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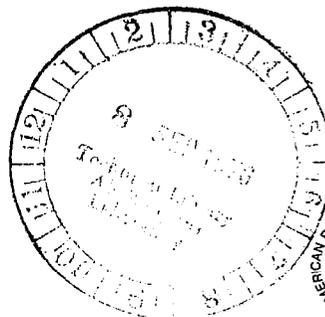
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ANALYSIS OF THE EFFECT  
OF NUMBERS OF AIRCRAFT OPERATIONS  
ON COMMUNITY ANNOYANCE

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ABSTRACT

The general validity of the equivalent-energy concept as applied to community annoyance to aircraft noise has been recently questioned by investigators using a "peak-dBA" concept. Using data previously gathered around nine U.S. airports, this report presents empirical tests of both concepts. Results show that annoyance response follows neither concept, that annoyance increases steadily with energy-mean level for constant daily operations and with numbers of operations up to 100-199 per day (then decreases for higher numbers), and that the behavior of certain response descriptors is dependent upon the statistical distributions of numbers and levels.

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SUMMARY

Studies of community response to aircraft noise, performed around nine airports in the USA in the period 1967-1971, produced a large data base containing response information obtained by social surveys as well as a detailed description of the associated aircraft noise exposure. In the final reports for these studies, noise exposure was formulated according to an equivalent-energy model, according to which a 10-decibel change in noise level is equivalent to a 10-fold change in number of noise events.

More recently, several investigators have questioned the general validity of the equivalent-energy concept, as applied to aircraft noise. Certain of these have offered an alternative concept, called in this report the Swedish model. According to this hypothesis, the influence of numbers of operations has two modes. Below 35 operations per day, annoyance is essentially zero except for maximum flyover levels above 90 dB, A-weighted, in which case there is an increase in annoyance. Above 50 operations per day, annoyance is a linear function of the highest level produced by any aircraft operation occurring at least three times per day.

The purpose of the present analysis is to document the behavior of annoyance response for different numbers of operations and to examine the results in terms of the equivalent-energy and Swedish models. This was done in three ways. First, the percentage

of highly annoyed respondents was determined for various categories of level and number. Next, the statistical distribution of the annoyance of individual respondents was determined for the same categories. Finally, regression of individual annoyance on level was established for different number categories. The results were as follows:

1. Annoyance response does not follow either an equivalent-energy model or the Swedish model.
2. Annoyance increases steadily with energy-mean level for constant daily operation.
3. Annoyance increases with numbers of operations up to 100-199 per day, then decreases for higher numbers.
4. The behavior of different response descriptors, such as percentiles or means of annoyance, is influenced by differences in statistical distributions depending on level and number.

The complexity of the data and variability in response preclude an obvious indication of some other model. Further studies are required to better define response to aircraft noise. In order to obtain meaningful results, such studies should be designed to test specific human response models and also should treat both stimulus and response as time-dependent variables. Both of these requirements will improve methodology, in comparison to previous studies.

At present, estimations of probable response can best be made considering level and number as separate variables. The data in this report afford a basis for such predictions.

## INTRODUCTION

The analysis reported here was performed as the second of two tasks under contract NASw-2774. The initial task was to consolidate and document the large data base produced during studies of community response to aircraft noise in the period 1967-1971 under previous contracts NASw-1549 and NAS1-10216 (refs. 1 and 2). This set of data contains responses from 8462 personal interviews and acoustical measurements representing over 10 000 aircraft operations, acquired in the vicinity of nine airports in the USA. The resulting data base is a useful resource for further analytical studies regarding community response to aircraft noise.

The purpose of the present investigation is to examine the role of the number of aircraft operations in determining community response to the noise of the operations. The number of operations is generally recognized as one component of cumulative noise exposure, which in turn is related to the acceptability or nonacceptability of the aircraft noise environment. A second important exposure component is the level of noise from each aircraft operation. The trading relationship between the two variables, number and level, at a given value of community acceptability, must be delineated as accurately as possible if a generalized measure of noise exposure is to be used for assessment, planning, and regulation in regard to aircraft noise.

Most current formulations of noise exposure incorporate a number versus level trading relationship such that an increment in level in decibels corresponds to an equal increment in  $10 \log_{10} N$ , where  $N$  is the number of occurrences. (For example, 10 aircraft operations at level  $L_1$  would be precisely equivalent to 100 operations at  $(L_1 - 10 \text{ dB})$ .) This relationship is in accordance with

the concept of "energy-equivalence," since the sum  $(L + 10 \log_{10} N)$  is a measure of total acoustic energy. Several investigators have found that their data do not strongly support the principle of energy-equivalence, and entirely different exposure-response models have been proposed. As this question has arisen since the original NASA surveys were performed, it is important to re-examine the data from those surveys in terms of equivalent-energy and other models. Such a re-examination, along with a detailed documentation of the trends of salient variables, is the basis of this report.

## PREVIOUS STUDIES

A brief review of studies of community reaction to aircraft noise is included here as an introduction to noise exposure models and indices, and as a historical context for the analyses in this report. A fuller review may be found in reference 3.

Community reaction investigations to date, by various researchers and in different countries, bear a strong resemblance in methodology. This similarity has the advantage of enhancing the breadth of data available and permitting cross-comparisons. On the other hand, it means that certain deficiencies in method limit the usefulness of the data, as discussed in a later section.

Typically, community response data were acquired through lengthy personal interviews of individual residents chosen according to a detailed sampling plan, the interviews being structured by a questionnaire. Various procedures commonly used in survey research to minimize biases due to improper sampling, interviewing, and data processing were employed as a matter of course (ref. 4). The questionnaires elicited response information primarily in terms of (a) disturbance of various daily activities by aircraft noise and (b) complaint activity. Questions concerning these matters were inserted among many other items dealing with demographic and attitudinal factors, so that the subject of the interview was concealed, at least initially.

Determinations of the acoustical environment in the various studies were not made according to consistent procedures. Measurement instrumentation ranged from manually operated meters to sophisticated monitoring and analysis equipment. In more recent investigations, the acoustical data tend to be much more complete

and more accurate. However, the complexity of aircraft noise exposure over a large geographical area is such that in no case was the exposure measured in detail in both spatial and time domains. Instead, reliance was placed, to varying extents, on acoustical sampling and prediction techniques.

### U.S. Air Force Studies

These surveys were performed in the late 1950's in response to the noise problems associated with the advent of jet aircraft at military air bases (ref. 5). The social survey methodology, as employed by NORC, provided the pattern for succeeding studies to the present. Although a large mass of data resulted, the analysis largely centered on a stimulus/response model, with an emphasis on overt response in the form of complaint. As a descriptor of the stimulus, the first noise exposure parameter for aircraft noise, called the composite noise rating (CNR), was developed. This was conceptually similar to an earlier rating (by the same name, but yielding alphabetic rather than numeric indices) devised for generalized use by Rosenblith and Stevens (ref. 6), and was adopted on the basis of a reasonable fit to the response data.

The CNR formulation is of particular importance here because it incorporated the equivalent-energy concept and formed the basis for many later-developed exposure parameters, including the noise exposure forecast (NEF) (ref. 7), community noise equivalent level (CNEL) (ref. 8), and day-night sound level ( $L_{dn}$ ) (ref. 9). It is given by

$$CNR = 10 \log_{10} \sum_j \text{antilog} \left\{ \left[ PNL_j + 10 \log_{10} (N_{Dj} + 20 N_{Nj}) \right] / 10 \right\} - 12$$

where  $j$  is a single class of operation (aircraft type, type of operation, flight path, etc.) producing a particular type of noise event at the point in question,  $N_{Dj}$  and  $N_{Nj}$  are the number of daytime and night-time occurrences in that class, respectively, and  $PNL_j$  is the maximum perceived noise level in that class. Thus the CNR contains

- 1) the perceived noise level, as developed by Kryter (ref. 10), as an event descriptor,
- 2) the equivalent-energy, or  $10 \log_{10} N$ , number versus level relationship,
- 3) a correction (penalty) for night events, and
- 4) an arbitrary constant.

Several things should be noted concerning the CNR formulation. First, it deals specifically with aircraft noise "events" and excludes other types of noise. (Later, Kryter offered a more general version which in effect provided a continuous integration of environmental sound due to all sources (ref. 11).) Second, the night penalty, which is equivalent to 13 dB, is based on an assumed increased community sensitivity during the night hours, rather than on the results of data analysis, as the proportions of daytime to night-time operations normally do not vary sufficiently to test reliably the difference in response, even with a complete curfew. Finally, if in accordance with the previous observation the day-night ratio is assumed to be essentially constant, the weighted sum ( $N_{Dj} + 20 N_{Nj}$ ) in the CNR formula can be replaced by the unweighted sum  $N_j = N_{Dj} + N_{Nj}$  for analysis purposes. The CNR equation can then be written

$$\text{CNR} = \overline{\overline{\text{PNL}}} + 10 \log_{10} N + \text{constant}$$

where  $\overline{\overline{\text{PNL}}}$  is the energy mean of the various maximum  $\text{PNL}_j$  values, given by

$$\overline{\overline{\text{PNL}}} = 10 \log_{10} \sum_j (N_j/N) \text{antilog} (\text{PNL}_j/10)$$

and  $N$  is the total of all daily operations or events, given by

$$N = \sum_j N_j .$$

The salient characteristics of an equivalent-energy model, as embodied in the above CNR equation for aircraft noise, combined with a simple, linear stimulus/response model, are shown in Figure 1. These characteristics include the trading relationship of 10 dB change in  $\overline{\overline{\text{PNL}}}$  for a tenfold change in number of events, and constant slope of the response function for any given number of events. This model will be compared with actual response data from the NASA surveys in later sections of this report.

#### Heathrow (London) Airport Studies

Comprehensive surveys were performed around Heathrow Airport in 1961 (ref. 12) and in 1967 (ref. 13), following generally the pattern of the U.S. Air Force studies but with improved acoustical measurements and statistical data analysis. On the basis of the first survey, an exposure measure known as the noise and number index (NNI) was formulated (ref. 14). This is given by

$$\text{NNI} = \overline{\overline{\text{PNL}}} + 15 \log_{10} N - 80$$

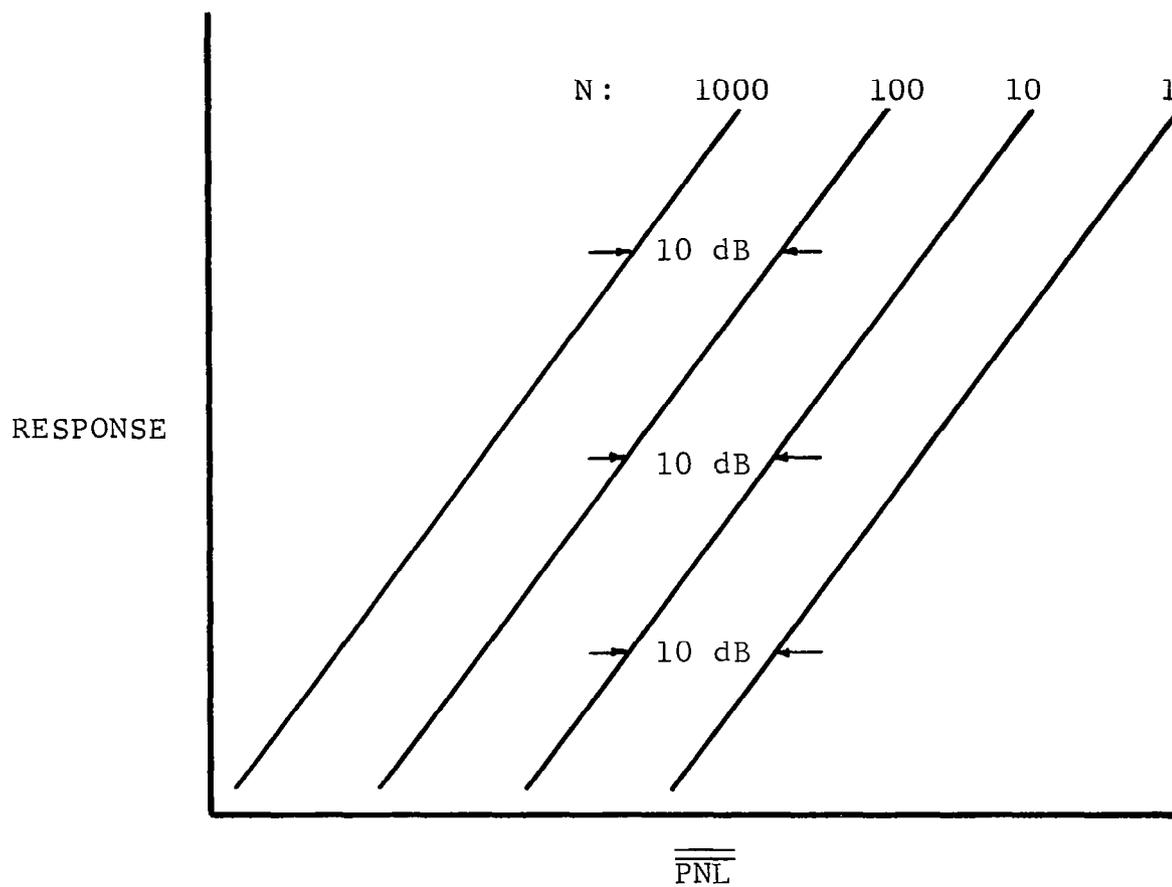


FIGURE 1 CHARACTERISTICS OF AN EQUIVALENT-ENERGY RESPONSE MODEL FOR AIRCRAFT NOISE, SHOWING CONSTANT SLOPE AND  $10 \log N$  RELATIONSHIP BETWEEN NUMBER OF EVENTS, N, AND ENERGY-MEAN PNL,  $\overline{PNL}$

It should be noted that the NNI is in part an equivalent-energy index (first term) and in part not (second term). It was developed as a best fit to average response, assuming a priori the involvement of both level and number variables.

In a later paper, McKennell (the principal investigator for the first Heathrow study) repudiated the NNI formulation as having any special merit, showing that the acoustical variables, including maximum PNLs and numbers of operations, were highly correlated among themselves, thus precluding an analysis of their separate effects on response. If either of these variables was used to predict response, then addition of the other would not greatly improve the accuracy of prediction (ref. 4). Of the two variables, number was a slightly better predictor than level (ref. 12).

The second Heathrow study, performed by other investigators, utilized linear regression techniques extensively in analyzing the effects of acoustical exposure variables. The problem of high correlation between levels and numbers of operations — essentially an artifact of the sample — was encountered as in the 1961 study. However, the energy-mean PNL was found to be a better predictor of response than was the number variable in this case. Correlation of the main response variable with level was 0.39; inclusion of  $N$  or  $\log N$  in a two-variable linear prediction scheme raised this to 0.41 - 0.46. The data offered little justification for a preference between a linear number correction, a logarithmic number correction, or no number correction at all. In connection with the latter choice, it was noted that an increase in number of operations from 1961 to 1967, with no concomitant decrease in level, did not produce heightened response (ref. 13).

## Further Development of the Equivalent-Energy Concept

Following the introduction of the equivalent-energy formulation in the early U.S. studies, the concept was developed and refined in two areas. First, the original perceived noise level parameter was modified to include explicitly the effects of flyover duration and discrete frequency content, yielding a new descriptor of an aircraft noise event called the effective perceived noise level (EPNL) (refs. 15 and 16). Using EPNL as the fundamental level parameter, a new, CNR-like exposure measure called the noise exposure forecast (NEF) was devised (ref. 17). It should be noted that the duration and discrete frequency corrections, although palpable in psychophysical laboratory experiments, are usually of the order of only a few decibels. Consequently, except for a numerical difference due to arbitrary constants, NEF and CNR are essentially interchangeable in relation to community response, which has wide variability due to other factors.

A second development was the generalization of equivalent-energy exposure to include all ambient noise, rather than only aircraft noise events, through continuous integration or summation over time. Although, as stated earlier, the original CNR concept was broadened along such lines by Kryter (ref. 11), the best known formulations are the equivalent level ( $L_{eq}$ ) used primarily in Europe (ref. 18) and the day-night level ( $L_{dn}$ ) (ref. 9). An important feature of the latter two formulations was the substitution of weighted sound level, which can be measured rather simply, for perceived noise level, which in the strict sense requires frequency analysis. The standard A-weighting (ref. 19) is normally used for this purpose. The foregoing are only representative examples of a large number of exposure measures, proposed

or utilized by various governments and agencies, which attest to the general acceptance and pervasiveness of the equivalent-energy concept.

### NASA Studies

Two studies conducted in the period 1967-1971 provided the data base which was used for the analyses described later in this report (refs. 1 and 2). These were performed along the lines established in earlier survey investigations and contained the following distinct phases:

#### Seven-city Study

<u>Phase I</u> (Summer 1967)	<u>Phase II</u> (Summer 1969)
Chicago	Boston
Dallas	Miami
Denver	New York (KIA)
Los Angeles	

#### Two-city Study (Fall-winter 1970-1971)

Chattanooga  
Reno/Sparks

The three separate survey efforts differed somewhat in acoustical measurement methodology as well as in site circumstances, with possible consequences regarding the data obtained. In Phase I, much of the measurement effort was directed toward detailed frequency analysis of individual aircraft noise events, in accordance

with advisory group recommendations. Analysis of the event data showed high correlations between weighted levels and calculated perceived noise levels, and also among the exposure parameters CNR, NEF, and NNI. Since these correlations were much higher than those between exposure and response variables, it was concluded that acoustical measurement resources should be applied to more complete sampling in time and space rather than further frequency analysis. Therefore in Phase II a single exposure measure (CNR) based upon weighted level data was used.

Another important difference between Phases I and II was the availability of detailed operations data. In 1967 none of the airports studied maintained operations logs with breakdowns of runway usage, flight paths, aircraft types, and time of day sufficient, in combination with event noise level data, to define noise exposure accurately; therefore considerable extrapolation was necessary in obtaining exposure values. In Phase II (1969), airport data were very complete. Much better correlation between individual annoyance and exposure was obtained (coefficient of linear correlation 0.49 as contrasted with 0.37 for Phase I), probably indicating an improvement in estimation of exposure due to the two factors just discussed.

In the two-city study, the numbers of daily operations were so small that it was possible to maintain a detailed operations log. Also, since five continuous level recording monitors were used at various community sites, providing a good sampling of each category of noise event, noise data were quite complete. The response at most stimulus levels in the two-city study was notably lower than in the previously surveyed larger cities. This could have been due to the low numbers of operations (in accordance with Swedish findings discussed below), to the season of the year, or to some basic smaller-city characteristic not reflected in the social survey data. The latter is thought to be unlikely in view

of the large number of psychosociological variables considered. A longitudinal study appeared appropriate to test the seasonal hypothesis, but this was not possible at the time.

In the analysis following the two-city survey, the equivalent-energy model was extended to fit the seven-city and two-city data separately in terms of the percentage of highly annoyed persons as a function of CNR. The linear equations describing this fit (applicable for  $CNR \geq 85$ ) are

$$\% \text{ Highly Annoyed (7-city)} = 1.59 (CNR - 85)$$

$$\% \text{ Highly Annoyed (2-city)} = 0.73 (CNR - 85)$$

The second equation above holds only up to CNR 125; for higher values, the two-city sample displayed about the same level of annoyance as the seven-city. If one makes the simplifying assumption that night-time operations constitute ten percent of total daily operations, then the above equations may be used as a basis for a particular version of the equivalent-energy model in which response is in terms of percentage of highly annoyed persons. This may be expressed

$$\% \text{ Highly Annoyed (7-city)} = 1.59 \frac{\overline{PNL}}{\overline{PNL}} + 15.9 \log N - 146$$

$$\% \text{ Highly Annoyed (2-city)} = 0.73 \frac{\overline{PNL}}{\overline{PNL}} + 7.3 \log N - 67$$

with the same restrictions on range of applicability as given above. These equations are presented graphically in Figures 2 and 3 respectively.

One other aspect of the NASA studies which should be noted is that they bore a special emphasis on sociopsychological factors influencing response, such as positive or negative valence in regard to aircraft or the air transportation industry. It was shown that such attitudinal factors have a strong effect upon

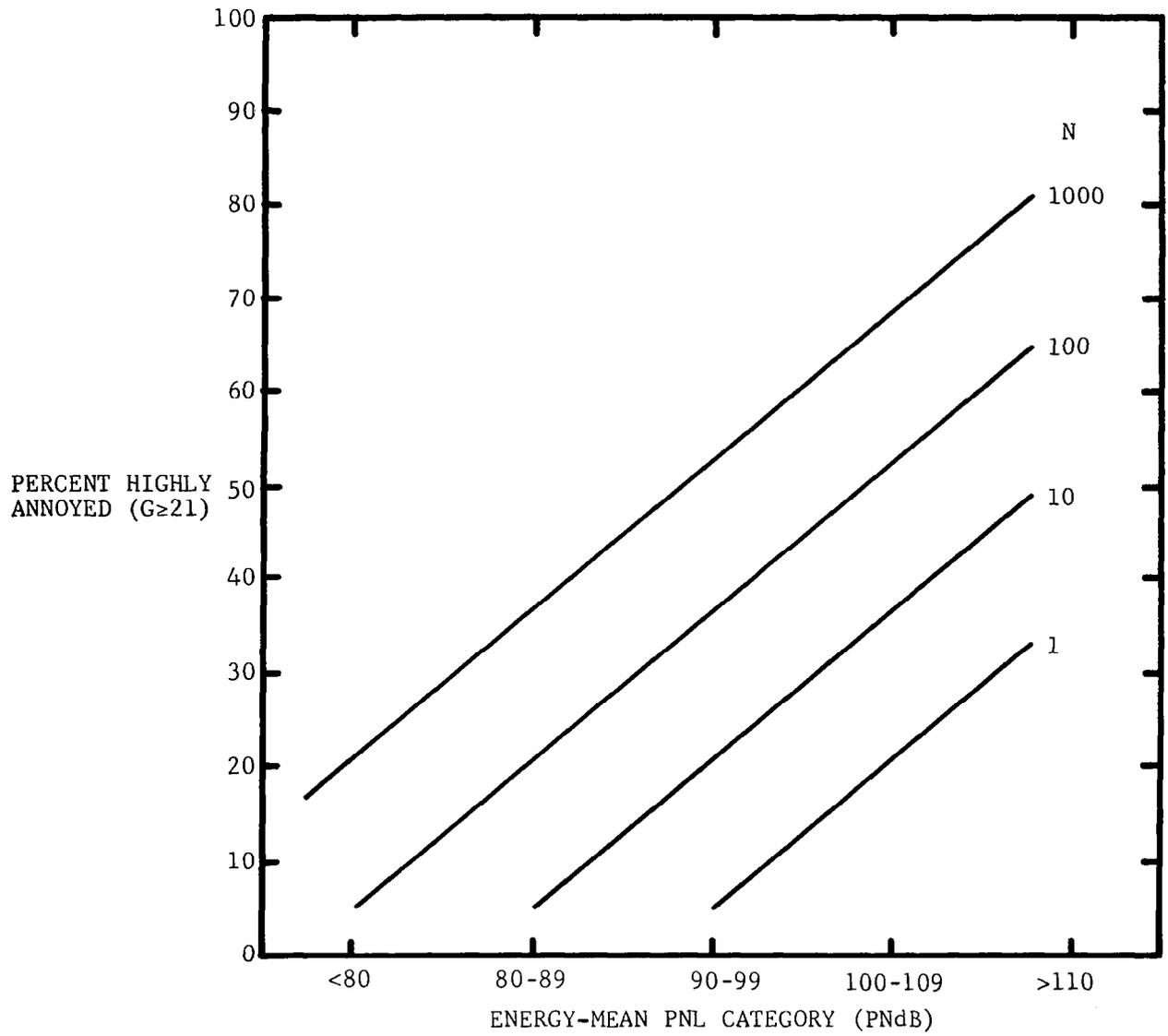


FIGURE 2 EQUIVALENT-ENERGY MODEL FOR PERCENT HIGHLY ANNOYED BASED ON SEVEN-CITY DATA (ref. 2)

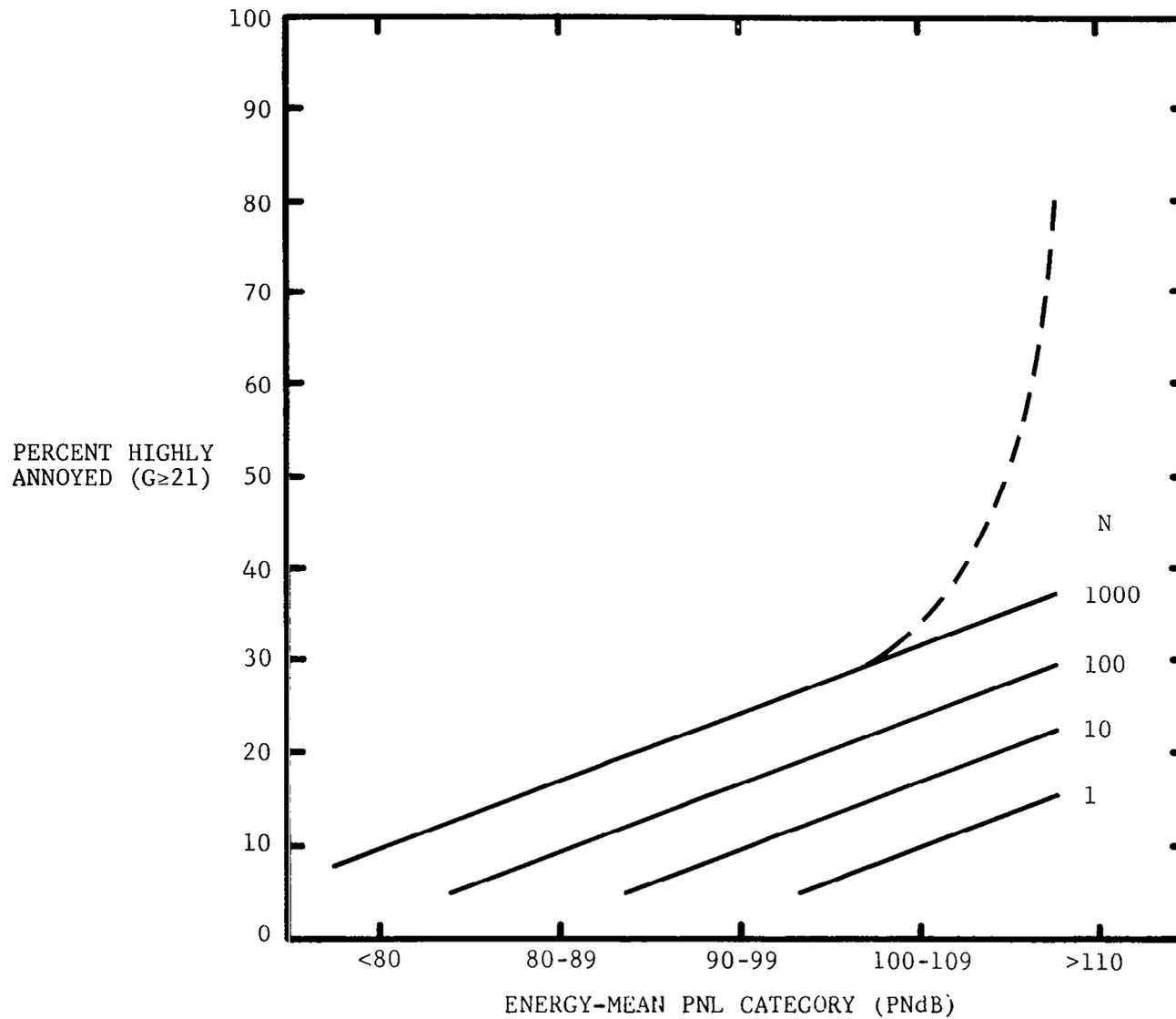


FIGURE 3 EQUIVALENT-ENERGY MODEL FOR PERCENT HIGHLY ANNOYED BASED ON TWO-CITY DATA (ref. 2)

individual human response. In relation to the restricted stimulus/response models which are examined in this report, the influence of these factors should thus be considered one of the important sources of variation.

