An Investigation of Community Attitudes Toward Blast Noise:

Final Report

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Contents

Contents ..... **i**
List of Figures ..... **v**
List of Tables ..... **viii**
List of Acronyms ..... **x**
Abstract ..... **xiii**
Keywords ..... **xv**
Acknowledgements ..... **xvi**
1 Introduction **1**
1.1 Problem 1
1.2 Objective 3
1.3 Approach 4
2 Background **6**
2.1 Characteristics of Military Blast Noise 6
2.2 Current US Military Blast Noise Assessment Procedures 6
2.2.1 L_{Cdn} and Percent Highly Annoyed (%HA) 6
2.2.2 Complaint Risk 8
2.3 Community Tolerance Model 9
2.4 Blast Noise Levels used in CHABA 1996 Recommendations 10
3 Complaint Survey **11**
3.1 Background 11
3.1.1 Complainant Demographics 11
3.1.2 Relationship between Complaints and Annoyance 12
3.2 Data Collection 12
3.3 Survey Instrument 13
3.4 Sampling Procedures 14
3.5 Analysis Methods 14
3.6 Results 16
3.6.1 Overview of Data Collected 16
3.6.2 Covariates in the Final Model 16
3.6.3 Annoyance of Complainants compared to Non-Complainants 17
3.7 Discussion 19

3.7.1 Percent Highly Annoyed 19
3.7.2 Installation Management of Complaints 20
3.8 Summary and Conclusions 22
4 Probability of Receiving a Complaint 23
4.1 Background 23
4.2 Methods 24
4.3 Results and Discussion 25
4.3.1 Probability of Receiving a Complaint around Study Site A 25
4.3.2 Probability of Receiving a Complaint around each Monitor 26
4.3.3 Demographics of the Regions around the Monitors 28
4.4 Summary and Conclusions 29
5 In situ Study 30
5.1 Materials and Methods 30
5.1.1 Overview 30
5.1.2 *In situ* Data Acquisition 31
5.1.3 Post Processing of the *in situ* Noise Data 31
5.1.4 Matching Noise and Survey Data 32
5.2 Statistical Analyses 33
5.2.1 Daily / Nightly Summary Survey Statistical Analysis 33
5.3 Results and Discussion 35
5.3.1 Daily/Nightly Summary Survey Subjective Responses 35
5.3.2 Comparison of Noise Environments 36
5.3.3 Mixed Model Initial Results 39
5.3.4 Noise Sensitivity 42
5.4 Summary and Conclusions 45
6 General Community Survey 46
6.1 Materials and Methods 46
6.1.1 Overview 46
6.1.2 Response Data 46
6.1.3 Estimating Blast Noise Levels at GCS Participants' Homes 46
6.2 Statistical Analyses 55
6.2.1 Data Preparation 55
6.2.2 Model Selection 57
6.3 Results and Discussion 57

6.4 Summary and Conclusions 59
7 Community Tolerance to Blast Noise 60
7.1 Background 60
7.2 Model Preparation 61
7.3 Results and Discussion 62
7.3.1 4_{wk} CT Analysis Results 62
7.3.2 Binning of Annoyance Responses 66
7.4 Summary and Conclusions 68
8 Variability of the blast noise environment 69
8.1 Panel Sample 69
8.2 Dynamic Blast Noise Environments 72
8.3 Most Disturbing Time of Day 75
8.4 Summary and Conclusions 76
9 Recommendations and Conclusions 77
9.1 Objective (i): Investigate Blast Noise Metrics Currently used by the US Army 77
9.2 Objective (ii): Examine Relationship between Individual Complaints and General Community Annoyance 78
9.3 Objective (iii): Recommend Criteria to Actively Manage Noise at an Installation so that the Sustainability of Testing and Training is Ensured 79
9.3.1 Recommendations for Managing Blast Noise at the Installation Level 79
9.3.2 Universal Criteria for Managing Blast Noise 79
9.4 Lessons Learned 83
9.4.1 Approvals 83
9.4.2 Noise Data Collection 83
9.4.3 Quality and Accuracy of the Blast Noise Datasets 84
9.5 Future Research 84
9.5.1 An Intelligent Noise Monitoring System to Manage Noise on a Community-By-Community Basis 84
9.5.2 Improvements in the Prediction of Annoyance to Blast Noise 85
10 Literature Cited 87
A Supporting Studies 94
A.1 Personal Interview Study 94
A.1.1 Summary 94
A.1.2 Sampling of Comments from PI Study Participants 94
A.2 General Community Survey (Installation A) 101

A.2.1 Noise Data Processing 101
A.2.2 Summary 104
A.3 In Situ Single and Series Event Survey Statistical Analysis 105
A.3.1 Model Exploration 105
A.3.2 Relationship to Noise Metrics 106
A.3.3 Series/Single Events Results 106
B List of Scientific/Technical Publications 109
B.1 Peer-Reviewed Journal Articles 109
B.2 Non-Peer-Reviewed Reports & Presentations 110
C Survey Instruments 111
C.1 General Community Survey Instrument 111
C.2 In situ Survey Instrument 132

List of Figures

Figure 2-1. The percent highly annoyed (%HA) as a function of Day Night Level (Ldn) for 43 airport community noise surveys (left panel; data from Fidell et al., 2011) and for blasts/sonic booms (right; data from National Research Council, 1996). 8

Figure 2-2. Community Tolerance Level model (Fidell et al. 2011) fit to the data from the National Research Council 1996 report on blast noise annoyance. (Left) Ft. Lewis, CTL=71.2 dB, (Right) Ft. Bragg, CTL = 79.2 dB. (after Valente et al., 2013)..... 9

Figure 2-3. CHABA 1996 datasets. The proportion of respondents highly annoyed as a function of the LCdn. This figure is reproduced directly from CHABA, 1996. 10

Figure 3-1. Mean annoyance to CRBE for complainants and their non-complaining neighbors or matched-sample (left), and mean annoyance to CRBE between groups of respondents who self-report that their neighborhood is quiet, average, or noisy. 17

Figure 3-2. Noise sensitivity between groups of non-complainants, first-time complainants, and repeat complainants (left), and mean annoyance to general military noise between groups of non-complainants, first-time complainants, and repeat complainants (right)..... 18

Figure 4-1. Probability of receiving a blast noise complaint within 5 km of any noise monitor on a given day, in terms of the max L_{Zpk} (left) and $L_{Cdn,24hr}$ (right). 26

Figure 4-2. Probability of receiving a blast noise complaint within 5 km of Monitor 4 (top left), Monitor 7 (top right), Monitor 10 (bottom left), and Monitor 43 (bottom right), on a given day and in terms of the $L_{Cdn,24hr}$. The lines fit by the model are only given over the range of data that was used in the analysis..... 28

Figure 5-1. Distribution of annoyance ratings across Installations B & C 35

Figure 5-2. Density plots relating annoyance to Loudness, Interferences, Rattle, and Vibration. Red shows areas of high density (large joint responses of rating values); gray shading shows low values. Due to the preponderance of 0-valued ratings, these have been left off of the scale above to highlight the otherwise strong linear relationship that each of these subjective variables has with annoyance. 36

Figure 5-3. Boxplots of C-weighted day night level (L_{Cdn}) for each community in the in situ study. The lines in the center of the box indicate the median level for that community. The extent of the box spans the interquartile range. 38

Figure 5-4. Annoyance as a function of C-weighted day night level (L_{Cdn}) for each individual who completed at least 1 daily/nightly survey. The points on each plot are colored by the community from which the individual comes. Note the relative preponderance of low annoyance ratings in the Installation C participants. 38

Figure 5-5. The coefficients for the community factors in the mixed model, with standard errors. These coefficients represent the annoyance for each community when noise is at its mean levels for each individual. For comparison, the vertical black line is the intercept of the fixed effects model, and the gray shaded area is its standard error. 41

Figure 5-6. The coefficients for each individual's factor in the mixed model, with standard errors. The y-axis labels each participant's ID. These coefficients represent the annoyance

for each community when noise is at its mean levels for each individual. For comparison, the vertical black line is the intercept of the fixed effects model, and the gray shaded area is its standard error. 41

Figure 5-7. Individual Baseline Annoyance, as estimated from the mixed effects model of Section 4.3.4, as it relates to the Noise Sensitivity Index for each participant. Those who are more noise sensitive tend to have higher baseline annoyance values. The majority of noise-sensitive individuals come from Community B3..... 42

Figure 5-8. The coefficients for the community factors in the mixed model, with standard errors, when the Noise Sensitivity Index is included in the model. For comparison, the vertical black line is the intercept of the fixed effects model, and the gray shaded area is its standard error..... 44

Figure 5-9. The coefficients for each individual's factor in the mixed model, with standard errors, when the Noise Sensitivity Index is included in the model. The y-axis labels each participant's ID. These coefficients represent the annoyance for each community when noise is at its mean levels for each individual. For comparison, the vertical black line is the intercept of the fixed effects model, and the gray shaded area is its standard error. 44

Figure 6-1. Locations of in situ noise monitors (open circles) and GCS participants (open circles) for each community in the study. 49

Figure 6-2. The coefficients used in the final fixed effects model with 95% confidence intervals. Statistically significant effects are given in red. 58

Figure 6-3. The coefficients for the each individual's factor in the model with standard errors.. 59

Figure 7-1. CT model results for the 5 GCS communities (B1, B2, B3, C1, and C2). The circles represent the binned data points and the lines represent the CT model fits of the best CT model. The size of the circle is proportional to the number of data points in that bin (the weight applied in the model)..... 64

Figure 7-2. CT model results by installation (B and C, left), and post (ON POST and OFF POST, right). The circles represent the binned data points and the lines represent the CT model fits of the best CT model. The size of the circle is proportional to the number of data points in that bin or the weight applied in the model..... 65

Figure 7-3. CT model results when all of the communities from study site B and C are combined. The circles represent the binned data points and the lines represent the CT model fits of the best CT model. The size of the circle is proportional to the number of data points in that bin or the weight applied in the model..... 65

Figure 7-4. Percent of the community (C2) that is not at all annoyed (blue, annoyance response of 1), somewhat annoyed (orange, annoyance response of 2 or 3), and highly annoyed (red, annoyance response of 4 or 5). A CT_{LINE} model fit (line) is shown for each category of points. The size of the circle is proportional to the number of data points in that bin or the weight applied in the model. 67

Figure 7-5. Percent of the study sites (B, left; and C, right) that are not at all annoyed (blue, annoyance response of 1), somewhat annoyed (orange, annoyance response of 2 or 3), and highly annoyed (red, annoyance response of 4 or 5). A CT_{LINE} model fit (line) is shown for

each category of points. The size of the circle is proportional to the number of data points in that bin or the weight applied in the model. 67

Figure 7-6. Percent of the study sites (OFFPOST, left; and ONPOST, right) that are not at all annoyed (blue, annoyance response of 1), somewhat annoyed (orange, annoyance response of 2 or 3), and highly annoyed (red, annoyance response of 4 or 5). A CT_{LINE} model fit (line) is shown for each category of points. The size of the circle is proportional to the number of data points in that bin or the weight applied in the model. 68

Figure 8-1. Change in annoyance between the initial GCS survey and the panel survey. Graphs show the percentage of GCS panel participants in each delta annoyance category for the question of annoyance to blast noise over the past 4 weeks (left), and past 12 months (right). 70

Figure 8-2. The timing of the initial and panel GCS surveys shown with the $L_{Cdn,4wk}$ levels calculated every day over the entire study. 71

Figure 8-3. Box plots of the change in the number of blast events over an L_{Zpk} of 110 dB (left) and change in $\Delta L_{Cdn,4wk}$ (right) shown for each delta annoyance category. 72

Figure 8-4. Time series plots of the daily L_{Cdn} blast noise environments with accompanying GCS annoyance response for 4 sub-communities: B1 (top-left), B2 (top-right), B3 (middle), C1 (bottom-left), and C2 (bottom-right). 73

Figure 8-5. Probability density function of the time of day when noises from participants' neighborhood are most disturbing across all study sites (installations A, B, and C). 75

Figure 8-6. Probability density function of the time of day when noises from participants' neighborhood are most disturbing at each study sites: Installations A (left), B (middle), and C (right). 76

Figure 9-1. Dose-response curve (black line) based on data gathered at study site B (black dots), compared with the CHABA 1996 curve (dashed line). The size of the circle is proportional to the number of data points in that bin or the weight applied in the model. 81

Figure A-1. Location of noise monitors at study site 1. Triangle markers represent the noise monitors used for this study. 102

Figure A-2. Annoyance as a function of LCdn for weekday events (green circles) and weekend events (blue circles), with corresponding model fits. The high-annoyance cutoffs are shown as dotted lines on the Installation B plot. Due to the preponderance of low annoyance at Installation C, high-annoyance cutoffs could not be calculated. 108

List of Tables

Table 1-1. Overview of the three study sites and three study types. 4

Table 2-1. Land use zones from AR 200-1. 7

Table 2-2. Complaint Risk Criteria (AR 200-1). 8

Table 3-1. Questions used in the ANOVA model. 15

Table 3-2. Percent highly annoyed (matched-sample vs. complainants). 19

Table 3-3. Percent highly annoyed between NC, FC, and RC. 19

Table 4-1. Complaint threshold level of first time and repeat complainants. 23

Table 4-2. Complaint threshold level of first time complaints that occur during the day and the evening. 23

Table 4-3. Complaint threshold level of single shot (blast) complaints and multi-shot complaints.23

Table 4-4. Results of logistic regression analysis, done for each monitor separately. This table shows the number of blast days (N_{blast}), the number of complaint days ($N_{complaint}$), range of blast noise levels (Min L_{Cdn} and Max L_{Cdn}), and the probability of receiving a blast noise complaint at a L_{Cdn} of 57, 62, and 70 dB (PCR_{57}, PCR_{62}, PCR_{70}, %). 27

Table 5-1. Metrics calculated for the acoustic waveforms. A-weighted, C-weighted, and un-weighted versions of each of these metrics were calculated. 32

Table 5-2. The number and type of surveys filled out by community. 33

Table 5-3. The number and type of surveys filled out by community that could be paired with noise data. 34

Table 5-4. Pearson correlation coefficients between subjective variables from the daily/nightly summary surveys. 36

Table 5-5. The coefficients for the fixed effects in the mixed-effects model of annoyance in the daily/nightly summary surveys with and without noise sensitivity as a fixed effect. 39

Table 6-1. Total number of blast records per community. 49

Table 6-2. Total number of one monitor and 2^+ monitor blast events per community. 52

Table 6-3. Precision results for the blast noise classifier at each installation. 53

Table 7-1. AIC values for each model and community group (4_{wk} data). The model with the lowest AIC value is considered the best model. 63

Table 7-2. RMSE values for each model and community group (4_{wk} data). 63

Table 7-3. Summary statistics for the best model per community group (4_{wk} data), where N is the number of data points, Min and Max L_{Cdn} give the range of the noise data, the slope of the line fit, and the percent of the community highly annoyed (PHA) at L_{Cdn} = 57, 62, and 70.64

Table 9-1. Land use zones using the dose-response curve in Figure 9-1 compared with the land use zones given in AR 200-1. 82

Table A.1. Top 4 Maximum Likelihood estimates of the BIC for the models using noise metrics. All top metrics were day-night level metrics. 107

List of Acronyms

AAPOR	American Association for Public Opinion Research
AIC	Akaike Information Criteria
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
ANSI	American National Standards Institute
APL	Accumulated Peak Level
AR	Army Regulation
BIC	Bayesian Information Criterion
CATI	Computer-assisted-telephone-interviewing
CERL	Construction Engineering Research Laboratory
CHABA	Committee on Hearing, Acoustics and Bio-Acoustics
CL_{MAX}	Maximum C-weighted Fast-exponential-time-weighted Level
CONUS	Continental US
CRBE	Complaint-referenced blast event
CSEL	C-weighted Sound Exposure Level
CT	Community tolerance
CTL	Community Tolerance Level
CT_{LINE}	Linear 2-parameter model
CT_{MEAN}	Linear 1-parameter model
CT_{NL1}	Nonlinear 1-parameter model
CT_{NL2}	Nonlinear 2-parameter model
CTS	Community tolerance spread
DoD	Department of Defense
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
FC	First-time complainants
GAO	Government Accountability Office
GCS	General Community Survey
HA	Highly annoyed

HL	Hearing Loss
Hz	Hertz
ICBEN	International Commission on the Biological Effects of Noise
IRB	Institutional Review Board
ISO	International Organization for Standardization
kHz	Kilohertz
L_{Adn}	A-weighted day-night level
L_{Cdn}	C-weighted day-night level
L_{CE}	C-weighted sound exposure level
L_{Ceq}	C-weighted equivalent continuous noise level
L_{dn}	Day-night level
$L_{eq,d}$	Equivalent continuous noise level over the reported time period
L_{Zpk}	Unweighted peak level
ML	Maximum likelihood
N_{blast}	Number of blast days
NC	Non-complainants
$N_{complaint}$	Number of complaint days
NS	Noise-sensitive
OMB	Office of Management and Budget
PCR	Probability of receiving a blast noise complaint at a LCdn
PHA	Percent of the community highly annoyed
RC	Repeat complainants
REML	Restricted Maximum Likelihood
RMSE	Root mean square errors
RMTK	Range manager’s toolkit
SEL	Sound exposure level
SERDP	Strategic Environmental Research and Development Program
SLM	Sound level meter
SON	Statement of Need
TDOA	Time difference of arrival
USEPA	U.S. Environmental Protection Agency

UTM	Universal Transverse Mercator
Z_{Pk}	Unweighted peak pressure level

Abstract

The current methods used by the United States Army and Department of Defense for predicting community response to blast noise — the noise produced by large weapons, heavy artillery, and explosions — have low predictive validity and do not account for the intermittent and dynamic nature of the blast noise environments that occur on and around military installations. The models in use were based on five studies conducted between 1965 and 1995, each of which shows a large variability in annoyance to blast noise. These studies were conducted with noise measurement technologies that have since been replaced by the more accurate and advanced technologies available today. In addition, each study used different procedures to quantify the blast noise environment, which may explain the drastic variability in results.

Objectives

The research performed within SERDP WP-1546 focused on the three objectives laid out by the SERDP Statement of Need (SISON-07-03, 2005). These were to (i) investigate the metrics currently used by the US military to assess high-energy impulsive noise (i.e., blast noise) and assess whether these metrics adequately account for the intermittent, impulsive, nature of blasts; (ii) examine the extent to which individual complaints are indicative of general community annoyance, and (iii) recommend scientifically defensible criteria which can be used to actively manage noise at an installation so that the sustainability of testing and training is ensured.

Technical Approach

To address the Statement of Need (SON), three main studies were conducted over a five-year period: the Complaint Survey (Section 3), the *in situ* Study (Section 5), and the General Community Survey (GCS, Section 6). These studies were conducted at three military testing/training facilities spread across the Continental US. In addition to the three main study types, the research included a reanalysis of some early blast noise complaint work (Section 4) that looked at the probability of receiving a blast noise compliant, and a smaller scale study (the Personal Interview Protocol; Appendix A.1), which compared the language/terminology used by people living near military installations when describing their community, environment, and blast noise to the language used in surveys that were to be administered during the three main studies.

The Complaint Survey directly addressed Objective (ii). The *in situ* Study and the GCS were more labor-intensive measurement-based efforts that addressed Objective (i). The *in situ* study was designed to enhance the understanding of how individuals respond to blast events over a short time period (i.e., on the order of hours or days) while going about their daily lives, and the GCS was designed to enhance the understanding of how communities respond to blast events over a longer time period (i.e., on the order of weeks or months).

There are some important differences between the studies presented in this report and previous community response to military noise studies. Primarily, unlike previous military noise studies that relied on noise propagation models to estimate the noise environment, our studies aimed to measure the blast noise level of each and every blast event that occurred over the entire study

time period. This proved to be very difficult (see Sec. 9.4 for further discussion), but was instrumental to achieving Objective (iii).

Results

Across all of the studies, blast noise was clearly the most annoying noise source among the eight sources asked about on the survey. It was found that individuals, communities, and installations (i.e., the communities around an installation) all have a unique tolerance to blast noise and that the blast noise environment in each community is unique as well, which suggests that it may not be appropriate to assess and/or manage testing/training noise with universal criteria. Rather, the findings in this study suggest that it may be appropriate to assess/manage military on a community-by-community basis.

The complaint studies found that those who complain about blast noise report much higher annoyance than their non-complaining neighbors, which may suggest that installations should not immediately implement testing/training restrictions to appease a few individuals, and installations might be too overly restrictive with their local noise management policies. However, this statement should NOT be interpreted that noise complaints be dismissed outright (see Sec. 9.2 for further discussion). This project also found that the probability of receiving blast noise complaints is rather low, and that high levels (e.g., unweighted peak levels > 120 dB) occur often without complaints. The complaint work did, however, find that the probability of receiving a complaint was high in a few communities, which further supports that hypothesis that each community has a unique tolerance to noise. Lastly, this study found that the C-weighted Day-Night-Level (CDNL or L_{Cdn}) calculated over a 24-hour time period better predicts the probability of receiving a complaint than the current standard metric, maximum unweighted peak level (L_{Zpk}).

The metrics currently used to assess and manage blast noise do not adequately capture the dynamic nature of blast noise environments produced by testing/training activities; however, the results from the *in situ* studies and general community survey (GCS) studies found no evidence to move away from the using the L_{Cdn} as the preferred metric to predict community annoyance. Rather, it was found that there was a higher correlation with community annoyance between blast noise levels (L_{Cdn}) calculated over a short time period (i.e., 4 weeks) in comparison to blast noise levels calculated over a longer time period (i.e., 9 – 12 months).

The GCS studies found the following non-acoustical factors contributed to community annoyance. There was increased annoyance if the respondent (1) indicated that there was a time of day which blast noise was most disturbing, (2) spent more time at home between the hours of 6 and 10PM than the average, (3) indicated that noise had disturbed them (irritated, startled, frightened) in the last 12 months, (4) heard blasts more frequently, (5) thought their neighborhood was an excellent place to live, and (6) ever experienced more than one object rattling in response to blast noise. There was decreased annoyance if (1) more than the average number of adults lived in the household, (2) the importance of the installation was larger than average, (3) the respondent lived in a single-family attached home, and (4) the respondent felt they could habituate to noise. The GCS studies also found that the annoyance to blast noise

varied by community, thus supporting the community tolerance hypothesis, however, the variance between communities decreased once the non-acoustical factors were accounted for.

Benefits

This project greatly enhanced the current understanding of community response to blast noise, and resulted in a total of 10 peer-reviewed papers and 9 non-peer reviewed reports and presentations (see Appendix B). Also, this project was the first of its kind to attempt to measure each and every blast event that occurred over the entire 5-year project, which resulted in (perhaps) the most comprehensive examination of the dynamic nature of the blast noise environment to date. This was ultimately possible with the help of the knowledge and technology of the sister ESTCP project (WP-201117) and an US Army Engineer Research and Development Center (ERDC) basic research project. The project also contributed advancements to the state-of-the-art in the statistical models used to assess community response to blast noise.

The project was successful in that it achieved all three-project objectives, which focused on making recommendations to improve the current blast noise assessment/management procedures. In summary:

1. We recommend that policy/decision makers move away from using a universal criteria and move towards assessing/managing blast noise on a community-by-community basis, which can be accomplished using the noise monitor technology recently demonstrated in ESTCP project WP-201117.
2. In terms of community annoyance assessment/management, we recommend that the L_{Cdn} be calculated over a much shorter time window (e.g., 4 weeks, $L_{Cdn,4wk}$).
3. In terms of complaint assessment/management, we recommend that the L_{Cdn} calculated on a daily basis be used to manage complaints and that complaint risk should be managed on a community-by-community basis.
4. In terms of the daily L_{Cdn} ($L_{Cdn,24hr}$) levels, we find some evidence that there is an increase in the percentage of the community that will be highly annoyed when the levels exceed 60 dB and an increase in the percentage of the community that will be not at all annoyed if levels are below 45 dB.
5. In terms of single event levels, we recommend using the C-weighted sound exposure (CSEL or L_{CE}) level. We suggest implementing a universal policy that no community should be exposed to a L_{CE} of 118 dB, and that caution should be exercised if the single event levels approach or exceed 112 dB.

Keywords

Human response, annoyance, blast, impulse, military noise, community survey

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The opinions expressed in this document are solely those of the authors and are not to be construed as an official Department of the Army position unless so designated by other authorized documents [Distribution Statement - A (Approved for public release; distribution unlimited)].

