions, and $d(L_{dn})$ is the differential change in day-night average sound level. NOTE: PHL is in decibels since the weighting function of loss of hearing has not been normalized.

Again, the integral forms may be replaced by summation over successive increments of day-night average sound level. It is recommended that increments of day-night average sound level less than five decibels (e.g. 2 decibels) be used in calculating values of PHL.

NOTE: A term similar to the level weighted population may be calculated by using only the numerator of the above expression. While use of such a term is not recommended for residential areas, such a term could be useful for evaluation of regulations and other such actions. In the evaluation of the effect of noise on hearing for situations in which residential exposure is of no or minimal concern (e.g. exposure of passengers in transportation), the eight hour average sound level (L_{8h}) should replace the day-night average sound level in calculating the potential loss of hearing.

E. Sound Level Weighting Functions

Two different weighting functions are provided for use in the analysis of environmental noise impact, one for general application in the majority of analyses in which the overall impact of the noise on the "Health and Welfare" of residential populations is involved, and one for evaluating the potential for hearing damage when the day-night average sound level exceeds 75 decibels.

1. Sound level weighting function for overall impact analysis. In the majority of analyses the primary concern is the effect of a noise environment on the residential population living in the environment under consideration. The weighting function used for this form of analysis is based on the documented reaction of populations to living in noise impacted environments (see Chapter VI) and is numerically derived from social survey data relating the fraction of sampled population expressing a high degree of annoyance to various values of day-night average sound level. (See Appendix B.) The weighting function is arbitrarily normalized to unity at $L_{dn} = 75$ decibels. (However for specific applications, it is always possible by way of the appendix to translate the level-weighted population into the actual number of people highly annoyed by the environment under consideration.) Values of the function are listed in Table VII-1, and the function is plotted in Figure VII-1. The analytic expression for the function is:

$$W(L_{dn}) = \frac{\left[3.364 \times 10^{-6}\right]\left[10^{0.103L_{dn}}\right]}{\left[0.2\right]\left[10^{0.03L_{dn}}\right] + \left[1.43 \times 10^{-4}\right]\left[10^{0.08L_{dn}}\right]}$$

In a number of environmental noise assessments conducted by EPA an early form of population weighting has been used where the day-night average

TABLE VII-1

Sound Level Weighting Function for Overall Impact Analysis

The right hand column is included for convenience for finding the weighting of certain 5 dB increments.

L_{dn} -dB	$W(L_{dn})$	$\frac{W(L_{dn}) + W(L_{dn} + 5)}{2}$
35	0.006	0.010
40	0.013	0.021
45	0.029	0.045
50	0.061	0.093
55	0.124	0.180
60	0.235	0.324
65	0.412	0.538
70	0.664	0.832
75	1.000	1.214
80	1.428	1.697
85	1.966	2.307
90	2.647	