### Swedish Studies

As mentioned earlier, the relatively low level of response found in the NASA two-city study, possibly associated with a low number of daily operations, was similar to certain results obtained at Swedish airports. The latter findings were first published in 1971 (ref. 20). On the basis of these and subsequent results, a new response model was developed. This was called by its proponent, Rylander, "the peak dBA concept." It has been well documented in several papers (refs. 20-23) and articles (refs. 24-26).

The Swedish model, as it will be called here, is quite different from earlier concepts, with strong implications regarding airport noise abatement. In its present form, this model may be summarized in the following statements:

1. The basic descriptor of an aircraft noise event is the maximum A-weighted sound level ( called "dBA" by Rylander).
2. Effective exposure (as related to response) is determined by the maximum level of the noisiest aircraft having at least three daily operations (called "peak dBA" by Rylander).
3. If the total number of daily operations is less than or equal to 35 (counting all aircraft, not

merely the noisiest), annoyance is low and relatively constant for maximum A-weighted levels up to 90 dB, beyond which annoyance increases. (Areas in this operations category are called "low exposure" areas.)

4. If the total number of daily operations is greater than or equal to 50, annoyance increases linearly with the maximum level of the noisiest aircraft meeting the qualification in (2) above. (Areas in this operations category are called "high exposure" areas.)

The Swedish model is graphically depicted in Figure 4. This set of curves was taken from a recent publication (ref. 25) and adapted for comparison with the NASA study response data. Rather than "peak dBA," the abscissa represents "largest PNL" categories. This transformation was made according to the relation  $PNL \simeq L_A + 13 \text{ dB}$ , which has been shown in the NASA studies (ref. 1) and elsewhere to be a reasonable approximation, the two parameters being highly correlated for community noise due to aircraft. The ordinate scale of "percent highly annoyed" has been tacitly assumed to track with the Swedish scale of "percent very annoyed" which usually represents the response variable. In fact there may be some difference in scaling, but this should be small because of the similarity in methodology for assessing response and should not alter the general nature of the relationship shown.

There is some question whether the data reported by the Swedish investigators are adequate to support the Swedish model as contrasted with other response models. In particular, the acoustical exposure data appear to be much less complete than in the British and U.S.A. studies. In some of the Swedish investigations, the noise of only departing aircraft was considered; in

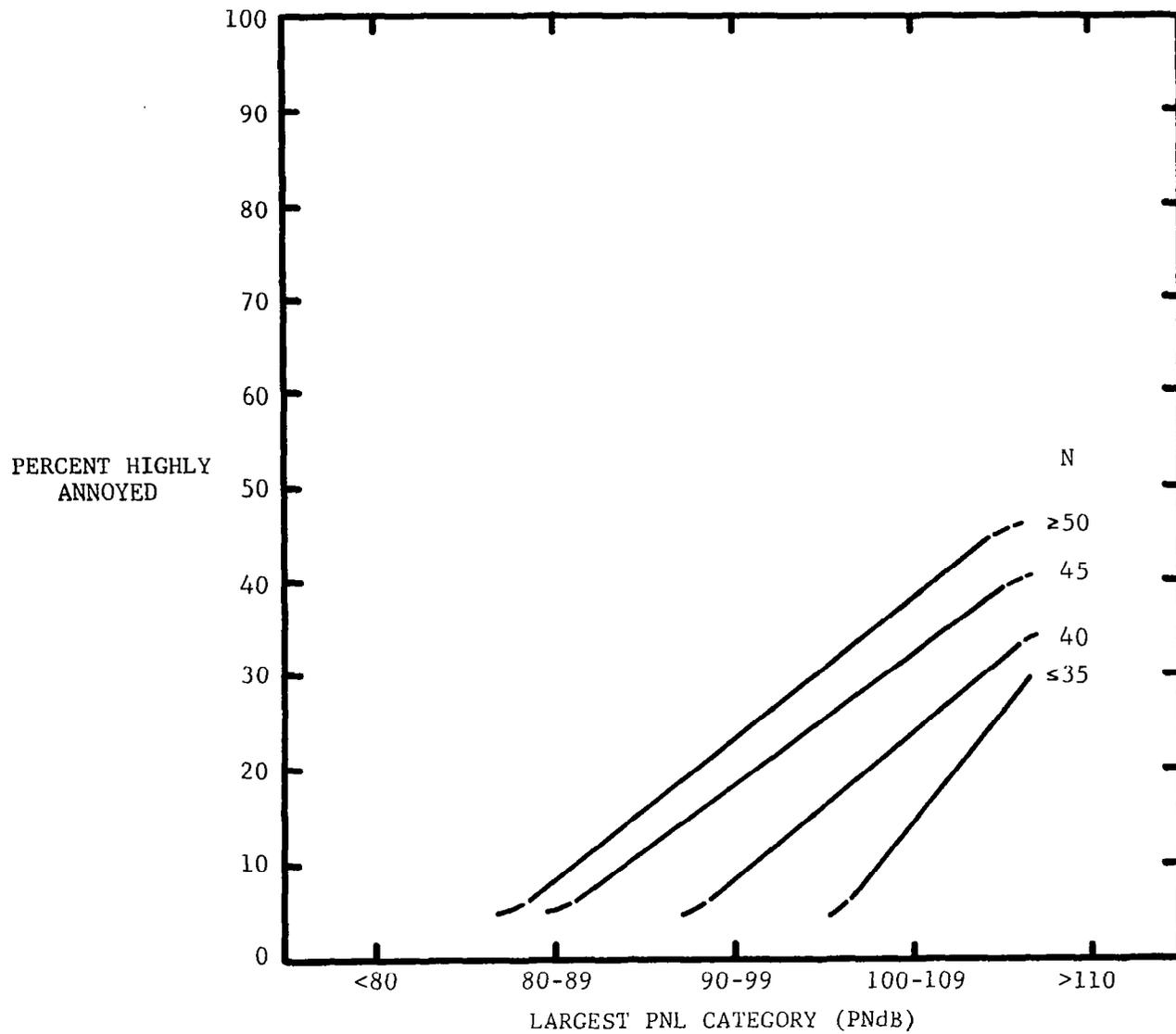


FIGURE 4 POSTULATED SWEDISH RESPONSE MODEL  
(after ref. 25)

others, level data were obtained from standard contours with minimal or no corroborating field measurements. Also, statements were published without supporting analysis (ref. 27). Pending independent validation, the Swedish response model should not be used as the basis for important decisions.

The foregoing notwithstanding, it is clear that the Swedish investigations document response effects which have a significant bearing on aircraft noise abatement policy and which were previously not taken into account. Hence the need for the re-examination of the relationship between levels and numbers of operations which is presented in this report.

#### Limitations of Studies to Date

This survey of prior investigations of community response to aircraft noise should mention certain inherent problems, common to American and European studies alike, which limit the usefulness of existing data and indicate a need for additional investigations. One problem was lack of a comprehensive research framework to establish data requirements and provide hypotheses against which data could be tested. Such a framework could have been a hypothetical response model based upon known or plausible human behavior. Instead, the typical approach, in the final analysis, was to determine the best fit between preselected indices of stimulus and response. This presupposed a clear understanding of at least one of these variables as well as a reasonably well defined relationship between them. In fact, both assumptions are valid subjects for further study (refs. 4, 28, 29).

Another shortcoming in previous studies was ambiguity in time factors related to stimulus and response. Survey questions

were indefinite as to time: "Are you annoyed ----?"; "Have you ever been disturbed-----?" It was thus not determined whether the respondent answered in terms of the day of the interview, the preceding few days, months, years, or some kind of mental average. Similarly, aircraft noise exposure was specified in average terms, usually for a period of several months. In retrospect it appears that lack of specific time references may be responsible for part of the apparent variance in response (ref. 30). Certainly any cogent response model will contain temporal elements or dependencies and the data requirements in future studies should reflect this (ref. 3).

It should be noted that the above comments apply to the data base and analysis described in succeeding sections. However, the analysis provides a needed evaluation of a slightly expanded stimulus/response model (separating the effects of number and level) and the variability in results is clearly presented, so that the user may decide on what terms to accept them. In particular, data are not grouped, or measures of central tendency used, in such a way as to conceal or minimize the variation in response.

## ANALYSIS PARAMETERS

The dependent variable in the analyses to follow is "Annoyance G," a scale developed and used in prior studies. For a detailed description of the construction and rationale for this scale, the respective reports should be consulted (refs. 1 and 2). Annoyance G is similar to scales of annoyance used in other investigations and is what McKennell called a scale of "annoyance-caused-through-activities disturbed" (ref. 30). It was constructed from interview responses to a series of questions regarding the nine following daily activities:

1. Relaxing/resting inside
2. Relaxing outside
3. Sleeping
4. Listening/watching radio/TV
5. Conversation
6. Telephone conversation
7. Listening to records/tapes
8. Reading or concentration
9. Eating

First, the respondent was asked whether each activity was disturbed by aircraft noise. Then, for each activity disturbed, the respondent was asked to indicate how much he/she was bothered. The latter response was scored from 0 to 5 and Annoyance G was constructed by adding the scores for all nine activities, thus having a range from 0 to 45. This method of scale construction is called the Likert or summated rating technique (ref. 31).

As the response distributions in a later section show, there is often a wide variation in annoyance scores at a given exposure level and the distribution of the scores is not consistent. Thus the mean or median annoyance at a given level is not a good

indicator of response. In order to provide a straightforward measure of response under these conditions, it has become conventional to select a point on the scale of annoyance beyond which the respondent is said to be "very annoyed" or "highly annoyed" and to express response in terms of percentage of respondents at or above that point, in a given exposure class. In the NASA studies utilizing Annoyance G, the highly annoyed are those with scores of 21 and higher, out of a possible 45. Another way of expressing this criterion is that a respondent must score 3 (moderate bother) or higher on at least 7 of the 9 activities considered.

In the original NASA studies, the primary stimulus variable was noise exposure in terms of the equivalent-energy CNR measure. Calculation of CNR values required a maximum PNL and associated number of operations for each category of aircraft operation affecting a respondent area. Again, for details the final reports should be reviewed (refs. 1 and 2). In the present analysis, the following exposure-related variables are considered:

N - average daily (24 hour) number of aircraft operations affecting an area (all types)

$\overline{\text{PNL}}$  - energy-mean PNL for all operations included in N

Largest PNL - highest value of PNL associated with a category of at least 3 daily operations included in N

In accordance with the discussion of the preceding section, N and  $\overline{\text{PNL}}$  may be used to compute effective exposure in terms of an equivalent-energy model, whereas N and "largest PNL" may be used to determine effective exposure according to the Swedish model.

In order to obtain meaningful distributions of Annoyance G for various exposure combinations, the above stimulus variables were categorized in most of the analyses. The class intervals, determined partly according to the overall distribution of respondents in the survey sample and partly for convenience in evaluating the models, are as follows:

N: <50, 50-99, 100-199, 200-399, ≥400  
 PNL: <80, 80-89, 90-99, 100-109, ≥110

Numbers of respondents in each cell thus created are given in Tables 1-4 below, respectively for the entire nine-city sample and for the component Phase I, Phase II, and two-city subsamples.

TABLE 1  
 CELL DISTRIBUTION OF RESPONDENTS  
 IN NINE-CITY SAMPLE\*

PNL Category	Number of Operations Category					All
	<50	50-99	100-199	200-399	≥400	
<80	237/158	117/28	85/1	120/127	75/0	654/314
80-89	897/692	845/735	711/620	370/241	123/121	2946/2409
90-99	992/932	282/377	900/799	765/540	181/149	3120/2797
100-109	481/795	78/182	415/589	416/592	59/144	1449/2402
≥110	71/101	0/0	110/212	108/199	4/28	293/540
All	2678	1322	2221	1799	442	8462

\* Entries in Tables 1-4 are [number of respondents for PNL category / number of respondents for Largest PNL category].

TABLE 2  
CELL DISTRIBUTION OF RESPONDENTS  
IN PHASE I SAMPLE

PNL Category	Number of Operations Category					All
	<50	50-99	100-199	200-399	≥400	
<80	160/106	94/28	85/1	140/127	75/0	554/262
80-89	221/275	547/471	265/275	243/158	123/121	1399/1300
90-99	89/80	100/202	213/228	486/321	181/149	1069/980
100-109	79/88	5/45	78/133	296/491	59/144	517/901
≥110	0/0	0/0	0/4	47/115	4/28	51/147
All	549	746	641	1212	442	3590

TABLE 3  
CELL DISTRIBUTION OF RESPONDENTS  
IN PHASE II SAMPLE

PNL Category	Number of Operations Category					All
	<50	50-99	100-199	200-399	≥400	
<80	52/52	23/0	0/0	0/0	0/0	75/52
80-89	59/58	298/264	446/345	127/83	0/0	930/750
90-99	58/51	182/175	687/571	279/219	0/0	1206/1016
100-109	0/8	73/137	337/456	120/201	0/0	530/802
≥110	0/0	0/0	110/208	61/84	0/0	171/292
All	169	576	1580	587	0	2912

TABLE 4  
CELL DISTRIBUTION OF RESPONDENTS  
IN TWO-CITY SAMPLE

PNL Category	Number of Operations Category					All
	<50	50-99	100-199	200-399	≥400	
<80	25/0	0/0	0/0	0/0	0/0	25/0
80-89	617/359	0/0	0/0	0/0	0/0	617/359
90-99	845/801	0/0	0/0	0/0	0/0	845/801
100-109	402/699	0/0	0/0	0/0	0/0	402/699
≥110	71/101	0/0	0/0	0/0	0/0	71/101
All	1960	0	0	0	0	1960

## ANALYSIS OF PERCENT HIGHLY ANNOYED

For direct comparison with the equivalent-energy and Swedish response models, the NASA data were analyzed in terms of percent highly annoyed respondents for the various categories of level and number. Two sets of data were plotted, each containing separate graphs for the entire nine-city sample and for each of the three component subsamples. The first set, given in Figures 5-8, is based on energy-mean PNL categories for direct comparison with the equivalent-energy response models represented in previous Figures 2 and 3. The second data set, given in Figures 9-12, is based on the "largest PNL" concept for comparison with the Swedish model shown in Figure 4. In all these plots, points are omitted unless they represent a cell population, as given in Tables 1-4, of at least 20 respondents.

It should be noted that the exposure to aircraft noise of each respondent is characterized by a set of PNL values and associated operations counts, rather than by a single PNL and daily count. This fact, together with the large variability in individual response, makes it impractical to establish a number versus level trading relationship empirically, from the data alone. It is necessary rather to postulate relationships or models and test them with the data, as done below. The two models employed are rudimentary in that they represent attempts to fit simple algorithms to existing response data. The validation of more sophisticated models, however, may require a more detailed data base.

### Equivalent-Energy Model

The response curves shown in Figure 5 have a fairly consistent slope, in accordance with the equivalent-energy model.

However, the relationship of the curves does not meet a  $10 \log N$  characteristic. Instead, response tends to peak with 100-199 operations per day. The response curves for  $N = 50-99$  and  $N = 200-399$  tend to track closely, whereas energy equivalence would require a separation of 6 dB. The  $N < 50$  curve falls well below the others, its displacement being much greater than accounted for by the energy principle. It is concluded that response in terms of percent highly annoyed does not follow an equivalent-energy model very well.

The subsample response plots of Figures 6 and 7 show the same peaking in the 100-199 operations category as in the combined sample. The  $N < 50$  curve for Phase I rises more steeply with level than in any other case. On the evidence from this subsample alone, as shown in Figure 6, it might be surmised that the number of operations has no systematic effect on response, except possibly at the lowest levels. This indication should be tempered, however, by the fact that this subsample offers less data accuracy than subsequent phases, as discussed previously.

The relative contribution of each of the three subsamples to the nine-city composite can be assessed by comparing the cell populations in Tables 1-4. It will be noted that the  $N \geq 400$  category is represented only in Phase I. The  $N < 50$  category in the composite sample is dominated by the two-city subsample (1960 respondents out of a total of 2678), with a moderate contribution from Phase I (549 respondents) and less from Phase II (169 respondents). Only about 150 respondents in Phase I were responsible for the rise in response, noted previously, for  $N < 50$ . Because the two-city data influence the results for low numbers of operations so strongly, further research regarding the effects of the special circumstances of that study would be helpful.

## Swedish Model

Although the second data set (Figures 9-12) is rather similar to the first, it is included in order to permit examination of the Swedish model in the terms set forth by its proponents, i.e., the peak dBA/largest PNL concept.

The data follow the model of Figure 4 in a general way but are not consistent with specific tenets of the Swedish concept. There is a clear effect of numbers of operations for  $N \geq 50$  categories, with the same peaking at 100-199 operations per day as noted in the previous data set. Also, while response is lower for  $N < 50$ , there is a steady increase with level rather than a sudden rise at higher level categories.

The similarity in behavior of the two data sets has one notable exception: the sharp decrease in response with increasing level for  $N \geq 400$  shown in Figure 9. This anomalous behavior, probably reflecting a large proportion of operations with much lower levels than the "largest PNL" value, is a contraindication of the validity of the Swedish model. Aside from this point, the similarity would be expected unless the sample contained wide variations in the distributions of level and number. This apparently is not the case for the NASA data and thus, within that context, there is no particular value in the peak dBA/largest PNL concept over the earlier energy-mean formulation.

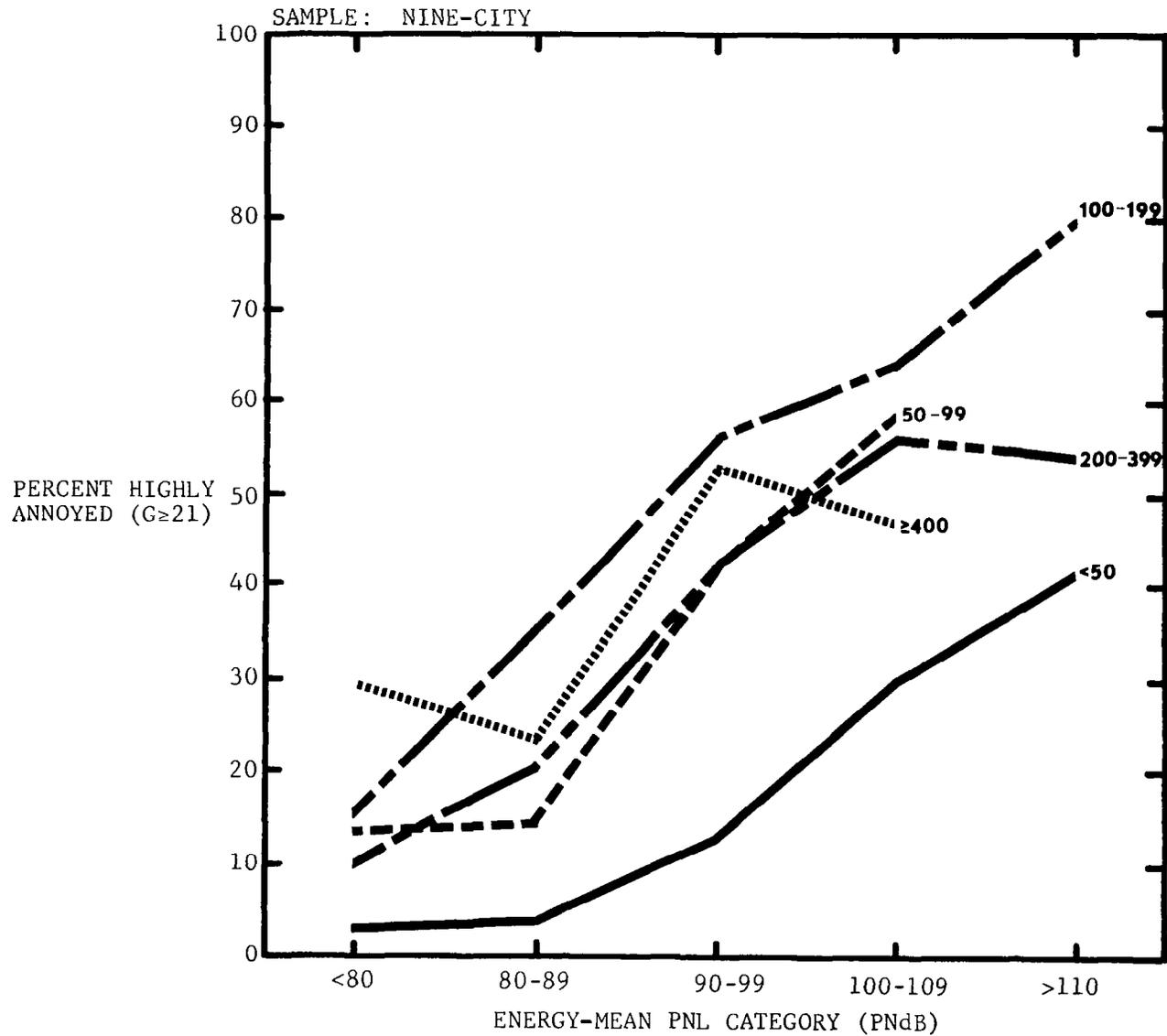


FIGURE 5 PERCENT HIGHLY ANNOYED ( $G \geq 21$ ) VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL FOR VARIOUS NUMBERS OF OPERATIONS, NINE-CITY SAMPLE

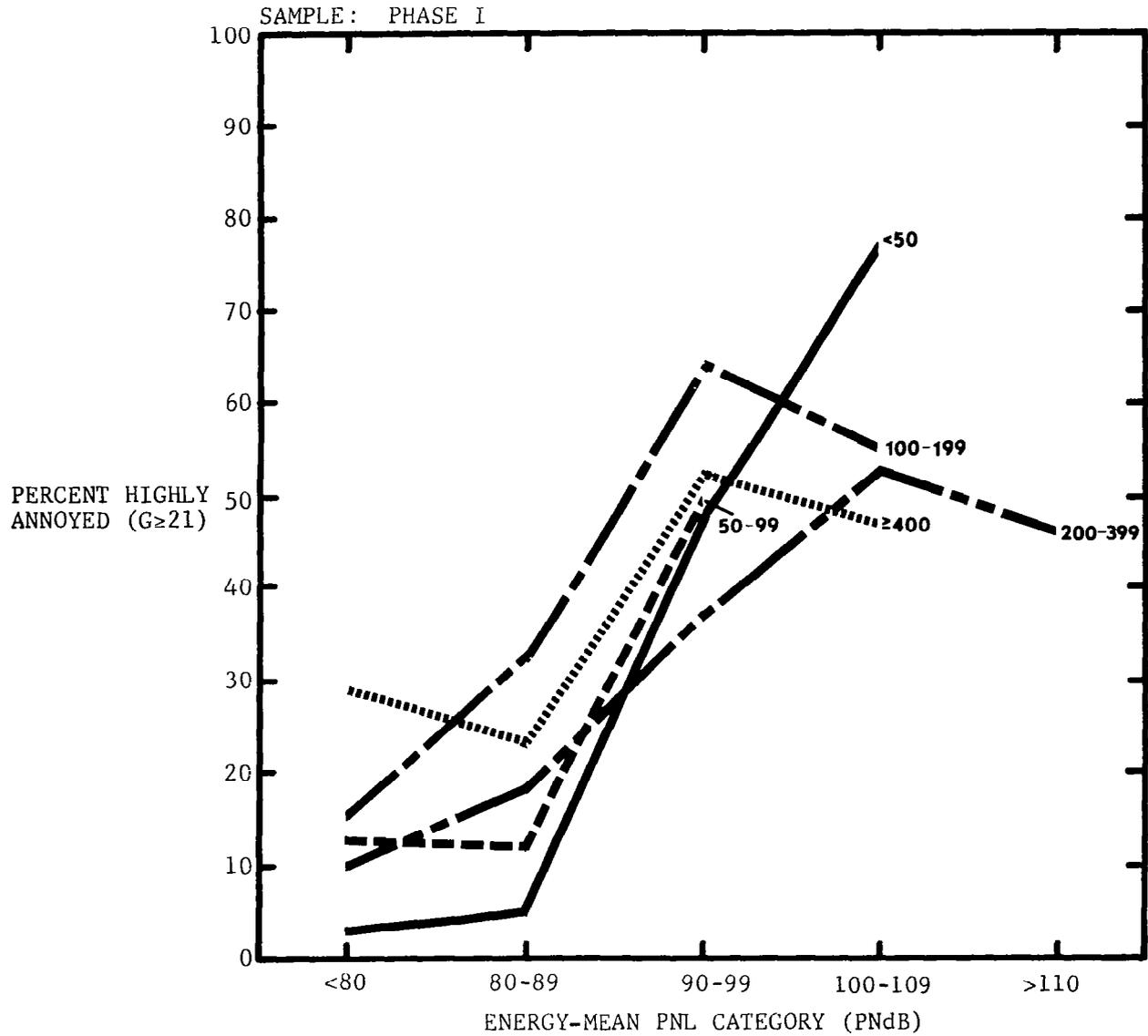


FIGURE 6 PERCENT HIGHLY ANNOYED ( $G \geq 21$ ) VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL FOR VARIOUS NUMBERS OF OPERATIONS, PHASE I SAMPLE

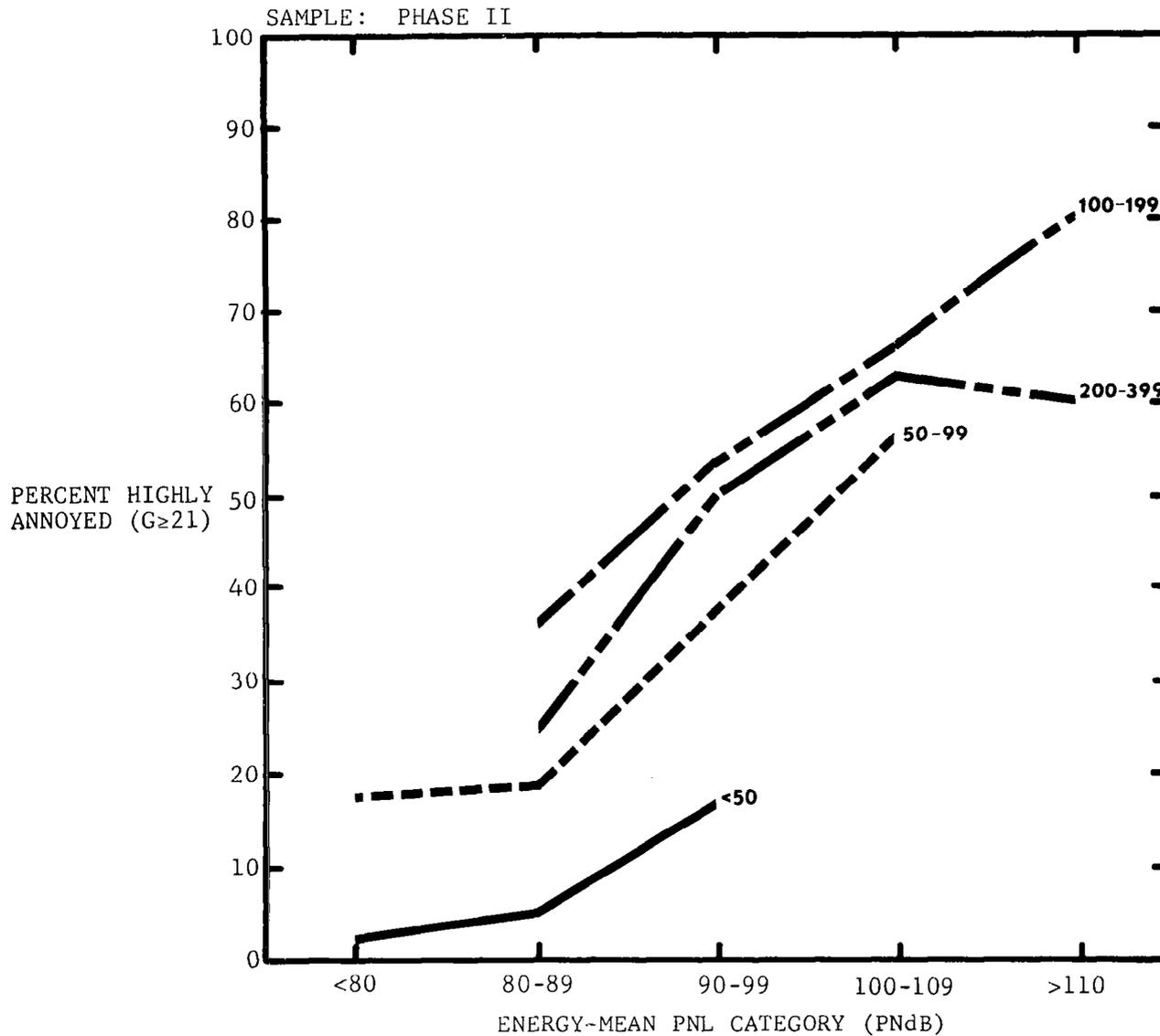


FIGURE 7 PERCENT HIGHLY ANNOYED ( $G \geq 21$ ) VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL FOR VARIOUS NUMBERS OF OPERATIONS, PHASE II SAMPLE