1 Introduction[‡]

For over forty years, the military has had an abiding interest in understanding how humans respond to the high-intensity impulsive noise emitted by large weapons, heavy artillery, and explosions, which are collectively referred to as blast noise. In the United States (US), the management and documentation of the impact of blast noise is mandated by the National Environmental Policy Act (US Congress, 1969), the Department of Defense (DoD),[1] Army,[2] and local noise policies and regulations. There is both an obligation to inform the public about the environmental consequences of blast noise and a concern about the loss of training lands and capabilities caused by implementation of curfews and/or restrictions due to negative community reaction to this noise.[3] The main goal of each of the above policies and regulations is to "control operational noise to protect the health and welfare of people, on- and off- post, impacted by all Army produced noise, including on- and off-post noise sources,"[2] as well as "reduce adverse effects from the noise associated with military test and training operations…for the purpose of maintaining military readiness."[1]

1.1 Problem

Military installations do not have a reliable way of predicting community response to blast noise, despite 50 years[§] of research into this problem.[4] The bottom line is that most models of the relationship between military noise exposure and community annoyance have relatively low predictive validity.[4-6] This statement includes the models proposed in the literature over the past 50 years and the current models used in Army/DoD regulations,[2] and the American National Standards Institute (ANSI) and International Organization for Standardization (ISO) standards.[7,8]

There are several reasons why the problem of predicting community response to blast noise has remained unsolved. First of all, measuring/predicting both sides of the dose-response equation is difficult. Blast noise environments are dynamic by nature, and measuring/predicting blast noise levels is subject to many uncertainties and errors.[9] Unlike transportation noise sources that typically occur in regular patterns throughout the year and have small variation in level from day to day, blast noise events occur intermittently, and the noise levels vary drastically from day to day. It is not uncommon to have several consecutive days of intense, and often loud, training exercises intermixed with periods of relative quiet. Further, blast noise can travel distances of up to 20 kilometers from the source; therefore, blast noise footprints can encompass many

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[‡] The material provided in this section has been adapted from Nykaza et al. 2013, and Valente et al. 2013.

[§] The number of studies that have examined how communities respond to blast noise is small compared to the number of transportation noise studies.

communities living on and near installations. To make matters worse, received blast noise levels can vary by as much as 50 dB at distances greater than 2 kilometers due to the variability of local meteorological conditions.[10,11]

On the other side of the dose-response equation, measuring and predicting community response (i.e., in terms of community annoyance or individual complaints) is an even more difficult challenge than estimating noise environments. Annoyance to noise is a notoriously subjective psychological phenomenon,[12,13] and the circumstances that drive someone to complain are often numerous and complex.[14,15] Furthermore, the factors that often have the highest correlation with community response are, in fact, non-acoustical.[4] In a related manner, there is a growing body of literature suggesting that different communities may have different tolerances to noise,[16,17] and these studies have shown that better predictive fits of community annoyance are obtained if each community is examined independently. However, the problem with this approach is that it hasn't been proven whether the superior fit of the dose-response curve is actually due to differences in the community tolerance or is merely an artifact of the errors and uncertainties implicit in the differing measurement procedures used between studies.

Given the difficulties in measuring and predicting both noise environments and community reaction, it is not surprising that several problems exist within the current Army/DoD standards. One potential problem with the current standards is that the yearly averaged noise metric that is used —the day-night level (DNL or L_{dn})—may not adequately capture the dynamic nature of the blast noise environment. For example, using the current standard methods from AR 200-1, 100 events of 142 dB peak pressure level yield an annualized C-weighted DNL (CDNL or L_{Cdn}) of 62 dB, which is deemed to be suitable for all land uses (see Table 2-1 in Sec. 2.2). However, a peak level of 142 dB is so loud that it would almost certainly cause a strong negative public reaction, and in fact exceeds the 140 dB threshold for human hearing damage.[**18,19]

Another potential problem with the current standards is that the L_{dn} method ignores any effect of the timing of noise events; there is no difference between 10,000 noise events spread over 1 year or 10,000 events all occurring in 1 day. An underlying assumption behind this method is the "equal energy hypothesis," which states that the noise is accounted for by averaging the total sound exposure over the assessment period, regardless of the magnitude of any individual noise event. This means, for example, that the effect of 1,000 events of a given sound exposure level (SEL) is taken to be the same as that of 1 event containing 1,000 times as much sound energy (30 dB greater SEL).

[**] The potential for hearing damage is not as simple as measuring the unweighted peak level. Hearing hazard depends on the shape of the impulse. For example, an impulsive noise from an M-16 rifle at 140 dB is more likely to cause hearing damage than an artillery blast at 140 dB because the spectral energy of the M-16 is more similar to the resonance frequencies of the cochlea, whereas the spectral energy for blasts occurs at much lower frequencies.

Whether community response to blast noise depends more on event timing than the equal energy hypothesis still remains to be determined.

To account for some of the above problems, AR 200-1 also contains supplemental criteria for predicting complaints to blast noise. These criteria, however, are not without their flaws. Specifically, the model used to predict the risk of receiving blast noise complaints[2,20] is based on data obtained in the 1970s at a single installation, and has not been validated in the scientific literature. Further, the data from which the criteria were derived no longer exist (Pers. Comm. Larry Pater, 2004), and therefore cannot be independently evaluated. Regardless, most installations do not, in fact, have a way of measuring the actual sound pressure levels emanating from their installations (e.g., with noise monitoring systems); and those installations that do have noise monitoring systems either have unreliable systems[21] or do not have enough noise monitors in the right locations to make accurate estimates of the actual noise levels.[9]

In general, blast noise complaints received at military installations are taken very seriously and are typically used to guide day-to-day training decisions. Range managers impose testing and training restrictions to appease complainants, often restricting certain weapons and/or the time of day when certain weapons can be fired.[21-23] However, the peer-reviewed literature has not established whether imposing testing and training restrictions in reaction to individual blast noise complainants is an effective means of reducing blast noise impacts on the general public, and there is no evidence that complaints prove the existence of an adverse noise environment. The crux of the problem is that the range manager does not know whether imposing testing/training restrictions in reaction to blast noise complaints from a few individuals is an appropriate and necessary response to appease the community at large.

1.2 Objective

To address the above problems, the research performed within SERDP WP-1546 focused on three major objectives as laid out by the SERDP Statement of Need (SON, SISON-07-03, 2005). These were to:

i. investigate the metrics currently used by the US military to assess high-energy impulsive noise (i.e., blast noise) and assess whether these metrics adequately account for the intermittent, impulsive, nature of blasts;

ii. examine the extent to which individual complaints are indicative of general community annoyance, and

iii. recommend scientifically defensible criteria which can be used to actively manage noise at an installation so that the sustainability of testing and training is ensured.

1.3 Approach

A series of research studies were proposed[24] to meet the diverse and ambitious objectives of the SON. The 5-year project, 2008 – 2013, included 3 main study types, which are referred to as the Complaint Survey (Section 3), the *in situ* Study (Section 5), and the General Community Survey (GCS, Section 6). These studies were conducted at three military testing/training facilities[††] spread across the Continental US (CONUS). In addition to the three main study types, the research included a reanalysis of some early blast noise complaint work (Section 4) that looked at the probability of receiving a blast noise compliant, and a smaller scale study called the Personal Interview Protocol (Appendix A.1).[25] The purpose of the Personal Interview Protocol, which was the first study in the project, was to compare the language/terminology that people from various CONUS regions (i.e., Northeast, South, and West) use to describe their community, environment, and blast noise to the language used in surveys that were to be administered at the three main study sites (Table 1-1).

Table 1-1. Overview of the three study sites and three study types.

Study Site	CONUS Region	Start Date	End Date	Complaint Studies	*in situ*	GCS
A	Northeast	09/2008	03/2009	X		X*
B	Southeast	08/2009	07/2010		X	X
C	Midwest	08/2011	07/2012		X	X

* The GCS at Study Site A served as a pilot for the GCS studies at Study Sites B and C. The lessons learned from the GCS at Study Site A are given in Appendix A.2.

The first main study, in terms of chronological order, was the Complaint Survey. It was designed to directly address Objective (ii), "examine the extent to which individual complaints are indicative of general community annoyance." The other two studies, the *in situ* and GCS were more labor intensive "field" or measurement-based study efforts that address Objective (i). Here "field" refers to the fact that the studies were done in actual or realistic noise environments within communities on and adjacent to active testing/training installations. More specifically, the *in situ* Study was designed to enhance the understanding of how individuals respond to blast events over a short time period (i.e., on the order of hours or days), and the GCS was designed to enhance the

[††] Each study site was anonymously coded to protect the identity of the participating installation. This was done for three reasons. First, some installations were hesitant to participate in the case that the study revealed noise problems at their installation. Second, ever since the 9/11 terrorist attacks, there has been increased caution in disseminating information about DoD installations. Lastly, this study followed the precedent set by a 2004 study of sleep disturbance from blast noise, which simply reported that the study took place at a military installation located in the Southwest (Nykaza et al., 2009).

understanding of how communities respond to blast events over a longer time period (i.e., on the order of weeks or months).

There are some important differences between the studies presented in this report, in comparison to previous community response to military noise studies (see Valente et al. 2013[4] for a comprehensive review of previous military noise studies). Perhaps the biggest difference is the way the noise environment was captured. Unlike previous military noise studies that relied on noise propagation models to estimate the noise environment, ***our studies aimed to measure the blast noise level of each and every blast event that occurred over the entire study time period.*** This proved to be very difficult (see Sec. 9.4 for further discussion), but in the end was instrumental to achieving Objective (iii): recommend improved blast noise assessment criteria and management procedures.

2 Background[‡‡]

2.1 Characteristics of Military Blast Noise

Military blast noise is the noise emitted by large weapons, heavy artillery, guns, and explosions. It falls under the Committee on Hearing, Bioacoustics and Biomechanics' (CHABA) definition of high-energy impulse noise, which is taken as any individual impulse with a C-weighted sound exposure level (CSEL) in excess of 85 dB (75 dB at night), with 75% of the energy concentrated within 1 second and virtually all of the energy concentrated within 3 seconds.[6,26] The acoustical spectrum of a typical blast waveform ranges from 1 to 2000 Hz, with most of the acoustical energy concentrated between 10 and 100 Hz. Given that blast noise has most of its energy centered at low frequencies, it travels with relatively little attenuation in comparison to transportation noise and can be loud at distances on the order of tens of kilometers from the source. Blast noise event durations range from milliseconds to a few seconds depending on distance from the source and propagation paths.

The medium and paths through which the sound travels from source to receiver also influence received blast noise levels. As a result, blast noise levels in communities surrounding military installations are highly variable, primarily due to fluctuations in atmospheric parameters. For example, a several-week propagation experiment that held all variables constant, except for the atmosphere, found that received levels 2 miles from the explosion site varied by as much as 50 dB.[11] These findings were also confirmed and expounded upon in a more recent research effort (Valente et al., 2012).[10] This covers a range from barely noticeable to extremely loud, due primarily to changes in atmospheric meteorological parameters. The irregularity of testing and training schedules adds to the variability in the received noise level. At most military installations, blasts occur intermittently throughout a year and it is not uncommon to have a few days of intense testing or training followed by weeks of little activity.

2.2 Current US Military Blast Noise Assessment Procedures

2.2.1 L_{Cdn} and Percent Highly Annoyed (%HA)

The current military blast noise assessment procedures given in AR 200-1 (Department of the Army, 2007) mandate that C-weighted Day-Night Level (L_{Cdn}) contours are used to manage noise-sensitive land (e.g., locations for housing, schools, and medical facilities) in terms of noise zones (Table 2-1). The Day-Night Level (L_{dn}) averages sound energy over a specified time period such that the resulting value gives an indication of

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‡‡ The material provided in this section has been adapted from Nykaza et al. 2013, and Valente et al. 2013.

the typical daily noise exposure. The L_{dn} also penalizes sounds that occur at nighttime (between 10PM and 7AM) by 10 dB. The use of long-term average noise metrics, such as L_{dn}, has been adopted internationally for virtually all types of noise, including blast noise.[4]

Table 2-1. Land use zones from AR 200-1.

Noise Zone	% HA	L_{Cdn}	Compatible for residential use (schools, housing, and medical)
Zone I	< 15%	< 62	Yes
Zone II	15-39%	62-70	Not normally recommended
Zone III	> 39%	> 70	Not recommended

The impact of environmental noise on a community is typically assessed in terms of annoyance. Annoyance, in general, is a notoriously subjective psychological phenomenon, and annoyance to noise is no exception.[12,13] Noise annoyance is typically assessed through surveys that employ questions on either a fully-labeled response format with 5 categories or an 11-point numeric scale with only the endpoints labeled, prompting individuals to assess their subjective annoyance to different noise sources.[27] By surveying a large number of residents in a community, the percentage of them identifying themselves as highly annoyed by a particular noise (%HA; answers of "very annoyed" or "extremely annoyed" on the fully-labeled scale or 8-11 on the 11-point numeric scale) is used as the metric to relate to the measured average sound level in the community. The subjectivity of the measure is a major contributing factor to difficulties in relating noise levels to community response.

This method of noise assessment has been cemented in the community-response-to-noise research community since 1978, when Schultz published a dose-response curve that related the L_{dn} to the %HA for transportation noise (i.e., road, rail, and aircraft).[28] The "Schultz curve," as it is called, had been derived from worldwide social survey noise annoyance data published before 1978. Until very recently,[29] it has been considered the best way to predict the annoyance of people exposed to transportation and blast noise.[6] The Schultz curve appears to be rather precise, but when one examines the data used to calculate the curve, the variability can be disquieting.[29] Figure 2-1 shows an example of the drastic variability that occurs when noise surveys from multiple communities are compiled and the %HA is plotted as a function of yearly average L_{dn} ($L_{dn,1yr}$). In this context, "yearly average" means that all of the events that occur over a one-year period are averaged to give an indication of what the noise level is on a typical or average day. Figure 2-1 (left) shows 50 years of aircraft noise annoyance studies from Europe, North America and East Asia, and Figure 2-1 (right) shows similar data for blast and sonic boom noise. While the Schultz curve will fit within the scatter of points, it is hardly a good description of the data regardless of noise source, and there have been many efforts over the past twenty years to develop models which reduce this variance.[4,16,17,30-32]

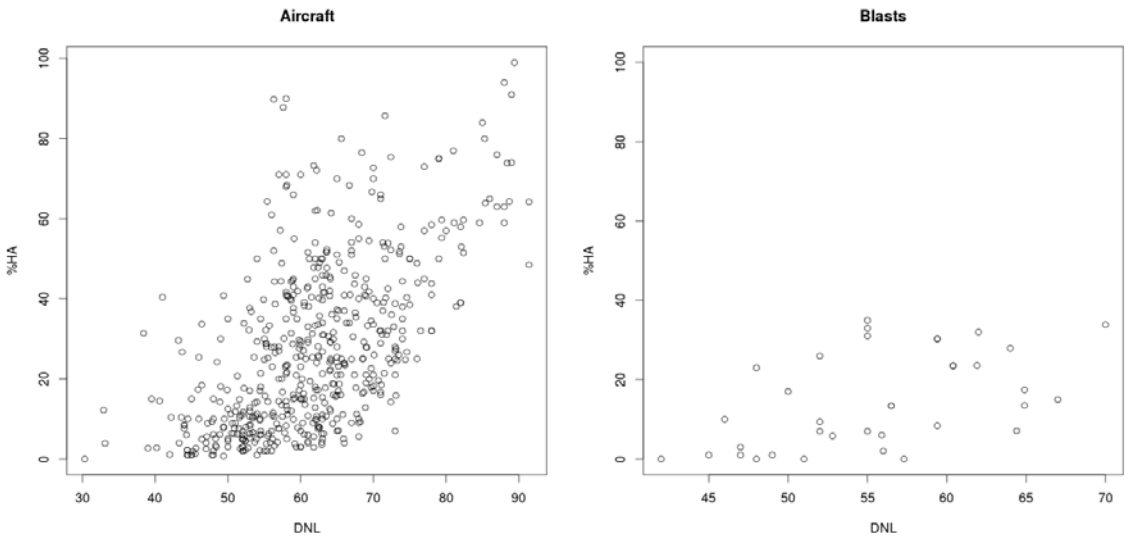

Figure 2-1. The percent highly annoyed (%HA) as a function of Day Night Level (Ldn) for 43 airport community noise surveys (left panel; data from Fidell et al., 2011) and for blasts/sonic booms (right; data from National Research Council, 1996).

2.2.2 Complaint Risk

In addition to assessing community response to blast noise in terms of annoyance and L_{Cdn}, a supplemental method is also given in AR 200-1 and in Appendix G of ANSI 12.9 Pt. 4 that predicts the risk of receiving blast noise complaints. The criteria stem from blast noise complaint risk guidelines that were developed by the Navy to balance the risk of noise complaints against the cost of canceling the training or testing activity.[20] These criteria, which are given in Table 2-2, state that the blast noise complaint risk is low when the unweighted peak level (L_{Zpk}) is below 115 dB, and high when the L_{Zpk} is above 130 dB.

Table 2-2. Complaint Risk Criteria (AR 200-1).

Risk of noise complaints	Single Event L_{Zpk} (dB)
Low	< 115
Moderate	115-130
High	> 130
Risk of physiological damage to unprotected human ears and structural damage claims	> 140

2.3 Community Tolerance Model

The main model that has been proposed to account for the variance in community response data first appeared in a set of papers by Green, Fidell, and Schulz.[33,34] This model was based on Stevens' 1957 "power law" to describe community annoyance to aircraft noise,[34] and was based on the assumption that annoyance increases with level in the same way as loudness (doubling for every 10 dB increase in level). This produced an annoyance curve that was similar in shape to Schultz's, and utilized only a single parameter that was estimated from noise survey data.

In 2011, Fidell et al. introduced the concept of the Community Tolerance Level (CTL).[16] CTL represents an L_{dn} value at which half of the people in a community describe themselves as "highly annoyed" by noise. The CTL is easily related to the single parameter in Fidell, Schultz, & Greens's original model. Fidell et al. demonstrated that if one considers each community in the meta-analysis *individually*, the variance of the scatter is dramatically reduced; each community has a unique CTL. Wilson et al. (2013) provided statistical justification for treating each community individually, and showed that the model could be further improved by relaxing the assumption that annoyance increases at the same rate as loudness, treating this as a community dependent parameter as well.[17]

Evidence that the same approach can be applied to understanding community response to blast noise comes from a reanalysis (Valente et al., 2013; Figure 2-2)[4] of two noise annoyance surveys conducted by USA-CERL in the 1980s at Forts Lewis and Bragg (National Research Council, 1996). In this comparison, the communities near Fort Bragg (CTL = 79 dB) appear to have been more tolerant to blast noise than those near Fort Lewis (CTL = 71 dB). There still exists, however, a great paucity of blast noise annoyance data, a problem that this current project (WP-1546) had the goal of remedying.

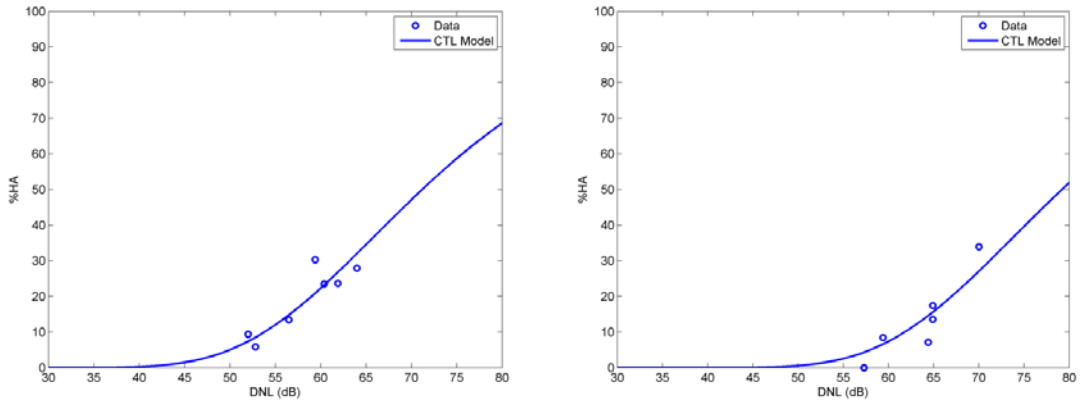

Figure 2-2. Community Tolerance Level model (Fidell et al. 2011) fit to the data from the National Research Council 1996 report on blast noise annoyance. (Left) Ft. Lewis, CTL=71.2 dB, (Right) Ft. Bragg, CTL = 79.2 dB. (from Valente et al., 2013).

2.4 Blast Noise Levels used in CHABA 1996 Recommendations

The current guidance for military blast noise assessment is largely based on the recommendations of CHABA's 1996 report,[6] which, in turn, was greatly influenced by the models described above. The CHABA dataset, which is reproduced in Figure 2-3, was composed of two sonic boom studies — Oklahoma City reported by Borsky (1965),[35] and NASA reported by Fields et al. (1994)[36] —and three blast noise assessment studies — Fort Bragg reported by Schomer (1981),[37] Fort Lewis reported by Schomer (1985),[38] and Sweden reported by Rylander and Lundquist (1996).[39] It is important to note that in each of these experiments, the procedures used to quantify the blast noise environment and the timing of the blast noise data collection related to the gathering of the community annoyance response were different. Before SERDP WP-1546 commenced, Figure 2-3 represented the state of knowledge in terms of blast noise annoyance and highlights the challenges outlined in the section above.

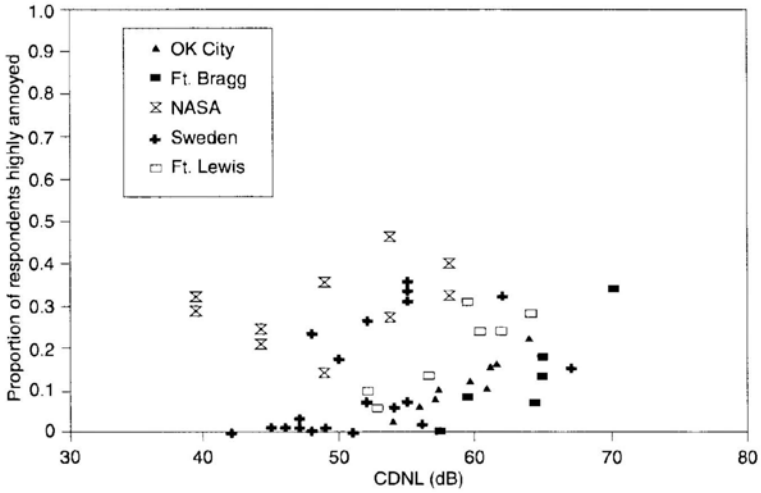

Figure 2-3. CHABA 1996 datasets. The proportion of respondents highly annoyed as a function of the LCdn. This figure is reproduced directly from CHABA, 1996.

3 Complaint Survey[§§]

This section examines the relationship between individuals that complain about blast noise and the annoyance of the larger community exposed to the same noise environment as the complainant, which directly addresses SERDP SON Objective (ii) "examine the extent to which individual complaints are indicative of general community annoyance." In particular, this research looked at whether there were significant differences in reported annoyance to complaint-referenced blast events (CRBE) between those who complain (referred to as *complainants* throughout this section) and their non-complaining neighbors (referred to as *non-complainants* or *matched sample*). This was done with the idea that if complainants and their non-complaining neighbors had a similar annoyance response, then installation decision makers could use individual complaints as a useful indicator of general community annoyance, and thus take the necessary actions to ameliorate the situation. The details of this study, which we refer to as the Complaint Survey Study, have been previously reported in Nykaza et al., 2013[40] and Nykaza et al., 2012b.[41]

3.1 Background

3.1.1 Complainant Demographics

A complaint is an outcome of an individual's decision that can be modeled as a discrete choice problem; either the individual complains or does not.[42] Complaining can also be regarded as a coping behavior,[43] or as noted by Hume et al., residents may complain because of inadequate coping strategies.[44] Unsuccessful coping might increase annoyance,[45] may explain the abundance of repeat complainants,[46,47] and may underlie the importance of responding to complaints correctly the first time individuals complain.[23] Those who are likely to complain typically do not fit the average population description.[48] Complainants are usually older and better educated, have higher economic and social status,[49] are members of environmental organizations,[14,43,50] and are more likely to sign petitions and attend public meetings and demonstrations.[15]

Key factors that influence complaint behavior are (1) knowledge of where to go to file a complaint, (2) the expectation it will do some good, (3) confidence in one's ability to deal with authorities, and (4) past complaint experience.[14] Some of the reasons why residents don't complain are (1) because the resident believes that the complaint will have no consequences, (2) that nothing can be done about the noise, or (3) that authorities will not do anything about the noise.[15] Whether the resident owns or rents his

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[§§] The material contained in this section is taken directly (and often verbatim) from Nykaza et al. 2013, and Nykaza et al, 2012b.

home and how busy the individual is may also affect the likelihood of complaining.[51] In terms of non-acoustical factors, complainants are typically more noise-sensitive, concerned about their health, fearful of a crash (for aircraft), highly annoyed, and likely to experience sleep disturbance.[43]

Regardless of the factors underlying complaints, Luz et al. suggested that complaints should be dealt with in a timely manner to reduce the risk of having a complaint grow into a more formal objection (e.g., congressional inquiries and lawsuits) and to prevent individuals from filing multiple complaints.[23] Wiechen et al. found that 70% of complainants complained more than once,[43] and Hume et al. found that 41% of complaints were from repeat complainants.[47]

3.1.2 Relationship between Complaints and Annoyance

There is considerable uncertainty about the relationship between complaints and annoyance,[15] and the assumption that those who complain about noise represent a significant percentage of the population that is equally annoyed is a relationship that has not been established.[29,52] Some early studies of community response to intrusive noise hypothesized that there was a relationship between the complaints of a few and the average annoyance of the entire noise-exposed population.[50,53] However, when Avery tested this hypothesis, he found no significant correlation.[54]

Complaints and annoyance are often related to noise exposure, but not always. For example, Hume et al. showed an orderly relationship at the Manchester (England) Airport between noise level of individual flights and the mean number of noise complaints over a two-year time period.[55] There have also been studies, however, that have shown high annoyance[38] and complaints[56] in areas that are exposed to low levels of noise, and low annoyance[57] and infrequent complaints[43] in areas that are exposed to high levels of noise.