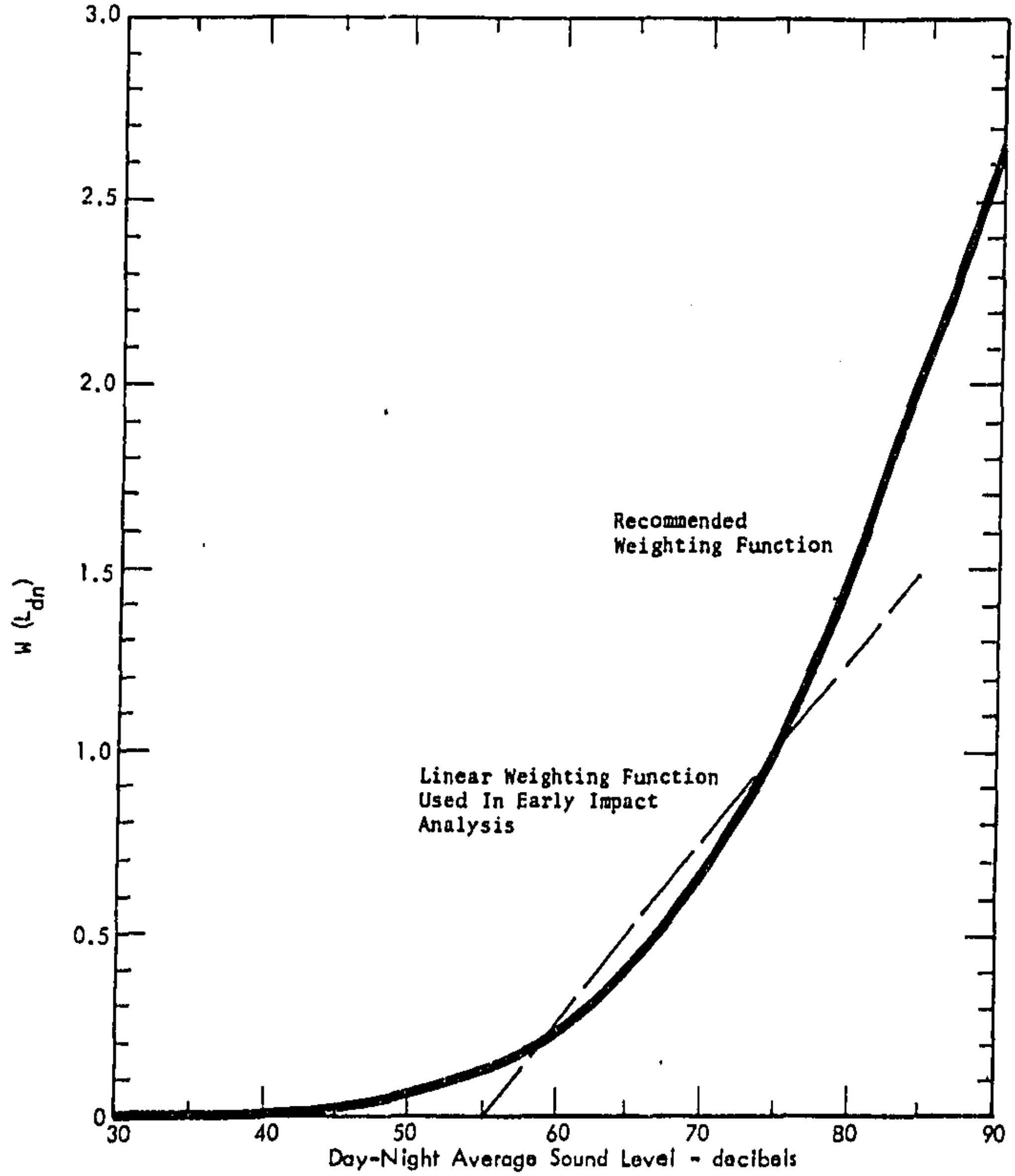

FIGURE VII-1. SOUND LEVEL WEIGHTING FUNCTION FOR OVERALL IMPACT ANALYSIS sound levels have ranged from 55 decibels, or higher, to 80 decibels. This weighting function was described as "fractional impact," FI, and has the form:

$$FI = 0.05\ (L_{dn} - 55)$$

This function is shown as the dashed line on Figure VII-1. It can be shown that, in the day-night average sound level range of 55 to 80 decibels, this linear weighting function will generate numerical values for level weighted population that differ only by the order of one percent from the more general weighting function, $W(L_{dn})$, in many applications.