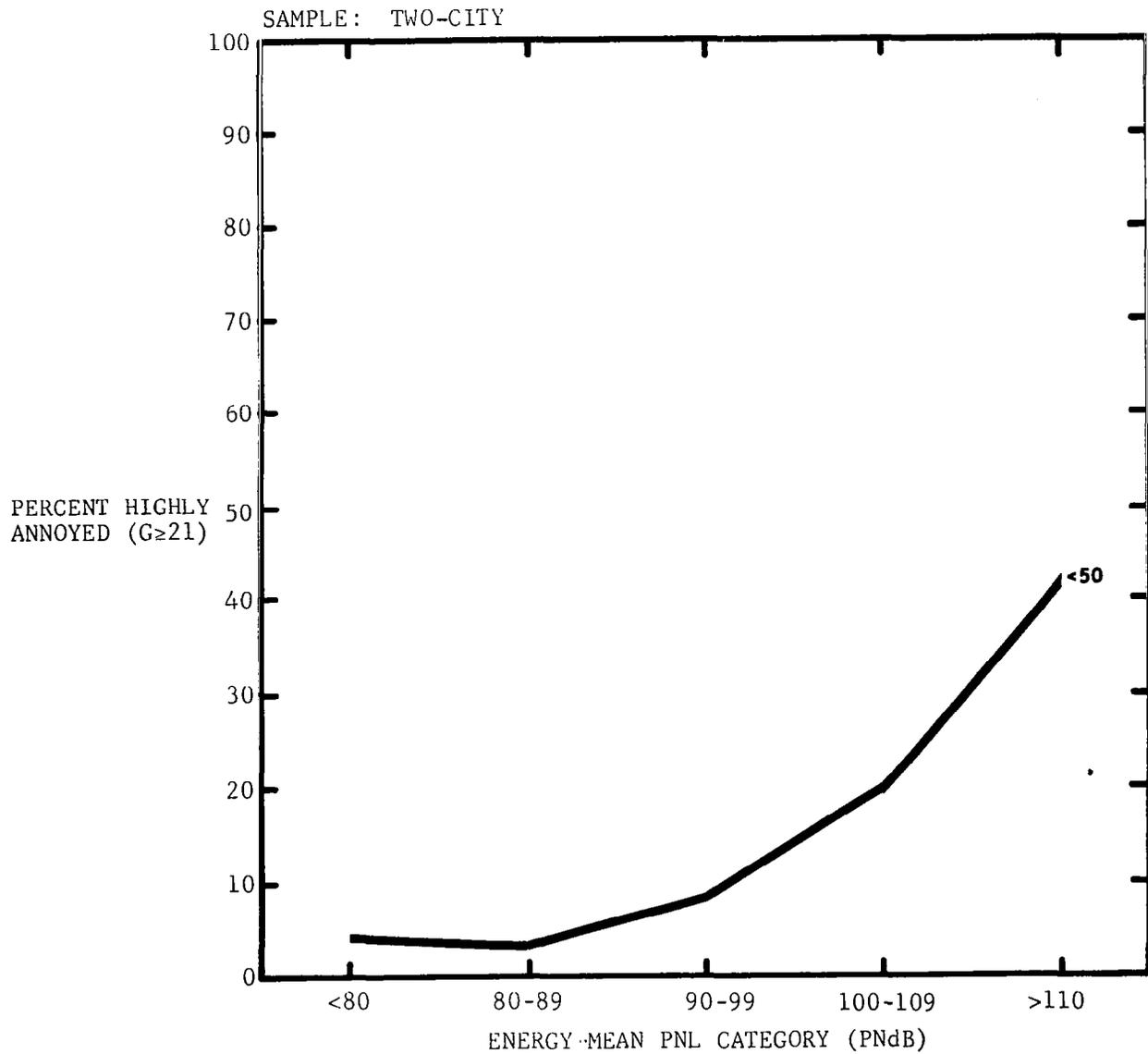


FIGURE 8 PERCENT HIGHLY ANNOYED ( $G \geq 21$ ) VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL FOR VARIOUS NUMBERS OF OPERATIONS, TWO-CITY SAMPLE

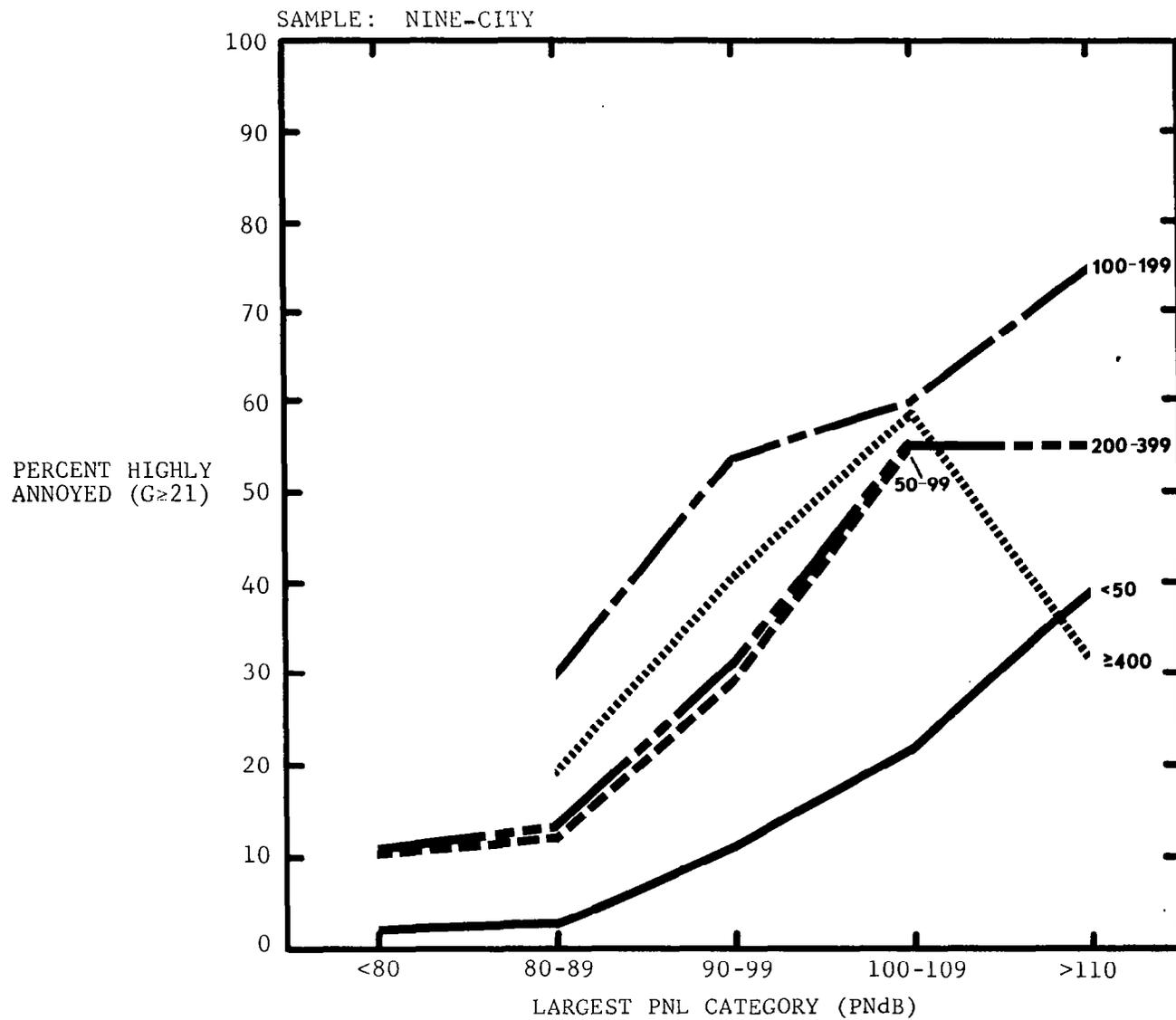


FIGURE 9 PERCENT HIGHLY ANNOYED ( $G \geq 21$ ) VERSUS LARGEST PERCEIVED NOISE LEVEL FOR VARIOUS NUMBERS OF OPERATIONS, NINE-CITY SAMPLE

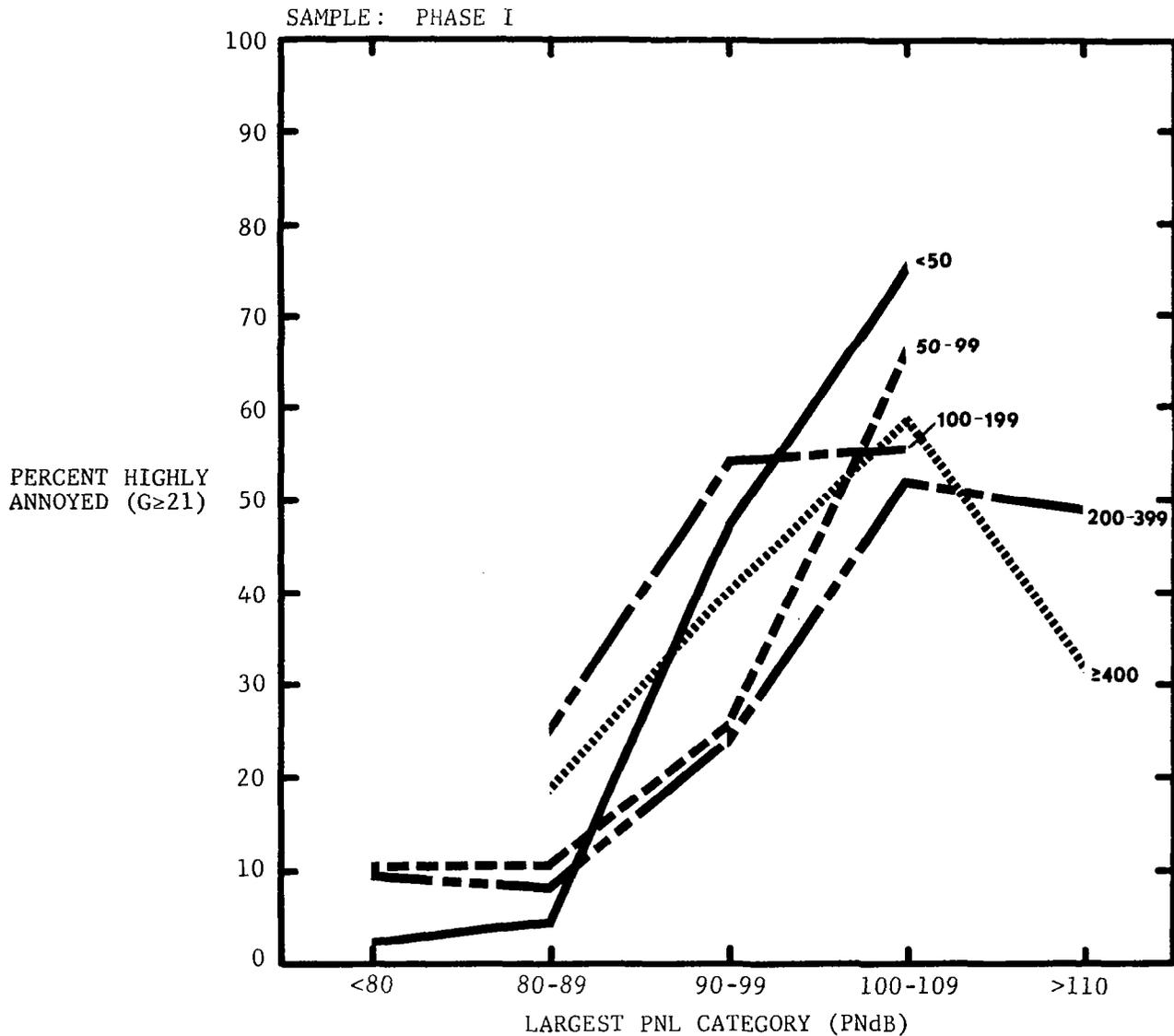


FIGURE 10 PERCENT HIGHLY ANNOYED ( $G \geq 21$ ) VERSUS LARGEST PERCEIVED NOISE LEVEL FOR VARIOUS NUMBERS OF OPERATIONS, PHASE I SAMPLE

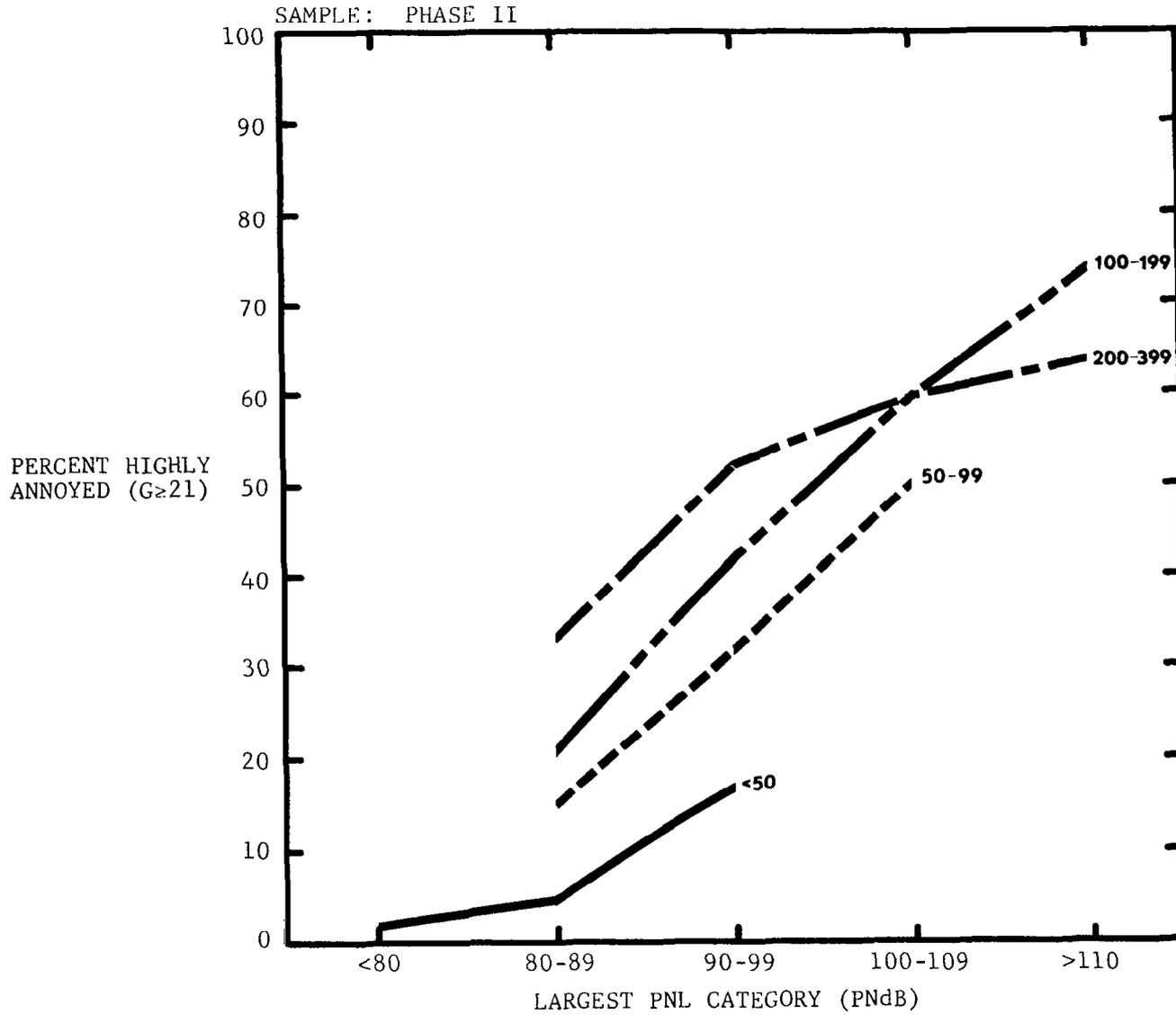


FIGURE 11

PERCENT HIGHLY ANNOYED ( $G \geq 21$ ) VERSUS LARGEST PERCEIVED NOISE LEVEL FOR VARIOUS NUMBERS OF OPERATIONS, PHASE II SAMPLE

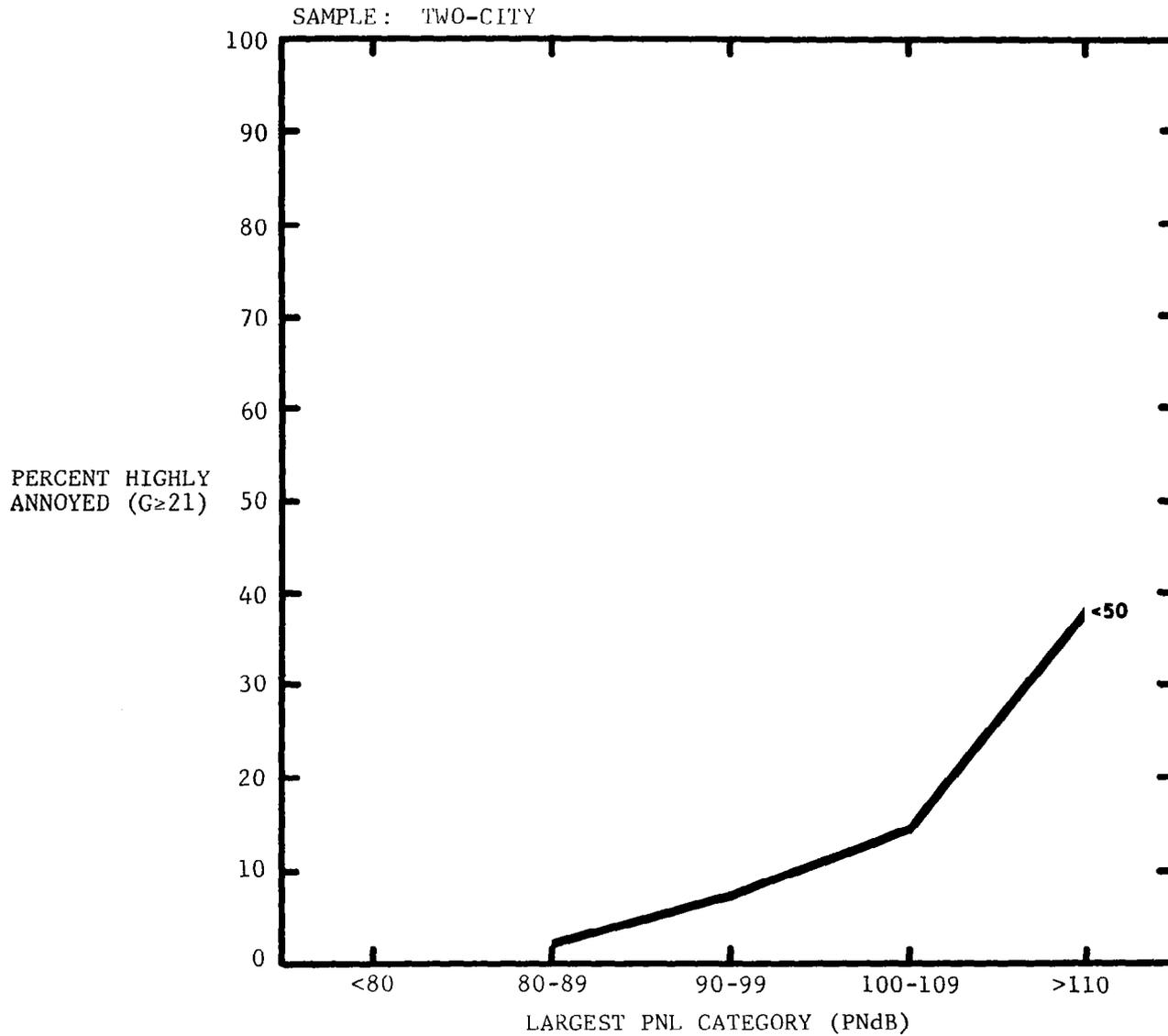


FIGURE 12 PERCENT HIGHLY ANNOYED ( $G \geq 21$ ) VERSUS LARGEST PERCEIVED NOISE LEVEL FOR VARIOUS NUMBERS OF OPERATIONS, TWO-CITY SAMPLE

## DISTRIBUTIONS OF RESPONSE

In order to show clearly the variation in individual response in the various level and number categories — not apparent in the usual plots of mean annoyance or percentage highly annoyed — distributions on Annoyance G were calculated and plotted. The complete set of distributions, for all samples and subsamples and for both energy-mean PNL and largest PNL categories, is given in the Appendix (Figures A-1 through A-30). Each distribution is characterized by 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentile values. For convenience in comparing the figures, the interquartile ranges are shaded.

Since each number of operations category requires a separate graph in the Appendix, a summary of these results is shown in Figure 13. The distributions in this summary were obtained by passing smoothed curves through the percentile values given in the Appendix. This was done only for the nine-city, energy-mean PNL data set, since the largest PNL set is very similar in behavior. Although this smoothing process leaves some irregularities in the lowest number category, it does permit a ready indication of basic trends in response.

It is immediately obvious from Figure 13 that the shape of the response distribution is not constant. Toward the extremes of the Annoyance G range the distributions are skewed and at intermediate values they are fairly symmetrical. It is clear that measures of central tendency do not in general present a good description of annoyance response, both because of the change in shape and because of the overall breadth.

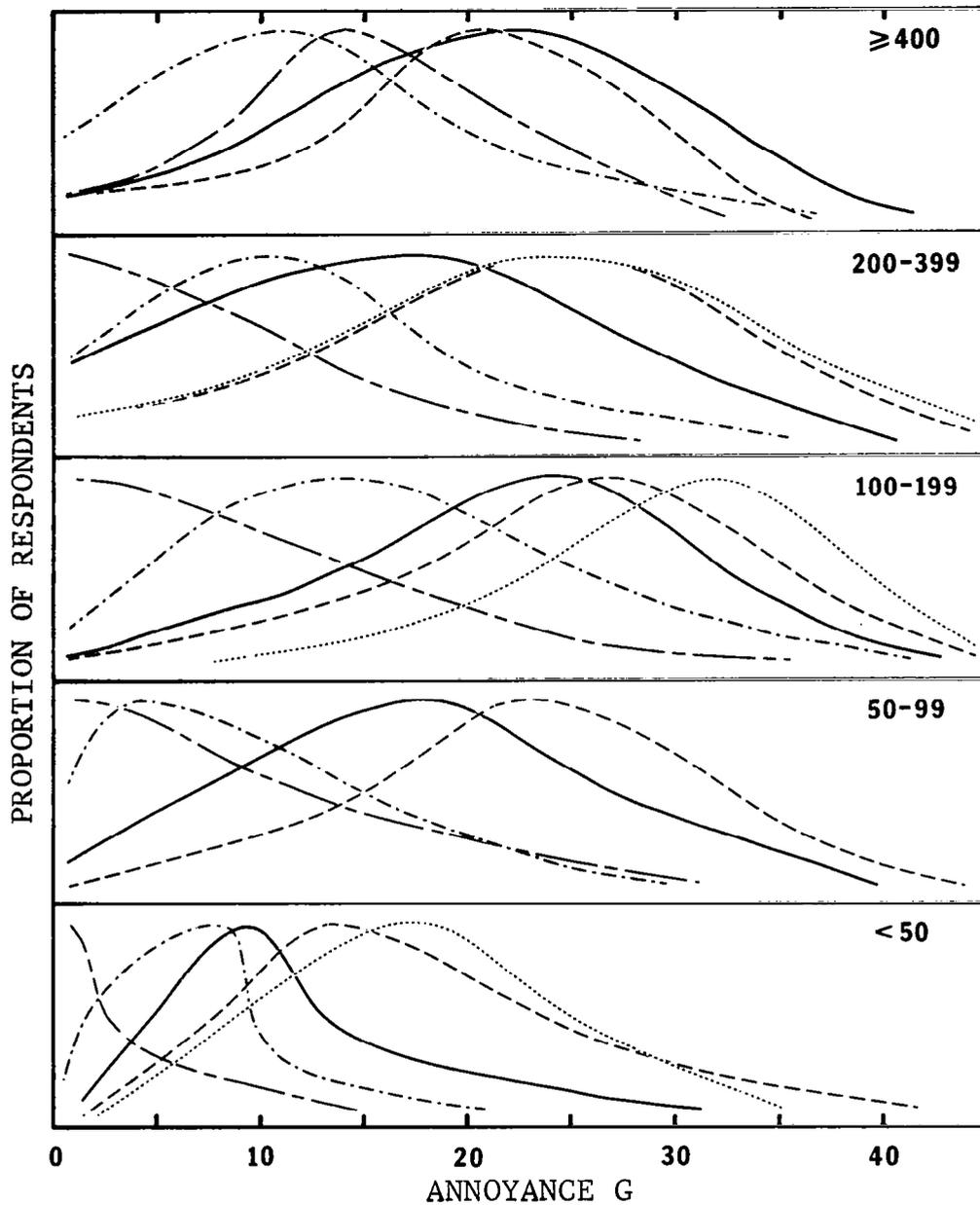
In the  $N < 50$  number category and at lower levels, the response distributions are distinctly narrower than in other cases. For a given median or mean value of annoyance, this has

the effect of lowering the percentage of highly annoyed (Annoyance  $G \geq 21$ ). This effect thus may be partly responsible for the markedly low response rate for low numbers of operations observed in this and other studies in which the primary response variable was "percent highly annoyed" or "percent very annoyed."

The annoyance response distributions in Figure 13 shift toward higher values of response with increasing numbers of operations, up to the 100-199 operations per day category, which shows the highest response. At greater numbers of operations, there is a definite downward shift in response. This parallels the behavior in percent highly annoyed described in the preceding section.

There is generally an increase in response (upward shift) with increasing PNL categories. This trend becomes less distinct at higher numbers of operations, however. For 200-399 operations per day, the distributions for the two highest level categories (100-109 and  $> 110$ ) nearly coalesce and for  $\geq 400$  operations per day, reversals occur.

The discussion in the preceding section regarding the composition of the nine-city sample also applies here. By consulting Tables 1-4, one can determine the relative contributions of the three subsamples to any particular level/number category. In fact, by combining the cell populations with the percentile data in the Appendix, one can evaluate the numbers of respondents in the original samples at given annoyance levels.