Many times non-acoustical factors are the dominant mechanisms that affect response. Expectation of the increase in noise has been shown to increase annoyance[58,59] and complaints,[55] and if the individual is already stressed by non-acoustical factors, the noise may be perceived to be more annoying than usual.[15] In some cases, annoyance or complaints may be explained by habituation,[5,60] and in other cases, noise sensitivity.[61]

3.2 Data Collection

This study was designed to capture the near real-time annoyance response of complainants and their neighbors to determine whether individual complainants can be used to predict community annoyance. Each time a complaint was made to the participating installation, the goal was to capture telephone survey responses from the complainant and nine residents living in close proximity to the complainant, also referred

to as the "matched-sample." For this study, it is assumed that residents living in close proximity (i.e., less than 1.5 km) to the complainant were exposed to the same noise environment; thus, the study was designed without the capture of stimulus or noise data. From previous complaint work done around this installation,[21] it was expected that all complainants and matched-sample would be located in the far field relative to the source, and individual complaint referenced blast events to range in unweighted peak level (L_{Zpk}) from 100 to 130 dB. The data collection goals, which were based also upon historical complaint data and feasibility constraints, were to complete a total of 500 telephone surveys with 50 complainants and 450 of their neighbors

3.3 Survey Instrument

The Complaint Survey survey instrument can be found in its entirety in the ERDC-CERL Technical Report,[41] and is very similar to the GCS survey instrument given in Appendix C.1. As with the other survey instruments (i.e., the *in situ* and general community surveys), the survey instruments were reviewed by the US Office of Management and Budget (OMB No: 0710-0015) and approved by the Pennsylvania State Office of Research Protections Institutional Review Board (IRB No. 27457).

The design of the survey, with two exceptions, utilized the set of noise-reaction questions recommended by the International Commission on the Biological Effects of Noise (ICBEN).[27] The first exception is that ICBEN suggests the use of both the fully-labeled response format with five categories and 11-point numerical noise-reaction questions for the purpose of making comparisons to other social surveys. This study only utilized the fully-labeled response format to reduce the burden on respondents. The second exception is that ICBEN discourages the use of screener questions such as "have you ever heard the noise of interest?" While it is possible that asking this question prior to the annoyance question could bias the annoyance response, a critical component to this study was establishing whether the respondent heard and was home during the time of the complaint referenced blast event (CRBE).

The survey asked a total of 43 questions, including two annoyance questions. The categories of questions on the survey ranged from general questions about the neighborhood and environment, to specific questions about CRBE, importance of the installation, and characteristics of the respondent household (see Table 3-1 in Sec. 3.5). Respondents were asked to rate their annoyance to the CRBE, as an instantaneous annoyance response, and to general military noise over the past six months. The annoyance questions were fully labeled Likert scale items. That is, the response specified five ordered categories and each category had a text description that was read, in full, to the respondent. The categories, or points on the scale, were "Not at all annoying," "Slightly annoying," "Moderately annoying," "Very annoying," and "Extremely annoying."

3.4 Sampling Procedures

The sample for this study was driven entirely by complaint behavior at the participating installation. That is, a sample point was generated when the installation public affairs office received a noise complaint. This information was promptly shared with the researchers overseeing the implementation of the survey, who then identified and drew an eligible sample for the surveys of matched households. The installation public affairs office documented the complaint, including the name, address, and contact information of the complainant, the date and time of the event, and any relevant notes.

Upon receiving the complaint information from the installation, the research team assessed the complainant's eligibility and randomly sampled residents living in close proximity to the complainant. In order to ensure that the matched-sample of households were sampled from the same noise environment as that of the complainant, the entire region was overlaid with a grid of one-square-kilometer areas (referred to as grid-cells), and nine households in the same or adjacent grid-cell as the complainant were randomly selected and interviewed. The surveys were also conducted as quickly as possible following the complaint to maximize reliability of respondents' reported annoyance about the noise event. In most cases, the survey team completed the surveys within one week of the complaint, and in all cases within an upper limit of two-weeks, which allowed for cases in which there was difficulty in obtaining matched-sample in sparsely populated areas or where it required more calls to locate individuals who were home at the time of the CRBE.

3.5 Analysis Methods

Two analysis of variance (ANOVA) models were implemented using SAS® software and the MIXED procedure to test differences in mean annoyance between those who complained and their non-complaining neighbors. One ANOVA model examined the mean annoyance to the CRBE, and the other examined the mean annoyance to general military noise. The respondents were divided into non-complainant and complainant groups, which differed slightly depending upon the annoyance response being analyzed.

For the analysis of mean annoyance to CRBE, complainants were simply defined as those who filed a complaint to the installation and the matched-sample were defined as the respondents living in close proximity to the complainant who were home during the CRBE and did not complain. For the analysis of mean annoyance to general military noise, complainants and matched-sample were grouped into one of three groups: non-complainants (NC), first-time complainants (FC), and repeat complainants (RC). NCs were defined as respondents who self-report no complaints in the preceding six months and were previously grouped as matched-sample; FCs were respondents who report one complaint in the preceding six months or report no complaints and were previously grouped as a complainant; and RCs were respondents who self-report more than one

complaint in the preceding six months or were previously grouped as a repeat-complainant.

For both analyses, an exploratory correlation analysis was done to examine the relationship between the annoyance response variable and possible covariates. The covariates considered included a composite noise sensitivity rating and a composite installation importance rating (see definitions given in Sec. 5.2.1), as well as the distance of the respondent from the source.

The final model, for both analyses, included responses to questions 1, 4, 30a, 32, 33, 34, 35, 36, 38, 39, and 42 (Table 3-1) as independent categorical variables. A weekday (yes/no) variable that captured the day of the complaint (i.e., weekday or weekend), and complaint (yes/no) that indicated whether the respondent was a complainant or matched-sample, were also included in the model. The event identification variable was used as a random blocking factor to account for correlations between responses to the same CRBE. Model reductions were performed to discard non-significant variables ($p > 0.20$) and at each reduction step a check was done to ensure the normality and homoscedasticity assumptions were satisfied.

Table 3-1. Questions used in the ANOVA model.

Question Number	Question
Q1	How would you rate this neighborhood overall as a place to live?
Q4	Do you think your neighborhood is quiet or noisy or about average?
Q30a	Do any children under age 6 live in your household?
Q32	What is the highest grade or year of schooling that you have completed?
Q33	How long have you lived at this address?
Q34	Do any members of this household work for the [Installation]?
Q35	Have any members of your family household ever served in the Armed Services?
Q36	Do any members of this household receive retirement or disability income as result of military or civilian service in the Department of Defense?
Q38	About how old is your home or the building your residence is in?
Q39	How old are most of the windows in your residence?
Q42	To the best of your knowledge is your hearing normal?

3.6 Results

3.6.1 Overview of Data Collected

The data for this study were collected from September 2008 through March 2009. The final dataset was comprised of 197 observations associated with 21 blast noise complaints and fell short of the desired number of 500 observations because a lower than expected number of noise complaints were received by the installation. Despite the low number of complaints over the study period, several significant differences between complainant and matched-sample annoyance were found. Also, the sample size of this study was comparable to prior studies. For example, a complaint comparison study conducted by Avery (1982) included 148 respondents,[54] and a study conducted by Hede and Bullen (1982)[62] assessing residents' responses to shooting range noise included a sampling of 201 residents.

In general it was found that the 89% of residents surveyed in this study report hearing military noises, 84% rate their neighborhood as a good or excellent place to live, and 68% report that their neighborhood is quiet. Of the residents who were home during the CRBE, the majority were located inside their home and approximately 87% experienced rattle or vibration from the CRBE. Of those respondents that mention rattle/vibration, approximately 78% report that their windows rattled.

3.6.2 Covariates in the Final Model

As mentioned above, the actual received blast noise levels were not gathered for this study. In an attempt to account for some of the variation that might be due to proximity from the source, the distance between source and receivers and between complainants and matched-sample were calculated. In this study, the distance from source to receiver ranged from 5 to 25 kilometers, and the distance between the homes of complainants and matched-sample ranged from 25 meters to 3 kilometers, with the majority or 75% of matched-sample being within 1.5 km.

The results of the exploratory analysis, given by the correlation coefficient r and statistical significance p, show that *Noise Sensitivity* ($r = 0.333$ and $p = 0.001$) and *Installation Importance* ($r = -0.277$ and $p = 0.009$) were significantly correlated with annoyance to CRBE; and *Noise Sensitivity* ($r = 0.457$ and $p < 0.001$) and *Installation Importance* ($r = -0.192$ and $p = 0.012$) were significantly correlated with annoyance to general military noise. In both cases, distance from the source was not significant, *Noise Sensitivity* was positively correlated with annoyance (i.e., as individuals become more noise sensitive, they tend to be more annoyed), and *Installation Importance* was negatively correlated with annoyance (i.e., increased feelings of importance of the installation tend to be associated with decreased annoyance). In both analyses, only the most significant covariate, *Noise Sensitivity*, was included in the analysis of covariance (ANCOVA) due to the limited sample size. In the end, this model was discarded and

replaced with an ANOVA because the relationship between the response variable and the *Noise Sensitivity* was not entirely linear over the range of possible values of the predictor, which was a violation of a key assumption underlying the ANCOVA model.

3.6.3 Annoyance of Complainants compared to Non-Complainants

The two analyses described in the methods section (Sec. 3.5) looked at (1) the mean annoyance to the CRBE between complainants and their non-complaining neighbors or matched-sample, and (2) the mean annoyance to general military noise between self-reported non-complainants (NC), first-time complainants (FC), and repeat complainants (RC). In general, most respondents answered the question regarding annoyance to general military noise, but only 61 of the 197 respondents were home at the time of and recalled the CRBE.

Annoyance to Complaint-Referenced Blast Events

As shown in Figure 3-1 (left), those who complained to the installation were significantly more annoyed by CRBE (mean annoyance = 4.7 on 5 point scale) in comparison to the matched-sample (mean annoyance = 2.3). For all the results discussed, a p-value of less than 0.05 was used to determine statistical significance. Respondents who report their neighborhood is noisy had a significantly higher mean annoyance than those who report their neighborhood is quiet or about average (Figure 3-1, right). It was also found that respondents who are receiving retirement or disability income had a statistically significant difference in mean annoyance to CRBE in comparison to those who do not, though the mean annoyance was only marginally different (3.2 vs. 3.8).

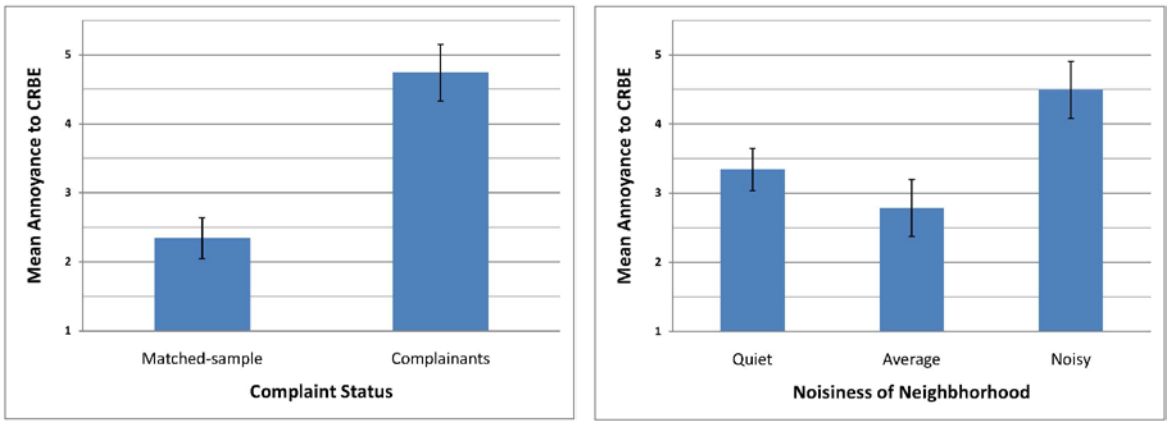

Figure 3-1. Mean annoyance to CRBE for complainants and their non-complaining neighbors or matched-sample (left), and mean annoyance to CRBE between groups of respondents who self-report that their neighborhood is quiet, average, or noisy.

Annoyance to General Military Noise

Given there was a significant positive correlation between *Noise Sensitivity* and annoyance in the exploratory analyses, the concept of *Noise Sensitivity* was explored further to see if there was a significant difference in *Noise Sensitivity* between NCs, FCs, and RCs. As shown in Figure 4, non-complainants had the lowest average *Noise Sensitivity* rating (2.15), followed by first time and repeat complainants (2.32 and 2.62, respectively). While it appears that *Noise Sensitivity* increases as the number of self-reported complaints increase, it should be kept in mind that there was only a significant difference (p=0.0495) in *Noise Sensitivity* between non-complainants and repeat complainants, and that the effect is rather small.

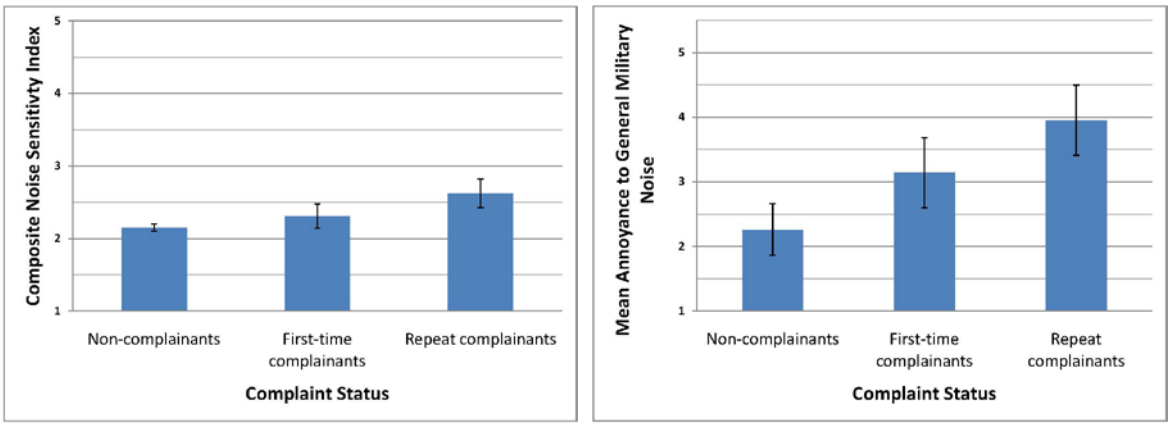

Figure 3-2. Noise sensitivity between groups of non-complainants, first-time complainants, and repeat complainants (left), and mean annoyance to general military noise between groups of non-complainants, first-time complainants, and repeat complainants (right).

It also appears that annoyance increases as the number of self-reported complaints increase. As shown in Figure 5, there was a significant difference (p = 0.0012) in the reported annoyance to general military noise between repeat complainants and non-complainants. The mean annoyance was 4.0 and 2.3, respectively. Similar to the annoyance to CRBE results, respondents who report their neighborhood is noisy had a higher mean annoyance than those who report their neighborhood is quiet or about average.

Percent Highly Annoyed

Most noise surveys are typically analyzed in terms of the percentage of the population that is highly annoyed (%HA). For the five-point annoyance scale, a response of 4 (very annoying) or 5 (extremely annoying) is considered highly annoyed. For purposes of comparison with previous studies, the %HA to CRBE and general military noise is given in Table 3-2 and Table 3-3.

Table 3-2. Percent highly annoyed (matched-sample vs. complainants).

Complaint-Referenced Blast Events	Data Points (N)	Mean Annoyance (1-5)	Stdev Annoyance (1-5)	% Highly Annoyed
Matched-sample	77	2.1	1.5	25%
Complainants	21	4.4	1.2	90%

Table 3-3. Percent highly annoyed between NC, FC, and RC.

General Military Noise	Data Points (N)	Mean Annoyance (1-5)	Stdev Annoyance (1-5)	% Highly Annoyed
Non-Complainant	153	2.5	1.4	23%
First Complainant	11	3.5	0.8	45%
Repeat Complainant	12	4.5	1.4	92%

It should be noted, however, that distilling the annoyance responses into binary responses of highly annoyed or not highly annoyed can hide important details. In hopes of better understanding the variance in human response to blast noise the ANOVA analyses presented in this section looked at average annoyance responses across all five annoyance categories. In general, the findings of the ANOVA in Figure 1 and Figure 5 are similar to the descriptive statistics presented in Table 3-2 and Table 3-3. Complainants are more annoyed than their non-complaining neighbors. Both the mean annoyance and %HA increase as complaint status increases from non-complainant to first-time to repeat complainant.

3.7 Discussion

3.7.1 Percent Highly Annoyed

The measurement of %HA with the matched-sample paradigm was not as straightforward as with the typical social survey. For example, two of the complainants in Table 2 reported a “1” (not at all annoying). This may suggest that some of the residents that call the installation are inquiring about the noise rather than complaining. Removal of the two respondents who reported an annoyance of 1 from the complaint group would increase the %HA to 100%. Also, %HA depends on whether respondents who were home at the time of the CRBE and did not recall the CRBE are included in the analysis. If it is assumed that those who were home during the time of the CRBE and did not recall the CRBE are categorized as “not at all annoyed,” then the percent of non-complainants or matched-sample %HA would be 25%. However, if the 36 respondents

that were home and did not recall hearing blast events are removed, this percentage would be 46%. Both of these measures of %HA for the matched-sample are significantly different than the complainant group, but the differences between 25%HA and 46%HA are also significant.

Despite these differing options in how to count %HA, three findings in the matched-sample data mirror findings in Brink and Wunderli's (2010) social survey of 1004 gunfire-exposed Swiss residents as summarized in their Table IV:

(1) Weak relationship with noise level. For every one unit increase in L_{AE}, Brink and Wunderli found that the odds of a respondent being HA increased by roughly 9.4%. In this case, the steps represented 3 dB bins, so that each one dB increase equated to about a 3% increase. On the surface, this looks like a reasonable relationship, but Brink and Wunderli's dose response curve was actually U-shaped. For individuals, they reported: "the 5-point verbal scale yielded an adjusted R^2 value of 0.08 for both L_{AE} and L_{CE} as predictor." Similarly, in our matched-sample data, the surrogate for noise level, distance between the complainants and the ranges, was statistically insignificant.

(2) Moderate relationship with noise sensitivity. Brink and Wunderli used a 9 question short form to measure noise sensitivity (Zimmer and Ellermeier 1998). For every one unit increase in noise sensitivity, the odds of a respondent being HA increased by roughly 8.3%. Using a more indirect approach to noise sensitivity, our matched-sample data yielded statistical significance with simple correlation but insignificance with ANOVA. This finding may suggest that *Noise Sensitivity* may be a characteristic of those who are highly annoyed, but not necessarily a characteristic of complainants.

(3) Strong relationship with importance of noisemaker. For every one unit increase on a five-point scale of favorable attitudes toward the Swiss Army, the odds of a Brink and Wunderli respondent being HA decreased by roughly 36.2%. In our matched-sample data, attitude toward the installation was significantly related to %HA with both simple correlation and ANOVA. Statistical significance was found even though the matched-sample study omitted any probing of attitudes toward 21st Century U.S. military engagements.

3.7.2 Installation Management of Complaints

Managers of U.S. military ranges have a recommended procedure for collecting information on the location, time and nature of noise complaints,[63] but little guidance on how to interpret these data beyond the admonition "Investigate without delay." It is commonplace for range managers to plot the locations of complainants on maps of the installation noise contours. Our findings suggest that more can be learned about a complainant through a personal visit. An excellent framework for structuring a site visit is Fields' list of personal and situational variables.[64] Fields concluded that **"**Annoyance is

related to the amount of isolation from sound at home and to five attitudes: fear of danger from the noise source, noise prevention beliefs, general noise sensitivity, beliefs about the importance of the noise source, and annoyance with non-noise impacts of the noise source."

For blast noise annoyance, rattle-prone architectural features of the complainant's home are especially informative. Schomer et al. published checklists of common sources of rattle in U.S. residential construction.[65] The importance of these lists is validated by research showing that the perception of rattle amplifies the annoyance of sounds, which on the basis of loudness *per se*, should not be very annoying. Perception of rattle amplifies the annoyance of loudness for both military helicopters[66] and blasts.[67]

Rattle-prone check lists address the first of the six personal and situational variables identified in Fields' meta-analysis of noise annoyance surveys (i.e. isolation from sounds in the home). Our findings show that another of Fields' variables, beliefs about the importance of the noise source, is significant for understanding complainant behavior. Complainants may disclose this attitude with phrases such as *"I am a strong believer in national defense but…."*

Not addressed in the current study were three attitudes omitted because of socio-political constraints. These were (i) Fear of danger from the noise source, (ii) Annoyance with non-noise impacts of the noise source, (iii) Noise prevention beliefs**.** In practice, fear of danger and annoyance with non-noise impacts are rarely mentioned in blast noise complaints.[21,23] Noise prevention beliefs are more common, because a large variability in blast noise level due to meteorology can lead complainants to believe that their experience of a blast noise focus is due to the military doing something out-of-the-ordinary and avoidable. Spontaneous expression of this attitude can provide an opportunity for the installation representative to explain the role of meteorology in received blast noise levels.

Our findings also show that general noise sensitivity is heightened among complainants, but deciding whether a complainant is noise-sensitive during the course of a site visit is a difficult task. Some hint may be found in Moreira and Byron's description of noise-sensitive (NS) people:

> "The most outstanding impression of those people who were NS was that they were typically friendly, generous and sociable and very much aware of their environment. As is well known about those who complain of noise they were equally liable to complain about other defects in their neighborhood, e.g. the drains, etc. On the positive side they were frequently active in the community, e.g. in voluntary social work and very much aware of the needs of others. Very often they were 'creative', having some hobby such as painting or writing. Usually they seemed to be of above-average intelligence compared with their neighbors."[68]

Of special importance are site visits to repeat complainants. People in this category would be expected to be more angry than their neighbors,[23] (Luz et al. 1983), complaining at lower noise levels than first time complainants[21] and, as demonstrated in the current study, more annoyed than their non-complaining neighbors or first time complainants.

3.8 Summary and Conclusions

This study looked at whether there are significant differences in reported annoyance to complaint-referenced blast events (CRBE) and general military noise between complainants and their non-complaining neighbors. It was found that complainants were significantly more annoyed to both noise sources than their non-complaining neighbors, which may suggest that range managers should alter the way they are currently managing complaints (see recommendations in Sec. 9.2). In general, it was found that the majority of respondents report that their neighborhood is a very nice (good or excellent) place to live and that the noise in their neighborhoods ranges between quiet and average. This finding includes complainants, but not necessarily repeat complainants or those who were highly annoyed. *Noise Sensitivity* was also found to be highly correlated with those who report high annoyance to military and blast noise, and the degree of sensitivity to noise increased as the number of self-reported complaints increased.

4 Probability of Receiving a Complaint

4.1 Background

A complaint study was conducted at Installation A in the mid 2000's and published in 2008,[21] which examined the blast noise levels associated with blast noise complaints. In this study, a total of 52 complaints were received over a 1.5 year time period (8/2006 to 5/2007), though only 40 of those records could be used given that 12 of the records did not have accurate address information for the complainants. This study found that the threshold level associated with the complaint depended on whether (1) the person was complaining for the first time (Table 4-1), (2) the complaint was in regards to blast events that occurred during the day or evening (Table 4-2), and (3) the complainant was referring to one single loud event, or multiple blast events (Table 4-3).

Table 4-1. Complaint threshold level of first time and repeat complainants.

Mann-Whitney Nonparametric Test	Sample Size	Median L_{Zpk} (dB)
First Time Complainants	26	120
Repeat Complainants	10*	107

*Sample size of repeat complainants is 14, but only 10 had matching acoustical data.

Table 4-2. Complaint threshold level of first time complaints that occur during the day and the evening.

Mann-Whitney Nonparametric Test	Sample Size	Median L_{Zpk} (dB)
Complaints During Working Hours (7 AM to 5 PM)	20	121
Complaints During Evening Hours (5 PM to 10PM)	6	111.5

Table 4-3. Complaint threshold level of single shot (blast) complaints and multi-shot complaints.