2. Weighting function for loss of hearing/severe health effects. In those specialized environments where people are directly exposed, on a regular, continuing, long-term basis to day-night average sound levels above 75 decibels, there is a potential for producing noise-induced loss of hearing and other potentially severe health effects. The weighting functio for loss of hearing/severe health effects, $H(L_{dn})$ or $H(L_{8h})$, is expressed as:

$$H\ (L_{dn}) = 0.025\ (L_{dn} - 75)^2$$

$$\text{or} \quad H\ (L_{8h}) = 0.025\ (L_{8h} - 75)^2$$

Table VII-2

Weighting Function for Loss of Hearing/Severe Health Effects

L_{dn} or L_{8h} (dB)	$H(L_{dn})$ or $H(L_{8h})$ (in dB loss per ear)
75	0
76	0.025
77	0.100
78	0.225
79	0.400
80	0.625
81	0.900
82	1.225
83	1.600
84	2.025
85	2.500
90	5.625
95	10.0

3. Changes in level weighted populations and noise impact indices. A primary concern in an environmental noise assessment is a quantification of the effect of the action being assessed on the noise environment before and after the action was to take place. Two types of description of the effect of the action are useful (in addition to the always required description of populations experiencing various day-night average sound levels). The first descriptor is simply the numerical change in sound level weighted populations before and after the action, the change being an increase or decrease in sound level weighted population (or the neutral effect case, no change).

A second descriptor is the percent change in sound level weighted populations, where the effect of the action is expressed as the value of the sound level weighted population after the action, divided by the sound level weighted population before the change.

F. Example Computation of Level Weighted Population, Noise Impact Index, and Population-Weighted Loss of Hearing

An estimate of the U.S. urban population exposed to various day-night sound levels of traffic noise in excess of 55 decibels is provided in reference 1. An example of the use of the day-night sound level weighting function applied to these data is shown in Table VII-3. The computation is performed by counting the population within successive 5 decibel increments of sound level, multiplying by the weighting function, then summing the weighted increments to obtain the sound level weighted population. The noise impact index is obtained by dividing the level weighted population by the total population. Note that, as in any noise impact analysis, the first requirement in the computation is to obtain the population distribution as a function of average sound level.

TABLE VII-3

Example of Level Weighted Population Computation
- Urban Traffic noise

L_{dn} -dB	Cumulative Population - millions	Incremental Population - millions	Weighting Function	Level Weighted Population - millions
80	0.1	0.1	1.695	0.17
75	1.3	1.2	1.203	1.44
70	6.9	5.6	0.832	4.66
65	24.3	17.4	0.538	9.36
60	59.6	35.3	0.324	11.44
55	97.5	37.9	0.181	6.86
Total	97.5			33.9

$$NII = \frac{33.9}{97.5} = 0.35$$

In a comparable manner, the expected change in population-weighted loss of hearing can be calculated for the same example, now using two decibel increments in the computation.

TABLE VII-4

Example of Population-Weighted Loss of Hearing
- Urban Traffic Noise

L_{dn} -dB	Cumulative Population - millions	Incremental Population-ΔP - millions	Weighting Function	$H(L_{dn}) \cdot \Delta P(L_{dn}$
81				
79	0.25	0.25	0.625	0.156
/7	0.66	0.41	0.225	0.092
75	1.30	0.64	0.025	0.016
				0.264

$$PLH = \frac{0.264}{1.3} = 0.2 \text{ decibel}$$

An environmental assessment of this urban traffic noise example can be summarized as follows:

For the 97.5 million people in the urban portions of the United States who experience traffic noise in excess of a day-night average sound level of 55 decibels, the sound level-weighted population is 33.9 million, with a noise impact index of 0.35. For the 1.3 million of this population who experience day-night average sound levels in excess of 75 decibels, the average degradation in hearing acuity can be expected to be 0.2 decibel.

G. Assessment of Special Situations

The procedures described above are intended to apply most generally to the noise environment in most instances. Certain special situations arise, however, in which these methods are insufficient. In particular, high intensity impulsive sounds, infrasound, ultrasound, are not directly assessed by the procedures already described. These situations are described below.