ENERGY-MEAN PNL CATEGORY

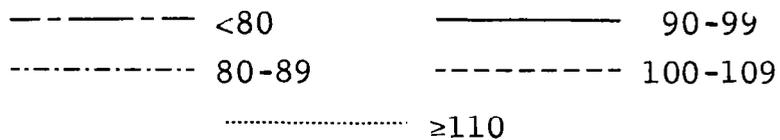


FIGURE 13 DISTRIBUTIONS OF RESPONDENTS ON ANNOYANCE G FOR VARIOUS ENERGY-MEAN PNL NUMBER CATEGORIES, NINE-CITY SAMPLE

## ANALYSIS OF INDIVIDUAL ANNOYANCE

As a means of comparing the trends in individual annoyance for various numbers of daily aircraft operations, regression analyses of Annoyance G on both PNL variables were performed for each number of operations category. Analyses were made of the nine-city composite sample and each of the three subsamples. The PNL parameter was treated as a continuous variable, rather than categorized as in the preceding sections.

Table 5 shows the correlations obtained in the various cases. It will be noted that the pattern of correlation is essentially the same for both energy-mean and largest PNL parameters. Therefore the discussion will center on the former only. Except for the  $N < 50$  values, the correlation coefficients are of about the same order (0.3 - 0.4) as observed in previous studies examining the correlation of annoyance response with noise exposure expressed in equivalent-energy terms. The value of 0.68 for the Phase I,  $N < 50$  category is an unexplained anomaly, as is the relatively steep slope of the associated response functions.

The regression lines for the analyzed cases are shown in Figures 14-17 for the respective data samples. Two general comments should be made regarding these lines. First, tests of linearity indicated significant nonlinear trends only in the lowest three number categories of the Phase I sample; all other cases were highly linear. In the Phase I categories just mentioned, however, the departure from linearity was not large. It was thus decided that representing the overall trends of the data in terms of linear models was a reasonable procedure. It should also be noted that, owing to the large sample sizes, the various regression lines are all statistically distinct.

The nine-city regression lines of Figure 14 show a considerable amount of crossing which, upon examination of the subsample results, can be attributed to the Phase I sample (Figure 15) primarily. The Phase II regression lines of Figure 16 do not cross, and the line for  $N < 50$  agrees rather well with that for the two-city sample, shown in Figure 17. The average slope, weighted by numbers of respondents, is 0.616 annoyance units per PNdB; this value would be appropriate for use in a simplified, uniform-slope model. It is clear that, as in the preceding analyses, the annoyance variable does not obey the equivalent-energy rule regarding the relative effect of level and numbers of operations. The growth of response is rapid with increasing numbers up to 100-199 per day, following which there is a definite decline.

For predicting individual response from level and number information only, the best existing basis is probably the set of lines in Figure 14, or perhaps a constant-slope version of the same, in addition to generalized distribution shapes developed from data in the preceding section or the Appendix. For assessment of impact of aircraft noise in a community, values of percent highly annoyed, estimated from Figure 5, would be appropriate.

TABLE 5

CORRELATION OF ANNOYANCE G WITH ENERGY-MEAN PNL AND  
LARGEST PNL FOR VARIOUS NUMBER OF OPERATIONS CATEGORIES

Number of Operations	Nine-city Sample		Phase I Sample		Phase II Sample		Two-city Sample	
	Energy- Mean PNL	Largest PNL	Energy- Mean PNL	Largest PNL	Energy- Mean PNL	Largest PNL	Energy- Mean PNL	Largest PNL
<50	0.42	0.40	0.68	0.68	0.37	0.38	0.29	0.29
50-99	0.40	0.42	0.32	0.38	0.38	0.39	—	—
100-199	0.37	0.34	0.36	0.34	0.34	0.31	—	—
200-399	0.37	0.39	0.34	0.38	0.36	0.36	—	—
≥400	0.25	0.24	0.25	0.24	—	—	—	—

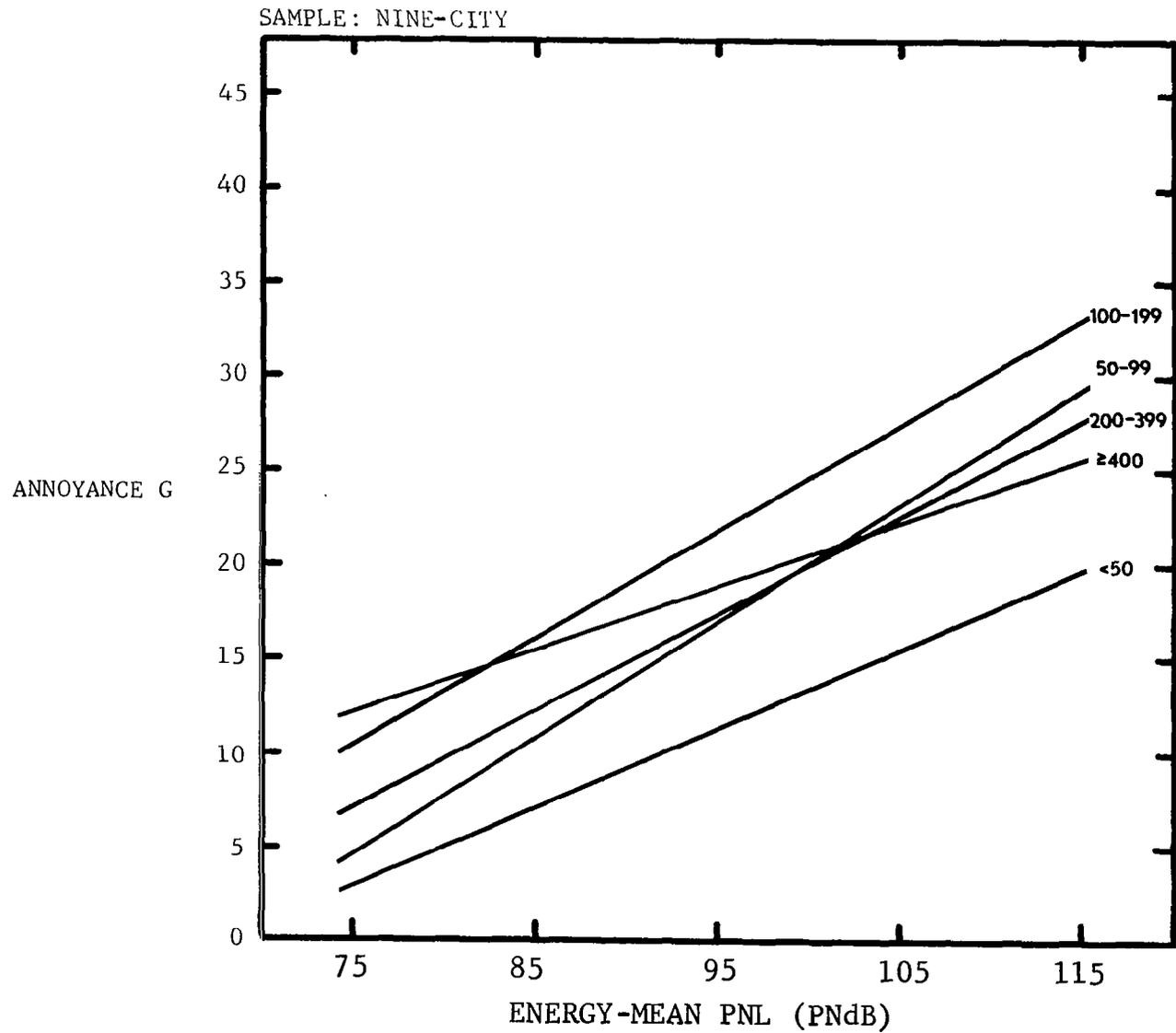


FIGURE 14 REGRESSION OF ANNOYANCE G ON ENERGY-MEAN PERCEIVED NOISE LEVEL FOR VARIOUS NUMBERS OF OPERATIONS, NINE-CITY SAMPLE

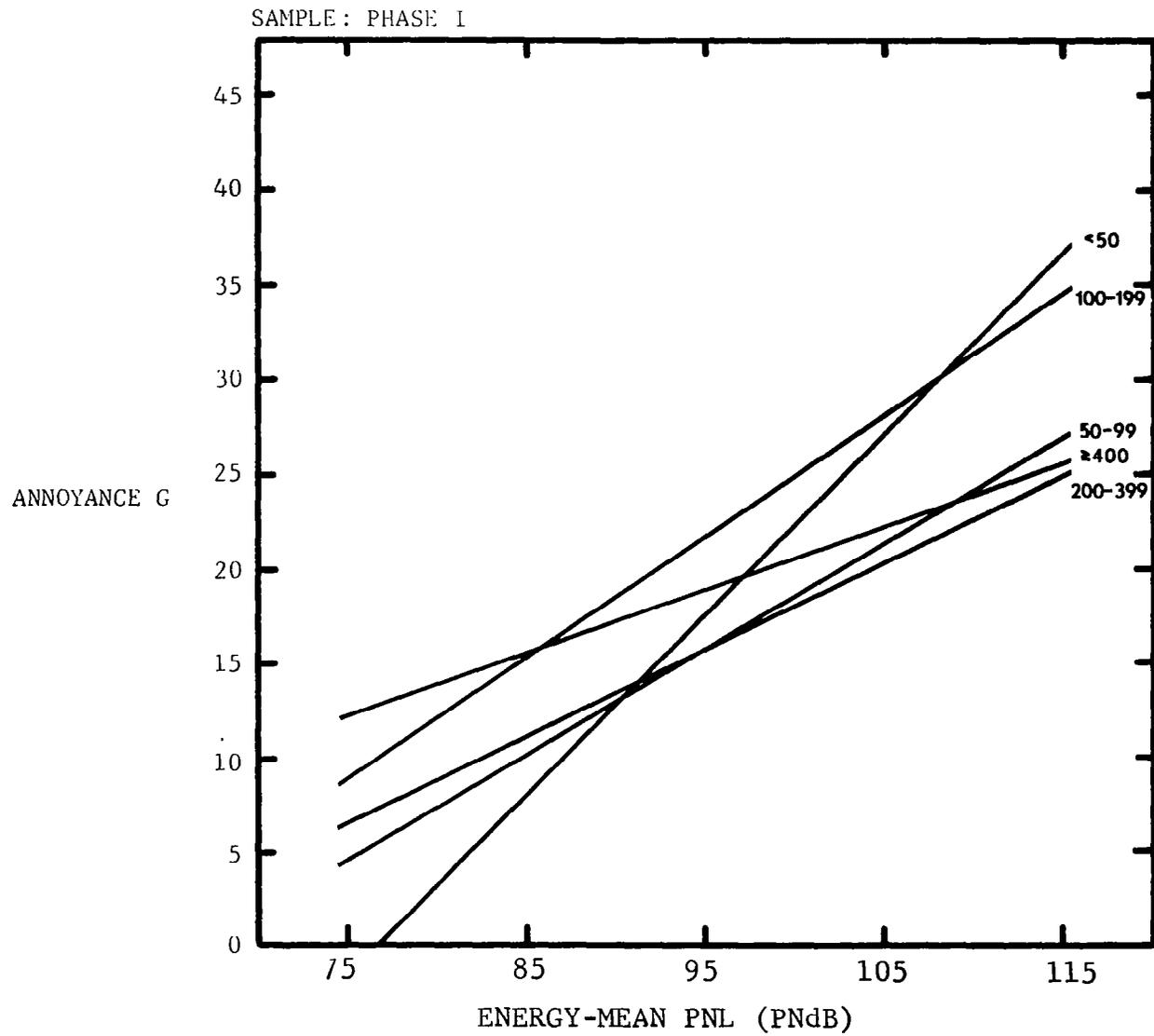


FIGURE 15 REGRESSION OF ANNOYANCE G ON ENERGY-MEAN PERCEIVED NOISE LEVEL FOR VARIOUS NUMBERS OF OPERATIONS, PHASE I SAMPLE

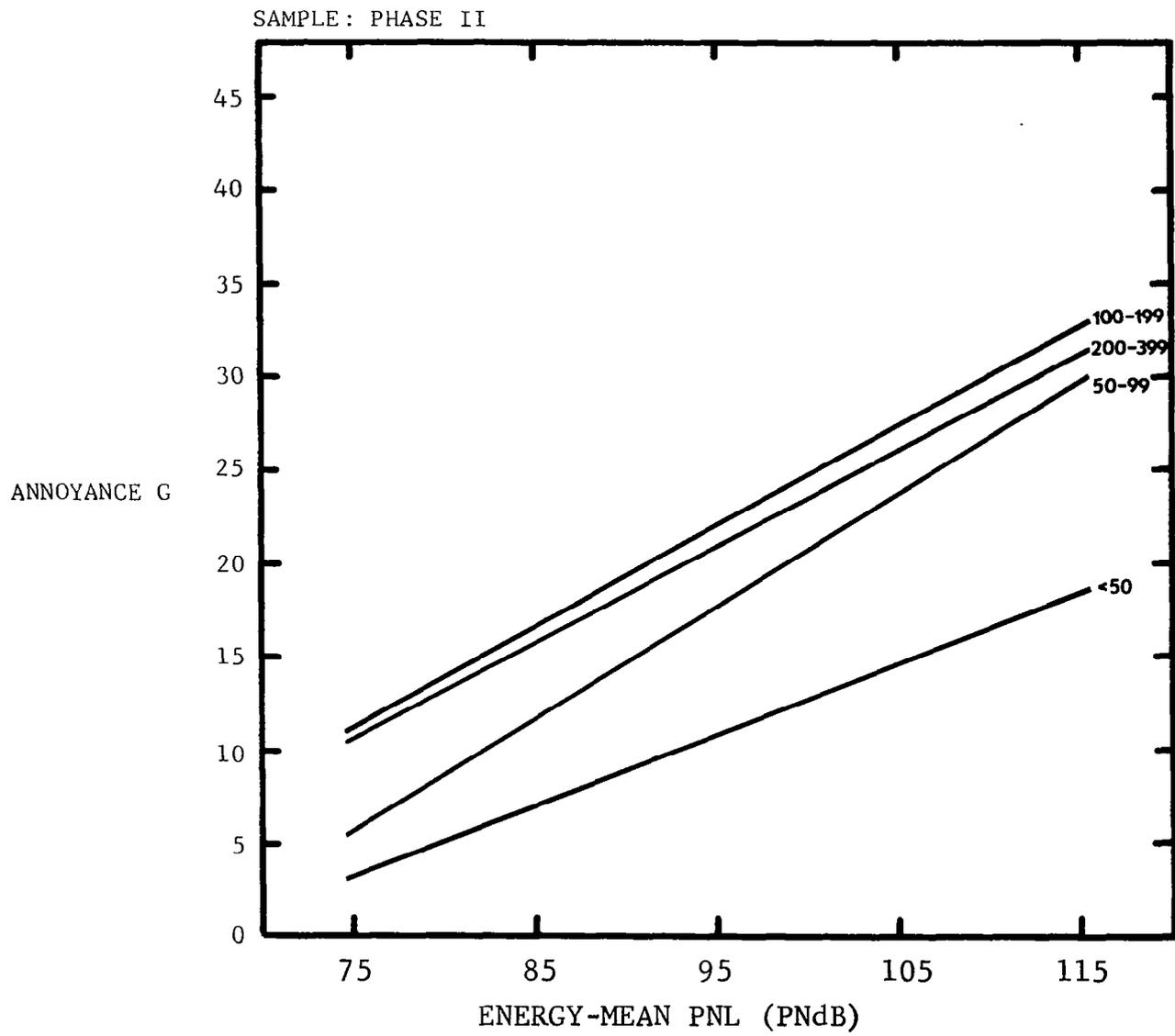


FIGURE 16 REGRESSION OF ANNOYANCE G ON ENERGY-MEAN PERCEIVED NOISE LEVEL FOR VARIOUS NUMBERS OF OPERATIONS, PHASE II SAMPLE

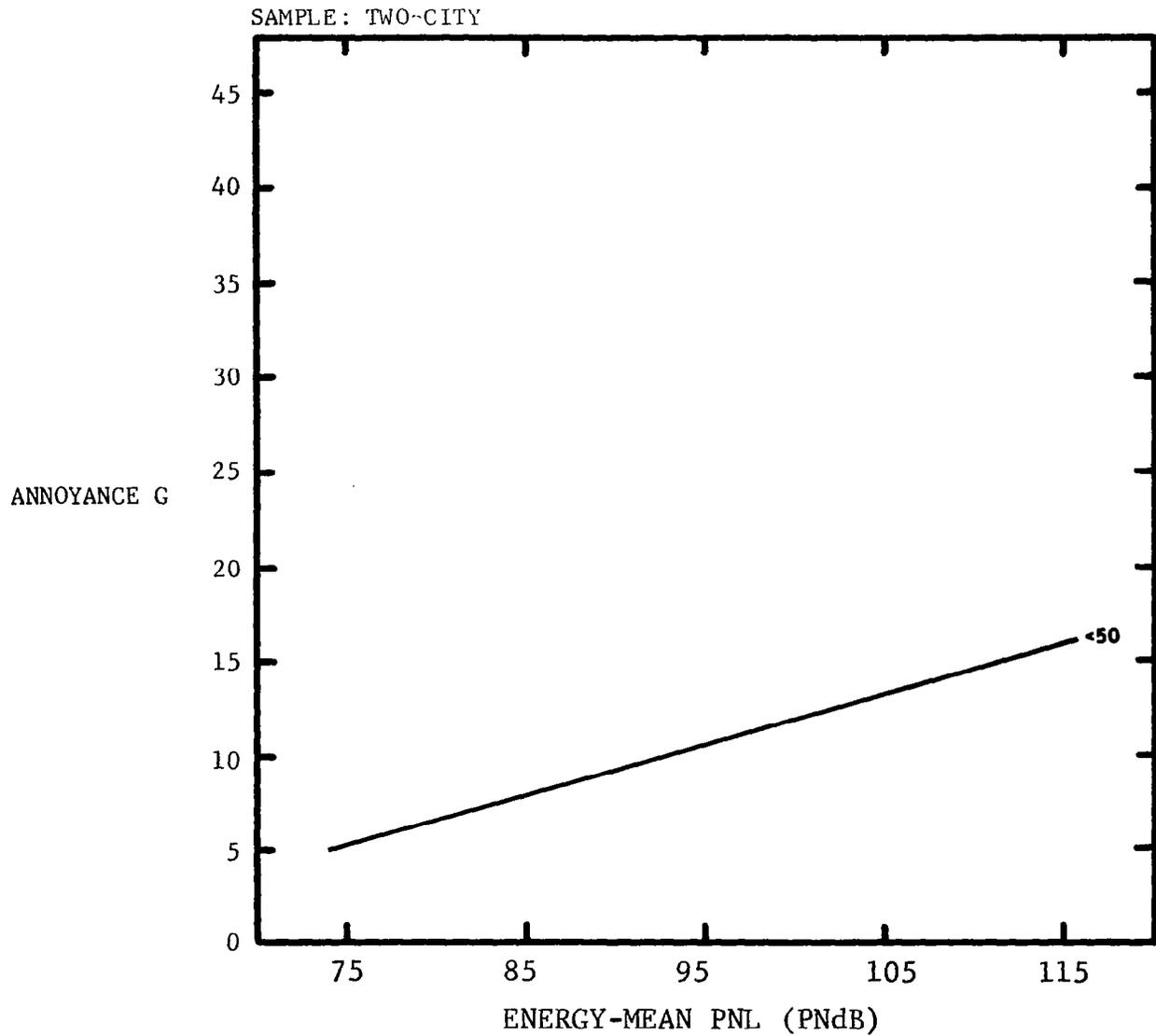


FIGURE 17 REGRESSION OF ANNOYANCE G ON ENERGY-MEAN PERCEIVED NOISE LEVEL FOR VARIOUS NUMBERS OF OPERATIONS, TWO-CITY SAMPLE

## CONCLUSIONS

1. In various recent studies of response to aircraft noise conducted in different countries, it has been found that the relationship between annoyance, event level, and numbers of events is not consistent with earlier assumptions. Recent Swedish studies have called attention to the inconsistency and have offered a new "peak dBA" model purporting to resolve the problem.
2. On the basis of data from the NASA studies in the USA, annoyance response to aircraft noise does not follow either an equivalent-energy model or the "peak dBA" concept.
3. For the present, annoyance response can best be predicted by treating level and number as separate variables, rather than combining them in a single-number exposure parameter; the data in this report provide a basis for such predictions.
4. Annoyance increases steadily with energy-mean level for constant daily operations.
5. Annoyance increases with numbers of operations up to 100-199 per day, then decreases for higher numbers.
6. The statistical distribution of individual annoyance varies with level and number, thus influencing the behavior of any single descriptor, such as a mean or a percentile value, relative to that of another descriptor.
7. Further studies are required to better understand and predict response to aircraft noise. Future investigations or analyses should be structured around specific, reasonable human response models and should treat both stimulus and response as time-dependent variables.

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APPENDIX

DISTRIBUTIONS OF ANNOYANCE G  
FOR VARIOUS LEVEL AND NUMBER CATEGORIES

INDEX TO APPENDIX FIGURES

Figure Number	Sample	Level Parameter	Number Category
A-1			<50
A-2			50-99
A-3	Nine-city	$\overline{\overline{\text{PNL}}}$	100-199
A-4			200-399
A-5			≥400
A-6			<50
A-7			50-99
A-8	Phase I	$\overline{\overline{\text{PNL}}}$	100-199
A-9			200-399
A-10			≥400
A-11			<50
A-12	Phase II	$\overline{\overline{\text{PNL}}}$	50-99
A-13			100-199
A-14			200-399
A-15	Two-city	$\overline{\overline{\text{PNL}}}$	<50
A-16			<50
A-17			50-99
A-18	Nine-city	Largest PNL	100-199
A-19			200-399
A-20			≥400
A-21			<50
A-22			50-99
A-23	Phase I	Largest PNL	100-199
A-24			200-399
A-25			≥400

INDEX TO APPENDIX FIGURES - Continued

Figure Number	Sample	Level Parameter	Number Category
A-26			<50
A-27	Phase II	Largest PNL	50-99
A-28			100-199
A-29			200-399
A-30	Two-city	Largest PNL	<50