Mann-Whitney Nonparametric Test	Sample Size	Median L_{Zpk} (dB)
Single Shot Complaints	8	125
Multiple Shot Complaints	18	117.5

There are a few things to note about the complaint study published in 2008. First of all, there were only a small number of complaints used in the analysis (40). Secondly, the study examined complaint thresholds, but did not assess the probability of receiving a

complaint. The study only considered the levels associated with complaints and did not consider the blast noise environment on days when no complaints occurred. Lastly, a lot of effort went into estimating the blast noise level at the complainants' locations given that primitive noise monitoring equipment was used, in the sense that the equipment only recorded a few simple noise metrics and had no onboard software to detect or classify blast events. The study occurred before the development of "smart" military noise monitors, such as the ones developed and demonstrated through the SERDP and ESTCP programs that have built-in noise classifiers.[69,70]

4.2 Methods

In 2012, a new blast noise complaint study was conducted as a part of this SERDP project (WP-1546). The study differed from the 2008 complaint study in several ways. First of all, the method used to characterize the blast noise environment was more accurate. In 2012, Cvengros et al. published a sound level meter (SLM) blast noise classifier algorithm.[70***] The SLM blast noise classifier had an accuracy of 95% and allowed the automatic classification of over 3.5 million noise events captured during the original complaint study.

With this large dataset on hand, which included blast noise data on days with and without complaints, a new research question could be answered: "What is the probability of receiving a blast noise complaint?" For this study, the specific research question addressed was, "what is the probability of receiving a blast noise complaint on a given day within 5 km of a noise monitor?" The question was posed in terms of a 5 km radius around the noise monitors to reduce the errors/uncertainty associated with interpolating/extrapolating the blast noise levels from the noise monitor locations to other regions of interest, though it is acknowledged that the received levels over the 5 km radius region can vary significantly.

The complaint study re-analysis presented here includes 148 complaint records and 102,116 blast events (<3% of the total recorded events) recorded on 35 noise monitors over the time period between 8/2006 and 5/2008. The re-analysis also includes an additional year's worth of noise and complaint data.

Logistic regression was used to assess the probability of receiving a blast noise complaint on any given day. The data were first divided into study days (i.e., all of the days between 8/2006 and 5/2008). Cumulative blast noise metrics were calculated for each study day (see Table 5-1. **Metrics calculated for the acoustic waveforms. A-weighted, C-weighted, and un-weighted versions of each of these metrics were calculated**), and each day was assigned a binary complaint classification of 0 or 1. Here, 0 indicates no

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*** The work of Cvengros et al. was the result of a synergy between ESTCP WP-201117 and this SERDP project (WP-1546).

complaints on that day and 1 indicates at least 1 complaint that day. The analysis also explored the idea of breaking the complaint data into complaint categories such as first time complainants, repeat complainants, and multiple complaints; however, slicing the data into categories resulted in very sparse datasets and results that were very similar to the results of analyzing all of the data together.

4.3 Results and Discussion

Two logistic regression models were fit. First, the probability of receiving a complaint around any of the noise monitors on a given day was assessed; that is, all of the complaint and noise monitor data were combined. This analysis was performed on all of the cumulative metrics separately. The analysis was then repeated for each monitor separately to explore the idea that different communities may have a different complaint tolerance to blast noise. In this case, only the $L_{Cdn,24hr}$ was considered given that all of the metrics are highly correlated; it was found to be one of the best metrics in the first analysis, and it is the metric that has the most historical precedence.

4.3.1 Probability of Receiving a Complaint around Study Site A

When the data from all monitors are combined, the results show that the probability of receiving a blast noise complaint around Installation A is very low (Figure 4-1). The results are given in terms of L_{Zpk} (Figure 4-1 left), the metric recommended in AR 200-1 for complaint risk, and $L_{Cdn,24hr}$ (Figure 4-1 right), the metric recommended for annoyance. These results indicate that high blast noise levels occur without complaints, and give evidence that contradicts the current complaint risk criteria in AR 200-1. For example, the complaint risk criteria in AR 200-1 suggest that there is a high risk of receiving a blast noise complaint when the noise level exceeds L_{Zpk} of 130 dB. However, the results given below (Figure 4-1 left) indicate that there is less than a 3% chance of receiving a blast noise complaint at L_{Zpk} of 130 dB. Further, this analysis also found that the two best metrics (in terms of model deviance) for predicting the chance of receiving complaints) were the $L_{CLeq,24hr}$ followed by the $L_{Cdn,24hr}$. In this analysis, all of the blast noise metrics were found to be significant ($p < .05$), with exception to the metrics that looked at the number of blast noise events above a certain threshold. Lastly, the L_{Zpk} was ranked 9th out of the 16 metrics considered.

These results do not support the accuracy and utility of the current AR 200-1 complaint risk criteria for general use at installations today. In keeping with the idea of the community tolerance hypothesis, it may be that the criteria that Pater put together in 1976 was reflective of the community and time period from which he captured the data. Also, the noise level data in his study were more limited and less accurate than those of the current study, which was a major motivation for the current study (pers. Comm., Pater, 2013).

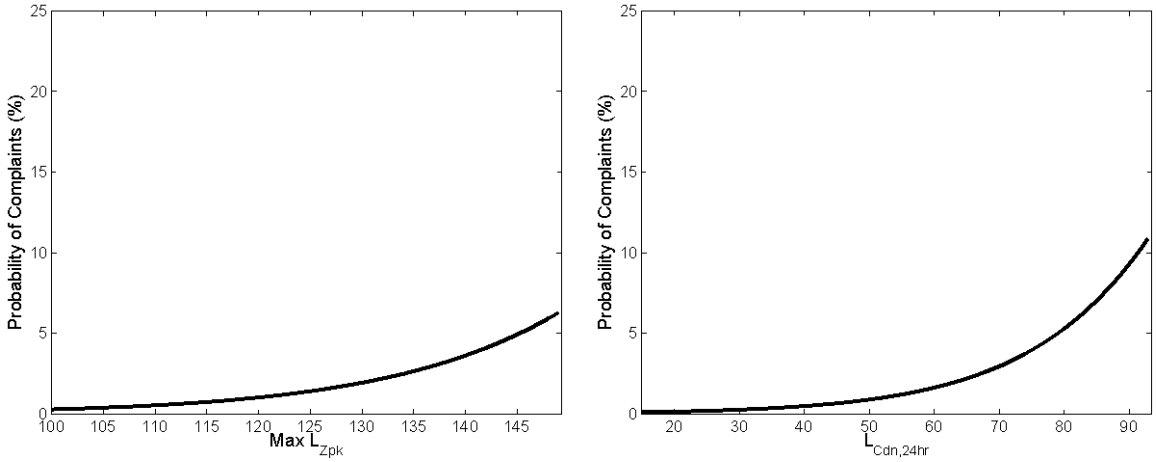


Figure 4-1. Probability of receiving a blast noise complaint within **5 km** of any noise monitor on a given day, in terms of the max L_{Zpk} (left) and $L_{Cdn,24hr}$ (right).

One possible application of the analysis presented here is a reliable real-time complaint risk criteria. That is, if installations coupled their noise monitoring systems to their complaint records, a simple algorithm could be built to predict the risk of receiving blast noise complaints, and unlike the current set of universal criteria, a unique complaint risk criteria could be built for each region of interest.

4.3.2 Probability of Receiving a Complaint around each Monitor

When the data around each monitor were analyzed separately, it was found that different regions had different blast noise complaint tolerances. A summary of all the results is given in Table 4-4, and a few examples of the differing blast noise complaint tolerances are given in Figure 4-2. From these results, it can be seen that there were several communities that had no risk of receiving a complaint, and several in which there was a very high risk (e.g., Monitor 4, 12, and 13).

Table 4-4. Results of logistic regression analysis, done for each monitor separately. This table shows the number of blast days (N_{blast}), the number of complaint days ($N_{complaint}$), range of blast noise levels (Min L_{Cdn} and Max L_{Cdn}), and the probability of receiving a blast noise complaint at a L_{Cdn} of 57, 62, and 70 dB (PCR_{57}, PCR_{62}, PCR_{70}, %).

Monitor	N_{blast}	$N_{complaint}$	Min L_{Cdn}	Max L_{Cdn}	PCR_{57}	PCR_{62}	PCR_{70}
1	314	7	26	79	2	3	4
3	343	5	24	86	2	3	5
4	123	17	23	62	55	93	100
6	280	7	23	62	12	24	56
7	222	8	17	87	12	17	31
8	101	0	19	63	0	0	0
9	339	2	24	68	2	5	23
10	398	12	28	66	6	12	30
11	115	2	25	72	2	3	4
12	209	11	25	63	2	15	85
13	380	5	20	65	3	14	71
14	166	5	17	62	3	4	8
15	153	8	25	66	6	11	25
16	213	0	21	60	0	0	0
17	343	0	24	84	0	0	0
18	227	9	22	65	15	23	41
21	199	0	15	67	0	0	0
22	232	0	17	69	0	0	0
23	197	6	18	55	8	11	17
24	159	0	20	63	0	0	0
25	258	3	24	76	0	0	0
26	187	2	24	88	0	0	0
27	90	0	17	66	0	0	0
28	197	0	23	65	0	0	0
29	251	4	18	72	7	12	24
30	272	0	24	68	0	0	0
31	218	0	25	80	0	0	0
32	181	0	22	63	0	0	0
34	199	0	26	66	0	0	0
35	296	4	22	65	4	7	14
36	182	24	24	81	3	3	2
37	196	0	24	93	0	0	0
42	104	3	24	87	1	2	4
43	201	17	23	70	3	8	32

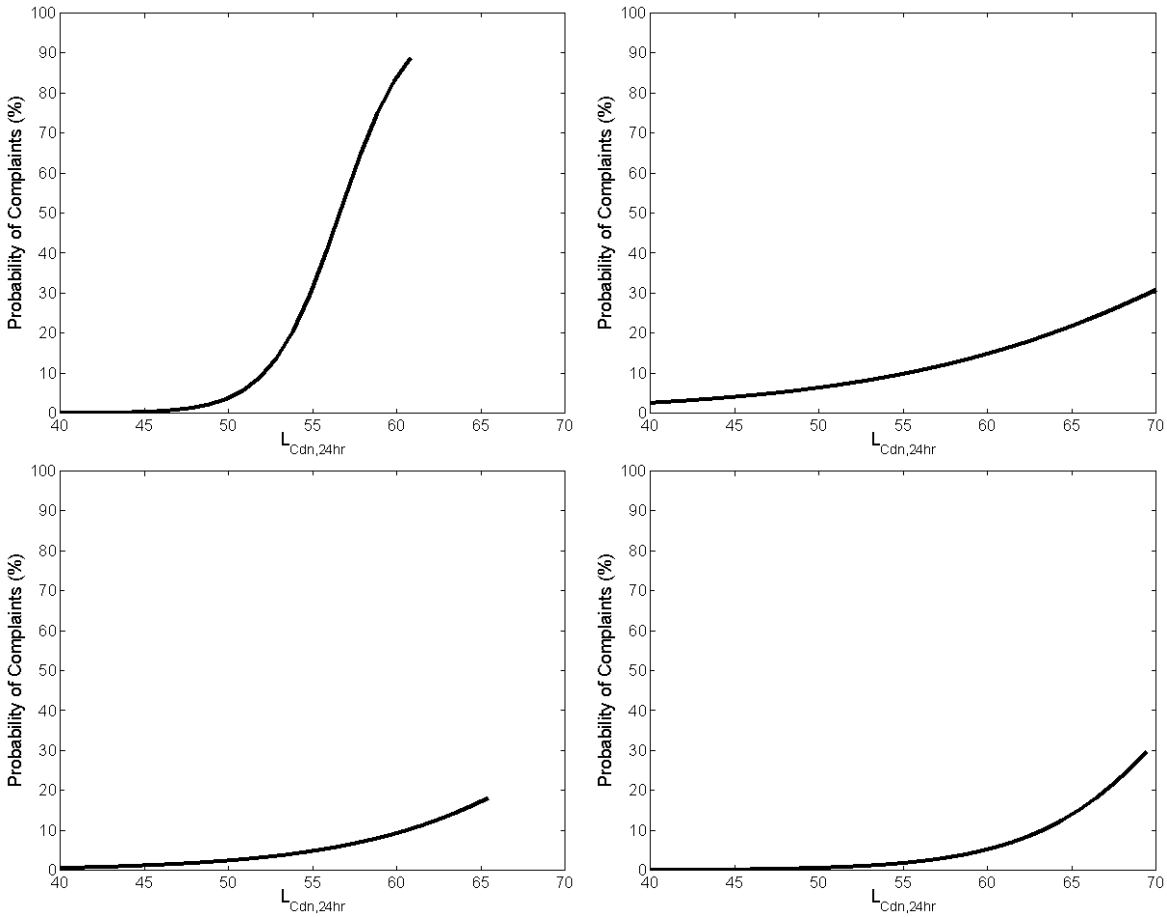


Figure 4-2. Probability of receiving a blast noise complaint within **5 km** of Monitor 4 (top left), Monitor 7 (top right), Monitor 10 (bottom left), and Monitor 43 (bottom right), on a given day and in terms of the $L_{Cdn,24hr}$. The lines fit by the model are only given over the range of data that was used in the analysis.

4.3.3 Demographics of the Regions around the Monitors

A criticism of the analyses presented above is that the model(s) do not account for the population density within the 5 km radius that surrounds each noise monitor. Future work should address this shortcoming. However, a post hoc analysis was done to examine the correlation between the probability of receiving a blast noise complaint at an $L_{Cdn,24hr}$ of 62 dB (PCR_{62}) and demographic data associated with the location of each monitor.

For this analysis, demographic data was obtained from the 2010 census for the zip code of the monitor location. The following demographic variables were considered: gender, age, education, employment status, percentage of people home during the day, and year

home was built. From this analysis, which only included 34 monitor regions, there were statistically significant ($p < 0.05$) correlations between PCR_{62} and the percentage of the population that are home during the day, under the age of 5, over the age of 65, over the age of 18, and unemployed. These results, however statistically significant, are likely practically insignificant because the correlations were quite low (Spearman correlation coefficient < 0.2). These results should be explored in more detail in future research.

4.4 Summary and Conclusions

This section addressed the probability of receiving a blast noise complaint in different regions surrounding one installation. Overall, the probability of receiving a complaint within 5 km of any noise monitor was very low, regardless of level. It was found that the $L_{Cdn,24hr}$ and $L_{Ceq,24hr}$ were better metrics to predict complaint risk than the L_{Zpk} currently recommended by AR 200-1. However, when examining the probability of complaint by region, different regions appeared to have different tolerances to noise. A demographic analysis of the relationships between these communities and complaint risk was ultimately inconclusive; however, it suggested that risk might be slightly correlated with the percentage of population that is home during the day, under the age of 5, over the age of 18, over the age of 65 and unemployed.

5 In situ Study

5.1 Materials and Methods

5.1.1 Overview

The purpose of the *in situ* study was to investigate individuals' responses to blast noise. Here, *in situ* refers to the fact that subjects participated in their own homes and were instructed to go about their normal routines. *In situ* survey data were collected daily in the form of surveys completed by the study participants. The participants were initially contacted by Tetra Tech Inc., and agreed to allow researchers to set up data collection equipment in and around their homes. They were also asked to fill out daily surveys regarding the blast noise they experienced during the 3-month duration of their participation. The participants were compensated for their participation in the project.

The hearing acuity of all subjects was assessed using an MA Model 25 portable audiometer. Hearing thresholds were screened across the audiometric frequency range from 250 Hz to 8 KHz. All subjects exhibited hearing sensitivity within normal limits (< 25 dB hearing loss (HL) re ANSI S3.6-1996 (1996)) across the frequency range of interest, below 4 KHz. The hearing test identified a cut-off for normal hearing level of 40 dB in the highest frequency range to include older members of the population.

Each participant was furnished with a laptop with which to answer a specific set of questions in regard to their exposure to blast noise and their opinion of the noise. (See Appendix C.2 for the *in situ* survey instruments and instructions). There were three classes of surveys to which the participants were asked to respond: (i) "single" surveys, which participants filled out after hearing isolated blasts; (ii) "series" surveys, which participants filled out after hearing a grouping of blasts in reasonably close temporal succession (e.g., several blasts over several minutes or hours) and; (iii) "summary" surveys, which the participants filled out at the end of each day (assessing their reaction over the entire day) and each morning (assessing their reaction during the night).

Acoustic data were also collected for the 3-month participation period outside the participant's home. To cut down on data storage, a trigger level of an unweighted peak level (L_{Zpk}) of 100 dB was used as the threshold for recording noise events. When this threshold was exceeded, six seconds of noise data were recorded (1 second pre- and 5 seconds post-trigger). Noise events that occurred but did not exceed 100 dB were not recorded. Participants were asked to note their responses as close to the time of the event as possible, to facilitate comparisons of dose and response during the analysis phase of the project.

5.1.2 *In situ* Data Acquisition

The equipment used during the study consisted of a tripod that was placed in the yard and oriented between each participant's home and the installation training ranges. Each tripod was outfitted with a PCB microphone (model number 377B11) at a height of 1.5 meters. Acoustic data collection was achieved with HBM Liberty data acquisition units, housed in a weather tight Pelican case (model 1620). These cases were modified to allow signal and power cables to pass through via weatherproof box connectors. Absolute time was kept with a signal from a Masterclock GPS200A time code generator, which uses the Inter-range instrumentation group[71] time codes generated and broadcast by a GPS satellite system to provide a very precise record of the arrival time of the blast wave at the microphone (to 10 milliseconds). The antenna for the Masterclock time code generator was also affixed to the tripod. All outdoor equipment was powered from an Interstate 12 volt, 100 amp-hour sealed lead acid battery, and was charged by a Deltran Battery Tender.

Equipment deployed within each participant's home included a laptop computer (Systemax model SYX D15TS), a 2 TB Western Digital hard drive on which all data were stored, and an uninterruptable power supply should the residence experience a loss of or surge in electrical power. The laptop served multiple roles in data collection: it recorded the daily surveys completed by participants, stored these surveys, retrieved data recorded on the Liberty DAQ, and transferred data to the Western Digital hard drive. This was accomplished using custom software specifically written for this task.

5.1.3 Post Processing of the *in situ* Noise Data

Not every event with a level greater than the 100 dB trigger corresponded to a blast event. Some causes of spurious triggers include, but are not limited to: thunder, wind, car door slams, shouting, electrical noise, or physical tampering with the triggering microphone. Because over 6 million triggers were recorded across all participants in the study, there was no feasible way to listen to each event recorded to determine the source of the triggered event. In lieu of this, a blast noise classifier was developed to determine whether the event in question was, in fact, a blast. The classifier is described in detail in Cvengros et al.[70] Briefly, a Support Vector Machine was trained on a previously obtained human-classified blast noise dataset of over 120,000 waveforms. Using 14 sound level metrics as features for each waveform, the classifier achieved 95% accuracy. A secondary step that grouped events based on coincident measurements at two or more monitors (see Sec. 6.1.3) increased the confidence in the labeling of blasts.

To process the data obtained from each participant's home, a computational pipeline was developed in which the following steps were carried out:

1. Events were organized by time and calibrated using pre- and post-calibration signals recorded when the equipment was installed and removed from each

site. If the pre- and post-calibration signals disagreed by more than 1.5dB (indicating a problem with the equipment), those events were discarded.

2. Single-event metrics (Table 5-1) were calculated for each calibrated event. Those events that had an L_{Zpk} < 90 dB were discarded, as they likely indicated a problem with the equipment.
3. Each event was then preliminarily classified as a blast or non-blast event using the Cvengros et al. classifier.[70]
4. The single-event blast noise events from each *in situ* location were then grouped using time of arrival information, and blast noise levels were estimated at each General Community Survey (GCS, Section 6) and *in situ* location using a hybrid geostatistical – acoustical interpolation model.[9] The methods described in this step are the same as those used to estimate levels at GCS participants' homes, and are given in detail in Sec. 6.1.3.
5. Events that were preliminarily labeled as blasts from step 3 and were measured by two or more *in situ* monitors (as determined by step 4) were retained as "actual" blasts.
6. Blasts that occurred during the time frames in which the residents reported their blast noise annoyance on the in-home survey were extracted.
7. Cumulative metrics (see Table 5-1) were calculated for the specified time frame

It is the cumulative metrics with which we associate the annoyance response for the reasons discussed in Sec. 5.2 below.

Table 5-1. Metrics calculated for the acoustic waveforms. A-weighted, C-weighted, and un-weighted versions of each of these metrics were calculated

Single Event Metrics	Cumulative Metrics
Peak Level	Maximum peak
Maximum level, fast	Largest maximum level, fast
Maximum level, slow	Largest maximum level, slow
Sound exposure level	Day-Night Level
Equivalent continuous sound level	Accumulated peak level
Crest factor	Number of events above X dB (where X=110,115,120,125,130)
Kurtosis	Equivalent continuous sound level over specified time frame

5.1.4 Matching Noise and Survey Data

Matching noise data to the time frames given on each survey was not a trivial task. For 'single' and 'series' noise event surveys, the respondents were prompted to enter the time at which the events occurred. The base assumption was that the time-of-event that survey respondents reported was accurate; we found that this was not always the case. To allow

for inaccurate reporting of times on the ‘series’ and ‘single’ type of surveys, we considered all events ± 30 minutes from the times reported. In addition, several respondents reported annoyance to noise sources other than blast noise or to blast events that were below our trigger threshold (e.g., with a comment saying that the noise was “barely audible”). Because these were either not classified as blasts or below our threshold, we could not associate them with this response. Lastly, due to equipment outages, failures, vandalism, and other unpredictable factors, there are some time frames for which we have no data. Therefore, one must keep in mind that our data do not comprehensively span the entire 3-month participation time frame for many respondents, and so the results must be interpreted in light of this.

5.2 Statistical Analyses

Because the summary surveys had a slightly different structure than the single / series surveys and encompassed a much larger time window, they were analyzed separately. The data for the single/series data were very sparse and showed high variability; the results from analysis of these data can be seen in Appendix A.3.3. The results described in this section focus on the summary surveys only.

5.2.1 Daily / Nightly Summary Survey Statistical Analysis

Across both installations, 56 participants filled out at least 1 summary survey. Table 5-2 shows the number of surveys filled out by each community in the study. A total of 1156 surveys were completed: 883 daily surveys and 273 nightly surveys. Installation B was more represented in the surveys (810 vs. 346 total surveys), likely because of the omission of one Installation C community (see discussion in Sec. 6.1.3) and a general propensity for Installation B participants to fill out more surveys than Installation C participants.

Table 5-2. The number and type of surveys filled out by community.

Community	Summary, day	Summary, night	Total
B1	176	72	248
B2	208	74	282
B3	208	72	280
C1	127	31	158
C2	164	24	188

Not all of the surveys could be associated with corresponding noise data (see discussion in Sec. 5.1.3). Table 5-3 shows the number of surveys in each community that could be matched to noise data. A total of 842 surveys had corresponding noise data: 680 daily surveys and 162 nightly surveys.

Table 5-3. The number and type of surveys filled out by community that could be paired with noise data.

Community	Summary, day	Summary, night	Total
B1	130	28	158
B2	163	47	210
B3	196	51	247
C1	109	15	124
C2	82	21	103

All statistical analyses of the summary data were performed using the R statistical computing language.[72]

Noise Sensitivity Index

To assess whether noise sensitivity played a role in the participants' opinions toward noise, a noise sensitivity index was created for each *in situ* participant. To create this index, questions B1-B16 from the General Community Survey (see Appendix C.1), relating a respondent's opinion of annoyance to a variety of noises, were combined, as well as questions E1-E5, which assessed how well a subject felt they could habituate to noise. Because of the wording of the questions, E2-E5 had to be reverse coded before being combined into a noise sensitivity index (i.e., higher values relate to higher noise sensitivity). This index was then normalized to lay between 0 and 1, with a value of 1 indicating extreme noise sensitivity. When the index was used as a fixed effect in the mixed model (below), it was mean-centered (the population mean was subtracted from each value).

Mixed Effects Model

A linear mixed effects model was used to assess the relationship of annoyance to the measured noise environment. A collection of model structures were tested and the Bayesian Information Criterion (BIC) was used as a selection criteria between these, both for selecting which metrics were the best for relating to annoyance, as well as assessing which fixed and random effects to include in the model. Only a subset of the 39 available metrics were examined, namely, the Day-Night Level metrics and the average equivalent continuous noise level over the reported time period ($L_{eq,d}$). For ease of interpretation, the noise metrics were centered on the mean of that particular individual. The residuals of the model fits appeared to be reasonably normally distributed, so no transformation was used for the annoyance measure.

5.3 Results and Discussion

5.3.1 Daily/Nightly Summary Survey Subjective Responses

Figure 5-1 shows the distribution of Annoyance ratings for the entire survey set. In all, reported annoyance was very low, with over half of the subjects (24 individuals) submitting summary surveys that only contained ratings of 3 or below on a scale ranging from 0 (no annoyance) to 10 (extremely annoyed). Included in this group are 7 individuals who reported "No Annoyance" for every survey they submitted.