1. High intensity impulsive sounds. The noise produced by sonic booms, artillery firing, blasting and similar activities is assessed in terms of C-weighted sound exposure level, as described in Section V. For these sounds, the composite day-night average sound level is computed as the logarithmic addition of the average sound level produced by the C-weighted sound exposure levels for the impulsive sounds and the A-weighted day-night average sound level produced by all other sources. The resulting composite day-night average sound level is then used in the assessment of impact exactly in the same manner as for non-impulsive sounds.

2. Infrasound. Infrasound is not normally an environmental problem, and when it does occur, usually higher frequency noises are present which

not only cause more of a problem, but which are properly assessed by day-night average sound level. However, the fractional impact method is not suitable for quantifying the impact infrasound itself. Instead, the qualitative impact is to be described; the effects that might occur at different sound levels are given in Section VI, Criteria.

3. Ultrasound. No quantification of the environmental impact of ultrasound is recommended. Rarely is ultrasound (except for some occupational situations, e.g., ultrasonic cleaners) an environmental problem of practical interest. Evaluation of ultrasound exposure above 105 dB requires additional investigation and research to evaluate the impact.

4. Temporary noise environnments. Screening methods for determining the degree of analysis required for consideration of temporary changes in noise environment have been discussed in Section III-E-2. For those situations in which a detailed analysis of the temporary noise environment is required, impact assessment is made in the same manner as for permanent noise environments by the use of sound level-weighted population and noise impact index calculations.

For both temporary and permanent noise environments the yearly average day-night average sound level should be used in computation of impact indices. In some instances it is useful to compute LWP and NII for two situations:

a) consider the temporary noise environment as if it were permanent, but also state its actual duration;

b) consider the temporary noise environment in terms of its contribution to the annual average day-night average sound level.

For example, consider a population of 1000 experiencing a temporary day-night average sound level of 70 decibels for nine months due to a construction project, after which the day-night average sound level drops to 60 decibels on a long-term basis. The following three situations would be described:

1. During the nine-month construction period itself, the level-weighted population is (0.664) (1000) = 664, and the noise impact index is 0.664.

2. The effect of the construction activity on annual average impact is obtained from the annual average day-night average sound level:

$$L_{dny} = 10\log_{10}\left[\left(\frac{9}{12} \times 10^{\frac{70}{10}}\right) + \left(\frac{3}{12} \times 10^{\frac{60}{10}}\right)\right] = 68.9 \text{ decibels}$$

For the year during which construction takes place the sound-level weighted population is 601 and the noise impact index is 0.601.

3. After construction is complete the sound level weighted population is 236 and the noise impact index is 0.236.

H. Assessment of the Impact of Vibration Exposure

1. General. There is a lack of data related to the assessment of the severity of the impact that results if the vibration guidelines proposed in this section are exceeded. It is recommended that the number of people exposed to vibration levels above the "no complaint" value (see Table VI-5) as well as the number of structures, if any, above the potentially structure damaging accelerations of 1 m/sec^2 and .5 m/sec^2 be estimated (see Section VI-D for structural damage). For a

specific action, therefore, contours of 1 m/sec^2, .5 m/sec^2 and appropriate "no complaint" acceleration value as determined by Table VI-5 should be predicted/measured. For example, if an action causes a steady vibration that lasts a total of 25 secs a day (during daytime hrs), the contour of .014 m/sec^2 should be evaluated ($.072/\sqrt{25} = .014$).

To evaluate alternative actions when the vibration values are above the "no complaint" values, the Vibration Weighted Population and the Vibration Impact Index as described below can be used.

2. Vibration Impact Index - Vibration Weighted Population. Figure VI-5 summarizes the complaint history from the Salmon Nuclear Event. For a single event the number of complainants for residential areas varies roughly as 10 log K (for peak acceleration range of 0.1 m/sec^2 to 1 m/sec^2), where K is the ratio of the observed acceleration to 0.1 m/sec^2. It is suggested that this concept be tentatively broadened to apply to the vibration exposure to more than one impulse or to intermittent/ continuous exposures by defining K as the ratio of the actual acceleration to the recommended "no complaint" acceleration value. A term for the impact of vibration on residential areas can then be defined by using a vibration weighting function. This function is described by:

$V(k) = 20 \log k$

where k is ratio of the actual acceleration to the recommended no complaint acceleration values listed in Table VI-5 for a specified time period and where k is limited to values from 1 to 20.