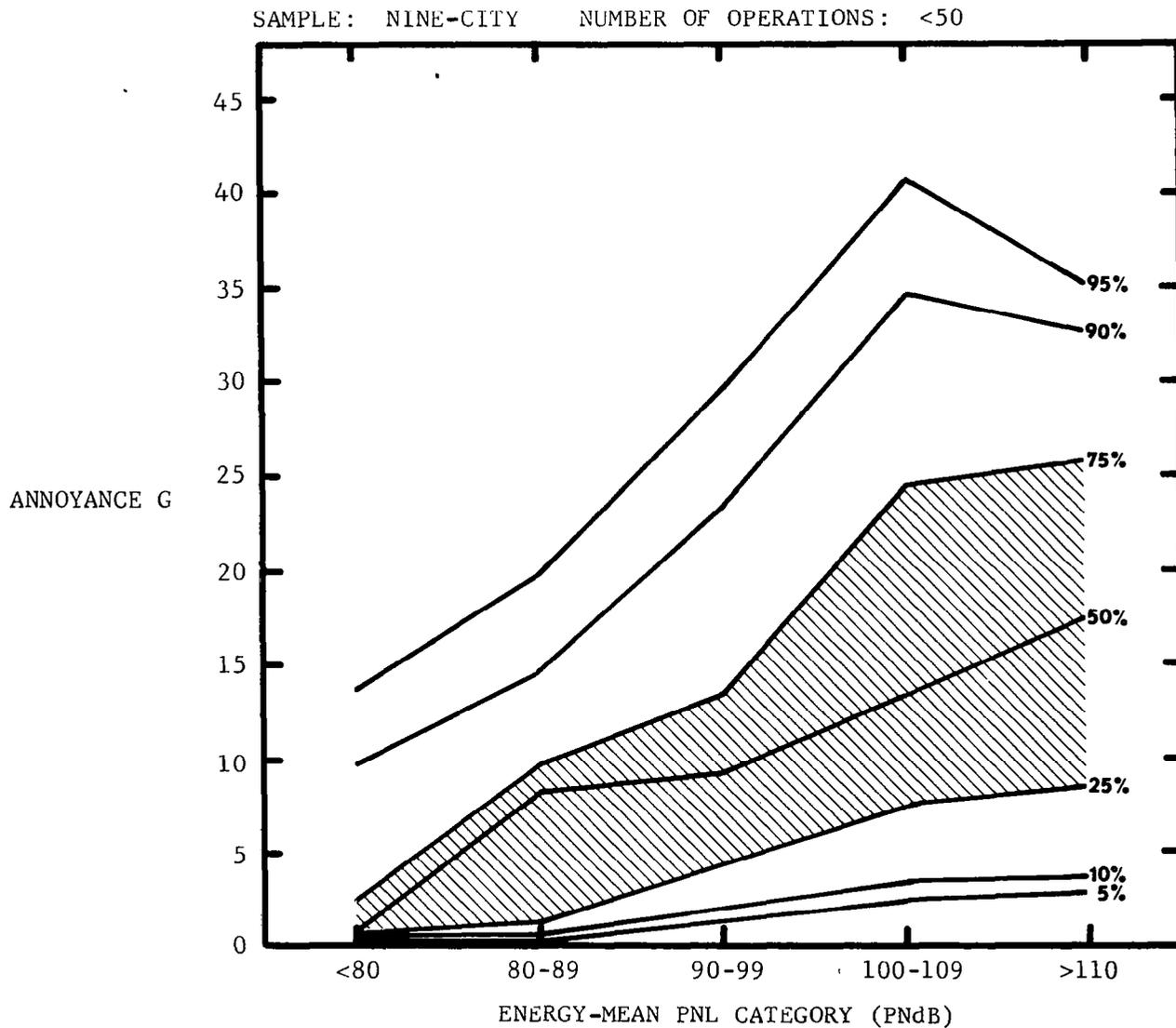


FIGURE A-1      PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, NINE-CITY SAMPLE, LESS THAN 50 DAILY OPERATIONS

SAMPLE: NINE-CITY NUMBER OF OPERATIONS: 50-99

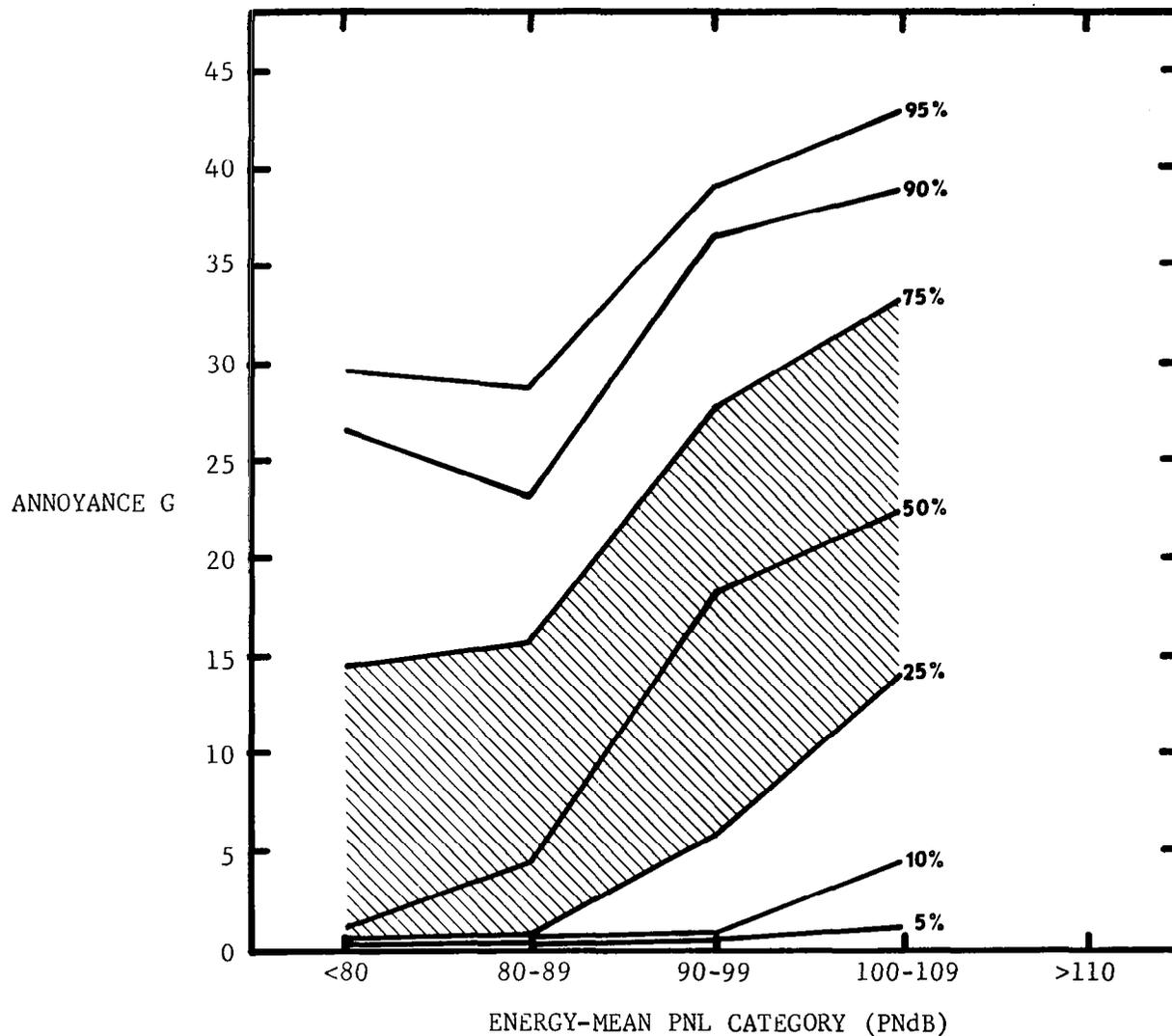


FIGURE A-2 PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, NINE-CITY SAMPLE, 50-99 DAILY OPERATIONS

SAMPLE: NINE-CITY NUMBER OF OPERATIONS: 100-199

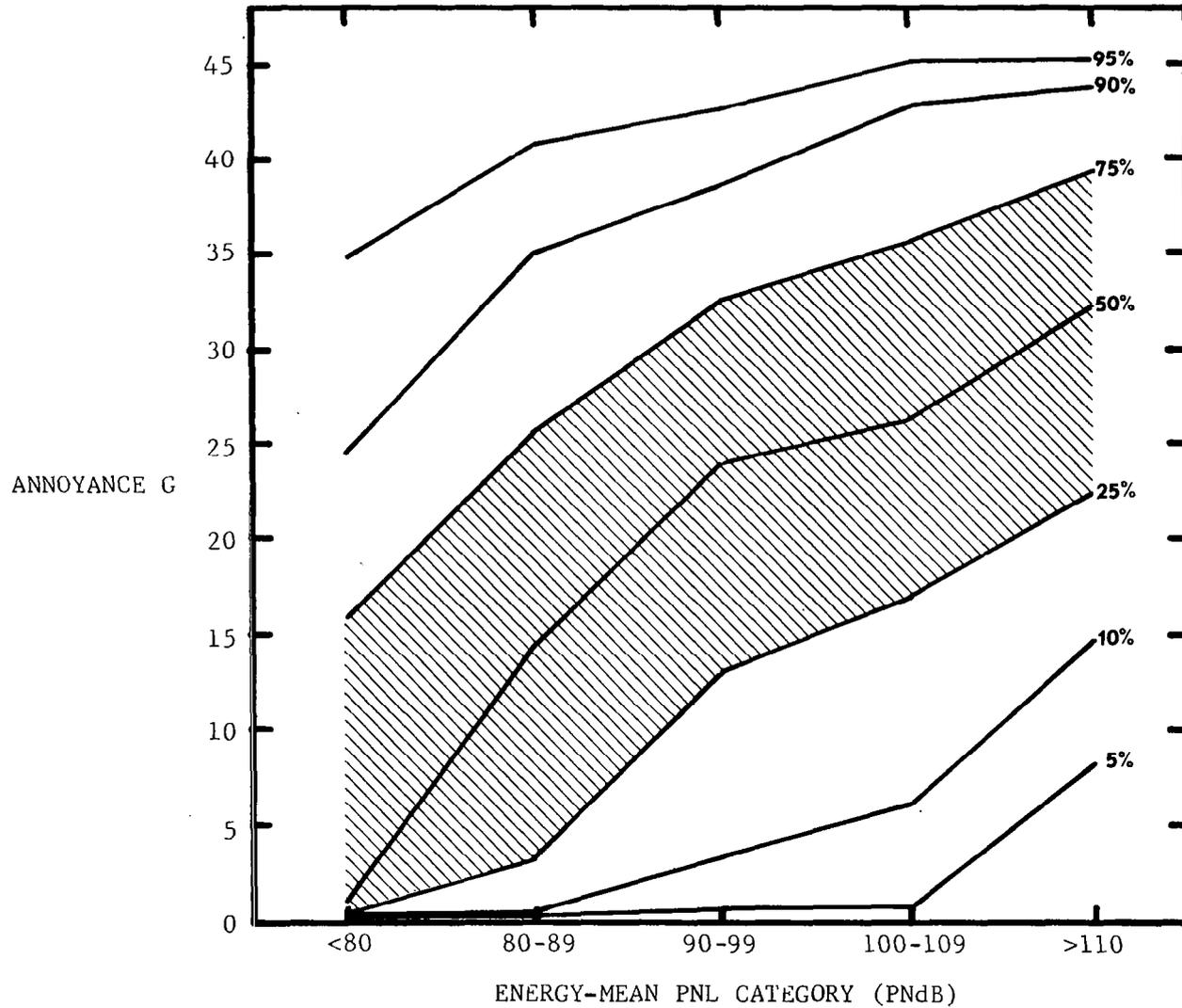


FIGURE A-3 PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, NINE-CITY SAMPLE, 100-199 DAILY OPERATIONS

SAMPLE: NINE-CITY NUMBER OF OPERATIONS: 200-399

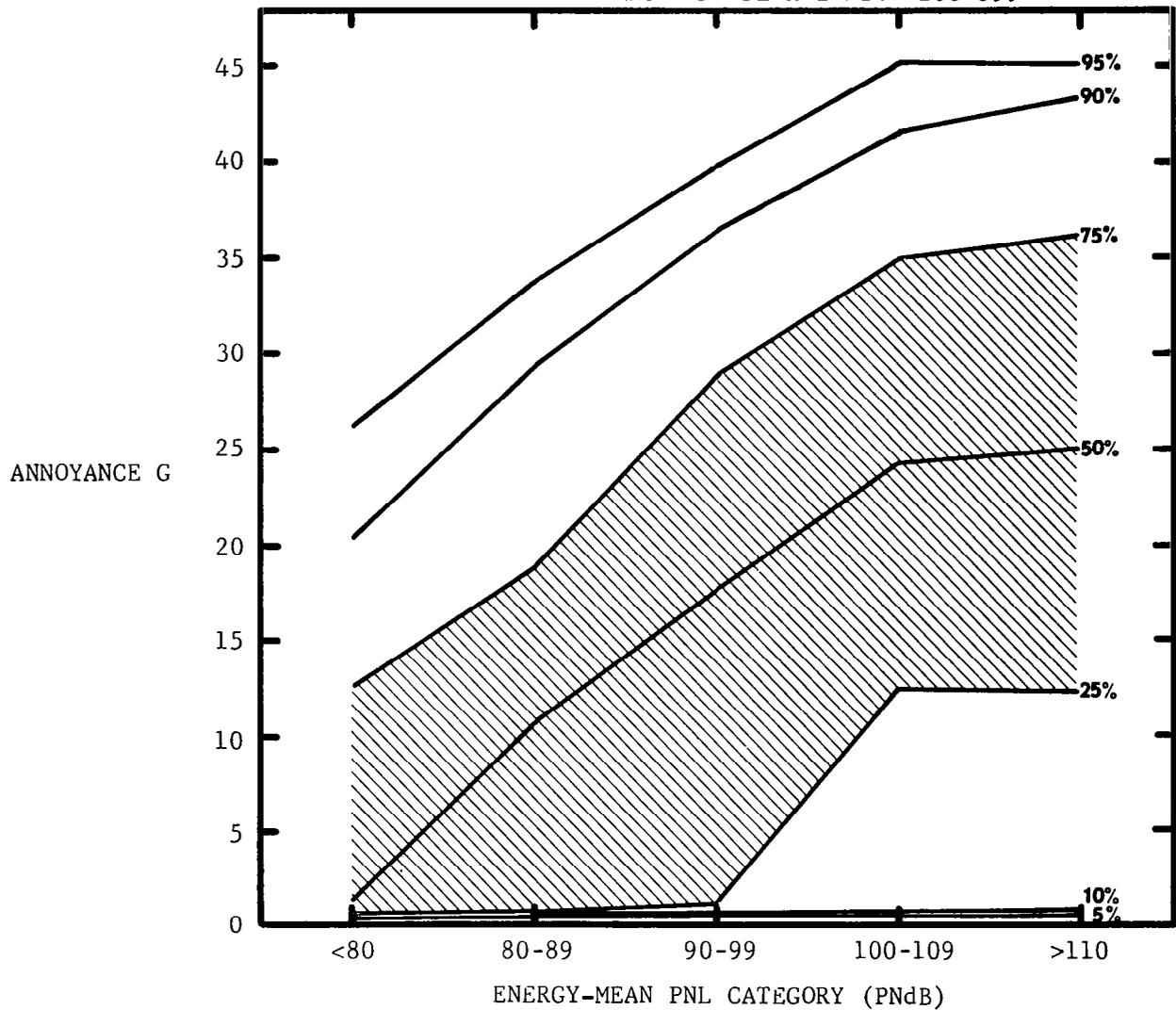


FIGURE A-4 PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, NINE-CITY SAMPLE, 200-399 DAILY OPERATIONS

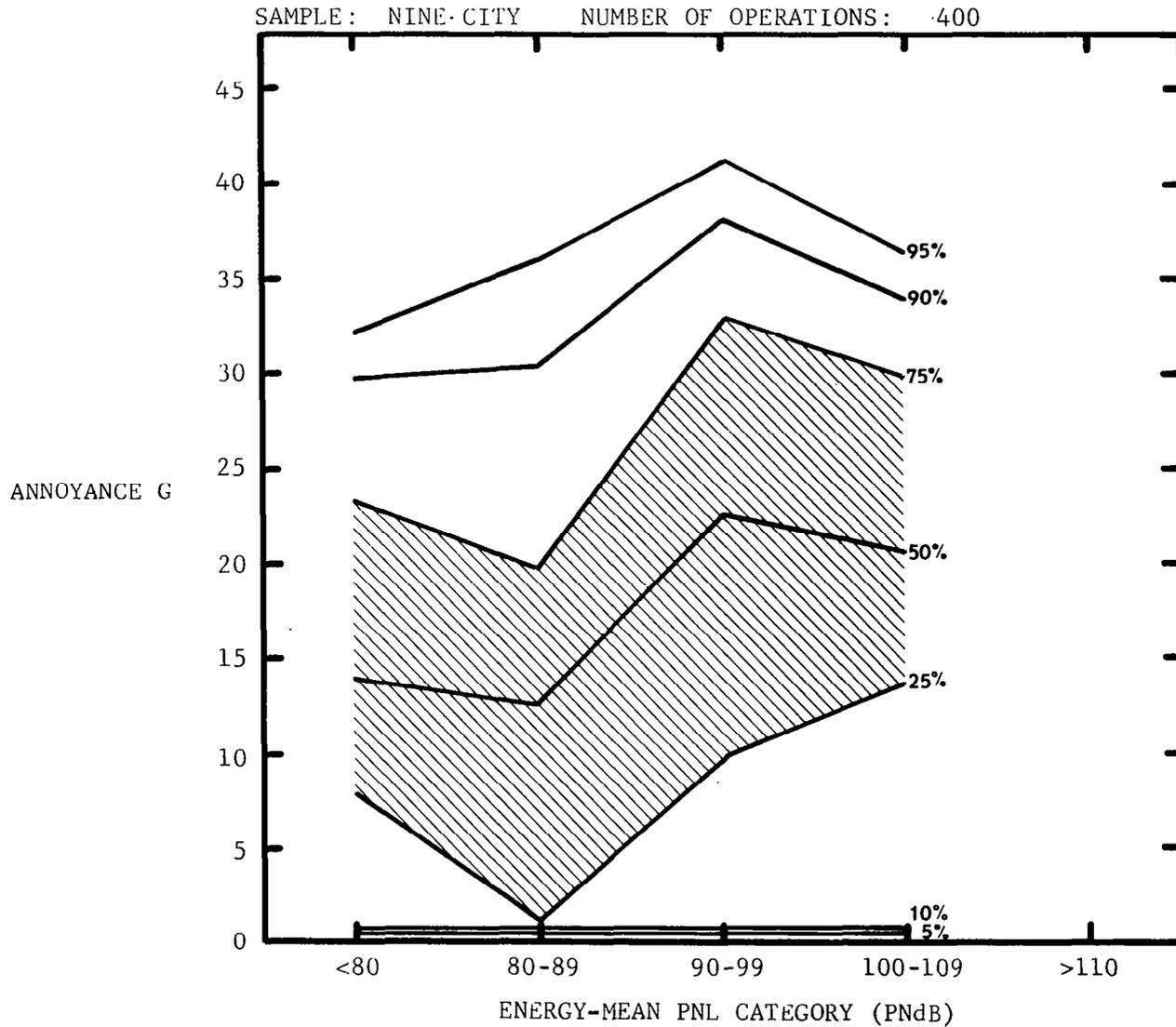


FIGURE A-5 PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, NINE-CITY SAMPLE, GREATER THAN 400 DAILY OPERATIONS

SAMPLE: PHASE 1 NUMBER OF OPERATIONS: <50

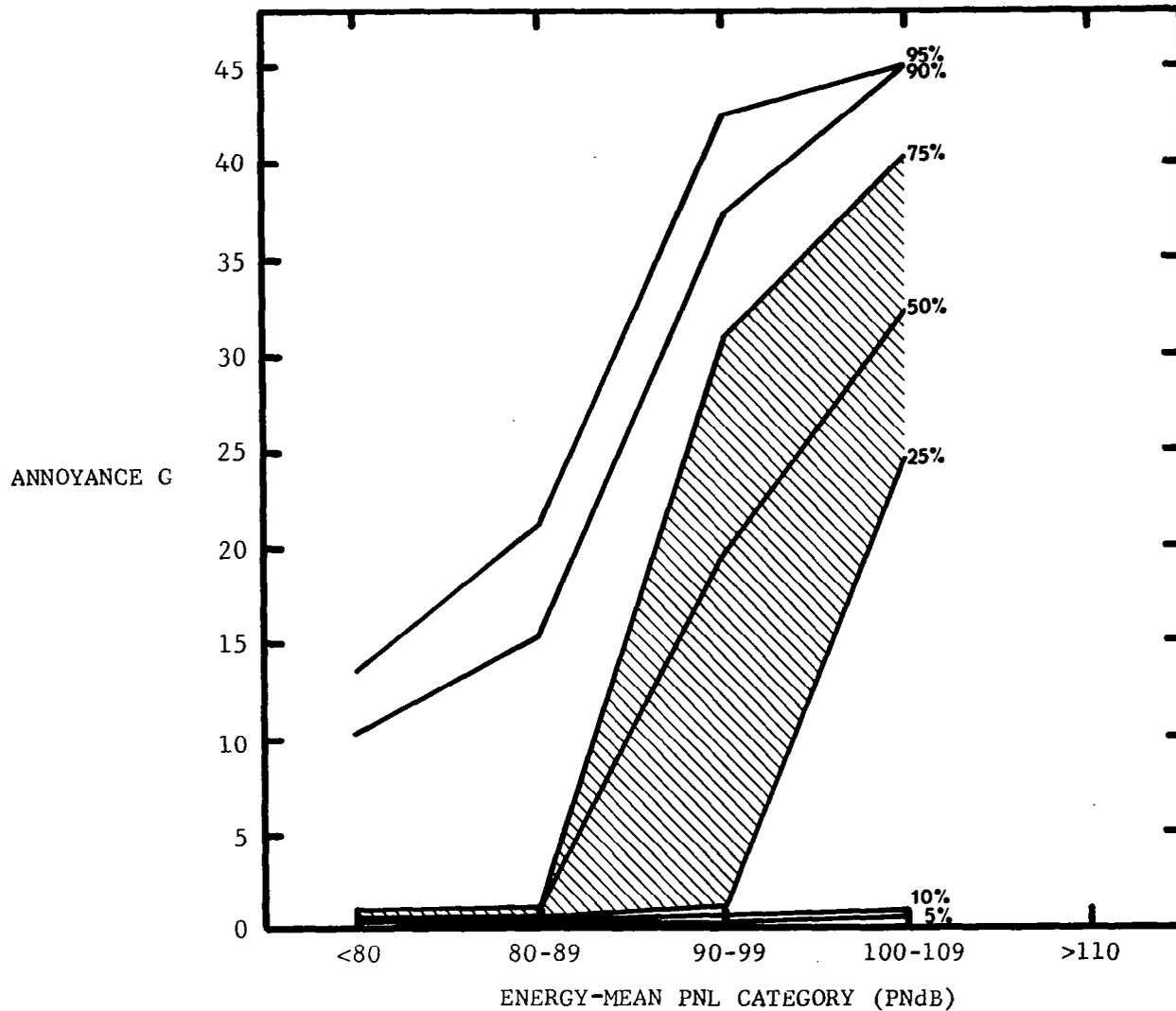


FIGURE A-6 PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, PHASE I SAMPLE, LESS THAN 50 DAILY OPERATIONS

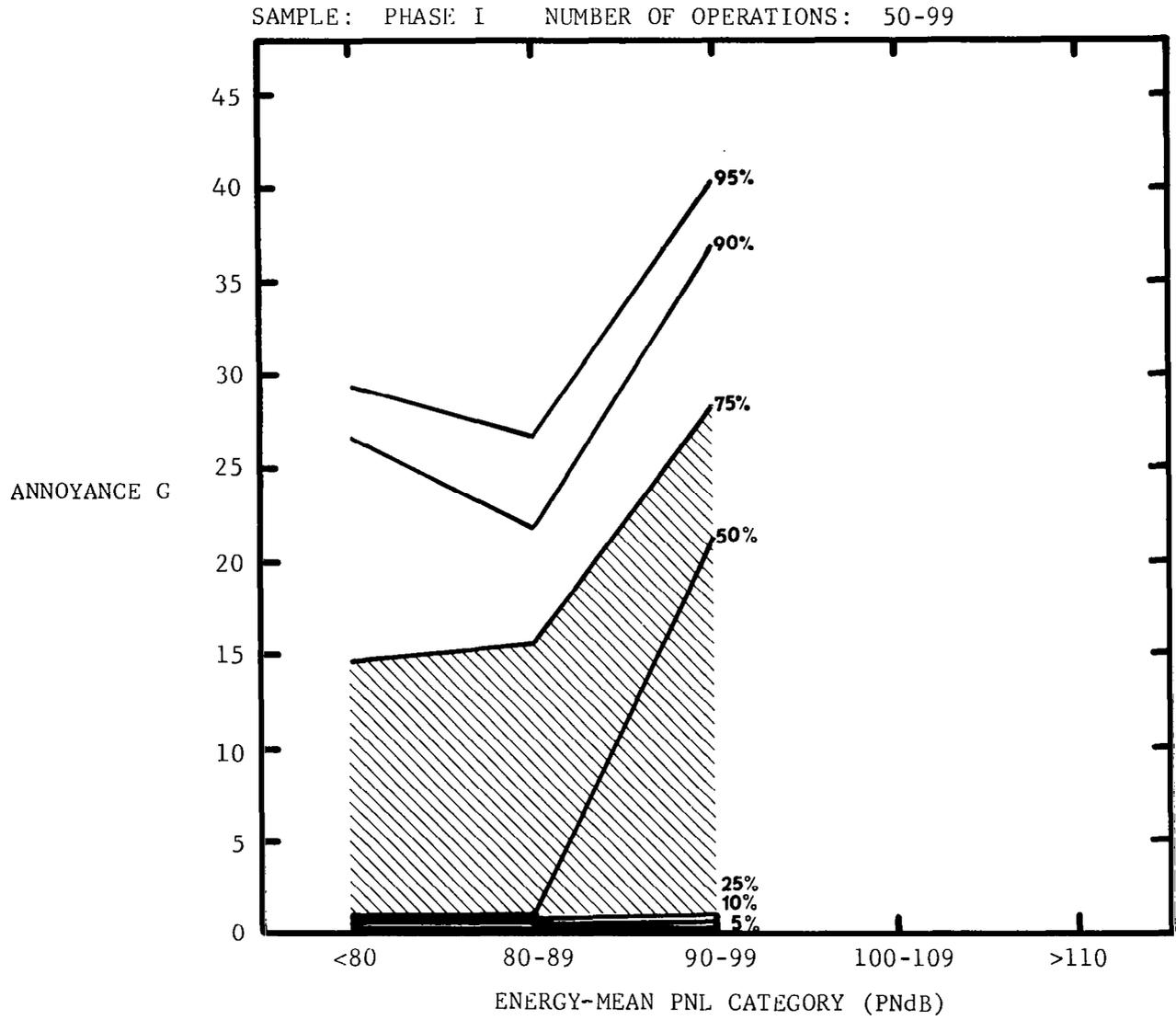


FIGURE A-7 PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, PHASE I SAMPLE, 50-99 DAILY OPERATIONS

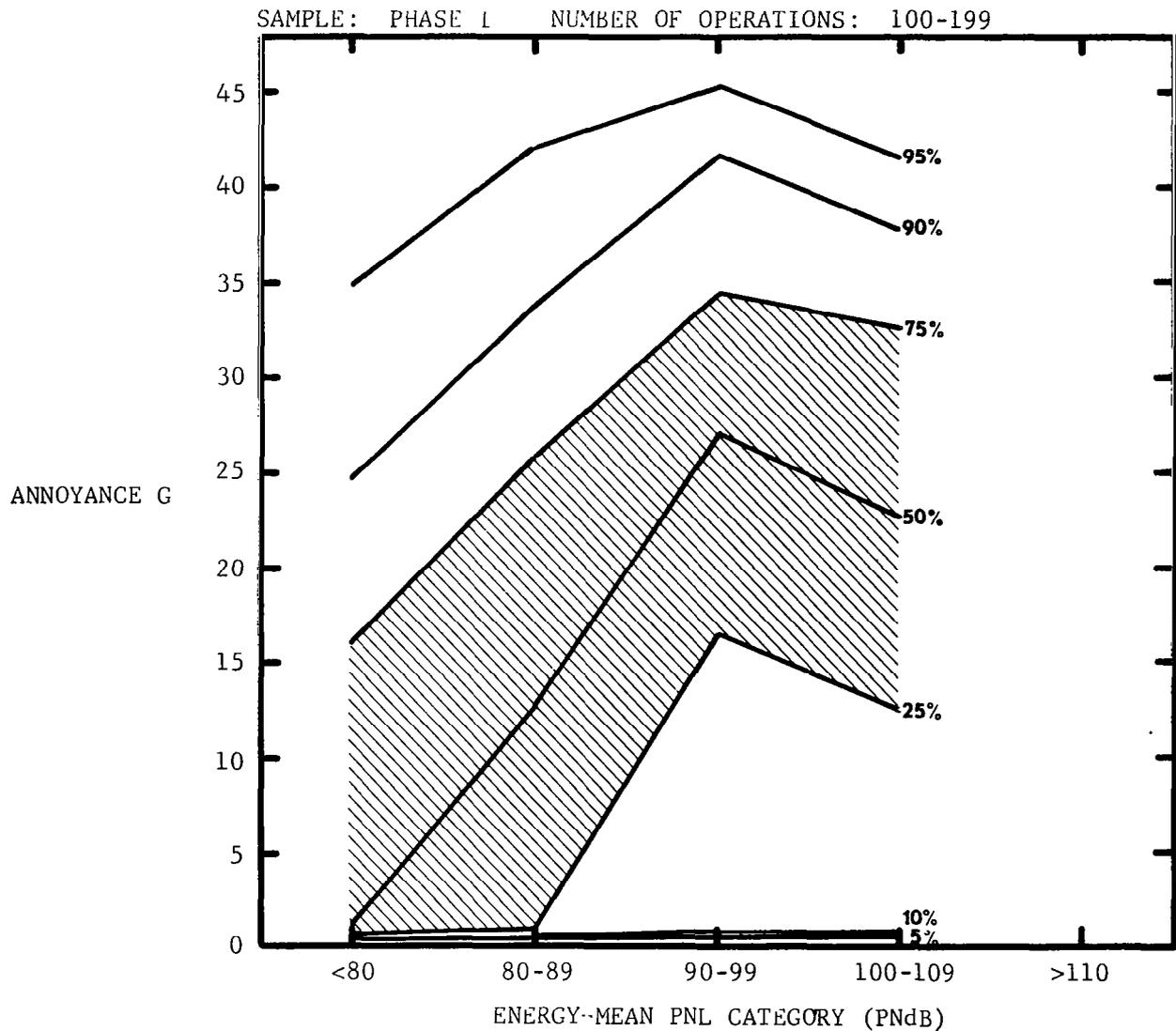


FIGURE A-8      PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, PHASE I SAMPLE, 100-199 DAILY OPERATIONS

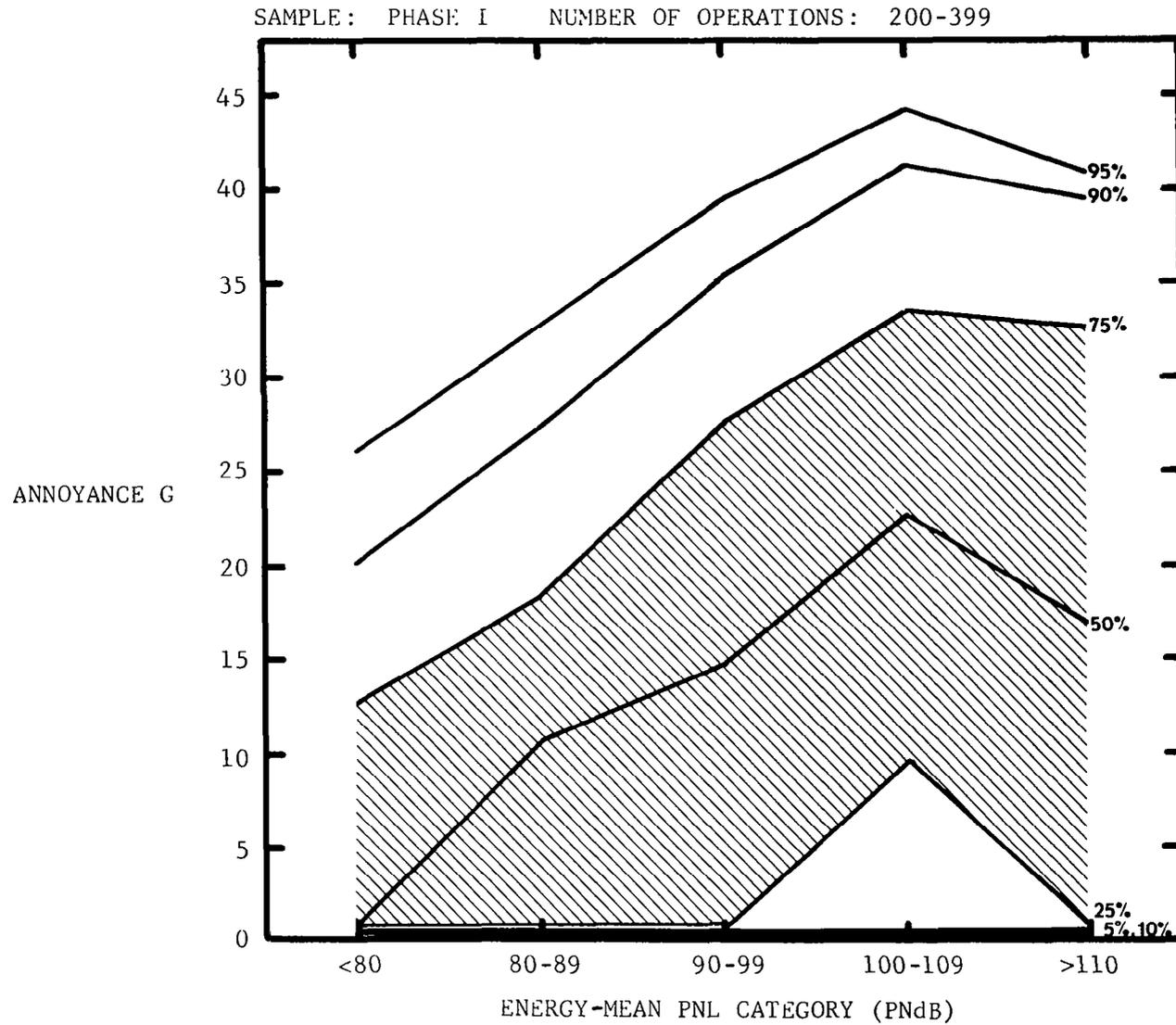


FIGURE A-9 PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, PHASE I SAMPLE, 200-399 DAILY OPERATIONS