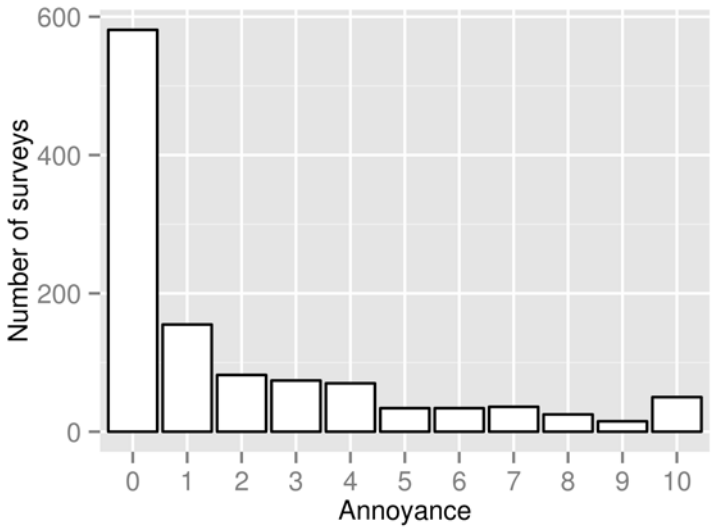


Figure 5-1. Distribution of annoyance ratings across Installations B & C

In each daily and nightly survey, subjects were also asked to assess the loudness of the events, whether the noise interfered with their activities, and whether they experienced rattle and/or vibration. Figure 5-2 shows density plots of how Annoyance relates to these subjective variables. The 0-rating levels have been removed on these plots to accentuate the strong linear relationship that is visible for all subjective rating categories (recall the preponderance of 0 ratings; Figure 5-2). Table 5-4 summarizes the Pearson correlation coefficients between annoyance and the other subjective variables. For Loudness, Vibration, and Rattle, the superfluity of low annoyance ratings pulls the correlation coefficients somewhat closer to zero. Nevertheless, all of the subjective variables show large correlations with annoyance, and these do not significantly change when subjects reporting zero or low-annoyance are removed from analysis. These results suggest that interference with activities is the major contributor to subjects' reported annoyance, followed by loudness, vibration, and rattle.

Table 5-4. Pearson correlation coefficients between subjective variables from the daily/nightly summary surveys.

	Interference	Loudness	Vibration	Rattle
All subjects	0.91	0.66	0.66	0.62
Without zero-annoyance subjects	0.91	0.7	0.67	0.64
Without low-annoyance subjects	0.91	0.68	0.65	0.62

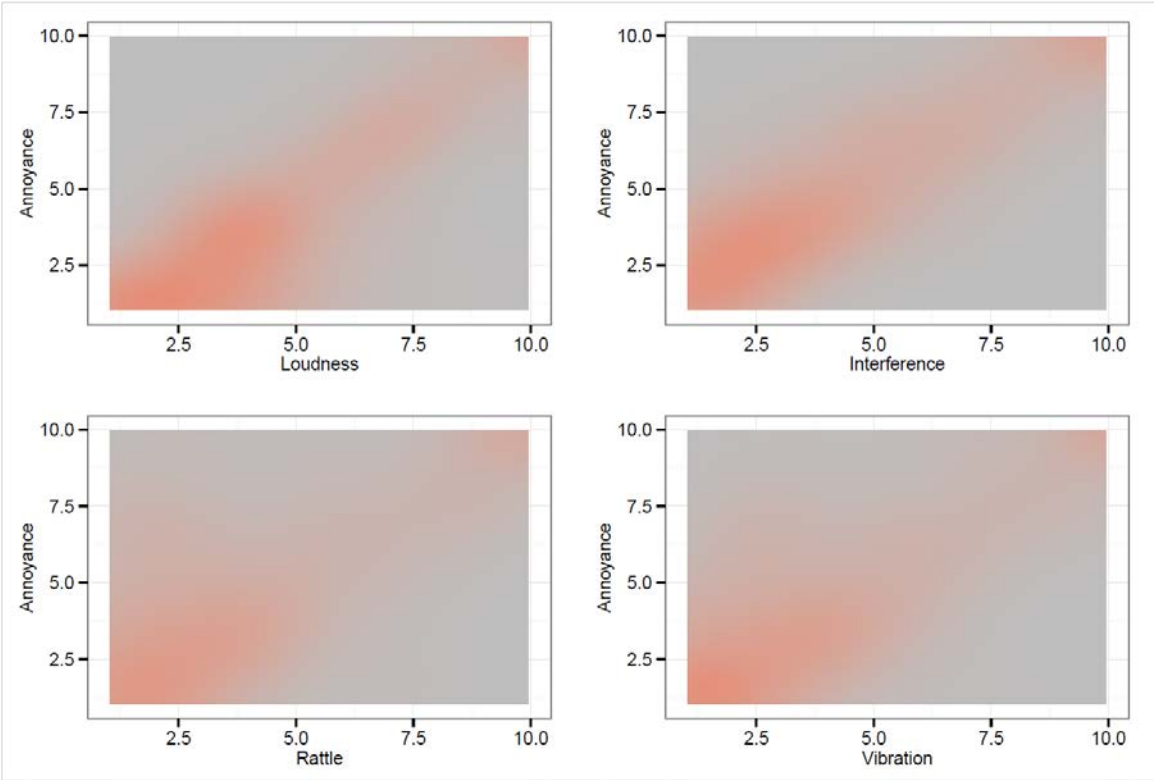


Figure 5-2. Density plots relating annoyance to Loudness, Interferences, Rattle, and Vibration. Red shows areas of high density (large joint responses of rating values); gray shading shows low values. Due to the preponderance of 0-valued ratings, these have been left off of the scale above to highlight the otherwise strong linear relationship that each of these subjective variables has with annoyance.

5.3.2 Comparison of Noise Environments

Each community in the study was exposed to very similar noise environments (Figure 5-3), both in terms of median levels and noise level variability, although there were some slight differences. For instance, community B3 was exposed to slightly higher median levels than any other community. Also, individuals living on-post at Installation B were exposed to less noise than those living off-post (B2 & B3), but at Installation C, on-post

individuals (C1) experienced slightly higher median levels. Community C2 showed higher variance in levels than all other communities. The individuals within each community were also exposed to different noise environments; however, it is difficult to directly compare noise environment distributions by individual, since many individuals (especially at Installation C) have very few surveys for which noise data could be matched. Figure 5-4 shows the relationship of annoyance to L_{Cdn} for each individual. The large variability both within and across subjects is evident in the figure, although there do seem to be common behaviors. For example, the zero-annoyance and low-annoyance respondents in each community are evident, as is the preponderance of low annoyance ratings from Installation C.

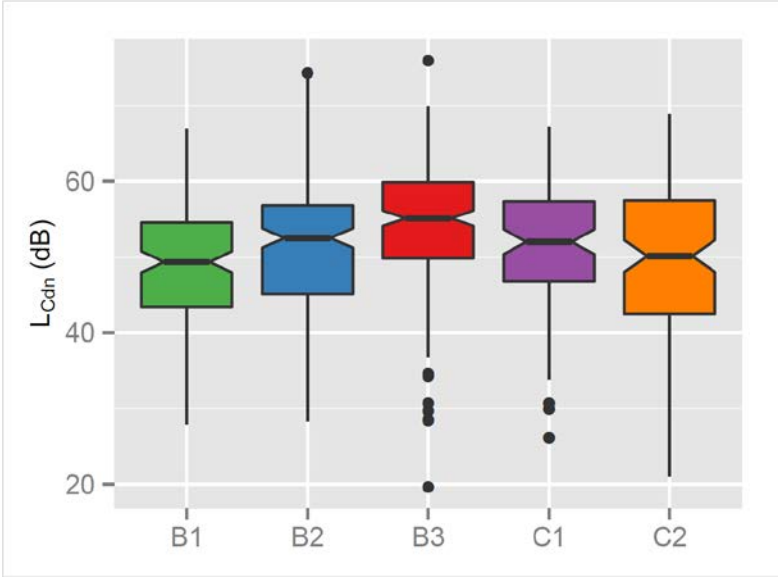


Figure 5-3. Boxplots of C-weighted day night level (L_{Cdn}) for each community in the in situ study. The lines in the center of the box indicate the median level for that community. The extent of the box spans the interquartile range.

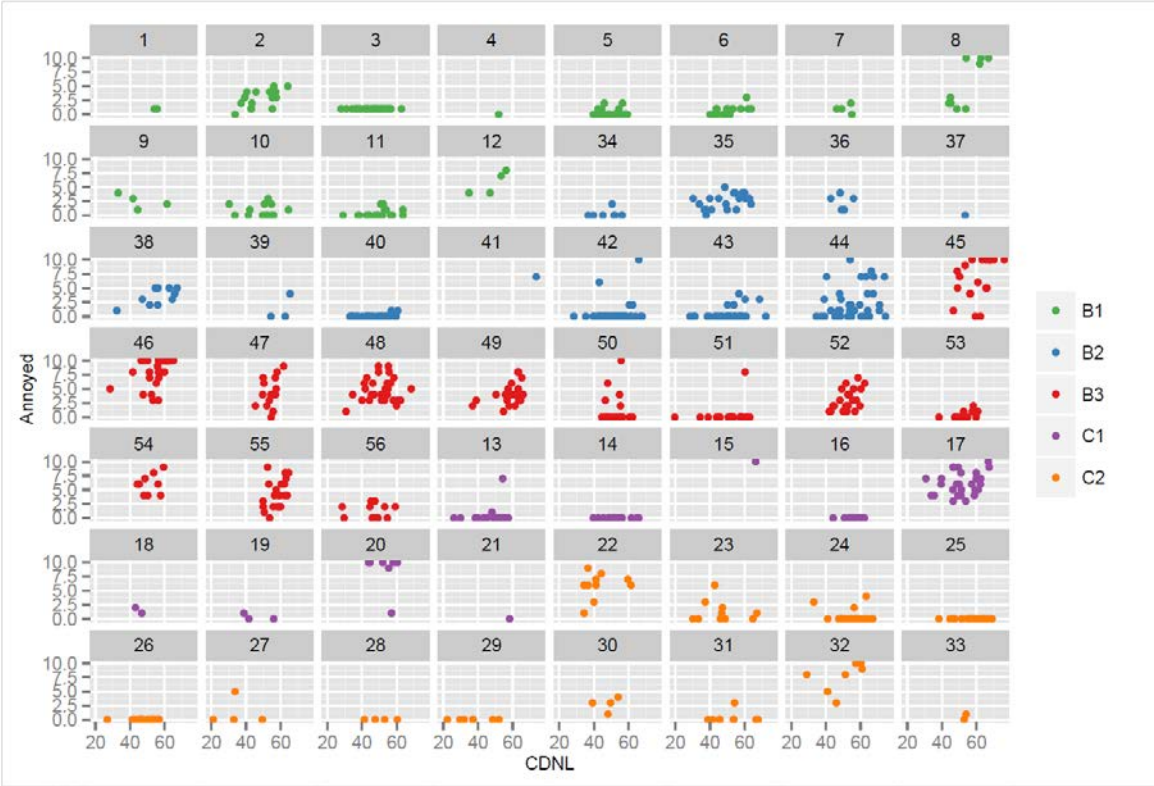


Figure 5-4. Annoyance as a function of C-weighted day night level (L_{Cdn}) for each individual who completed at least 1 daily/nightly survey. The points on each plot are colored by the community from which the individual comes. Note the relative preponderance of low annoyance ratings in the Installation C participants.

5.3.3 Mixed Model Initial Results

To examine the relationship of annoyance to noise, and to see if this was different between communities and individuals, a mixed-effects model was used to model annoyance to noise. There was not much difference between the BIC values for models using different L_{dn} metrics, and the resulting model coefficients were nearly identical. Therefore, for consistency with current policy, the L_{Cdn} was chosen as the metric to examine in further models. Model selection suggested that the best model for annoyance was one in which the L_{Cdn} was the only fixed effect, with the ID of the participant being the sole random effect. Adding in a community random effect improved the fit slightly but resulted in a slightly worse BIC. This increase in BIC was small, however, so the random community effect was retained in the final model for ease of comparison across communities. Interestingly, there was no significant difference between daily and nightly annoyance once L_{Cdn} was accounted for. This is perhaps because L_{Cdn} already contains a penalty for nighttime events.

The first row of Table 5-5 shows the coefficients of the fixed effects in the final model. We define the Baseline Annoyance as the annoyance that results when noise levels are at their average levels for each individual. On average, noise annoyance is quite low (2.4 annoyance points out of 11), and the rate of increase of annoyance is fairly weak — for every 10 dB increase in L_{Cdn}, annoyance increases only half a point.

Table 5-5. The coefficients for the fixed effects in the mixed-effects model of annoyance in the daily/nightly summary surveys with and without noise sensitivity as a fixed effect.

Overall Baseline Annoyance (intercept)	Rate of increase of annoyance (slope)	Noise sensitivity correction
2.4	0.05	0
2.1	0.05	13.65

The model also suggests that baseline annoyance values vary by community and by individual. Each community and individual effect can be interpreted as corrections to the Overall Baseline Annoyance in Table 5-5. The paucity of data precluded estimation of models in which the rate of increase in annoyance varied by community and/or individual as well.

Figure 5-5 shows the coefficients of the random effects with standard errors for each community. These coefficients represent the annoyance that occurs when the noise is at its mean level for each individual within the community. The black line in the plot and surrounding gray region shows the Overall Baseline Annoyance with standard errors (i.e., the fixed effect intercept). As can be seen from this plot, community B3 shows higher baseline annoyance than the other communities, followed by community C1, with other differences being quite small (< 0.5 annoyance points).

The coefficients for each individual are seen in Figure 5-6. Again, the vertical black line with corresponding gray shading shows the Overall Baseline Annoyance and its standard error. This figure gives a good summary of how baseline annoyance is distributed throughout the sample of individuals. The vast majority of respondents show very low annoyance when noise is at its mean level, however 11 respondents show baseline annoyance over 5.

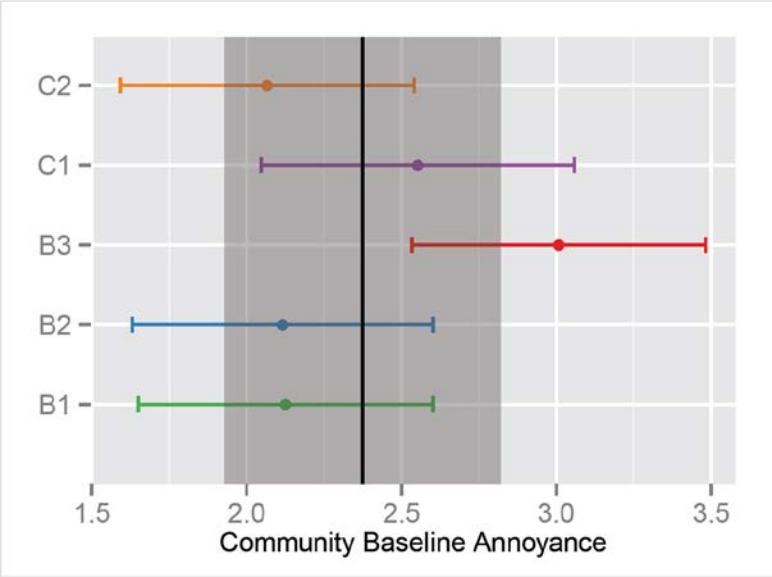


Figure 5-5. The coefficients for the community factors in the mixed model, with standard errors. These coefficients represent the annoyance for each community when noise is at its mean levels for each individual. For comparison, the vertical black line is the intercept of the fixed effects model, and the gray shaded area is its standard error.

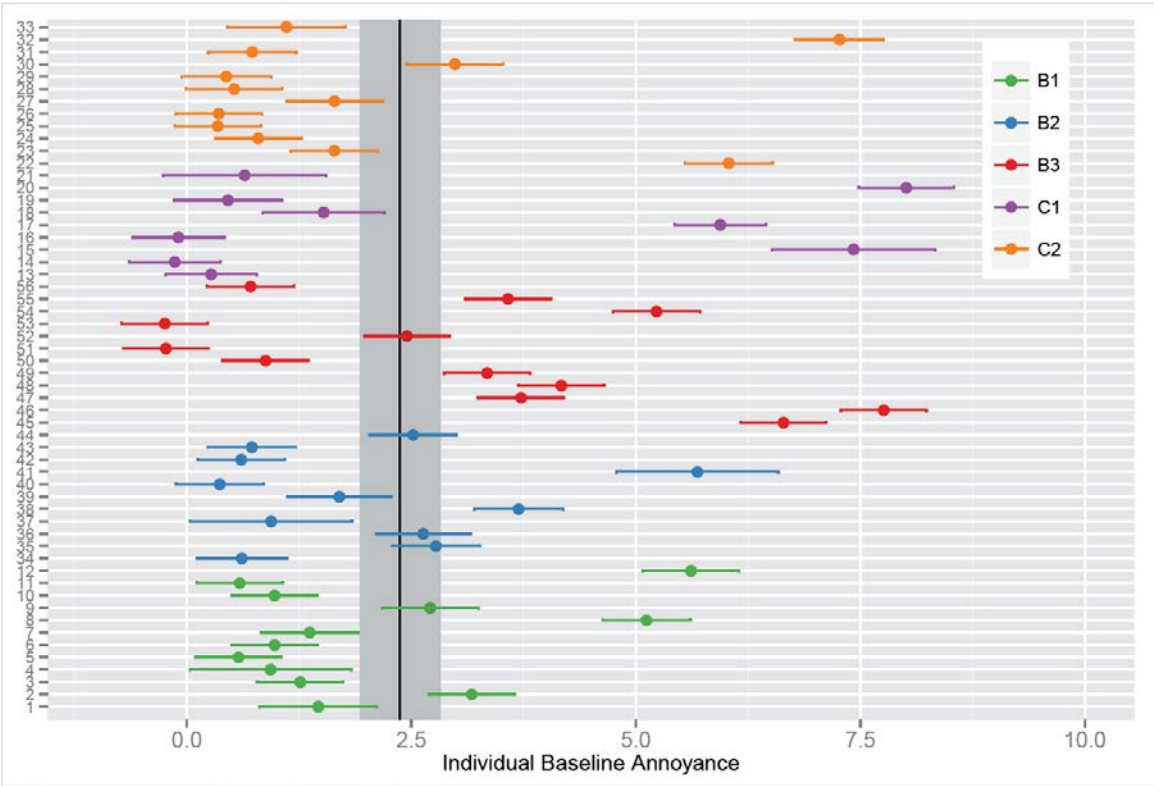


Figure 5-6. The coefficients for each individual's factor in the mixed model, with standard errors. The y-axis labels each participant's ID. These coefficients represent the annoyance for each community when noise is at its mean levels for each individual. For comparison, the vertical black line is the intercept of the fixed effects model, and the gray shaded area is its standard error.

5.3.4 Noise Sensitivity

One hypothesis for the high baseline annoyance values in a small subset of individuals is that these individuals may be more sensitive to noise. To examine the role noise sensitivity plays in the Baseline Annoyance, the relationship between the Individual Baseline Annoyance and the Noise Sensitivity Index was examined. This relationship is shown in Figure 5-7. As can be seen, there is an increasing relationship between baseline annoyance and noise sensitivity; that is, individuals with higher noise sensitivity ratings are more likely to have high baseline annoyance. Furthermore, the high noise sensitivity ratings come almost exclusively from Community B3, which has both higher average noise levels and higher baseline annoyance. Whether this increased noise sensitivity is a result of the noise environment to which residents are exposed, or is an inherent characteristic of their personality, cannot be determined from the survey data available.

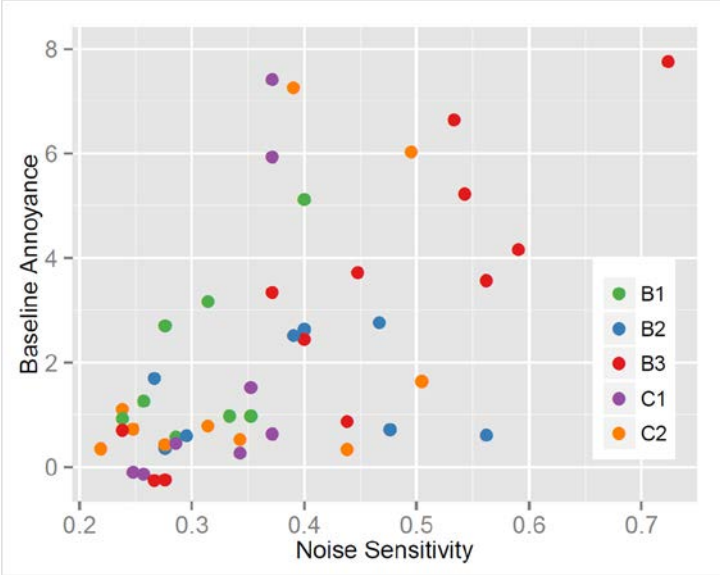


Figure 5-7. Individual Baseline Annoyance, as estimated from the mixed effects model of Section 4.3.4, as it relates to the Noise Sensitivity Index for each participant. Those who are more noise sensitive tend to have higher baseline annoyance values. The majority of noise-sensitive individuals come from Community B3.

Given the importance of noise sensitivity as determined above, a second linear mixed effects model was fit which considered noise sensitivity as a fixed effect in addition to the L_{Cdn}. The fixed effects of this model are given in the second row of Figure 5-5. Addition of noise sensitivity of the variables did not change the Overall Baseline annoyance drastically (2.1 annoyance points compared to 2.4) and the rate of increase of annoyance stayed the same (0.05 points/dB). Noise sensitivity, however, seems to drive annoyance in this model — a 0.1 point change in noise sensitivity increases annoyance by about 1.4 points. Overall, correction for noise sensitivity decreased baseline annoyance in communities, with all communities except B2 showing nearly identical baseline annoyance (Figure 5-8). Community B2 shows lower than average baseline annoyance when accounting for noise sensitivity.

On an individual level, nearly all participants show low baseline annoyance to their mean noise environment when correcting for noise sensitivity (Figure 5-9). Furthermore, the differences between the individual annoyance distributions in each community are reduced as well; that is, each community looks more like the others, with only a few outliers on either the high or low side of annoyance. Those individuals who are outliers are the few subjects who only used either the high end or the low end of the annoyance scale — they did not utilize the full range available.

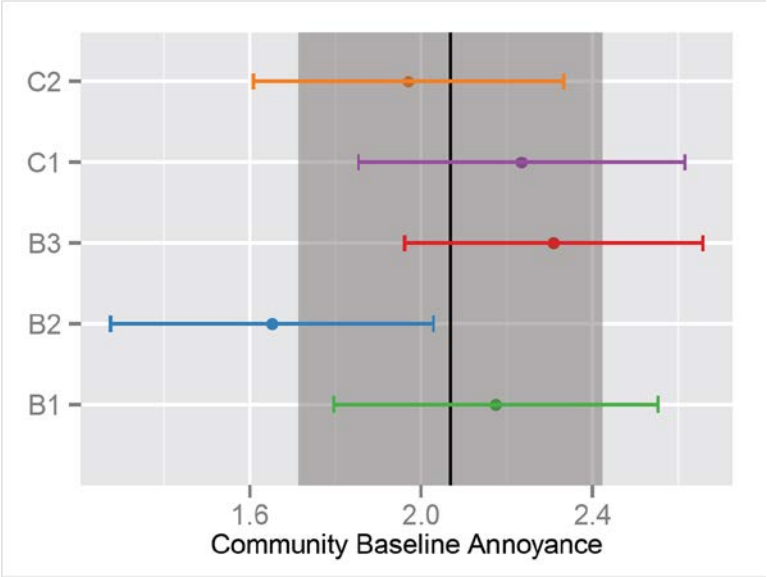


Figure 5-8. The coefficients for the community factors in the mixed model, with standard errors, when the Noise Sensitivity Index is included in the model. For comparison, the vertical black line is the intercept of the fixed effects model, and the gray shaded area is its standard error.

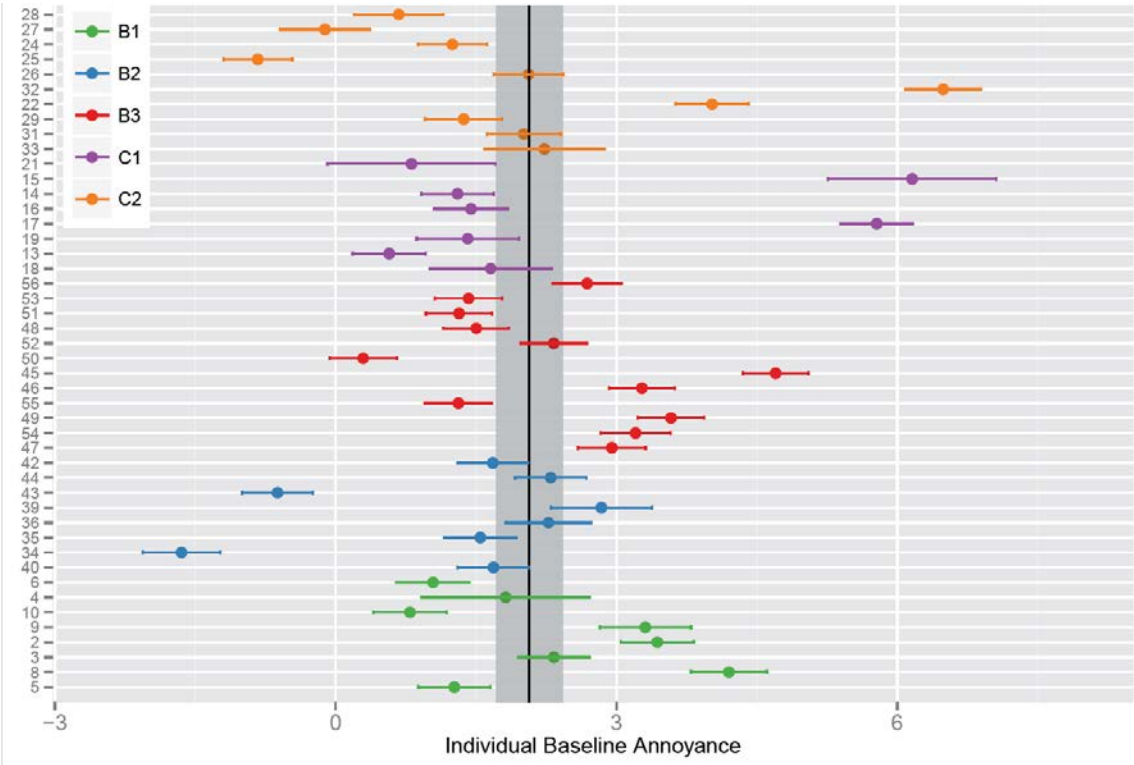


Figure 5-9. The coefficients for each individual's factor in the mixed model, with standard errors, when the Noise Sensitivity Index is included in the model. The y-axis labels each participant's ID. These coefficients represent the annoyance for each community when noise is at its mean levels for each individual. For comparison, the vertical black line is the intercept of the fixed effects model, and the gray shaded area is its standard error.