A descriptor of the total vibrational impact of a project can be obtained by multiplying the number of people exposed to each vibrational condition by the vibration weighting function for that condition, finding the sum of these products, and then dividing this sum by the total number of residences. This results in an index that is similar to the Noise Impact Index, but that applies to vibration. This index is called the Vibration Impact Index (VII) and is found from:

$$VII = \frac{\int_1^k P(k)\ V(k)\ dk}{\int_1^k P(k)\ dk}$$

where V(k) is the vibration weighting function described above, P(k) is the population distribution function and dk is the differential change in k.

The related-Weighted Population (VWP) is defined as:

$$VWP = \int_1^k P(k)\ V(k)\ dk$$

Changes in VWP and VII can then be used to evaluate various alternatives and actions with respect to vibration.

VIII. SUMMARY OF NOISE IMPACT ANALYSIS

This chapter summarizes the analysis that might be expected in an environmental impact statement on noise for each branch (or element) of the flowchart described in chapter three that requires a full noise environment documentation. Discussion under each element should not necessarily be limited to the information and procedures proposed in this document, but should include all relevant material and use any other appropriate procedures. For some of the elements, additional references are suggested.

A. Elements under Potential Change in Noise Environment

1. Animals exposed. First, the changes in the noise environment should be described in detail. The extent of the necessary discussion about these changes will be very dependent on whether or not the exposure of any specified animals is a commonplace situation. Specific effects of the expected noise on endangered species, or abnormally high sound levels on domestic or wild animals should be discussed in detail. Material of the Criteria Document and the associated references might be consulted. Where both people and animals are impacted in the same areas, the assessment of the noise impact on people should be considered sufficient to assess the noise impact on animals.

2. Structures exposed. The noise environment should be described for each building or set of buildings in terms of maximum sound pressure levels. Either a worst case or a statistical estimate of the distribution of max levels should be provided. A discussion of the possible damaging effects of noise on structures or monuments is required. The chance that such effects could occur should be estimated. Finally, the significance of such damage, either in monetary and/or non-monetary terms should be reviewed.

3. Developable land. In evaluating effects of a permanent project at 20 years in the future, it might often be necessary to assess the impact on developable land. Data for the undeveloped and developed situation should be included in the summary tables required in Chapter IV. The amount of land that still could be developed after 20 years can be mentioned. In some cases, especially if the future population density cannot be predicted, a sound level weighted area could be calculated and used. The concept of developable land need not be discussed for temporary projects. Wilderness land should be an identified special situation as listed in the tables of Chapter IV. A word description of how the noise will affect the wilderness area should be provided.

4. People exposed - those levels under 55 dB but greater than 40 dB. The full Noise Environment Documentation will be required when the expected day-night average sound level of the project is such that the project is not screened out per Figure II-1. When full NED is required, summary tables suggested in Chapter IV should be constructed. Since the prediction and identification of noise sources becomes more difficult at levels below 50 dB, reasonable accuracy in these tables may be difficult to obtain. The change in level weighted population and Noise Impact Index can be used to describe the impact, but the interpretation of these indicies becomes less direct as the noise levels discussed are lowered. It should be mentioned that no health and welfare effects are expected to occur. A word description describing the general degradation caused by the change in the noise environment should be presented.

5. People exposed - some day night average sound levels above 55 dB. The data tables listed in Chapter VI should be completed and the level weighted population calculated for the residential population of each table.