SAMPLE: PHASE 1 NUMBER OF OPERATIONS: >400

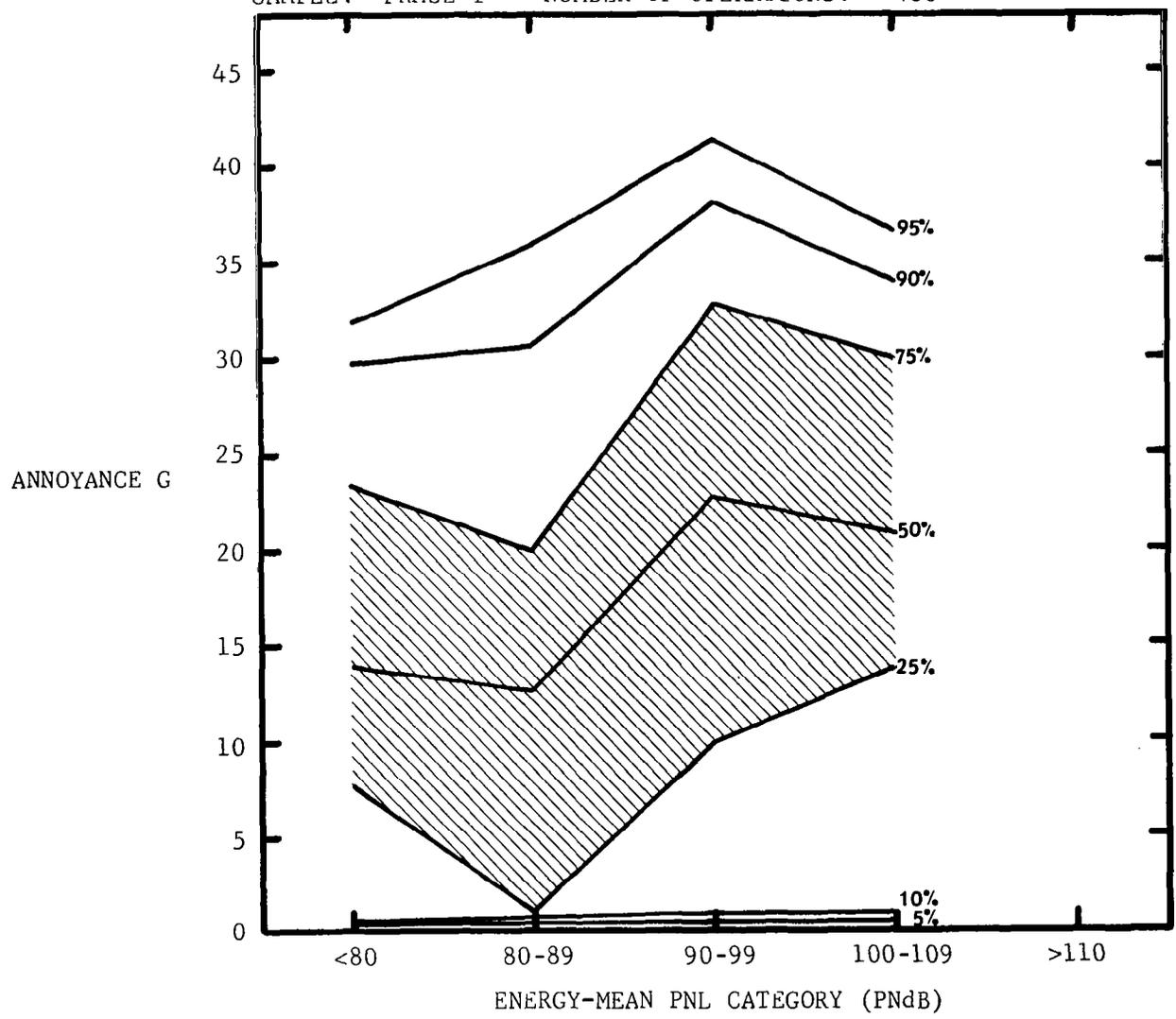


FIGURE A-10 PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, PHASE I SAMPLE, GREATER THAN 400 DAILY OPERATIONS

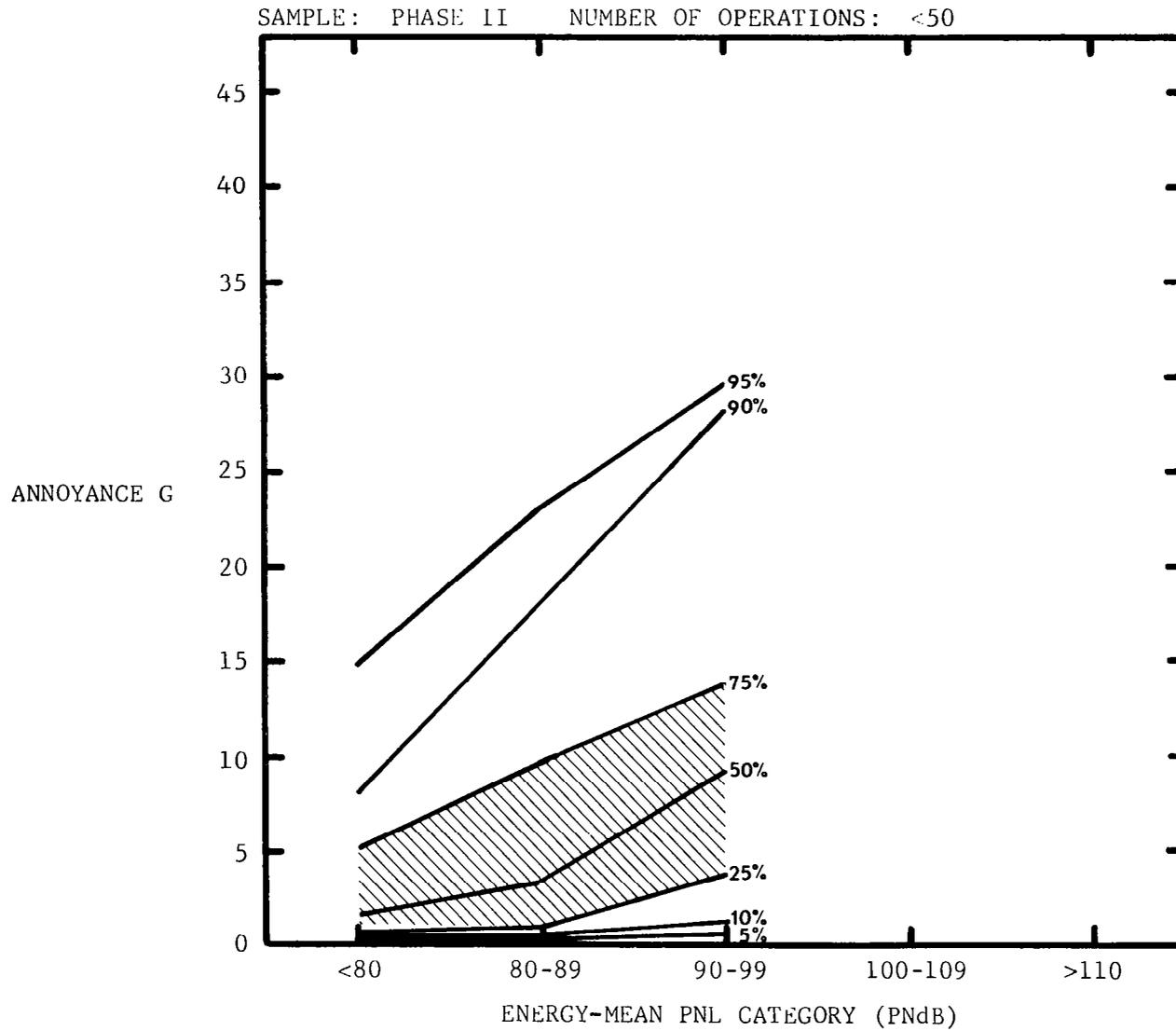


FIGURE A-11 PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, PHASE II SAMPLE, LESS THAN 50 DAILY OPERATIONS

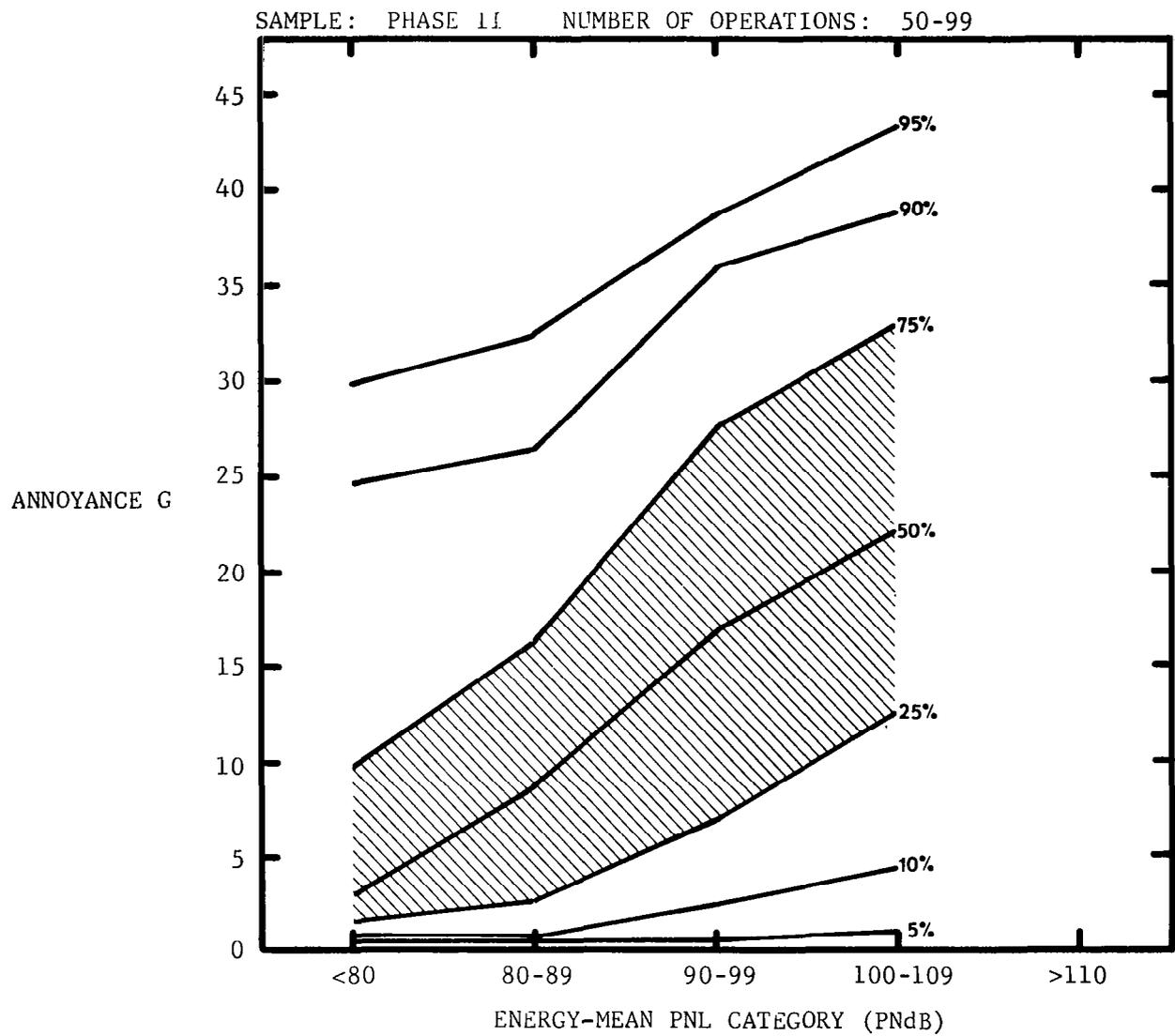


FIGURE A-12 PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, PHASE II SAMPLE, 50-99 DAILY OPERATIONS

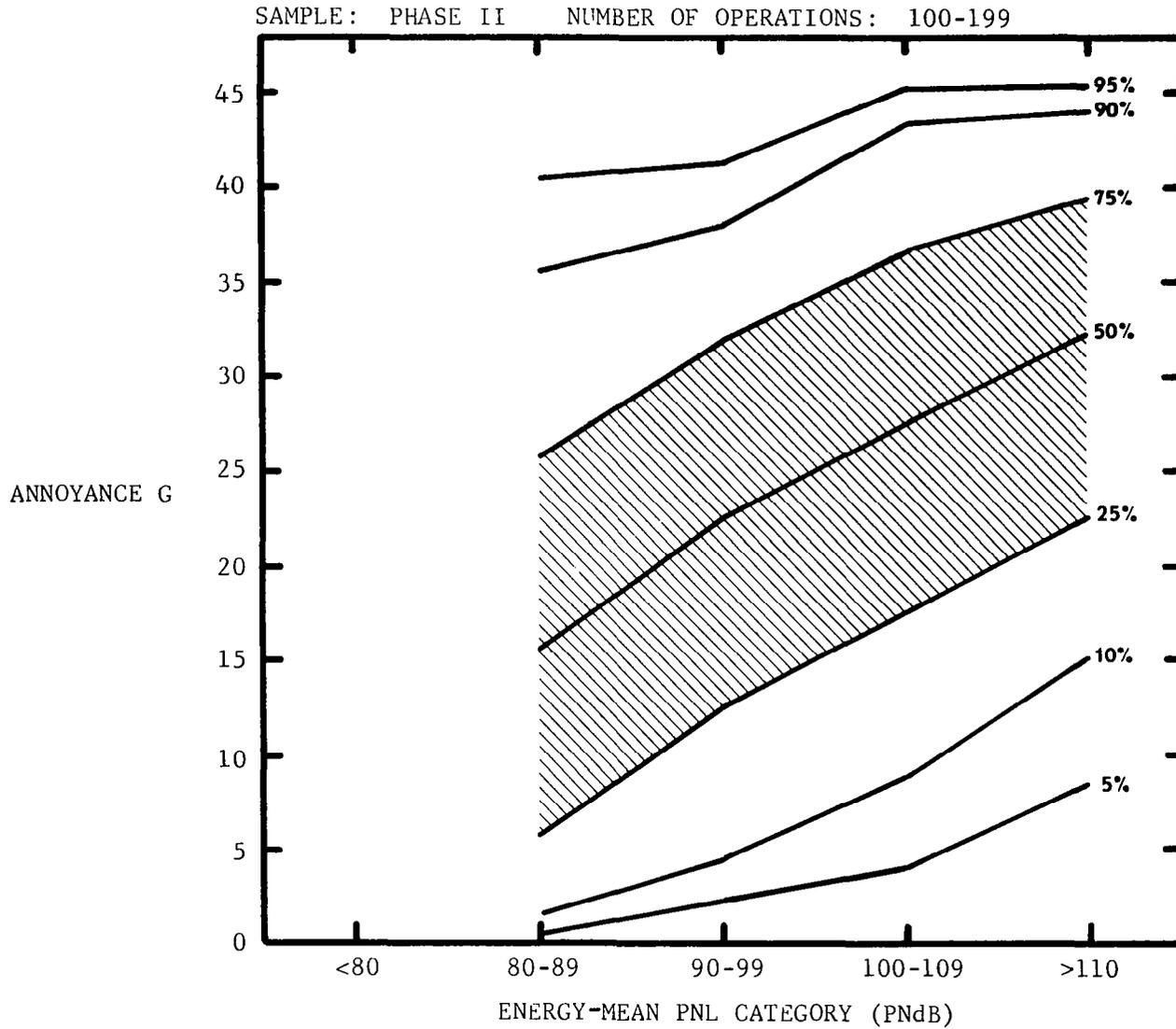


FIGURE A-13 PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, PHASE II SAMPLE, 100-199 DAILY OPERATIONS

SAMPLE: PHASE II NUMBER OF OPERATIONS: 200-399

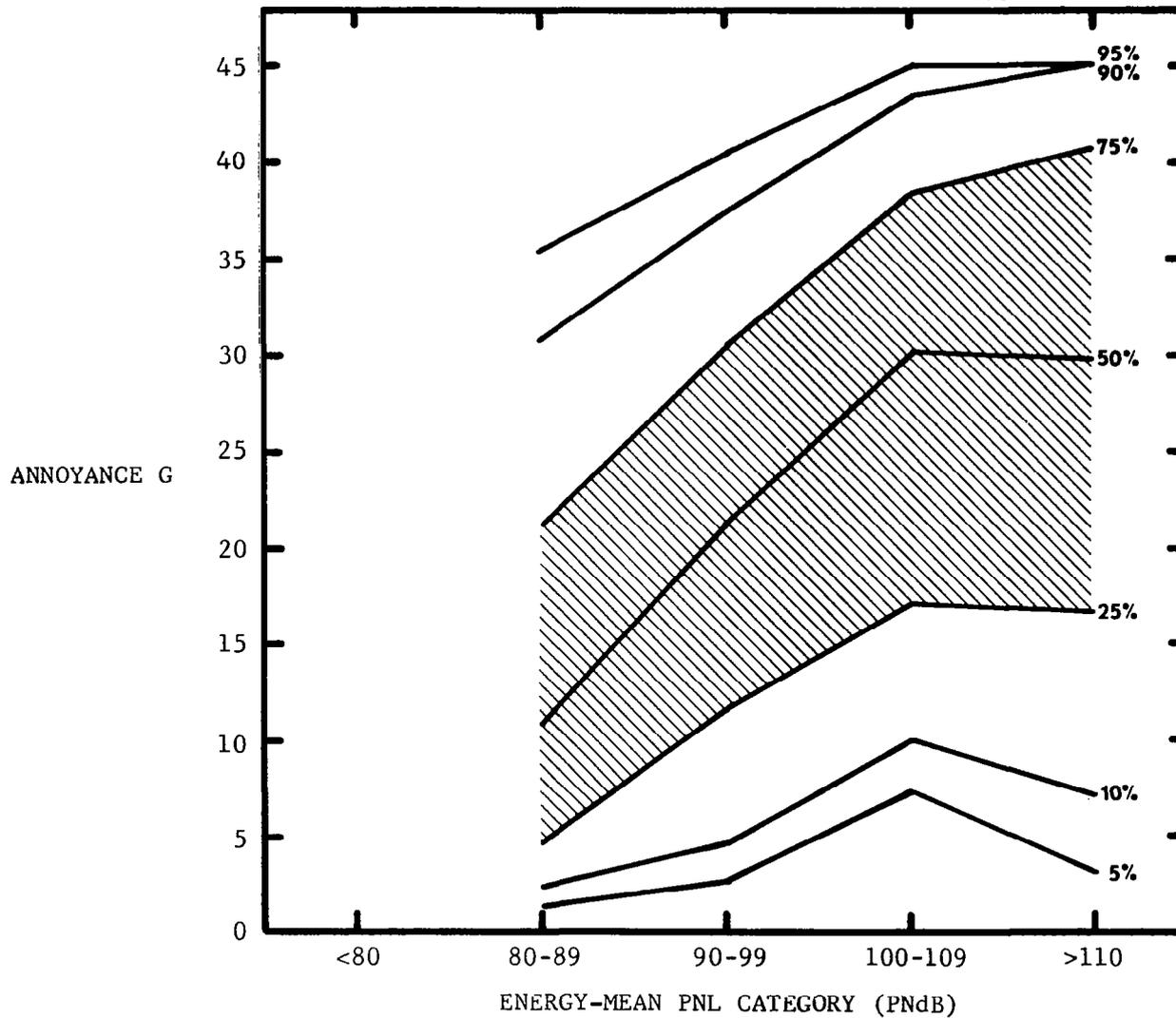


FIGURE A-14 PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, PHASE II SAMPLE, 200-399 DAILY OPERATIONS

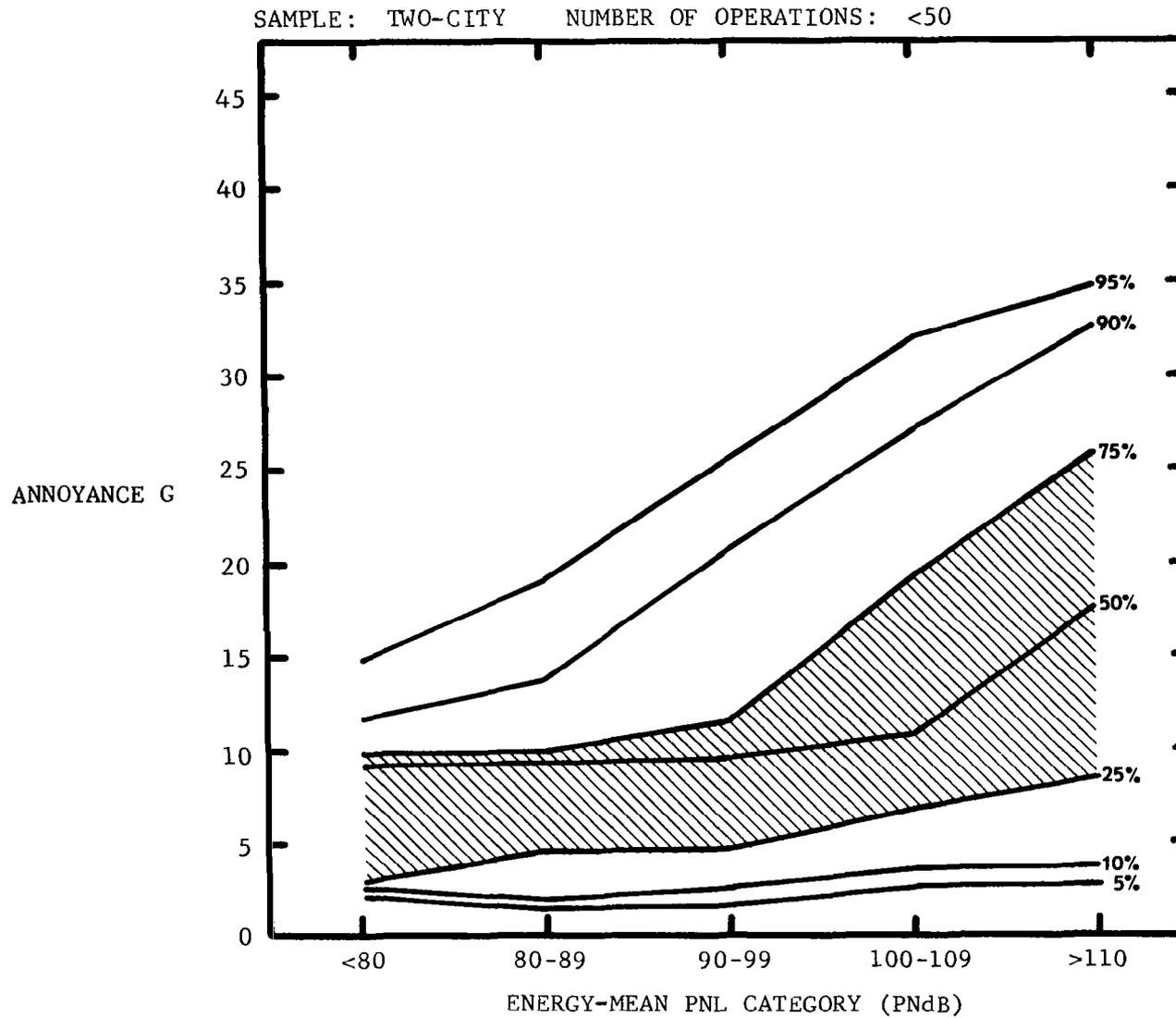


FIGURE A-15 PERCENTILES OF ANNOYANCE G VERSUS ENERGY-MEAN PERCEIVED NOISE LEVEL, TWO-CITY SAMPLE, LESS THAN 50 DAILY OPERATIONS