5.4 Summary and Conclusions

Both the analysis of the single/series event surveys (Appendix A.3.3) and the daily/nightly surveys show no strong evidence to prefer a metric other than the current C-weighted Day-Night-Level (L_{Cdn}) standard. It was found that at Installation B, weekend events are more annoying than weekday events, although there is large variability to the estimates for the thresholds that depict high annoyance. Furthermore, the results of the mixed-effects model on the daily/nightly surveys show that annoyance does vary by community, even after noise environment is corrected for. These differences seem to be driven by individuals that are noise sensitive, and noise sensitivity was not uniformly distributed across communities. That said, it is difficult (if not impossible) to determine from these data whether the individuals with high noise sensitivity are noise-sensitive because of their noise environment, or whether there is something other than the noise environment that is the driving factor. In addition, it is very hard to predict noise sensitivity *a priori*, so the models that *exclude* noise sensitivity are the most useful from a policy standpoint. These models show that most individuals exhibit fairly low mean annoyance to blast noise with an increase of 0.5 annoyance points (on the 11 point annoyance scale) for every 10dB increase in L_{Cdn}. This suggests that the rate of increase of annoyance with level is quite low, as can be seen for the majority of individuals in Figure 5-4. In fact, this increase is so low as to effectively demonstrate that these individuals would rarely consider themselves highly annoyed for any noise environment to which they were exposed. Furthermore, there was no strong difference between annoyance to daily and nightly events, perhaps because the L_{dn} metrics already penalize events occurring in the night.

One important caveat of these results is that Installation B was more represented in the final dataset, and showed higher annoyance to blast noise overall. Because only a small number of people in five communities were investigated (a total of 56 participants represented in the summary surveys and 49 for the single/series event surveys), it is difficult to ascertain how robust these findings will be for a larger population sample — the variability was quite large. Nevertheless, the models seem to suggest that different communities respond differently to noise, in line with the current community-response-to-noise literature.

6 General Community Survey

6.1 Materials and Methods

6.1.1 Overview

The purpose of the General Community Survey (GCS) was to assess the attitudes and noise environment of communities surrounding military installations in different geographic regions. Each installation chosen in the study was located in a different geographic region and climate, and each had different testing and training missions. The survey for Installation A covered a much larger geographic area than B & C; furthermore, acquisition of noise events and calculation of noise environments were much different (i.e., less precise and subject to more uncertainties) from those at B & C. Lessons learned during the Installation A survey resulted in more focused efforts at Installations B & C and as a result this section will focus only on the results from Installations B & C. Results from the GCS at Installation A can be seen in Appendix A.2.

6.1.2 Response Data

The GCS consisted of 43 questions that assessed respondents' opinions of their community and the noises to which they expected they might be exposed, and asked a variety of questions regarding the general environment within which they live (type of home, if they are associated with the military, etc.). The complete survey instrument can be found in Appendix C.1. At each site, a large-sample cross-sectional survey was administered to participants over the phone and in-person, followed by a panel survey (see Sec. 8.1 for panel sample analysis) of a subset of the cross-sectional participants so as to assess stability of their responses as time and noise environments change. Greater detail regarding the design of the GCS, the sampling procedure, statistical methods, and results can be found in Nykaza et al. (2012a).

The final dataset for the cross-sectional survey included 679 respondents at Installation B and 796 at Installation C, although many of these observations were incomplete due to refusals to answer or interviewer errors.

6.1.3 Estimating Blast Noise Levels at GCS Participants' Homes

This section describes the method used to estimate blast noise levels at the GCS participants' homes. Typical noise level prediction algorithms, without detailed knowledge of real-time meteorological conditions, can only estimate average noise levels at any given location. The huge variation in received noise level that occurs due to meteorology was discussed in Section 1.1. Thus such noise level algorithm estimates contain large uncertainty. To dramatically reduce this uncertainty, the noise level estimates in this study, described below, are based on noise levels that were measured

during the time period that participants were queried regarding their noise response. This procedure greatly improves the accuracy with which the noise level that evoked a response is known. This in turn yields a much more reliable assessment of the relation between noise level and response to noise.

The following terminology is defined to make this section easier to follow:

- **Noise monitor** – refers to both the data acquisition recorders that were located at *in situ* participants' homes and the recorders that were located on-post.
- **Noise record** – refers to data recorded at a noise monitor. Recall that the noise monitors used in this study were programmed to trigger (i.e., record or capture) noise signals that exceeded a threshold of 100 dB L_{Zpk} .
- **Blast and non-blast records** – in this study, noise records were classified using a binary blast noise classifier;[70] all of the noise records have been classified as either a blast or non-blast record.
- **Blast event** – refers to a collection of blast records (for different noise monitor locations) that have been grouped as coming from the same blast-producing source.
- **Single event vs. cumulative events** – a single event refers to a single blast event, whereas cumulative events refer to a collection of single blast noise events captured over a specified time period.

The blast noise records captured at *in situ* participants' homes were used to estimate cumulative blast noise level metrics at GCS participants' homes. This was possible because the *in situ* and GCS studies overlapped in time, and the *in situ* participants were located in close spatial proximity to the GCS participants. Another key component in the estimation process was the use of a recently developed acoustic-model-based interpolation model.[9] This model only requires knowledge of the source location, the receiver locations, and the noise event levels at the receiver locations. This model is an improvement over other acoustic estimation models/methods,[73-80] which require many inputs (e.g., ground, meteorological, and source frequency data) that are not routinely available. More details on implementing this model are given below.

The steps to estimate cumulative blast noise level metrics at GCS participants' homes are outlined as follows and are described in more detail below:

1. Noise records were classified into blast and non-blast records.

2. Noise monitor locations and blast records were divided into communities.

3. Blast records were grouped into single events, and a source location was associated with each single blast event.

4. The single event levels were estimated at GCS participants' homes using an acoustic-model-based interpolation model.

5. Cumulative blast noise metric levels were calculated from the single event levels from step 3, for time periods associated with the annoyance questions on the GCS survey (i.e., annoyance to the blast noise environment over the past 4 weeks and 12 months).

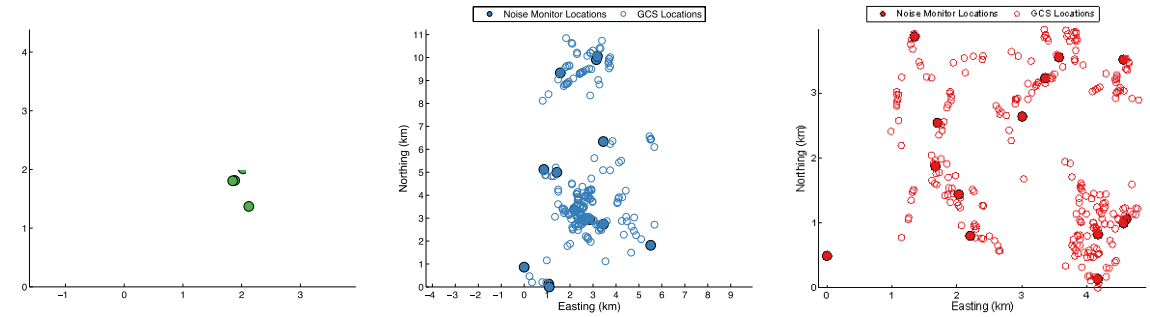
1. Classify the noise records as blast and non-blast records

The first step in the process of estimating cumulative blast noise level metrics at GCS participants' homes was to classify each monitor record as a blast or non-blast record. As described in Sec. 5.1.2, noise records were classified using the Cvengros et al. classifier, which was found to have an accuracy of 95%.[70] A total of 865,453 and 3,102,399 monitor records were classified from Installation B and C, respectively. Of these, 112,890 and 80,362 were classified as blasts, and 753,563 and 3,022,037 were classified as non-blast records. It is important to note the differences in the number of monitor records. Installation C had approximately 3.5 times more records than Installation B. This large discrepancy is likely due to the fact that study site C was prone to high wind conditions that cause spurious pressure fluctuations on the microphone diaphragm. It is also important to note that Installation B had 1.5 times more blast records than Installation C. This discrepancy could simply be due to the fact that there were fewer blast events at Installation C, or it could be associated with the fact that the Cvengros et al. classifier was trained using some data from Installation B and no data from Installation C. The implications of this fact on the study results are discussed in more detail in Sec. 9.4.

2. Divide noise monitor locations and blast records into communities

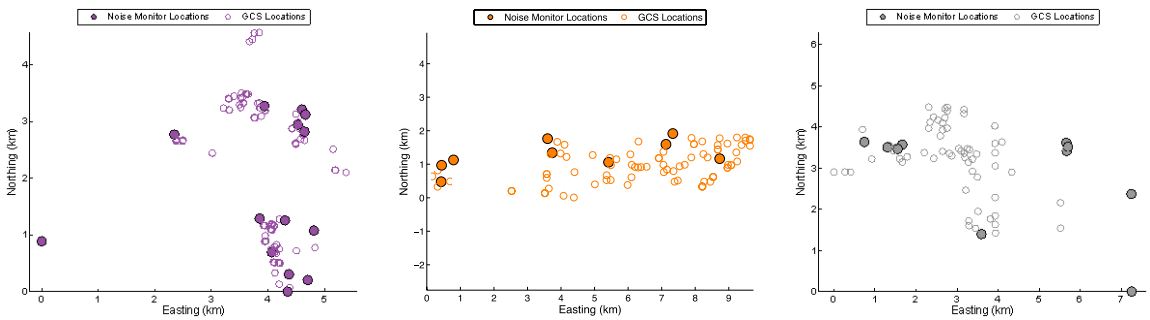
The next step in the process of estimating cumulative blast noise level metrics at GCS participants' homes was to divide the blast records by community. At the outset of the study, a total of 6 communities were identified at each of the 2 study sites (i.e., Installation B and C): 2 off-post communities (B2, B3, C2, and C3) and 1 on-post community (B1 and C1) at each installation. However, for the reasons given below, one of the communities at Installation C was dropped (C3). Figure 6-1 shows *in situ* and GCS participants in each of the 5 communities.

Installation B Communities



B1 B2 B3

Installation C Communities



C1 C2 C3

Figure 6-1. Locations of in situ noise monitors (open circles) and GCS participants (open circles) for each community in the study.

Table 6-1 shows the final number of blast records per community, after removing blast records that did not have accurate time stamps (i.e., readable time code).

Table 6-1. Total number of blast records per community.

Community	Post	Total Blast Records
B1	On	17,494
B2	Off	28,459
B3	Off	49,794
C1	On	25,205
C2	Off	34,233
C3	Off	7,074

3. Group blast records into single events, and determine a source location

Grouping noise records and determining the source location is notoriously difficult, especially when there are few noise monitors that pick up the event, when the monitors are spread over a large region, and when there is a possibility that two or more blast events could occur at the same time.[81] This section describes the process of grouping blast records into events and determining the source location of each event, both of which are required to run the acoustic interpolation model referenced above.

Determining the source location of a blast was accomplished by grouping blast records into single events according to the following steps. The procedure was done separately for each community.

A. Group blast records by time and classify the group type by the number of monitors in the group.
B. Determine the source location for groups that have three or more unique blast records in the group.
C. Break up groups that have three or more non-unique blast records into groups that contain unique blast records.
D. Determine the source location for the groups that contain three or more unique blast records from Step C, using Step B.
E. Use list of source locations from Steps B and D, to assign source locations to the groups that contain two unique blast records.
F. Discard the groups that only contain one blast record.
G. Check the precision of the blast noise classifier.

A. Group blast records by time and classify the group type.

First, records were sorted chronologically, and the time difference between consecutive records was calculated. Then, temporary group numbers were assigned at points in the sorted blast record time series where the time difference between consecutive events exceeded the maximum propagation time for that community. Here the maximum propagation time was defined as the time it would take the blast event to travel between the pair of noise monitors furthest from each other. Then, each blast record group was given a group type designation:

- 1 monitor (1M) – in this case, the group contained one or more blast records, but all of the records came from one monitor. Such groups will be discarded from the data set for reasons discussed later.

- 2 unique monitors (2U) – in this case, the group contained only two blast records and each blast record came from a different noise monitor. It is likely that the records were associated with one single/unique blast event, though not as likely as the 3+ unique monitor groups.

- 3^+ unique monitors (3^+U) – in this case, the group contained three or more blast records and each blast record was associated with a unique noise monitor; it is likely that the records were associated with one single/unique blast event.

- 3^+ non-unique monitors (3^+M) – in this case, the group had 3 or more blast records, and some of the blast records came from the same monitor; it is very likely that these records are associated with multiple blast events.

B. Determine the source location for the 3^+U group.

A time difference of arrival (TDOA) method was used to estimate the direction of the source relative to the monitors in the 3^+U blast group. Then, if the source direction appeared to originate from the same direction as a firing point or impact area on-post, a (pseudo) source location was tagged to the blast event. The pseudo-source location was chosen as the point along the direction of arrival 1 km from the perimeter of the community. A pseudo-source location was used rather than the actual source location for several reasons. First, the accuracy of the source location is dependent on propagation conditions during the time of the event and the size of the array. If the source location is incorrectly located at a far distance from the community, it could result in large estimated level errors. Secondly, using a source location that is 1 km from the community mimics the propagation conditions for which the acoustic interpolation model was validated. Lastly, the acoustic interpolation model used the blast records to estimate the source level through a regression procedure. In theory, the model should be robust to small errors in the source location and there should be no difference in the interpolated results.[9]

C. Break up 3^+M into 1M, 2U, and 3^+U groups.

The source locations from Step B were then used to break up the events in the 3^+M group into 1M, 2U, and 3^+U groups. First, each event in the 3^+M group was associated with a source from Step B. This was done by selecting the source shot-time closest to the arrival times of the blast records in the 3^+M group. Once a (temporary) source location was chosen, Step A was repeated using a smaller time window. The time window was determined by calculating the maximum time it would take a blast event to travel to the closest and furthest monitor from the (temporary) source. Here "temporary" is specified because the source location was merely used to break up the 3^+M group, with the actual source location being determined in the next step. As outlined in Step A, each event was then categorized into one of the 4 possible groups, though in the case of processing the data from this study all of the 3^+M groups were broken up into 1M, 2U, and 3^+U groups (i.e., none of the sub-groups were classified as a 3^+M group).

D. Determine the source location for the new 3^+U groups from Step C, using Step B.

After steps B and D, approximately 1% and 3% of the blast events in the 3^{+}U group from Installations B and C, respectively, had source locations that came from off-post. These events/records were discarded.

E. Use the list of source locations from Steps B and D to assign source locations to 2U events.

In this step, a source location from the list generated from Steps B and D was assigned to each 2U event. Like Step C, the source with the closest shot-time is assigned to each 2U event. This assignment serves as the actual source location and was done only if the estimated shot-time error was less than 1 second. The estimated shot-time error is the absolute difference between the estimated shot-time from the two blast records in the 2U group, where the estimated shot-time for each record was calculated by back-propagating the sound from the receiver to the source. If the estimated shot-time error was greater than 1 second, then all of the possible source locations were considered and the one with the lowest shot time error was tagged to that event.

F. Discard 1M blast events/records.

The last step in the process was to discard all of the blast groups that only had one monitor (i.e., group 1M); justification for this is provided later in this section. Table 6-2 gives the total number of 1M blast records discarded from each community, and the total number of blast events after discarding all of the 1M records. In addition to discarding all of the 1M blast records, community C3 was removed from the study because there were significantly fewer noise data available from this community. The data were not sufficient to reasonably or accurately characterize the blast noise environment. Community C3 was, in general, much smaller in terms of population than the other communities and contained less *in situ* and GCS participants.

Table 6-2. Total number of one monitor and 2^{+} monitor blast events per community.

Community	Post	Total (1M)	Total Blast Events (2^{+})
B1	On	7,672	3,111
B2	Off	12,499	5,238
B3	Off	9,901	10,015
C1	On	17,923	2,495
C2	Off	25,136	3,627
C3	Off	6,619	186

Table 6-2 also shows that Installation C had significantly more blast records that were categorized in the 1M group. This is likely due to the fact that Installation C was prone to

high wind conditions in comparison to Installation B, and that the blast noise classifier was not trained using data from Installation C.

G. Check the precision of the blast noise classifier

The fact that there were so many 1M blast events that did not fall into a group with the method above drew some concern from the research team. As a result, an ad hoc analysis was done to determine the precision of the blast noise classifier. For this analysis, two researchers listened to approximately 3,000 blast noise recordings from Installations B and C. An equal number of blast events were randomly selected from each *in situ* participant and each of the 3 blast group types (1M, 2U, and 3^{+}U groups). The precision of a classifier is defined as the ratio of the number of true positives over the total number of positives. In this case the number of true positives is the number of human classified events that were classified as a blast. The results of this analysis are given in Table 6-3, and are broken out by study site after removing community C3.

Table 6-3. Precision results for the blast noise classifier at each installation.

Study Site	Precision (1M)	Precision (2U)	Precision (3^{+}U)
B	63%	97%	99.7%
C	65%	78%	85%
Combined	64%	90%	94%

The results show that the precision of the blast noise classifier is very poor (approximately 64%) when there is only one monitor in the blast group, and the precision is greatly improved when there are 2 or more monitors in the blast group. The results in Table 6-3 also show that it is very likely that 22% of 2U events and 15% of 3^{+}U events from Installation C are not truly blast events. In general the precision of the blast noise classifier applied to Installation C is much lower than Installation B. It is also likely that many valid blast records were discarded at each site (approximately 35% of the 1M data). The decision to discard the 1M data is justified given that it is notoriously difficult to accurately interpolate/extrapolate noise monitor data from 1 monitor, and also because it is important to err on the side of analyzing only blast noise data. For example, if the 1M monitor data were included in the in the final dataset, a significant amount of non-blast data would have been added into the dataset as well; this is especially true for Installation C. The inclusion of the 1M monitor non-blast events (approximately 15,000 events) would have more than doubled the number 2+ monitor grouped blast events that were included in the study. Another consideration is that a source location, which is needed to verify that the event originated from the installation, cannot be determined for one monitor.

4. Estimate single-event levels at GCS participants' homes

Each 2^{+}monitor-blast-event was estimated at each of the GCS participants' homes using the source location, noise monitor location, single-event noise monitor levels, and an acoustic interpolation model. Full details of the acoustic interpolation model can be found in Nykaza (2013),[9] but the general concept is as follows. First, the noise environment was estimated using an acoustic-model-based regression model. Then the noise environment was corrected based upon the errors in the regression model at the known data points (i.e., the noise monitor locations). This approach also ensured that the estimates of the noise levels at the monitor locations were exactly the same as the levels measured at those locations.

The specific acoustic interpolation model used in this study is a residual kriging model, or geostatistical model, that uses the following 2-parameter acoustic-model-based regression:

$$P(x,y) = L_{r_0} - \beta \log_{10} \frac{r}{r_0} + \varepsilon \,, \tag{5.1}$$

where $P(x,y)$ is the estimated level (dB) at location (x,y), L_{r_0} is the level (dB) at the pseudo-source location, β is the geometrical spreading coefficient (dB), r is the distance of the estimation point (x,y) from the source.

In the case when there are only two monitors in the blast group, or if the noise monitors are clustered together so that they do not have good spatial coverage of the community, β is fixed to 35, and only L_{r_0} is estimated. The choice of picking a geometrical spreading constant greater than the typical "spherical spreading" constant of 20 is to account for attenuation due to terrain and meteorological effects.[9] In the case where there are more than three monitors in the blast group and those monitors have good spatial coverage of the community, both L_{r_0} and β are estimated by the model. β is bound between 10 and 60, which represents the full range values that were obtained from a simulation examining various ground, wind, and atmospheric boundary layer stability conditions.

After all of the blast events were interpolated, a manual quality assurance check was performed to ensure that none of the model output levels were unrealistically high. Only a small number of interpolated results gave unrealistic estimates, and those were discarded form the study. The number of the blast events discarded from each community were as follows: 60 (2%) from B1, 57 (1%) form B2, 0 (0%) from B3, 115 from B3 (3%), 17 (< 1%) from C1, and 115 (3%) from C2.

5. Calculate cumulative noise metrics associated with survey responses

Recall that the two primary questions addressed in the GCS survey were annoyance to blast noise over the past 4 weeks and annoyance to blast noise over the past 12 months. As such, cumulative blast noise metric levels were calculated from the single-event

levels at each GCS participant's home (i.e., the output from Step 4), for time periods associated with the annoyance questions on the GCS survey. More specifically, each of the cumulative noise metrics in Table 5-1 was calculated between the time the GCS participant filled out the survey and the 4 weeks and 12 months prior to the survey.

6.2 Statistical Analyses

6.2.1 Data Preparation

To analyze the survey data from the GCS, a mixed effects linear model was implemented using the R statistical programming language. Some survey questions were included directly in the analysis, others were combined with one another or altered to create new variables, and some were omitted entirely. First, because the aims of the overall project were primarily focused on annoyance to blast noise, all annoyance questions relating to other noise sources were omitted (B1-B7, B9-B15). Next, we had the highest confidence in the accuracy of the noise metrics calculated over the 4-week time span, as noise data existed for each respondent during this time frame; therefore, only the 4-week annoyance question (B16) was considered as the response variable. In addition, all questions relating to how often a respondent heard a particular noise source were omitted except B22, which pertained to how often a respondent heard blast noise. Next, any open-ended questions on the survey were excluded from the analysis; these included A6, A7, A9 (*neighborhood likes/dislikes*), C8 (*source of awakening)* and H9a (*moving)*. The few questions on the survey that required a quantitative response (as opposed to a response from a listing of possible categories) were identified and these questions were considered as potential covariates. These questions included A1 and A3 (*household variables*), B24 (*time of day noise most disturbing*), and G3-G6 *(hours of day at home*). B24 was dropped from the analysis due to a lack of responses.

In Section A, all remaining questions, i.e., A2, A4, A5, and A8 (*household and neighborhood characteristics*), were directly included as factors in the model. In Section C, Questions C1 and C2_1-C2_15 (*rattle and vibration*) were used to create a factor called "Total Rattle" which indicated one of three states, either: (1) no noticeable rattle or vibration from the military activity, (2) only one object in the home ever rattled or vibrated, or (3) more than one object in the home rattled. Questions C1 and C3-C6 (*vibration, rattle, and noise effects over the past 4 weeks*) were used to create another factor, called "Disturbance or Interference: 4 weeks." These questions asked about the disruptive effect of military noise/rattle in the last 4 weeks. This variable indicated one of three states: (1) the respondent did not notice any military rattle or vibration, (2) the respondent noticed the military rattle/vibration but was never disrupted by it, or (3) they were disrupted in at least one way. This variable was found to be collinear with "Total Rattle" and was subsequently removed from analysis. Questions C7, C9, and C10 were combined to create a three level variable, "Awakened" which described whether a

respondent reported to be (1) never awakened by noise, (2) awakened by noise in the past four weeks, or (3) awakened by noise, but not in last four weeks.

In Section D, questions D1-D4 asked about the effect the noise has had on the respondent in the last 12 months. Since these questions were highly intercorrelated (Cronbach's Alpha = 0.84), they were averaged to create a possible covariate called "12 mo. noise effect."

The five questions in Section E evaluated the tendency of a respondent to habituate to a noise source. With the exception of E1, all questions were written so that higher values of the response indicated a greater ability to habituate. As a result, E1 was reverse coded. These five questions were fairly intercorrelated (Cronbach's Alpha = 0.65), but when E1 was removed from the list, Cronbach's Alpha increased to 0.72. This indicated that people generally responded differently to E1 than they did to E2-E5 (possibly because of the fact that the answers were in reverse order). As a result, E1 was excluded from the group and E2-E5 were averaged to create a self-reported "Habituation Index".