For comparing the "before" and "after" day-night average sound levels of the same area or population, the absolute change in LWP as well as the percentage change in LWP can be used. If different noise sources or noise problems are compared with each other, the use of LWP as an absolute quantity and the use of the Noise Impact Index are recommended. For comparing the "before" and "after" changes in noise of different actions for different areas and/or populations, the LWP, change in LWP, NII, and % change in LWP are recommended; however, special emphasis should be placed on precisely defining the population/area considered when using these terms. A word description of the effect of the change in the noise environment on the special situations listed in the summary tables should be made. Of the special situations that are most likely to be the greatest impacted, the highest impact situation should be identified and discussed in reasonable detail.

As a final part of the assessment, a descriptive qualitative evaluation of the expected change in the acoustical environment should be made. This evaluation may be to some extent subjective and the opinion of the preparer, but it must be backed up with material that gives the opinion credibility. Previous experiences - if feasible in the same area - such as complaint listing, legal action, community surveys, with similar changes should be described.

6. <u>People exposed - some day night average sound levels above 75 dB.</u> In addition to the comments discussed in the preceding paragraph, the numbers of people exposed to day night average sound levels above 75 dB

should be given special attention. One descriptor, the population weighted loss of hearing can be used and the change and the percent change in PLH described. In residential areas, overemphasis of just the hearing loss consideration should be avoided. Instead emphasis should be placed on the possibility of severe health and welfare problems, using PLH as an indicator of the degree of severity. Finally, the effects on people of the highest DNL to which people are exposed should be discussed. The maximum Noise Induced Permanent Threshold Shift for the part of the population actually exposed on a daily basis to eight hour average levels above 75 decibels should be estimated (see Figure VI-2).

7. People exposed - special noises. For any special noise, enough Noise Environment Documentation must be provided to describe the noise environment for the population. As with general audible noise, tables such as those in Chapter IV may be needed. Except for large impulsive sound, only a word description of the effects of the special noise is recommended. The criteria of Chapter VI should be referenced, but in many cases additional reference material may be required. A discussion of previous experience with such noises must be made, if available. For high energy impulse noise, (see definition in Chapter V) the analysis can be carried further and the expected percent highly annoyed, and changes in this quantity, can be estimated as described in Chapter VI. The effects of high energy impulse noise may also be combined with general audible noise by use of a composite day-night average sound level.

B. Elements with a Potential Change in Populations

1. New population exposed to day night sound levels above 55 dB. The noise environment documentation required will consist of the development of

simplified summary tables as recommended in Chapter IV. Changes in the existing environment (before the change in population) introduced by the noise accompanying the population change should be used to define the final noise environment. Level weighted population from this environment can be compared to the LWP that would be calculated from the noise environment that would be predicted by Table IV-1. The Noise Impact Index should also be used in these situations and compared with the typical urban NII value calculated in Table VII-1. Unless there is evidence to the contrary, movement of an urban residential population into the area under evaluation can be assumed to be from an area with a NII of .35.

2. New population exposed to day-night sound levels above 75 dB. A complete noise environment documentation resulting in a summary table must be constructed similar to that of Chapter IV. An analysis similar to that of paragraph VIII-A.6 (people exposed - some day-night sound levels above 75 dB) should be made where a change in population results in exposures to a DNL greater than 75 decibels.

C. Potential Change in Vibration of Buildings

1. People exposed. The necessary NED should include documentation of the vibration environment such that the expected vibration acceleration values due to some action are provided for all residential areas, and other sensitive areas, in which the weighted acceleration exceed the "no complaint" level. The change in the vibration environment can be discussed by both using the average Vibration Impact Index for the exposed population and by listing the expected effects at the nearest residence. A discussion of the effects of the vibration environment on sensitive non-residential buildings is also needed.

2. Structures exposed. When structures are exposed to potentially damaging vibration, a description of the expected damage and the likelihood of such damage occurring should be provided for each type of structure. The information in Appendix C will be of some help in making this assessment, but often enough data will not be available to fully make this assessment. In such cases, a program for monitoring the actual damage, or lack of it, may be necessary.

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