SAMPLE: NINE-CITY NUMBER OF OPERATIONS: <50

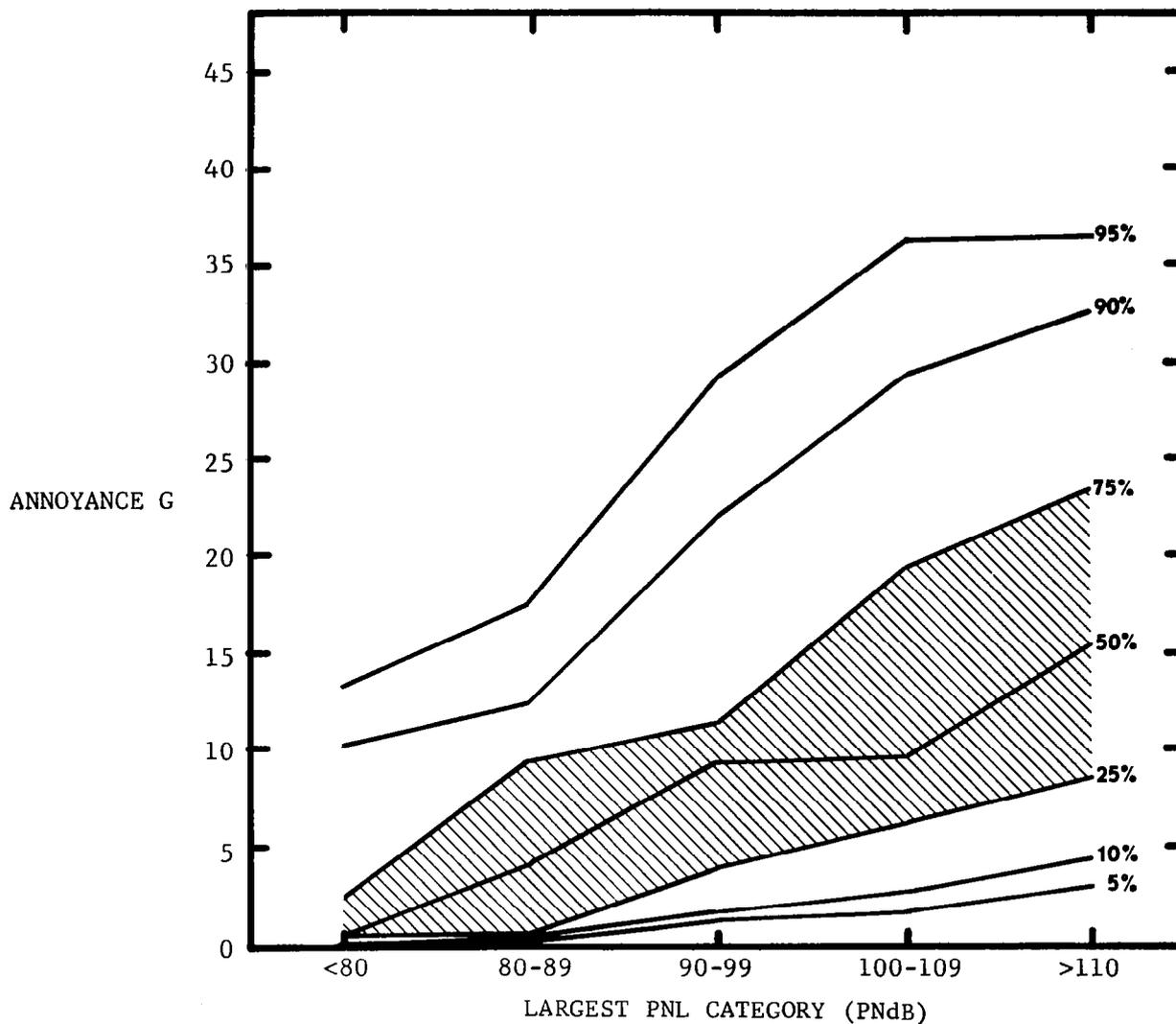


FIGURE A-16 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, NINE-CITY SAMPLE, LESS THAN 50 DAILY OPERATIONS

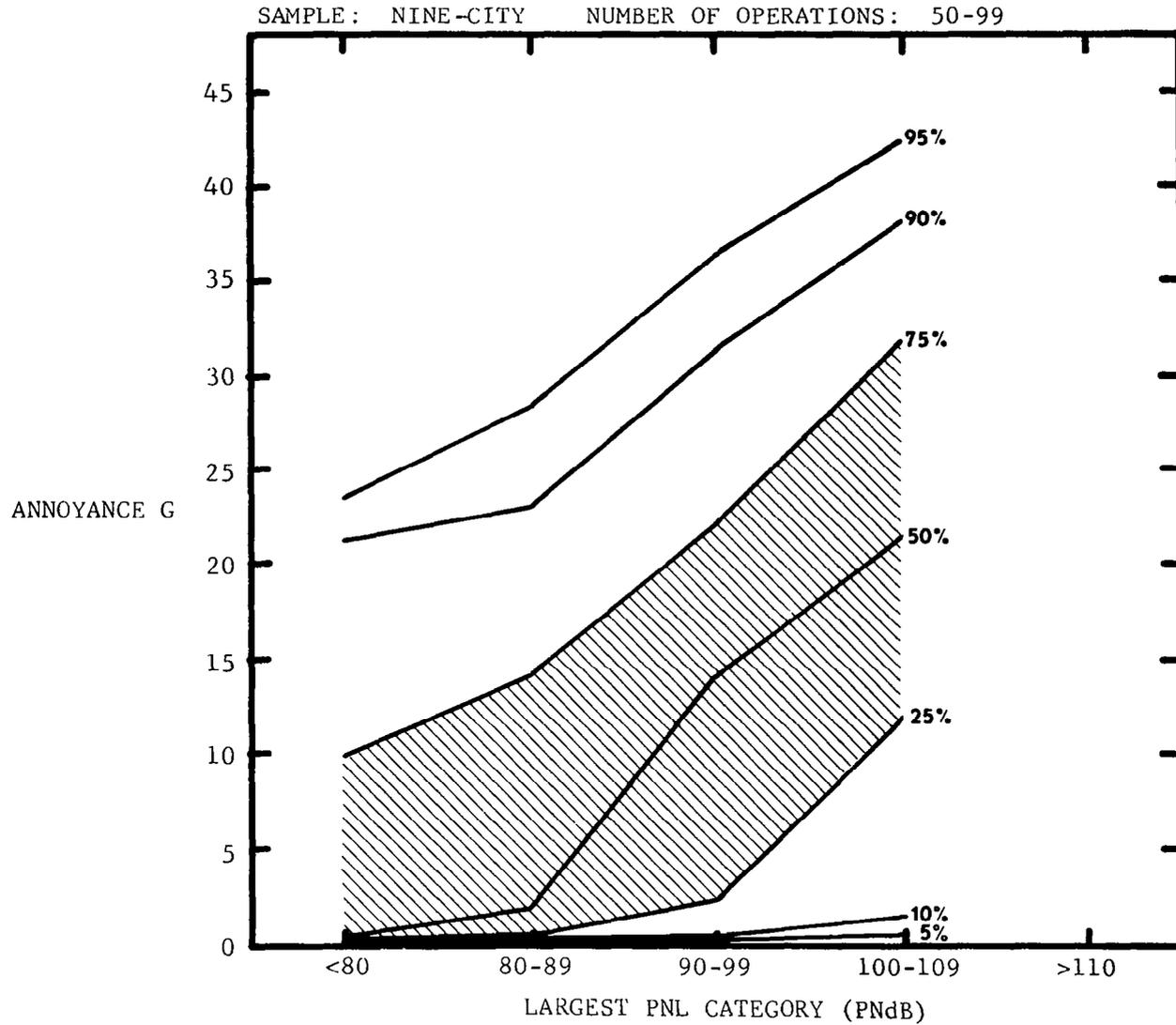


FIGURE A-17 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, NINE-CITY SAMPLE, 50-99 DAILY OPERATIONS

SAMPLE: NINE-CITY NUMBER OF OPERATIONS: 100-199

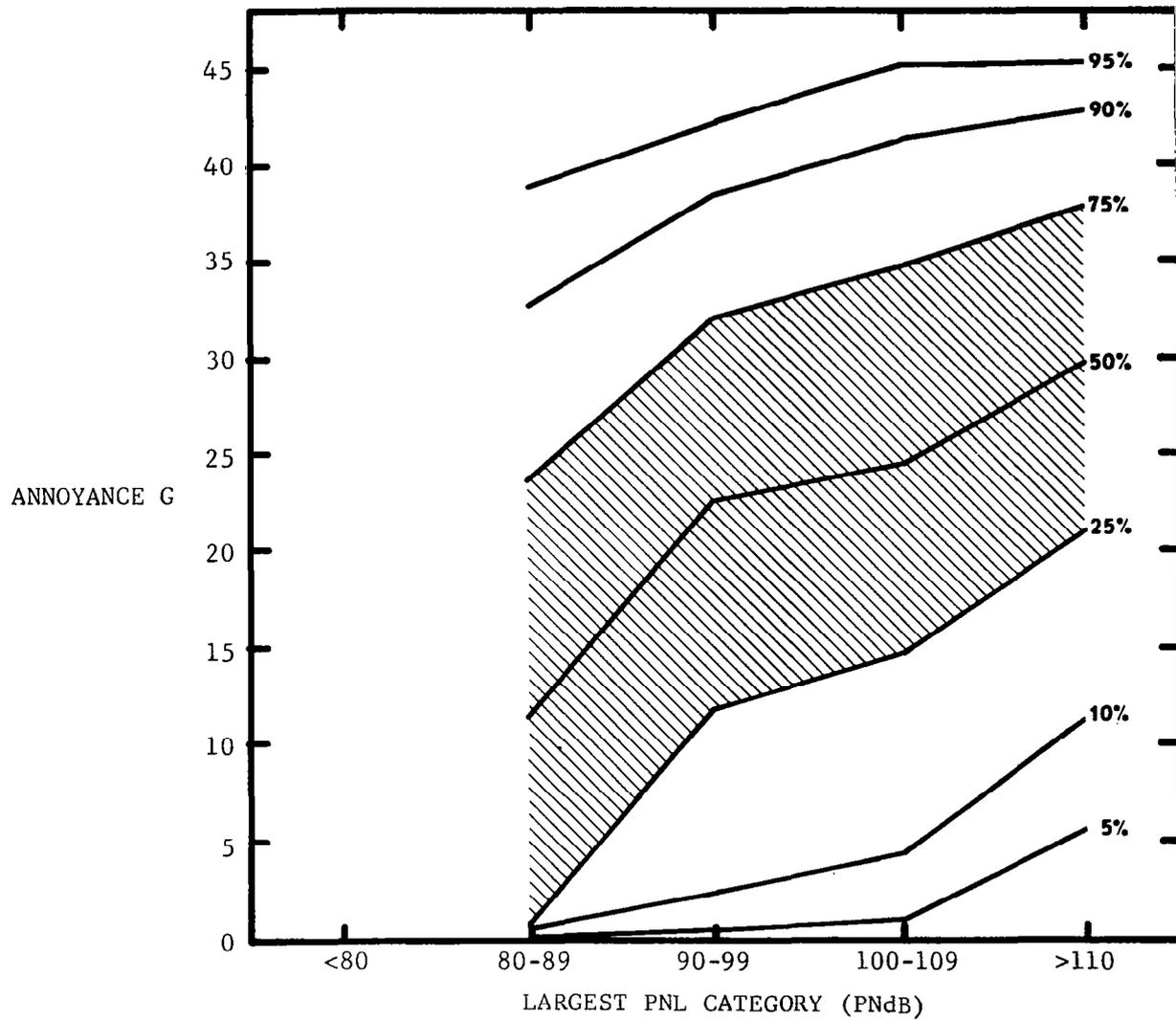


FIGURE A-18 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, NINE-CITY SAMPLE, 100-199 DAILY OPERATIONS

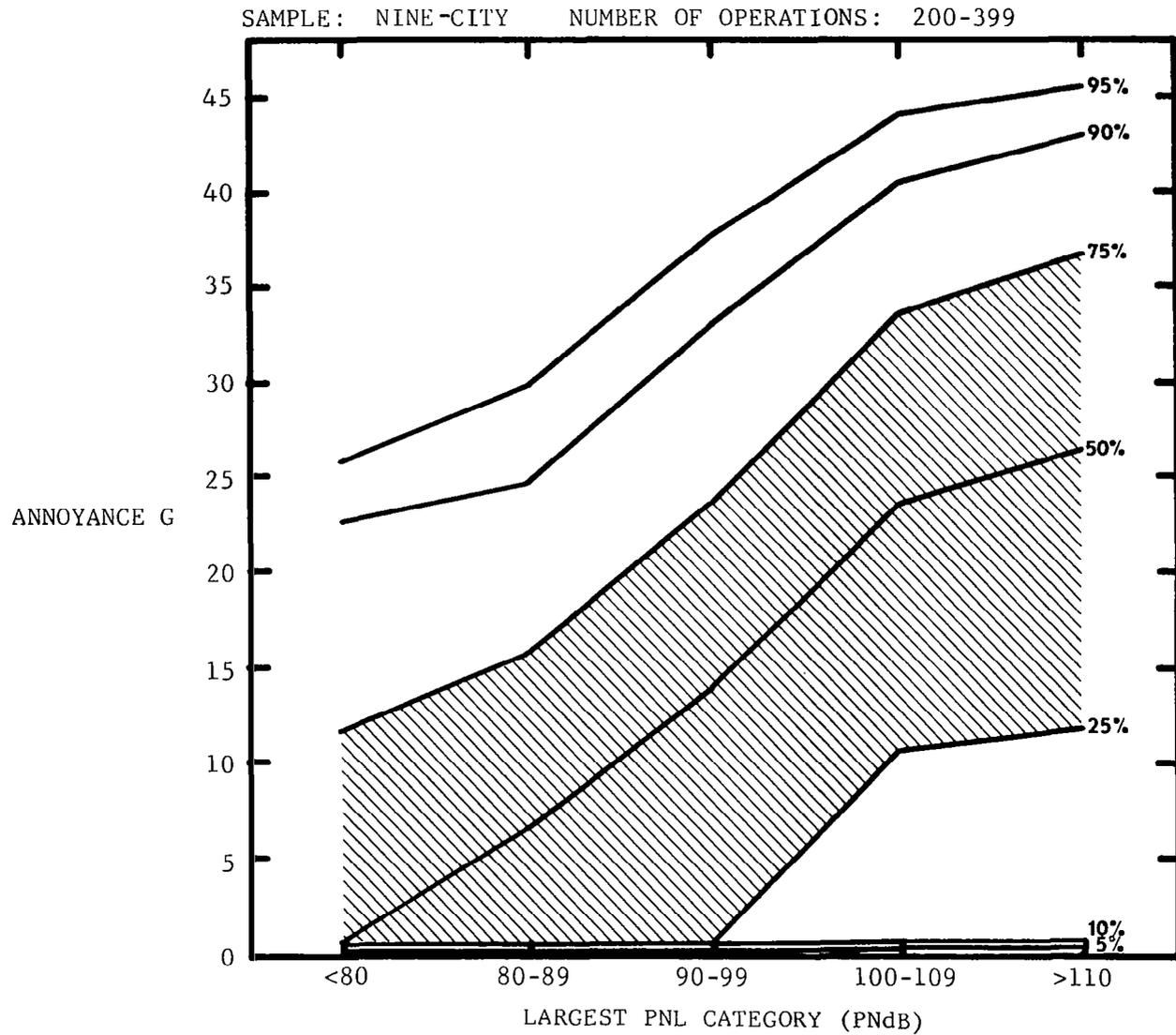


FIGURE A-19 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, NINE-CITY SAMPLE, 200-399 DAILY OPERATIONS

SAMPLE: NINE-CITY NUMBER OF OPERATIONS: >400

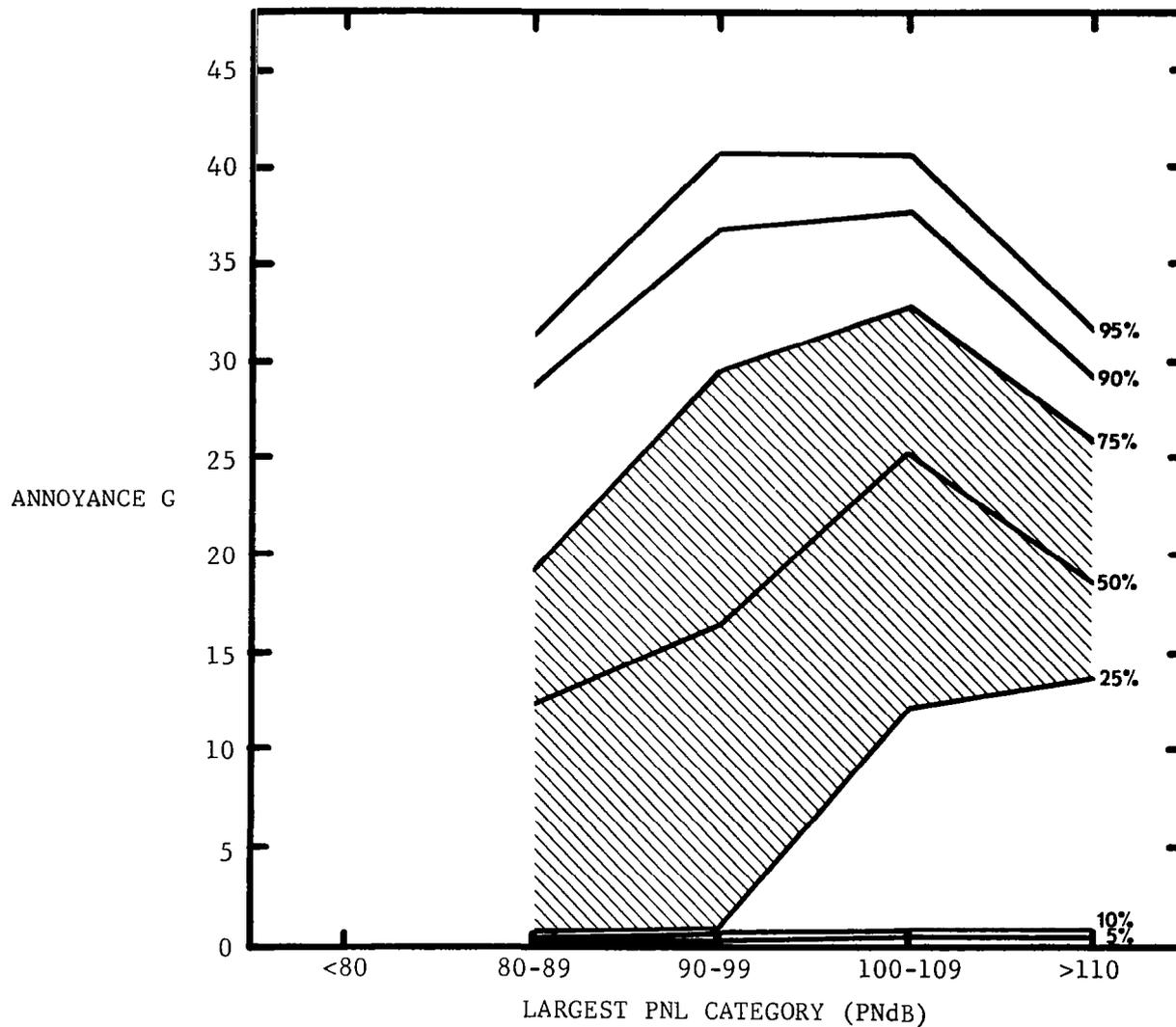


FIGURE A-20 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, NINE-CITY SAMPLE, GREATER THAN 400 DAILY OPERATIONS

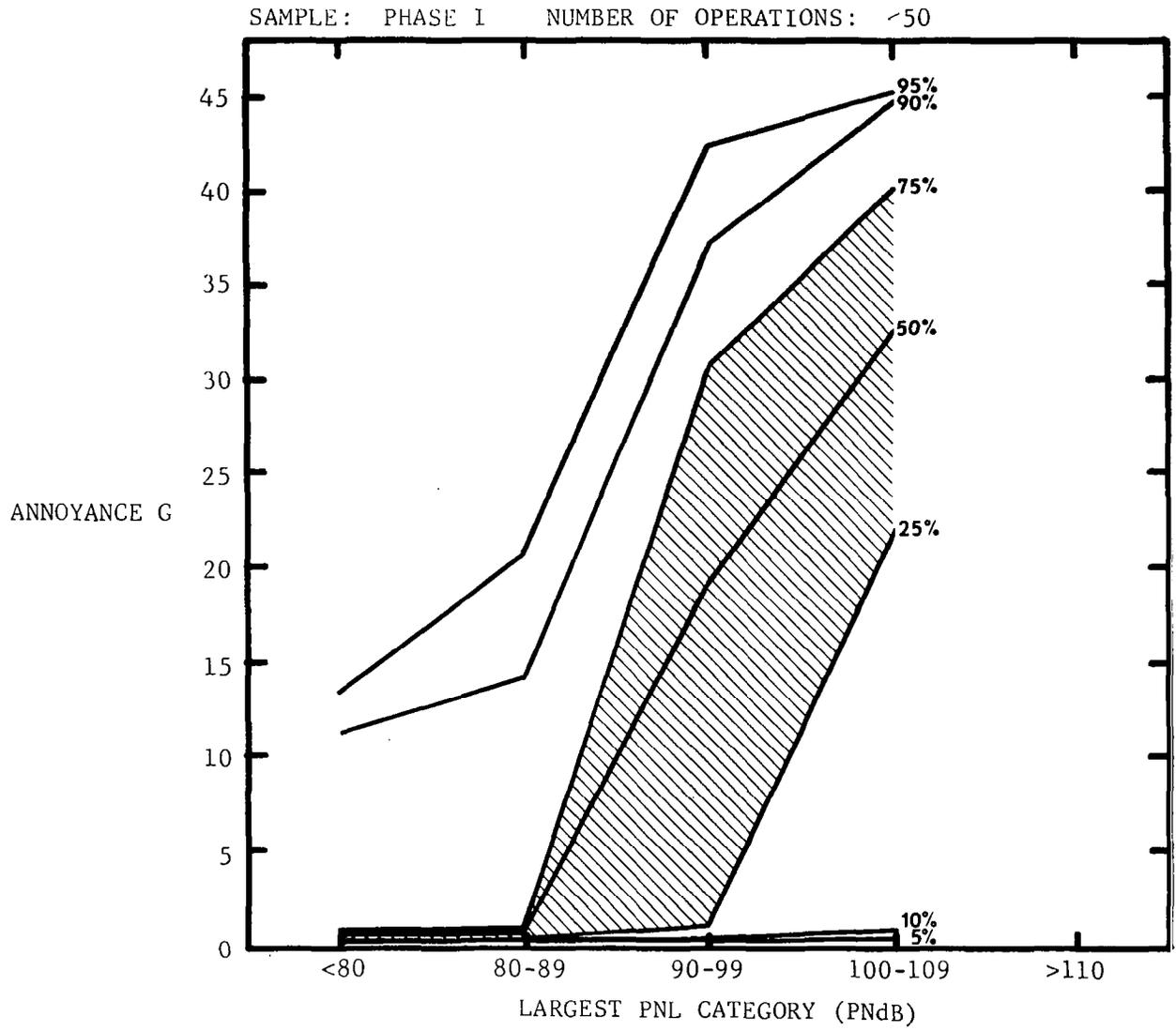


FIGURE A-21 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, PHASE I SAMPLE, LESS THAN 50 DAILY OPERATIONS

SAMPLE: PHASE I NUMBER OF OPERATIONS: 50-99

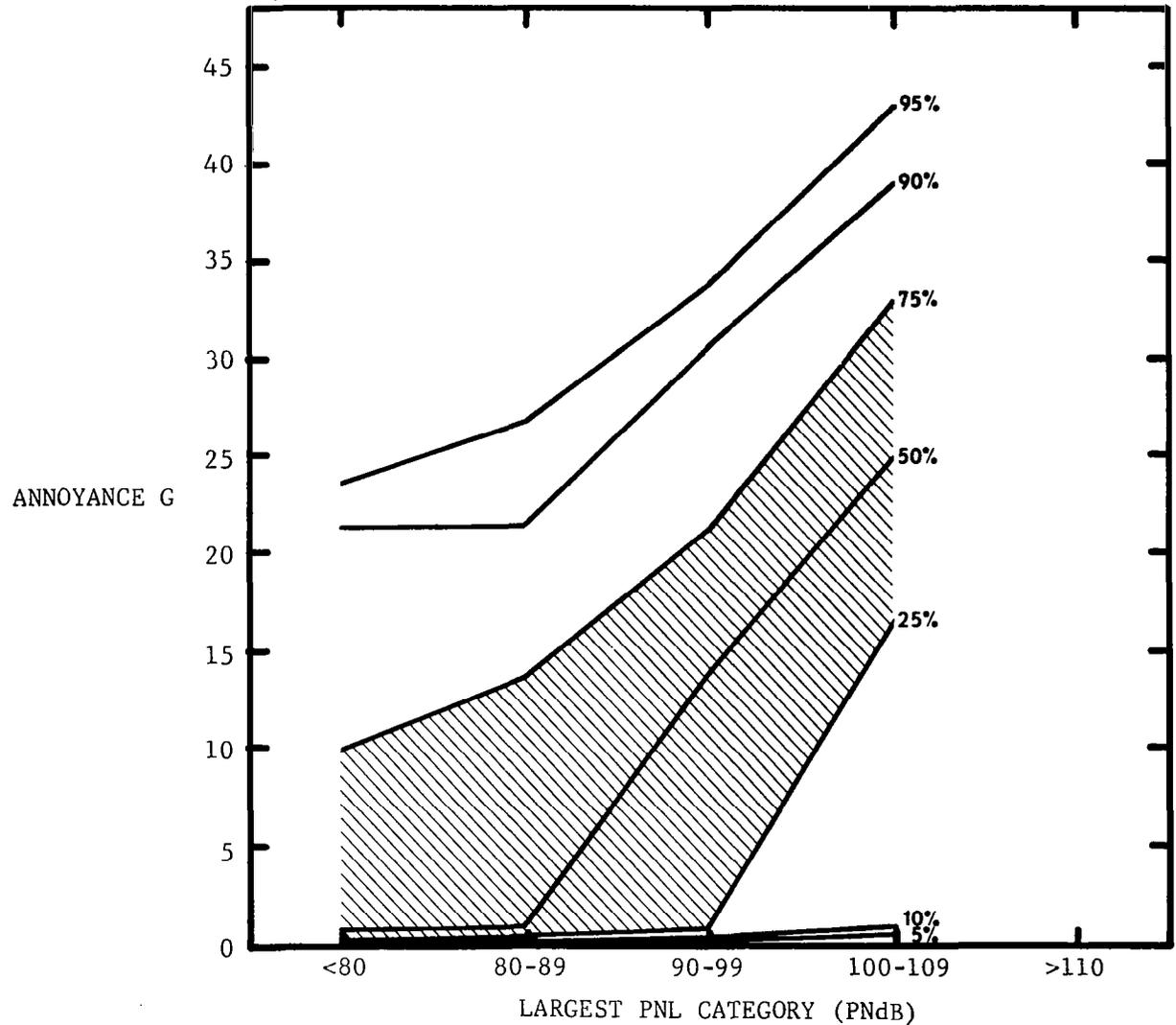


FIGURE A-22 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, PHASE I SAMPLE, 50-99 DAILY OPERATIONS

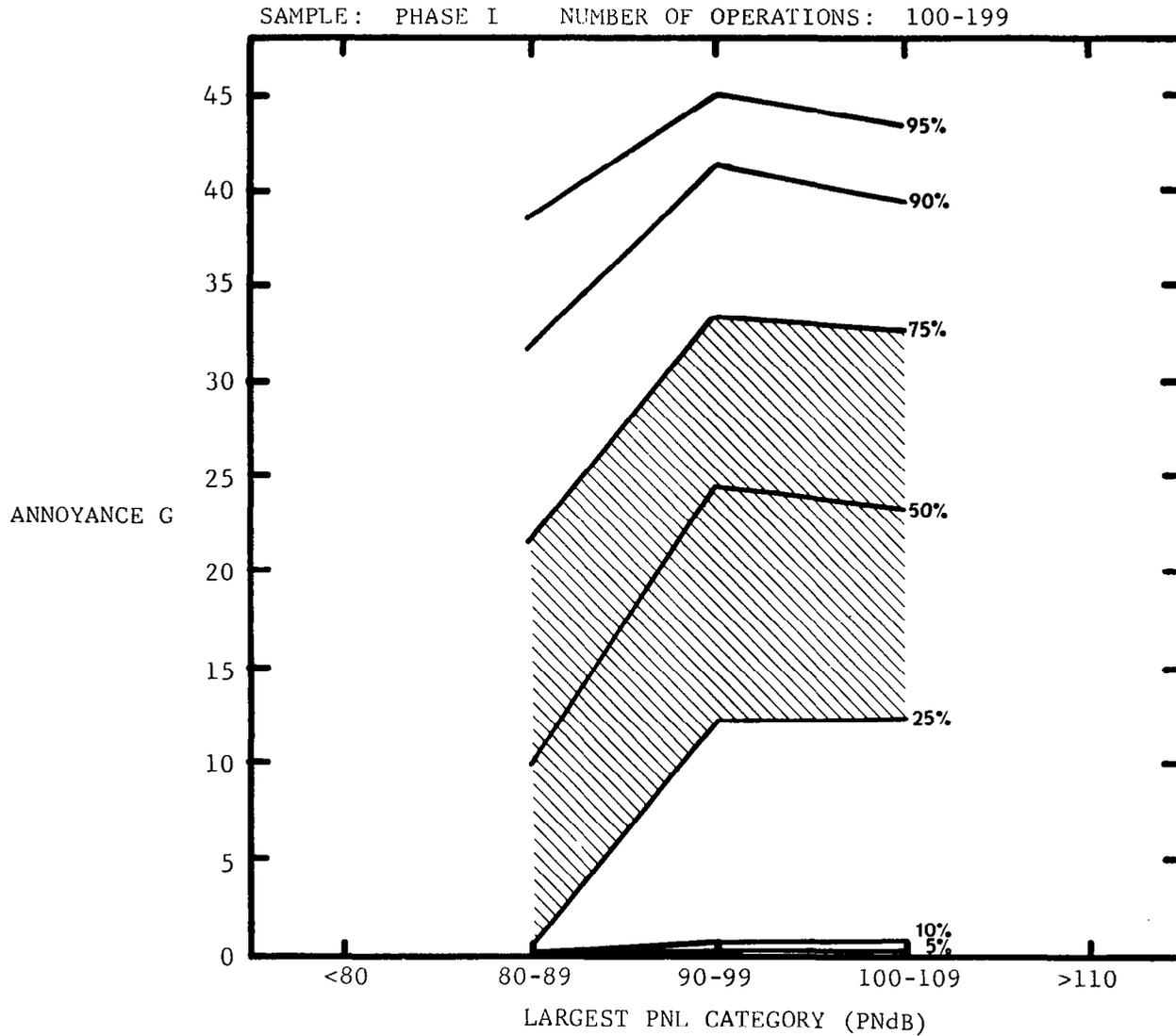


FIGURE A-23 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, PHASE I SAMPLE, 100-199 DAILY OPERATIONS