Section F had five questions; the first three asked about connections to the specific military installation, the Armed Forces and the Department of Defense. These responses were used to create a new variable called "Work for the Military" which took the value "Yes" if a respondent indicated connections in any one of these questions, and otherwise took the value "No." This variable was dropped, however, when it was found to be collinear with question H2 (rent/own/live on-post). The last two questions of Section F were averaged to create another possible covariate called "Installation Importance," indicating the economic importance of the military installation.

Section G assessed the times of day people wake up and fall asleep, as well as how many hours they spend at home during different times of day. G1 and G2 were omitted due to the fact that they could not be logically added into the model, either as covariates or factors. Adding them as factors seemed most reasonable; however, each had too many levels to get reliable estimates (> 45 levels each). G3-G6 were included as covariates.

In Section H, H1-H10 (*years at address, house construction variables*) were included directly as factors, except for H8 and H11, which were excluded due to the lack of responses; all remaining survey items were comments from the interviewer and were therefore omitted from the quantitative analysis.

For the sake of interpretability, all multi-level factors were referenced to an "Average" category if the question had such an option, otherwise factors were referenced to the most frequent response in the dataset. Binary factors were referenced to an answer of "No." Lastly, all numerical covariates were mean-centered. Thus, the intercept of the linear models could be considered as the annoyance to blast noise for an "average" case.

Because of a preponderance of missing data for each question, only complete case analysis was performed (i.e., no imputation). This reduced the dataset from 1475 to 868 respondents (403 at Installation B and 465 at Installation C).

6.2.2 Model Selection

After downselecting the questions as discussed above, 59 variables remained in the full model. For ease of interpretability and to uncover the questions which were most associated with annoyance to blast noise, reduction of the full model was performed using backward-selection stepwise linear regression, where variables were retained in the model by comparing the AIC value of the resulting model after removing each variable from the full model, fitting a reduced model, and iteratively taking the model with the smallest AIC. The stepwise regression resulted in a reduced model of 24 variables. Each of these variables was treated as a fixed effect in a mixed effects model. Based on the *in situ* analysis, the community from which a respondent came (community B1, B2, B3, C1, or C2) was treated as a random effect. Coefficients for both the full and reduced models were first estimated using Maximum Likelihood to allow for direct comparison. Comparison of the full model with the reduced model suggested that the reduced model was slightly superior as judged by the AIC (full model: AIC = 2377; reduced model: AIC = 2349). A model that included interactions of L_{Cdn} with each of these 24 variables in the reduced model was also examined but it resulted in an inferior model as well (AIC = 2366), and none of the L_{Cdn}/variable interactions were significant.

In order to assess whether a different noise metric would better correlate with annoyance, several additional noise metrics were examined with the same fixed and random effects as above. These noise metrics were: the A-weighted Accumulated Peak Level (APL), C-weighted APL, the Z-weighted APL, the total number of events, and the number of events over 110 dB. While this did not span the entire set of possible noise metrics, it provided a sample for how other noise metrics would perform. All models had AIC values that were nearly identical to the corresponding models built with the L_{Cdn}, so the L_{Cdn} was retained as the noise metric of interest.

The final model consisted of fixed effects coming from questions A1, A3, A5, A8, B22, B23, G5, H7, H9, H10, Total Rattle, 12 mo. Noise Effect, Habituation Index, Installation Importance, Installation, and L_{Cdn}, with Community being a random effect. Coefficients from this model were then estimated using the Restricted Maximum Likelihood (REML).

6.3 Results and Discussion

The coefficients of the fixed effects from the final model, along with 95% confidence intervals, can be seen in Figure 6-2. Twelve coefficients were significantly different from zero. Effects that were significant and associated with an increase in annoyance were: whether the respondent indicated that there was a time of day which blast noise was most disturbing, if they spent more time at home between the hours of 6 and 10PM than the average, if they indicated that noise had disturbed them (irritated, startled, frightened) in the last 12 months, if they had reported to have normal hearing, if they heard blasts more frequently, if they thought their neighborhood was an excellent place to live, and if they had ever experienced more than one object rattling in response to blast noise. Note that the L_{Cdn} contributed to only a very small increase in annoyance when the other variables

were accounted for. This suggests that the noise level is not a large contributor to annoyance increase *when these other factors are accounted for*.

The effects that were associated with a decrease in annoyance were: if more than the average number of adults lived in the household, if the importance of the installation was larger than average, if the respondent lived in a single-family attached home, and if they felt they could habituate to noise.

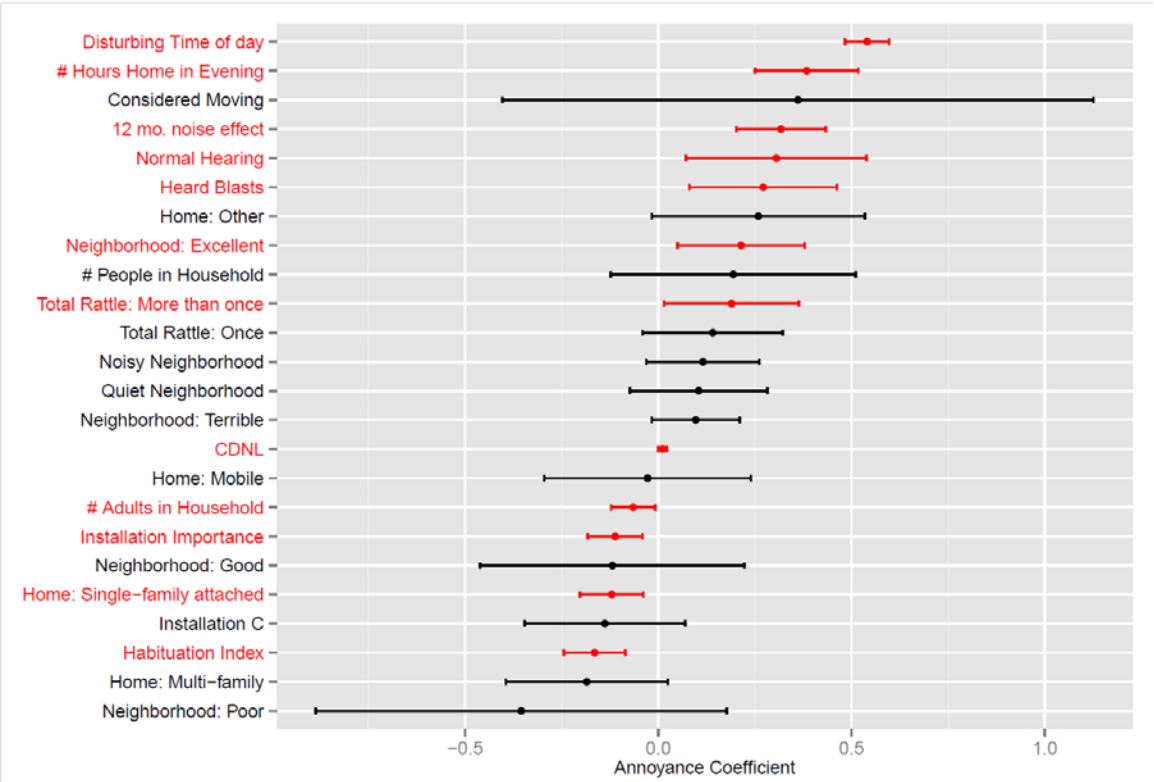


Figure 6-2. The coefficients used in the final fixed effects model with 95% confidence intervals. Statistically significant effects are given in red.

It was of interest if, like the *in situ* results, the community in which the respondents resided had an effect on their baseline annoyance. The total standard deviation of the community random effect was estimated to be quite small, at 0.08 Annoyance points. Figure 6-3 shows the coefficient for each community with 95% confidence intervals. On-post communities show slightly lower annoyance than off-post communities, but this effect was not very large. All else being equal, the effect of community slightly alters Baseline Annoyance, but this effect appears to be small in the presence of the fixed effects seen in Figure 6-2.

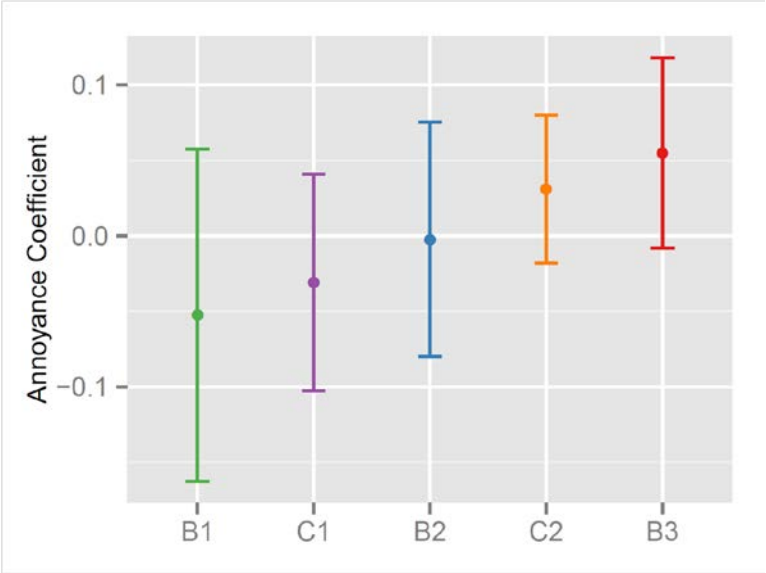


Figure 6-3. The coefficients for the each individual's factor in the model with standard errors.

6.4 Summary and Conclusions

The GCS was administered to over 1400 residents living around each of two installations and assessed their annoyance to blast noise. In addition, using the data measured at *in situ* participants' homes, a procedure was developed to obtain accurate estimates of noise levels at each GCS participants' home. A linear mixed effects statistical model was used to examine the factors associated with annoyance to blast noise for events occurring over the previous four weeks. The variables which significantly contributed to an increase annoyance were whether the respondent indicated that there was a time of day which blast noise was most disturbing, if they spent more time at home between the hours of 6 and 10PM than the average, if they indicated that noise had disturbed them (irritated, startled, frightened) in the last 12 months, if they had reported to have normal hearing, if they heard blasts more frequently, if they thought their neighborhood was an excellent place to live, and if they had ever experienced more than one object rattling in response to blast noise. The L_{Cdn} was found to be the noise metric best associated with annoyance to blast noise and was associated with a small increase in annoyance. The variables significantly associated with a decrease in annoyance were: if more than the average number of adults lived in the household, if the importance of the installation was larger than average, if the respondent lived in a single-family attached home, and if the respondent felt they could habituate to noise. It was also found that annoyance to blast noise varied significantly by community, however when the non-acoustical factors addressed by the GCS were accounted for, the variance by community greatly decreased.

7 Community Tolerance to Blast Noise

7.1 Background

The results from the *in situ* and GCS studies support the hypothesis that each community has a unique tolerance to noise. On the other hand, the GCS survey analysis suggests that the effect of the community is not as pronounced if non-acoustical factors (e.g., opinion of neighborhood, importance of the installation, hours spent at home in the evening, etc.) are accounted for. In fact, it is quite possible that the community tolerance model is merely capturing the differences in the methods that are used to capture the noise environment and/or response; see Sec. 2.3 for more background information on the community tolerance (CT) hypothesis.

In this section, the CT hypothesis is examined using the data captured at Installations B and C. As was done in Wilson et al.,[17] model selection criteria are used to decide on an appropriate model. In particular, the Akaike Information Criteria (AIC) is used to determine whether a nonlinear 1-parameter model,[16] a nonlinear 2-parameter model,[17] a linear 1-parameter model (i.e., the mean), or a linear 2-parameter model (i.e., a line fit) is the most parsimonious model (simplest model that best fits the data). These models are referred to as the CT_{NL1}, CT_{NL2}, CT_{MEAN}, and CT_{LINE}, respectively.

The CT_{MEAN} and CT_{LINE} models, which were not considered by Wilson et al., are proposed in this report for two reasons:

1. The relationship between the percentage of the community that is highly annoyed and the L_{Cdn} appears to be linear for the data collected in this study.
2. It is consistent with the idea of parsimony; these are two of the simplest models available.

Following the notation of Wilson et al., the CT_{LINE} model has the following form:

$$p_{\mathrm{HA}} = \beta L_{\mathrm{dn}} + \alpha, \tag{7.1}$$

where $p_{\mathrm{HA}}$is the percentage of the population that is highly annoyed (HA) at a given level (L_{dn}). The terms β and α are the slope (%/dB) and intercept (%), respectively.

The community tolerance level (CTL) and community tolerance spread (CTS) model are both given in terms of the level at which a certain percentage of the community is highly annoyed:

$$L_{\mathrm{HA}}(p) = \frac{f\left(\frac{p}{100}\right) - \alpha}{\beta}, \tag{7.2}$$

where L_{HA} is the level at which $100 * p$ percent of the population is highly annoyed. In this model α is the intercept term, β is a term that describes the rate at which annoyance increases as the level increases, and f is the link function (the functional relationship relating a linear function of noise level to the outcome probability). With this relationship (Eq. 7.2) the CTL is defined as:

$$\mathrm{CTL} = \frac{f(0.5) - \alpha}{\beta}, \tag{7.3}$$

and the CTS is defined as:

$$\mathrm{CTS} = \frac{f(0.9) - f(0.1)}{\beta}. \tag{7.4}$$

In the case of CT_{NL1}, it is assumed that community tolerance to noise increases at a fixed rate (i.e., $\beta = 0.3$), whereas with CT_{NL2} this assumption is relaxed and β is a parameter estimated by the model fit. The CTL and CTS values can also be found for the CT_{MEAN} and CT_{LINE} models, however, it is important to note that for the data considered in this study, the CTL and CTS values are often unrealistic given that several of the communities do not show an increase in annoyance with an increase in level. Therefore, in addition to reporting the CTL and CTS values, the percent highly annoyed (%HA) at specific L_{dn} levels are also reported. For the purposes of comparing with the levels associated with different land use zones in AR 200-1, the %HA at the L_{dn} = 57, 62, and 70 dB are given.

7.2 Model Preparation

Before the community tolerance (CT) models could be assessed, it was necessary to group the annoyance response data into finite L_{Cdn} bins. There is, however, no precedent in the noise literature on the appropriate way to bin levels. This is surprising given that we found that the relationship between the percent highly annoyed (%HA) and L_{dn} is highly dependent on how the data are binned. Several bin widths ranging from 1 to 10 dB were explored in preparation of this analysis, and it was found that the resulting CT model fits were highly sensitive to the choice of bin width. This was primarily due to the variability that arose due to the differing number of points in each bin. For example, if a bin width of 1 dB was used, there were often too few data points in many of the bins; however, bins with a width of 10dB contained many points, but resulted in too few bins to reliably fit a model.

For the analysis presented below, a bin width of 3 dB was used and the bins were weighted by the number of points in each bin. More specifically, a $\log_{10}(N+1)$ weighting was assigned to each bin, where N is the total number of points in the bin. Using this technique resulted in CT model fits that were similar regardless of the bin width size. Recall that the GCS survey asked participants to rate their annoyance to blast events that occurred over the past 4 weeks (4_{wk}), and over the past 12 months (12_{mo}). The CT models were fit to both the 4-week and 12-month noise level and annoyance data for each community (i.e., B1, B2, B3, C1, and C2) As noted in Section 6, the majority of GCS survey responses had accompanying 4_{wk} blast noise data, but only a small number of GCS survey responses had blast noise data going back 9-12 months as a result of the study design. Therefore, the results presented in this section will focus on the 4_{wk} analysis. The implications of calculating the annual average daily noise level (i.e., $L_{dn,12mo}$) with less than a full year's worth of noise data is discussed further in Sec. 9.4.3. Lastly, in the results presented below, only participants that had at least 2 weeks of data were included in the 4_{wk} analysis, and only participants that had at least 3 months of data were included in the 12_{mo} analysis.

In addition to looking at the CT models at the community level, the data were also grouped by installation, location relative the installation (i.e., all on-post communities and all off-post communities), and combined to include all communities. It is important to note that in the process of combining communities to form these groups, the data were re-binned. This re-binning stands in stark contrast to the way communities have been historically compared/combined in noise study meta-analyses (e.g., CHABA 1996).[6]

7.3 Results and Discussion

7.3.1 4_{wk} CT Analysis Results

As described above, model selection was performed to determine which of the four models considered (i.e., CT_{NL1}, CT_{NL2}, CT_{MEAN}, and CT_{LINE}) fit the data best. The AIC values for each model and community group are given in Table 7-1. Here, the model with the lowest AIC value is considered the best model. With the exception of the two on-post communities (i.e., B1 and C1), the CT_{LINE} was the best model. The root mean square errors (RMSE; Table 7-2) for all the models are very similar. This suggests that for the data in this study, a linear model is sufficient to describe the relationship between the %HA and L_{Cdn}, in contrast to the nonlinear models proposed by Fidell et al. and Wilson et al.. It was also found that the CT_{MEAN} model was the best model to describe the two on-post communities, which suggests that the %HA is not dependent on level in these communities. This is critically discussed in the next section.

Table 7-1. AIC values for each model and community group (4_{wk} data). The model with the lowest AIC value is considered the best model.

REGION	AIC CT_{NL1}	AIC CT_{NL2}	AIC CT_{MEAN}	AIC CT_{LINE}
B1*	-19	-20	-23	-21
B2	-9	-10	-12	-14
B3	-7	-6	-8.6	-9.1
C1*	-8	-13	-20	-19
C2	-28	-41	-49	-59
B	-23	-22	-9	-32
C	-26	-33	-43	-50
ON POST*	-16	-17	-23.5	-23.2
OFF POST	-18	-22	-19	-36
ALL	-20	-23	-22	-39

Table 7-2. RMSE values for each model and community group (4_{wk} data).

REGION	RMSE CT_{NL1}	RMSE CT_{NL2}	RMSE CT_{MEAN}	RMSE CT_{LINE}
B1*	0.07	0.06	0.05	0.06
B2	0.14	0.13	0.15	0.13
B3	0.15	0.15	0.17	0.15
C1*	0.13	0.08	0.08	0.08
C2	0.09	0.05	0.07	0.05
B	0.10	0.10	0.21	0.10
C	0.10	0.08	0.10	0.08
ON POST*	0.11	0.10	0.11	0.10
OFF POST	0.15	0.13	0.19	0.12
ALL	0.15	0.12	0.18	0.12

Table 7-3 summarizes the results of the best model for each community group or region, and Figure 7-1 displays these data. The first thing to note is that it does appear that each community has a unique tolerance to noise, where the most tolerant are the two on-post communities (B1 and C1), followed by C2, B2, and B3. It is interesting that the most tolerant (i.e., B1) has the lowest noise exposure (e.g., the maximum L_{Cdn} is 51), which begs the question of whether this community would be more annoyed if the noise exposure levels were higher. Similarly, the least tolerant community (i.e., B3) has one of the highest noise exposures and the lowest range of noise data (i.e., 15 dB), which suggests that this community is more regularly exposed to high levels of noise. In general, these results show that if the $L_{Cdn,4wk}$ is less than 50 dB the annoyance of most communities will be fairly low ($\%HA < 20\%$).

Table 7-3. Summary statistics for the best model per community group (4_{wk} data), where N is the number of data points, Min and Max L_{Cdn} give the range of the noise data, the slope of the line fit, and the percent of the community highly annoyed (PHA) at L_{Cdn} = 57, 62, and 70.

REGION	BEST MODEL	N	Min L_{Cdn}	Max L_{Cdn}	SLOPE (%/dB)	PHA_{57}	PHA_{62}	PHA_{70}
B1	CT_{MEAN}	100	30	51	0.0	4%	4%	4%
B2	CT_{LINE}	216	43	64	1.2	31%	37%	46%
B3	CT_{LINE}	269	47	62	1.5	49%	57%	69%
C1	CT_{MEAN}	222	40	58	0.0	9%	9%	9%
C2	CT_{LINE}	406	26	62	0.4	15%	17%	21%
B	CT_{LINE}	585	30	63	1.8	40%	49%	63%
C	CT_{MEAN}	631	26	62	0.5	17%	19%	23%
ON POST	CT_{LINE}	326	30	60	0.0	10%	10%	10%
OFF POST	CT_{LINE}	894	26	65	1.0	31%	36%	44%
ALL	CT_{LINE}	1220	26	65	1.0	28%	33%	40%

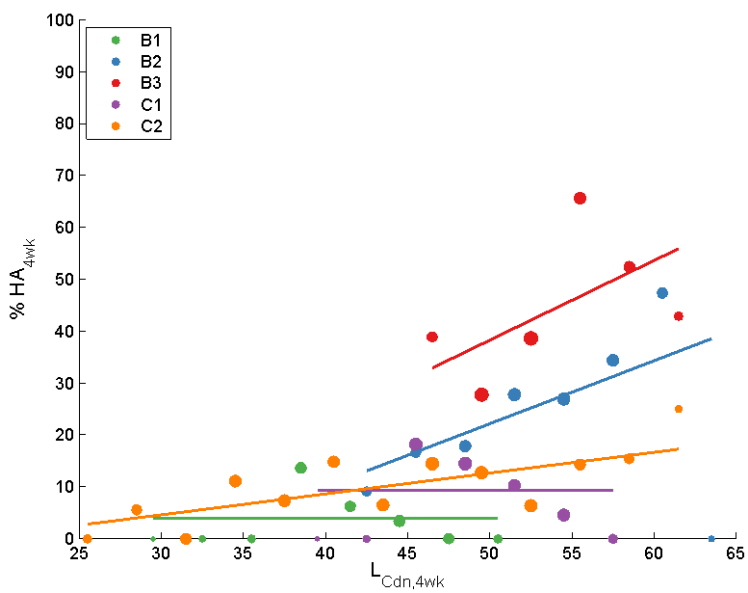


Figure 7-1. CT model results for the 5 GCS communities (B1, B2, B3, C1, and C2). The circles represent the binned data points and the lines represent the CT model fits of the best CT model. The size of the circle is proportional to the number of data points in that bin (the weight applied in the model).

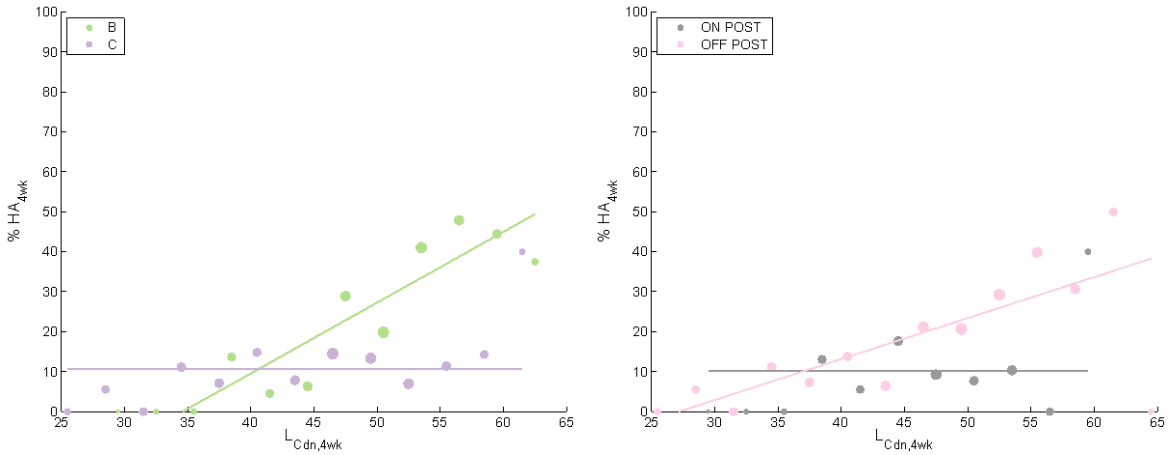


Figure 7-2. CT model results by installation (B and C, left), and post (ON POST and OFF POST, right). The circles represent the binned data points and the lines represent the CT model fits of the best CT model. The size of the circle is proportional to the number of data points in that bin or the weight applied in the model.

When the data is broken up by installation and by post, there appears to be a clear difference between groups. Installation B is less tolerant to noise than Installation C, and those living off-post are less tolerant than those living on-post (Figure 7-2). Lastly, when all the data are combined (Figure 7-3), there appears to be a linear relationship between the %HA and L_{Cdn}. However, this result belies the community dependent effects visible in Figure 6-2.

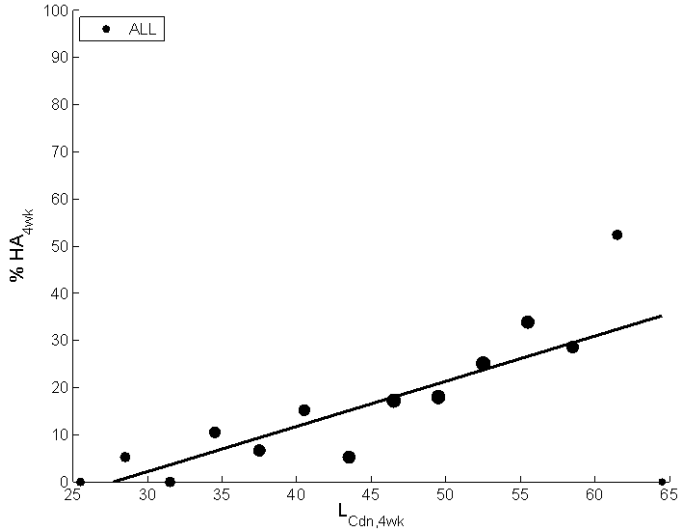


Figure 7-3. CT model results when all of the communities from study site B and C are combined. The circles represent the binned data points and the lines represent the CT model fits of the best CT model. The size of the circle is proportional to the number of data points in that bin or the weight applied in the model.