SAMPLE: PHASE I NUMBER OF OPERATIONS: 200-399

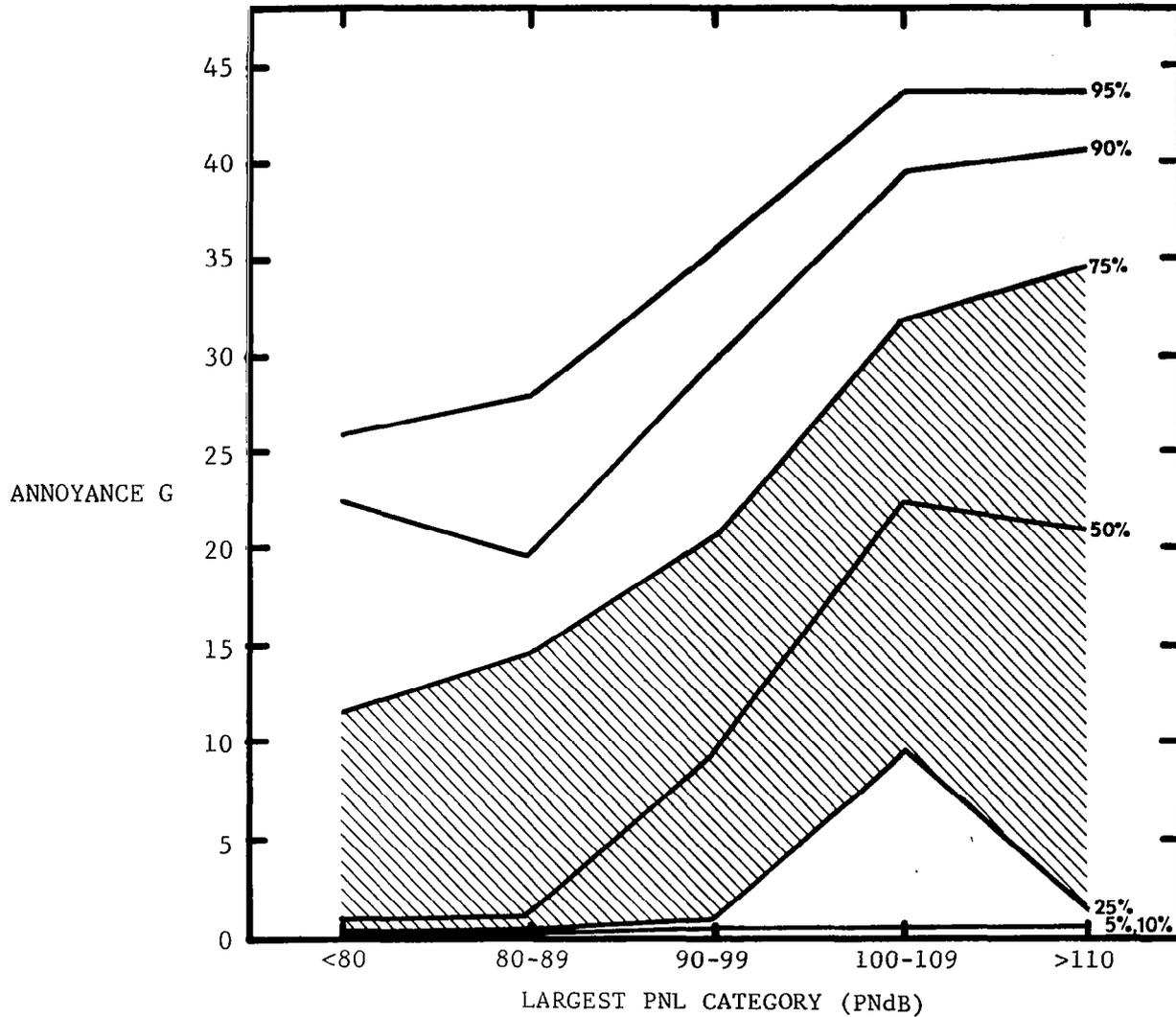


FIGURE A-24 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, PHASE I SAMPLE, 200-399 DAILY OPERATIONS

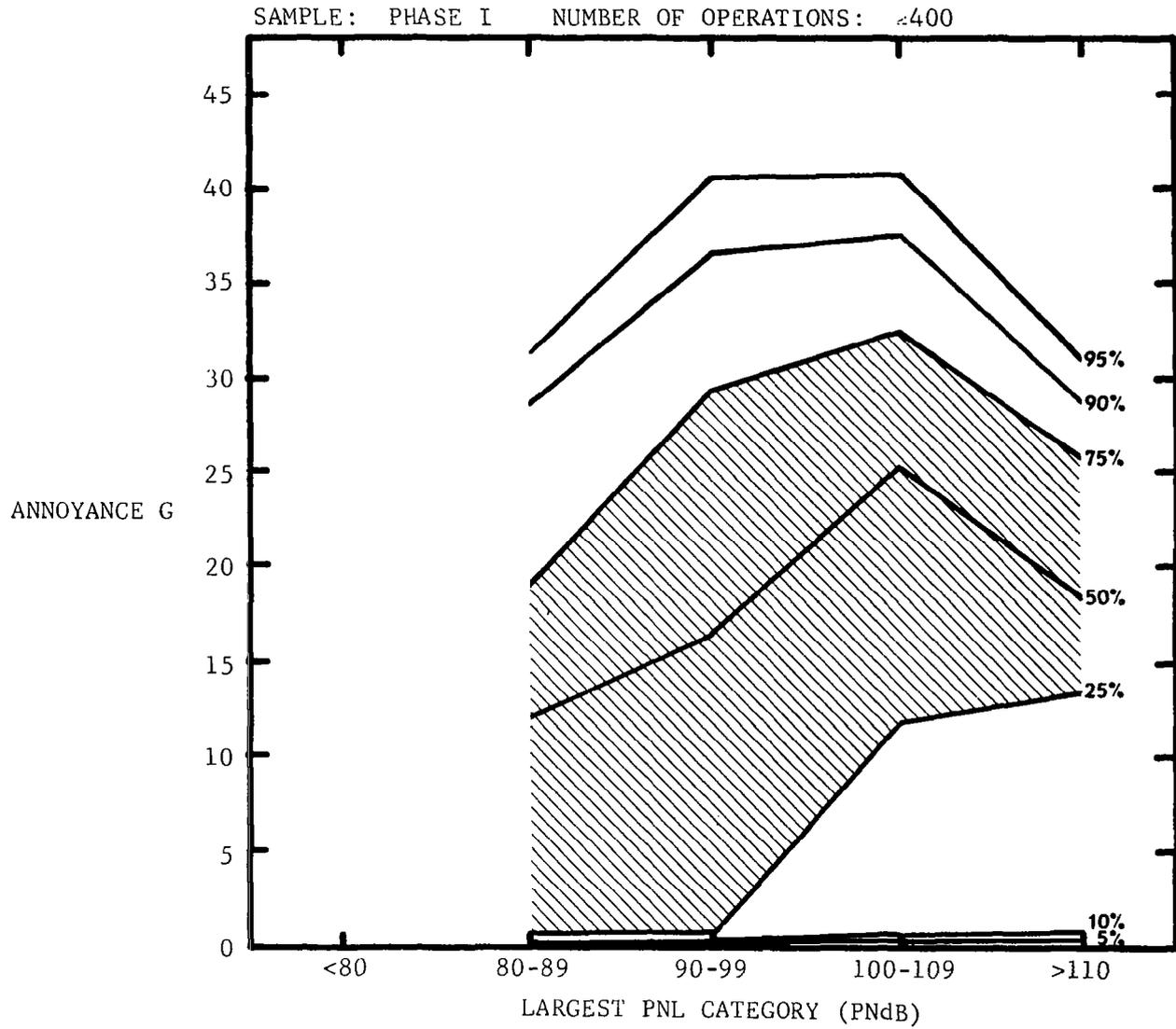


FIGURE A-25 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, PHASE I SAMPLE, GREATER THAN 400 DAILY OPERATIONS

SAMPLE: PHASE II NUMBER OF OPERATIONS: <50

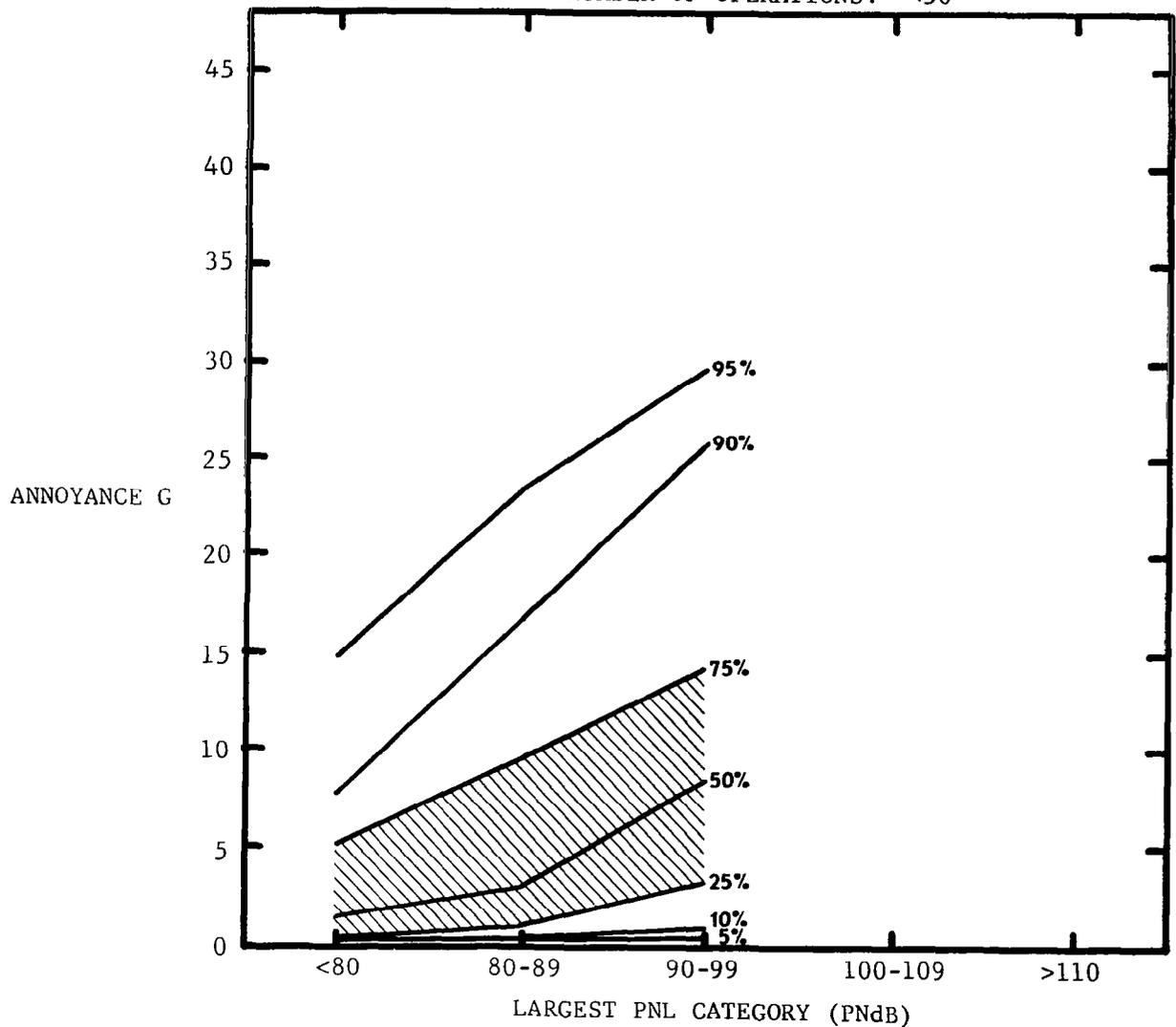


FIGURE A-26 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, PHASE II SAMPLE, LESS THAN 50 DAILY OPERATIONS

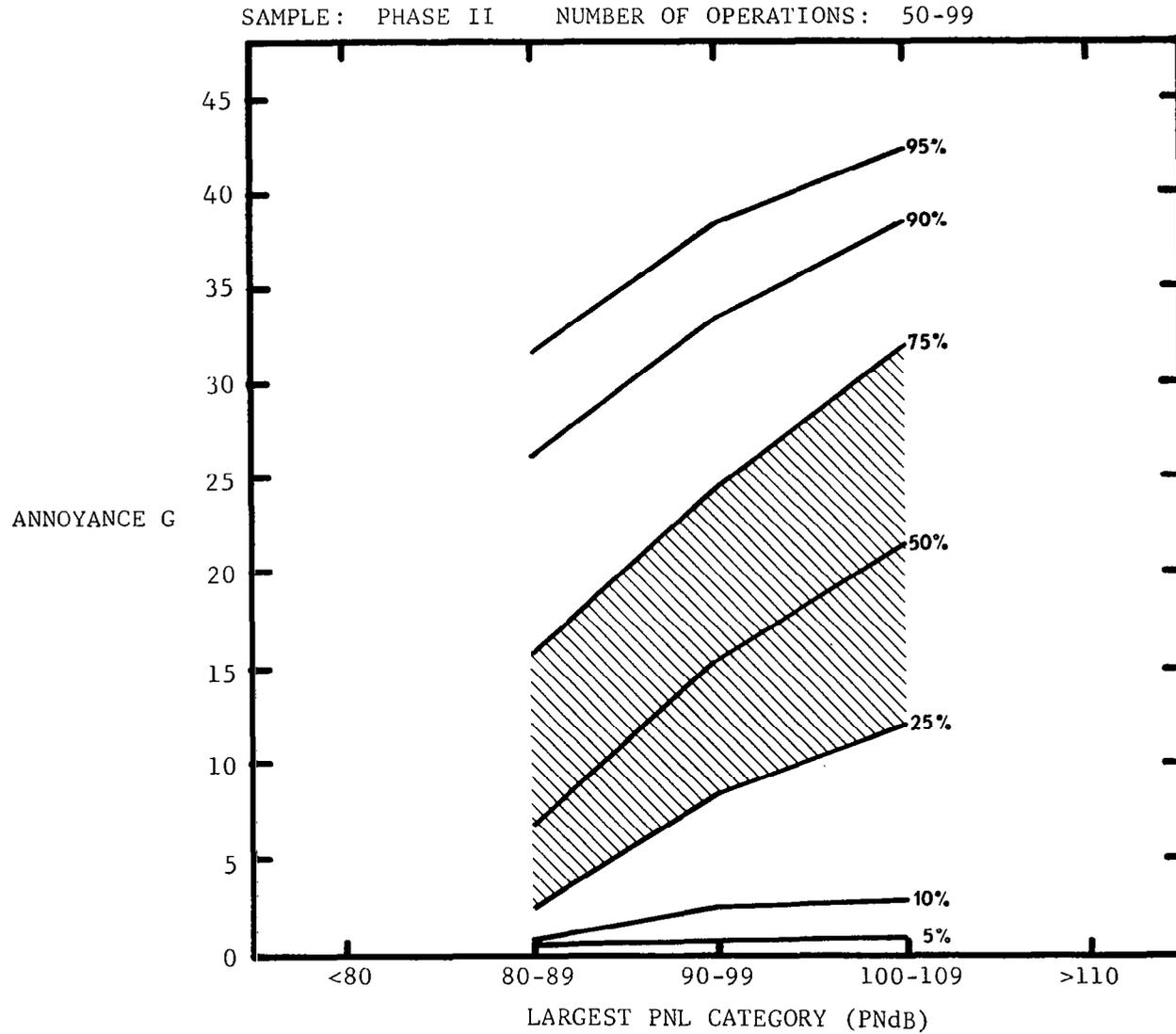


FIGURE A-27 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, PHASE II SAMPLE, 50-99 DAILY OPERATIONS

SAMPLE: PHASE II NUMBER OF OPERATIONS: 100-199

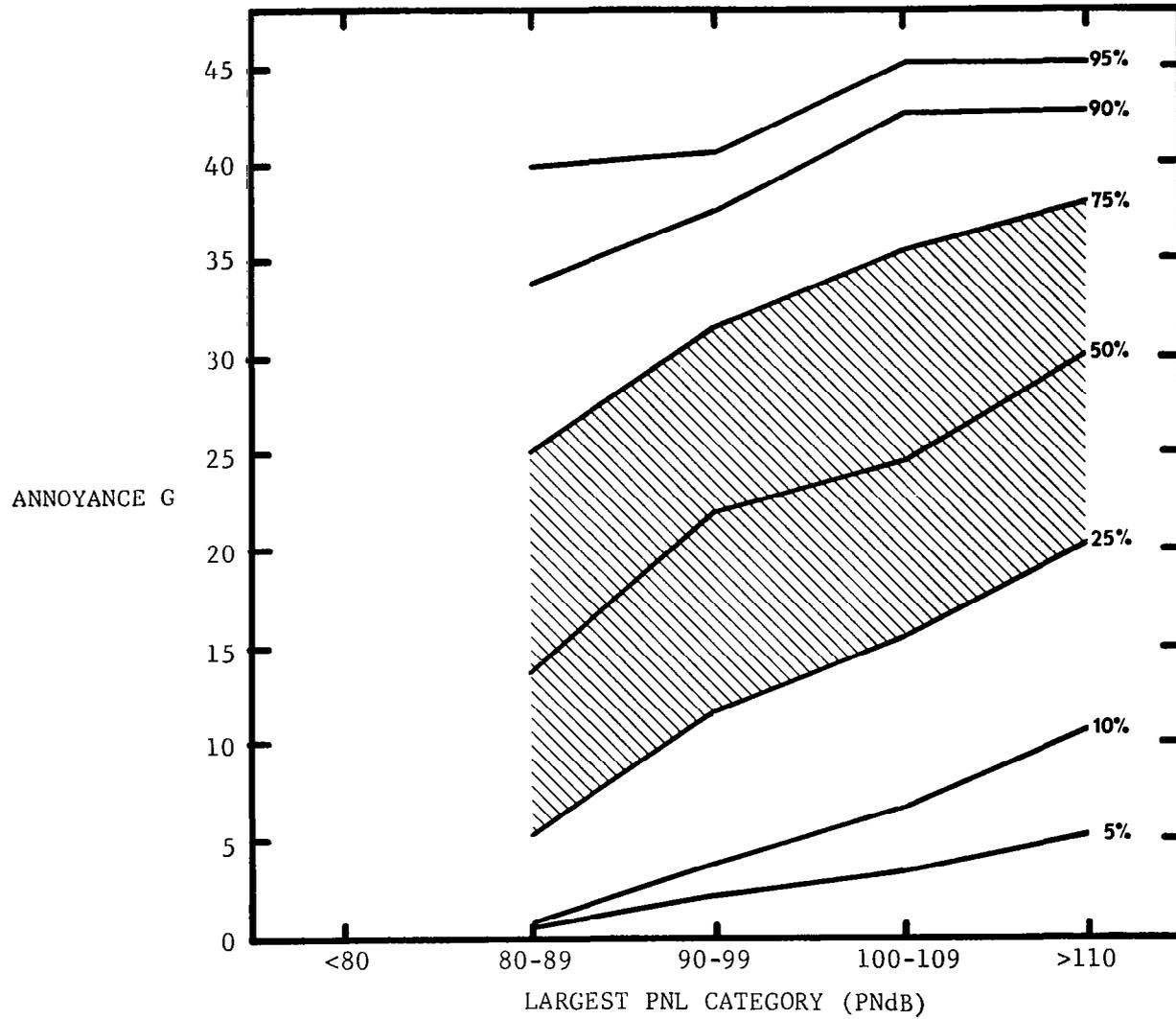


FIGURE A-28 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, PHASE II SAMPLE, 100-199 DAILY OPERATIONS

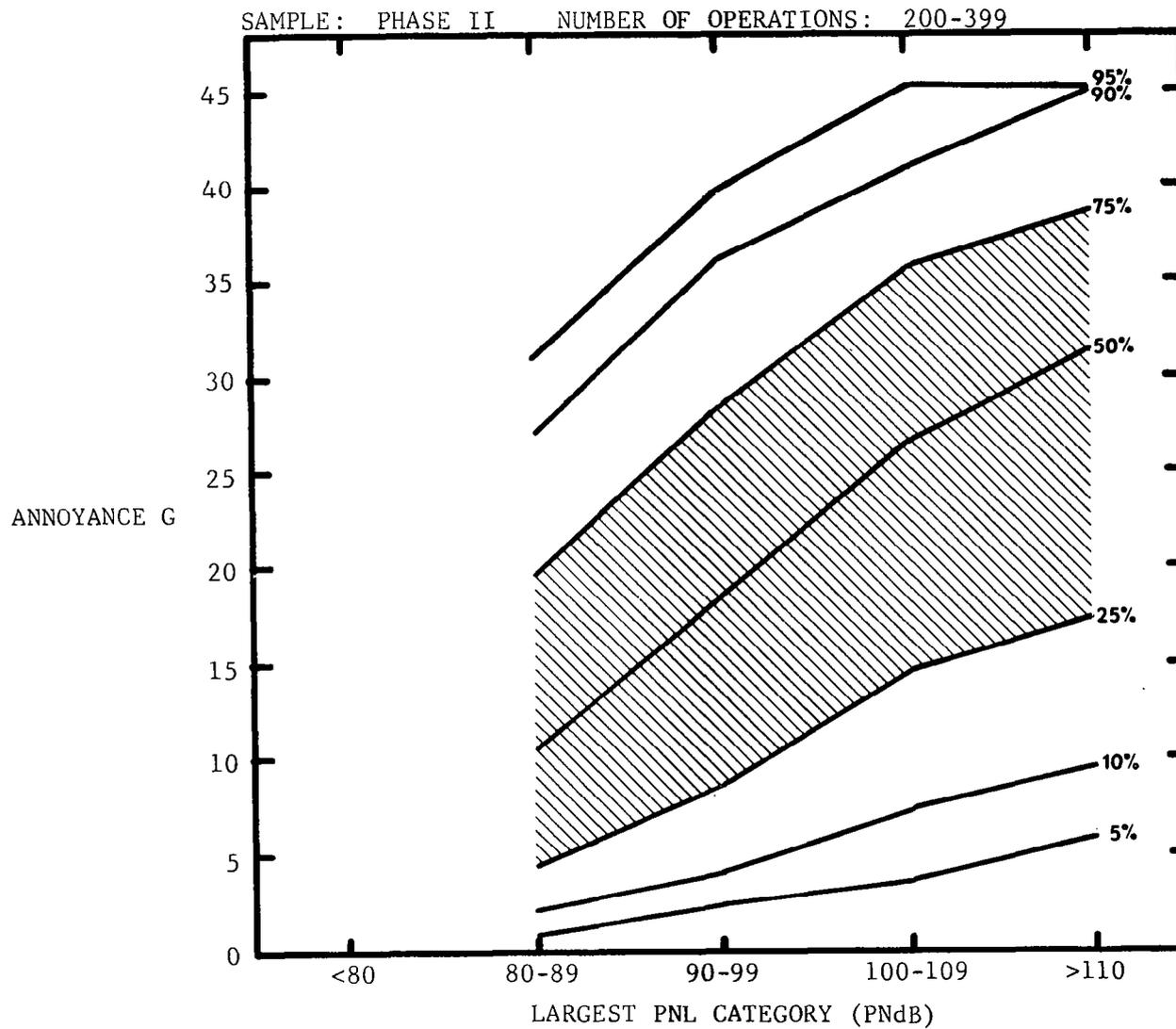


FIGURE A-29 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, PHASE II SAMPLE, 200-399 DAILY OPERATIONS

SAMPLE: TWO-CITY NUMBER OF OPERATIONS: <50

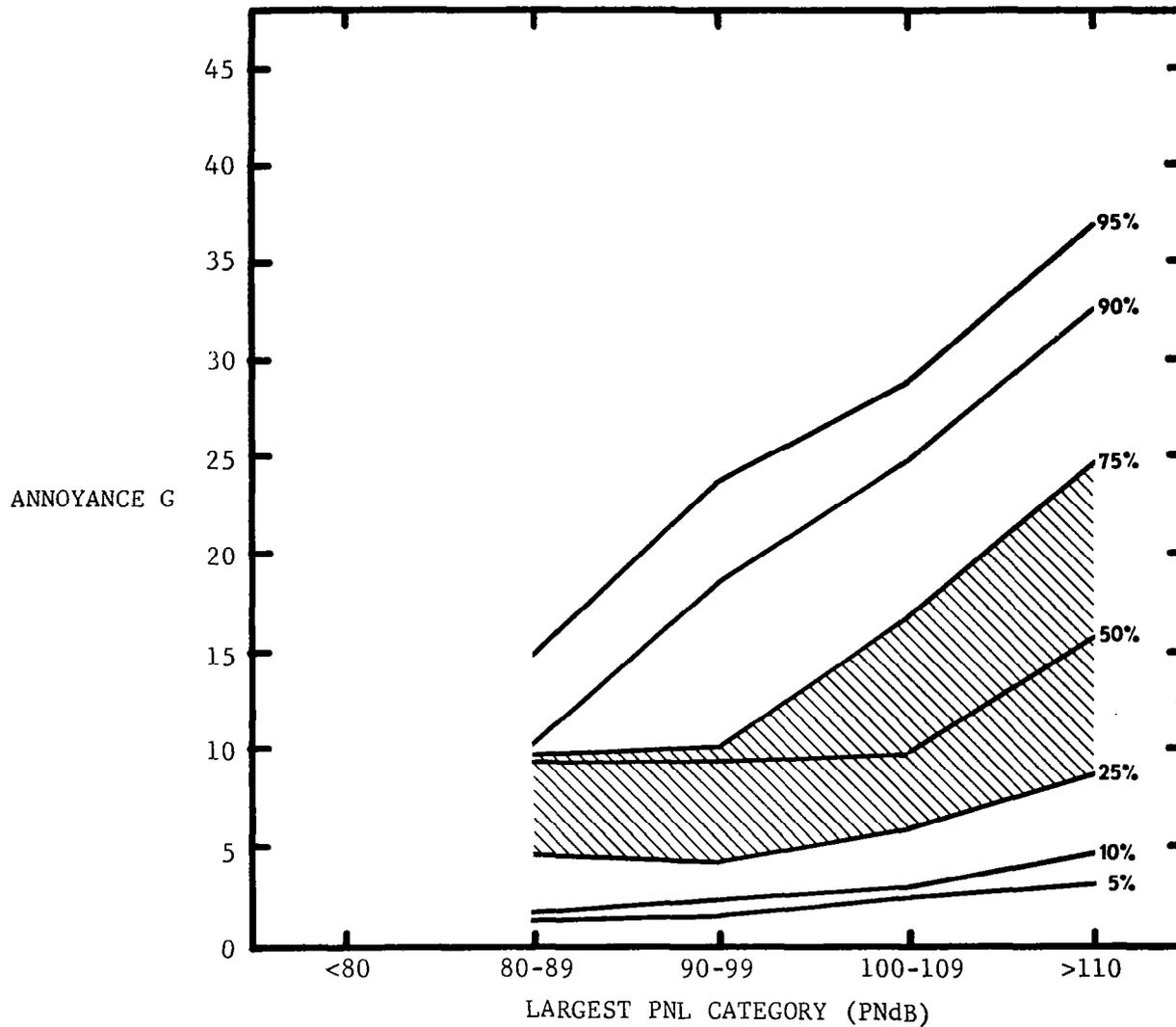


FIGURE A-30 PERCENTILES OF ANNOYANCE G VERSUS LARGEST PERCEIVED NOISE LEVEL, TWO-CITY SAMPLE, LESS THAN 50 DAILY OPERATIONS