7.3.2 Binning of Annoyance Responses

An equally important and overlooked binning issue is binning of annoyance responses. While it is the industry standard to assess community response in terms of the percent of the population that is HA (%HA), in doing so, information about the entire community response is discarded. Recall that when using a 5-point Likert scale to measure annoyance, the %HA is defined as the percentage of respondents at a given L_{dn} that respond "very annoyed" or "extremely annoyed." In this sense, information about the percentage of respondents that report being "not at all" annoyed," "slightly annoyed", or "moderately annoyed" are discarded, when they might be useful.

For example, in the 4_{wk} CT analysis above, off-post community C2 showed an almost uniform high tolerance to blast noise regardless of the blast noise level—a markedly different behavior than the other two off-post communities evaluated in this study (i.e., B2, and B3). What is missed by only examining the %HA, however, is the fact that the proportion of people who report being "slightly" or "moderately" annoyed (which we combine into a new category, *somewhat annoyed*) increases and the percentage of respondents that report no annoyance decreases as the $L_{Cdn,4wk}$ blast levels increase (Figure 7-4). Here the CT_{LINE} model is fit to each of the 3 categories of response data (not at all annoyed; somewhat annoyed (a combination of "slightly" and "moderately" annoyed; and *highly annoyed* (a combination of "very annoyed" and "extremely annoyed",). From this figure, it can be seen that that a transition occurs in this community when the $L_{Cdn,4wk} > 50$ dB.

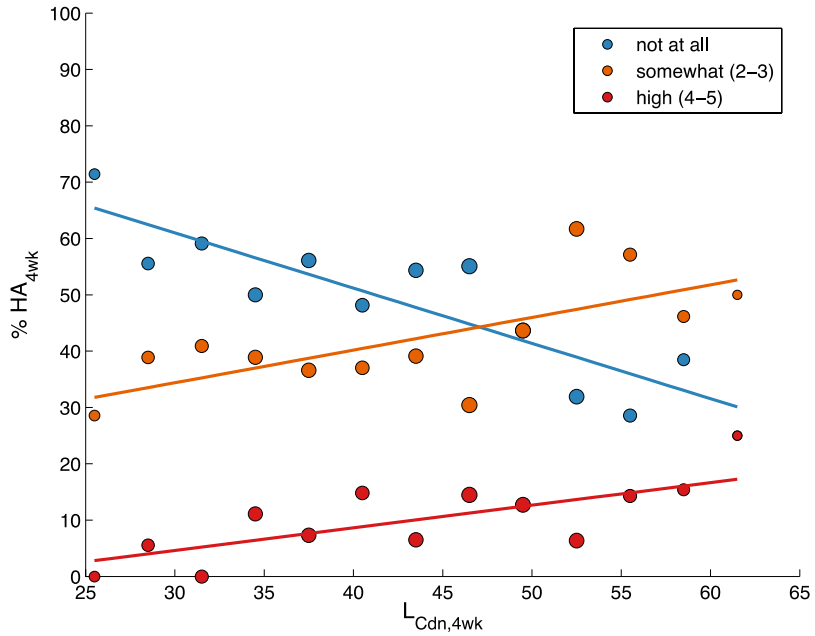


Figure 7-4. Percent of the community (C2) that is not at all annoyed (blue, annoyance response of 1), somewhat annoyed (orange, annoyance response of 2 or 3), and highly annoyed (red, annoyance response of 4 or 5). A CT_{LINE} model fit (line) is shown for each category of points. The size of the circle is proportional to the number of data points in that bin or the weight applied in the model.

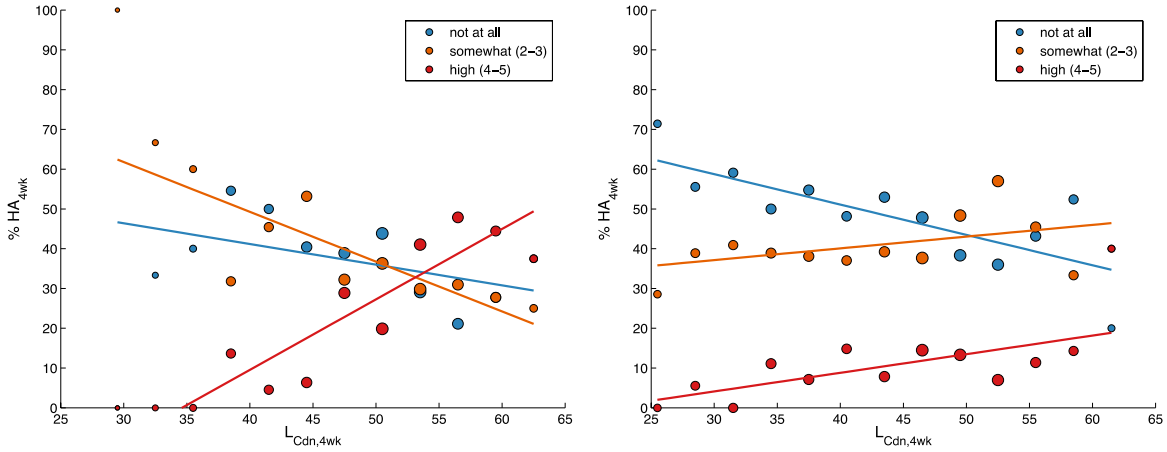


Figure 7-5. Percent of the study sites (B, left; and C, right) that are not at all annoyed (blue, annoyance response of 1), somewhat annoyed (orange, annoyance response of 2 or 3), and highly annoyed (red, annoyance response of 4 or 5). A CT_{LINE} model fit (line) is shown for each category of points. The size of the circle is proportional to the number of data points in that bin or the weight applied in the model.

When we look at Figure 7-5, which compares the findings from Installations B and C, and Figure 7-6, which compares those living on and off-post, we see that each of these community groups has a different tolerance to noise. At Installation B (Figure 7-5, left),

it can be seen that even at low levels there is a significant proportion of the community that is somewhat annoyed and unlike the other groups, there are more people that are annoyed than not annoyed. At Installation C (Figure 7-5, right), we see that there is a significant proportion of the population that is not annoyed, which decreases with level. When all of the off-post communities are combined (Figure 7-6, left), we again see that each of these community groups have a different tolerance to noise. Those living off-post have a tolerance to noise that that changes with the level (Figure 7-6, left), whereas those living on-post (Figure 7-6, right) do not change their annoyance.

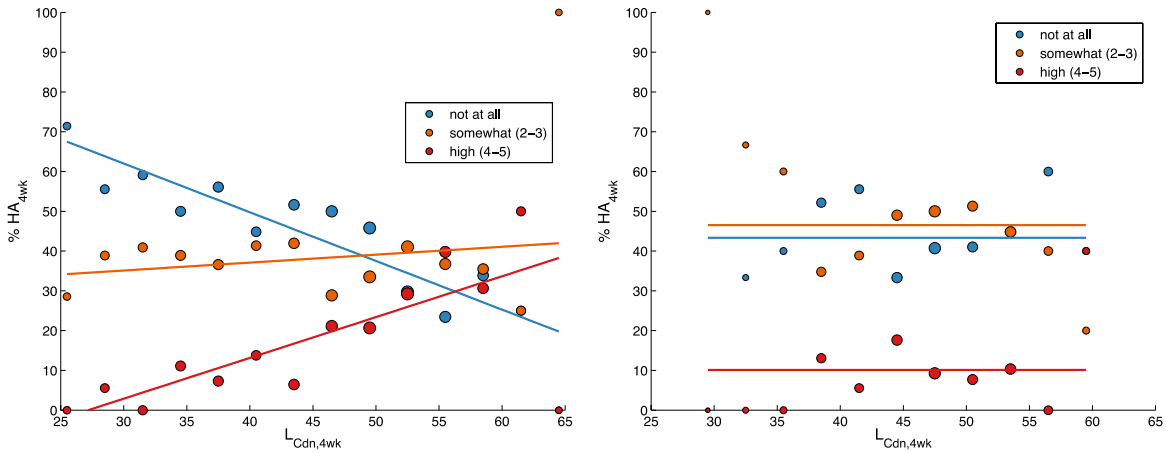


Figure 7-6. Percent of the study sites (OFFPOST, left; and ONPOST, right) that are not at all annoyed (blue, annoyance response of 1), somewhat annoyed (orange, annoyance response of 2 or 3), and highly annoyed (red, annoyance response of 4 or 5). A CT_{LINE} model fit (line) is shown for each category of points. The size of the circle is proportional to the number of data points in that bin or the weight applied in the model.

7.4 Summary and Conclusions

In this section, four different but related models describing the relationship between the noise environment as measured by the $L_{Cdn,4wk}$ and the percentage of the population highly annoyed by blast noise within that four weeks were examined. Fits were improved if each community was treated individually rather than grouped, as suggested by the community tolerance hypothesis. For the off-post communities, the best models were simple linear fits of the data, and on-post communities were best fit by the mean annoyance, as their annoyance did not show much change with noise level. Installation B showed much stronger response to noise than Installation C. It was further shown if the entire range of noise responses is examined, rather than simply the percentage of the population highly annoyed, transitions in population behavior become evident. For example, in Community C2, above 50 dB L_{Cdn} there is a marked increase in the percentage of people *somewhat annoyed* with a corresponding decrease in the percentage of people "not at all annoyed", with only a small change in the percent *highly annoyed*.

8 Variability of the blast noise environment

This section examines the variability of the blast noise environment over time and how it relates to community response. First, the data from the GCS panel survey are considered. Recall that part of the GCS survey design included a resample of a proportion of the GCS participants. This was done to see if individuals' responses to blast noise changed over time due to the change in the blast noise environment. Next, the variability of the blast noise environment and community response are explored on a smaller time and spatial scale. More specifically, time series of the daily blast noise levels are compared to the annoyance time series in several sub-communities. Like the panel sample, these data highlight the dynamic nature of the blast noise environment, and gives insight into the complexity of the overall research problem: predicting community annoyance to a dynamic blast noise environment.

8.1 Panel Sample

Part of the GCS survey design included a resample of approximately 25% of the GCS participants, which are referred to as the *panel sample*. Resampling some of the GCS participants several months after their initial survey was done to explore the hypothesis that individuals' annoyance responses change as the noise environment changes. In general, few panel sample participants changed their annoyance response between the initial cross-sectional GCS survey and the panel survey (Figure 8-1). This was true regarding both annoyance time periods: annoyance of the past 4 weeks (Figure 8-1, left) and over the past 12 months (Figure 8-1, right).

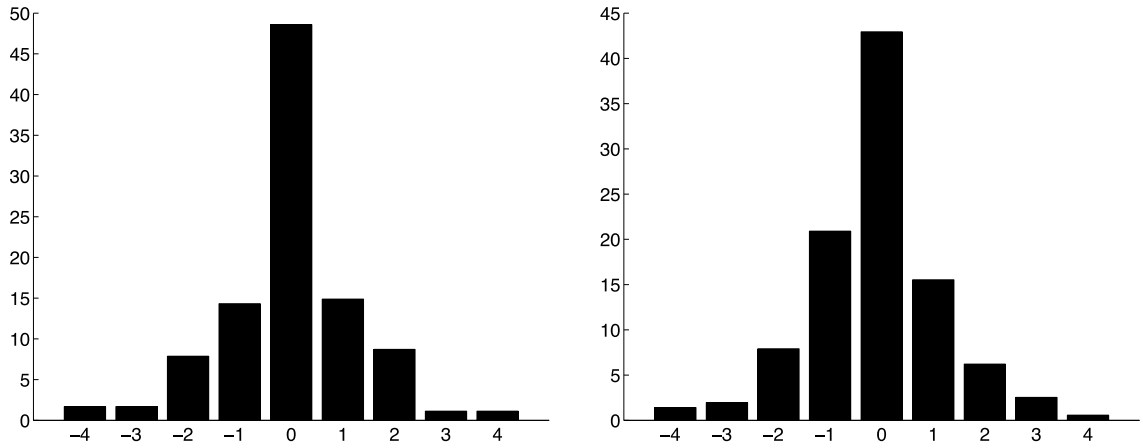


Figure 8-1. Change in annoyance between the initial GCS survey and the panel survey. Graphs show the percentage of GCS panel participants in each delta annoyance category for the question of annoyance to blast noise over the past 4 weeks (left), and past 12 months (right).

The question of whether the change in the annoyance response (or lack thereof) was due to the change in the noise environment was examined by comparing the change in four-week cumulative noise metrics and annoyance responses between the times of the panel survey and the initial GCS survey. A few metrics in addition to the noise metrics in Table 5-1 were used to capture the variability of the noise environment between the GCS and Panel surveys. These included the slope (m) of a line fit to the daily $L_{Cdn,4wk}$ between the times of the initial and panel survey, which was an attempt to capture the general trend of the noise environment, and the standard deviation (σ) of the daily $L_{Cdn,4wk}$ between the time of the initial and panel survey, which was an attempt to capture the variability of the noise environment. This was done to address the possibility that there could be no change in the $L_{Cdn,4wk}$ levels at the time of the initial and panel survey, while at the same time, there could be a drastic change in the noise environment between those two time periods. This notion is exemplified in Figure 8-2. The $L_{Cdn,4wk}$ levels in this figure come from actual data calculated every day over the entire study at one location. The timing of the initial and panel survey collection in this figure are hypothetical, to illustrate the point that the timing of the survey collection is important and can be confounding.

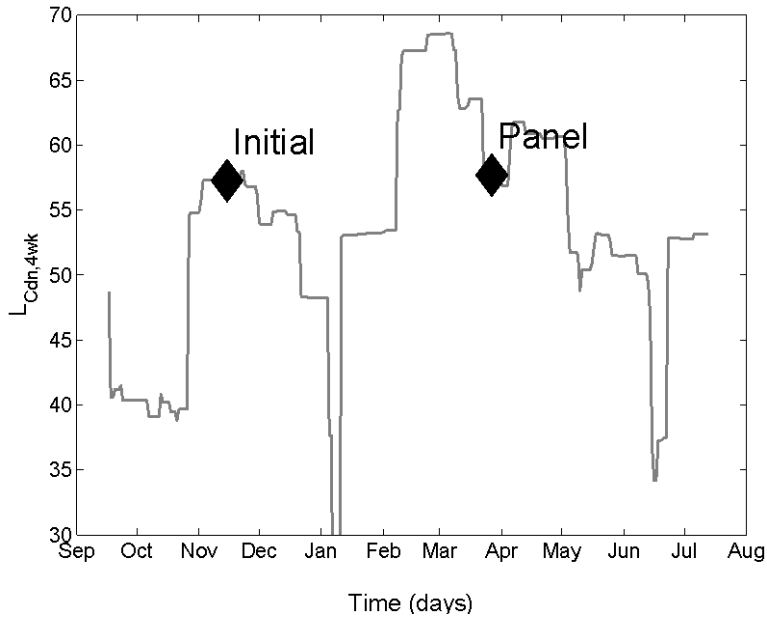


Figure 8-2. The timing of the initial and panel GCS surveys shown with the $L_{Cdn,4wk}$ levels calculated every day over the entire study.

The correlation between the change in the 4_{wk} annoyance responses (ΔA) and noise metrics (ΔL) was tested using Spearman's rank correlation coefficient. In general, all of the correlations were low ($\rho < 0.25$). The metric that had the highest correlation was the change in the number of blast events over an L_{Zpk} of 110 dB ($\rho = 0.23$), though there were several other noise metrics that had statistically significant correlations with the change in annoyance ($p < 0.05$). These metrics had correlation coefficients between $0.21 > \rho > 0.17$, and included the slope (m) and $\Delta L_{Cdn,4wk}$.

The distributions (boxplots) of the change in the number of blast events over 110 dB L_{Zpk} and the change in $L_{Cdn,4wk}$ at each ΔA category are presented in Figure 8-3. The median noise metric values (middle line in the boxplot) indicate that change in annoyance increases as the change in noise level increases. In regards to this relationship, it is interesting that there is little difference in the median noise metric values when the annoyance decreases $\Delta A < 0$, which may support the hypothesis that a short-term increase in the noise environment has a more immediate effect on the annoyance response than a short-term decrease in the noise environment.[60]

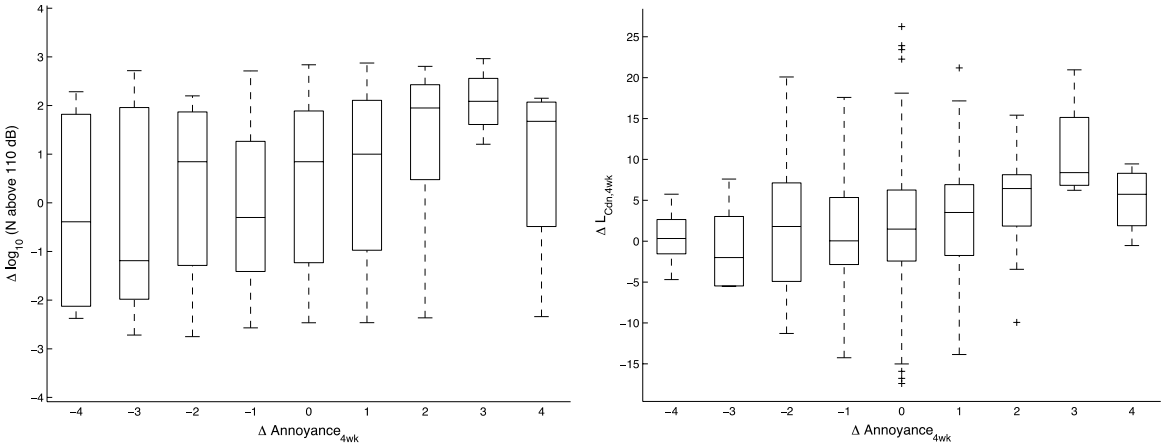


Figure 8-3. Box plots of the change in the number of blast events over an L_{Zpk} of 110 dB (left) and change in $\mathbf{\Delta}L_{Cdn,4wk}$ (right) shown for each delta annoyance category.

The caveat to these findings is that few people (panel participants) changed their annoyance response. Approximately 80% give the same rating or only change by one annoyance unit. This means that the trends in Figure 8-3 are based on 20% of the participants (approximately 70 participants), and even lower when one considers the fact that the correlations are being driven by the participants that reported an increase in annoyance (approximately 10%, 30 subjects). That being said, these results are still useful in the fact that they can be used to generate hypothesizes that can be tested later. The hypothesis then, is when there are on the order of 100s of more events over a four week time period or an increase of 10 dB in the $L_{Cdn,4wk}$, there is likely to be an increase in annoyance.

8.2 Dynamic Blast Noise Environments

The complexity and dynamic nature of the blast noise environment as it relates to community response is summarized in Figure 8-4. This figure shows the daily L_{Cdn} levels and annoyance responses over the course of the 12-month study, and focuses on 5 sub-populations made up of GCS participants living in close proximity to each other and within the following communities: B1 (Figure 8-4, top-left), B2 (Figure 8-4, top-right), B3 (Figure 8-4, middle), C1 (Figure 8-4, bottom-left), and C2 (Figure 8-4, bottom-right). The mean annoyance values shown on this figure include the annoyance responses of both the cross-sectional and panel survey respondents, binned into 4_{wk} time increments. Annoyance values are given only if there were at least 4 respondents in that bin.

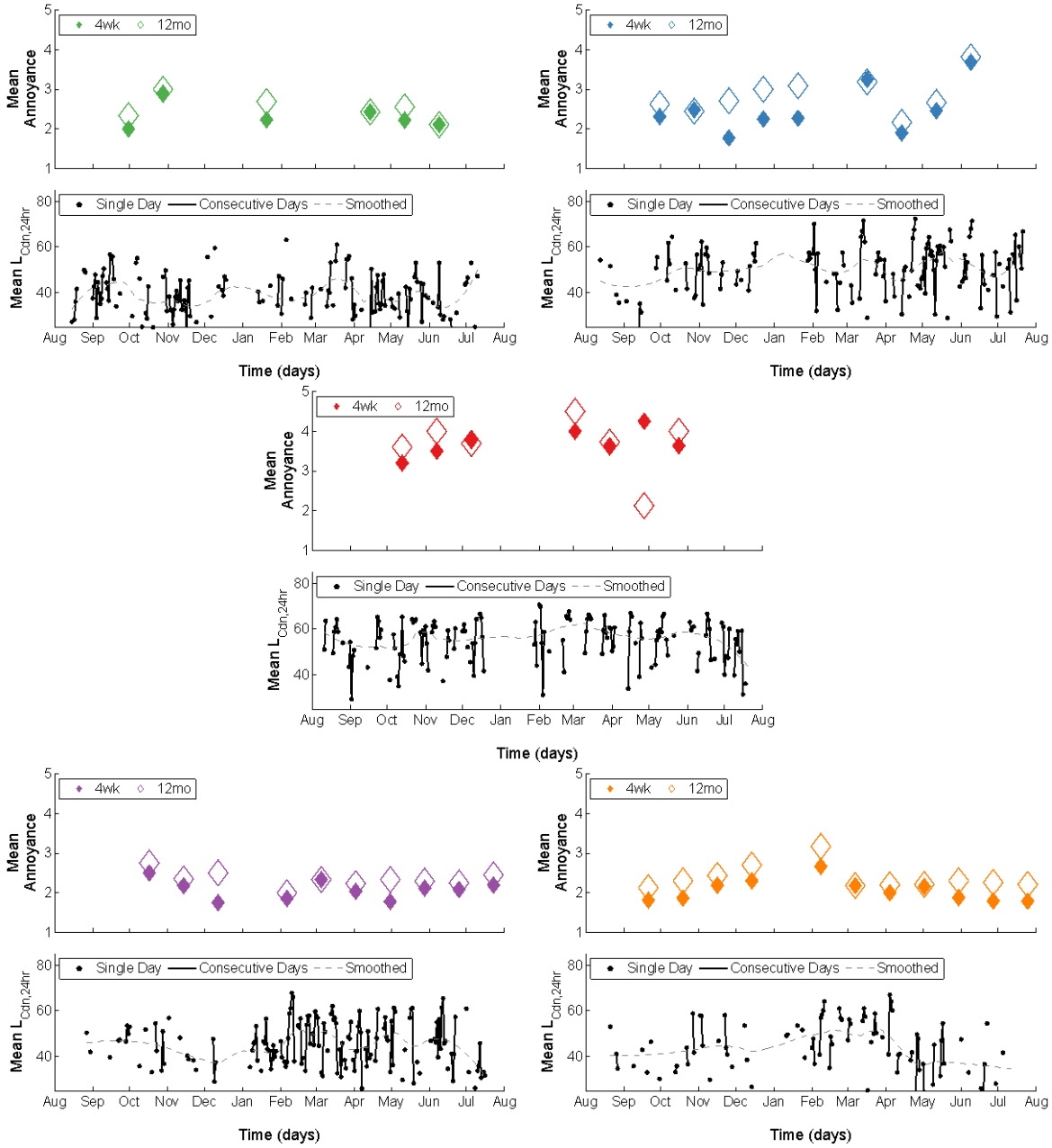


Figure 8-4. Time series plots of the daily L_{Cdn} blast noise environments with accompanying GCS annoyance response for 4 sub-communities: B1 (top-left), B2 (top-right), B3 (middle), C1 (bottom-left), and C2 (bottom-right).

Looking at Figure 8-4 across all communities, it is clear that the blast noise environment is dynamic. There are many days in which no blast noise events occur, and periods where there is much noise over a short time period (e.g., a few days) followed by periods of little or no noise. Also, most respondents report more annoyance to blast noise over the past 12 months in comparison to the past 4 weeks, which suggests that subjects treat the two questions differently. On the other hand, the general trends in 4_{wk} and 12_{mo} annoyance are very similar, and support the idea that community responses to 4_{wk} and 12_{mo} annoyance are correlated. Nevertheless, examination of these plots highlights community-specific trends in the relationship between the noise environment and annoyance.

At Installation B, Community B3 stands apart from the other communities in that it had the least varying noise environment and annoyance responses (with exception to the 12mo data point in May). B3 had the highest trend levels, the most days above 60 dB, and the highest mean annoyance across the entire study.

Community B1 (on-post) also didn't show much change in the annoyance over the duration of the study, but the annoyance response was fairly low in comparison to B3. The exception to this statement is the November time frame, where both the 4_{wk} and 12_{mo} annoyance slightly increased. This increase in annoyance did not, however, coincide with the noise environment; a finding that was similar to the on-post community at Installation C (C1). On the other hand, the noise environment in B1 was fairly consistent over the duration of the study. The daily noise levels very rarely rose above 60 dB, and the trend line seemed to hover around 40 dB.

In Community B2, there was less noise in general during the first 6 months of the study, and the 4_{wk} annoyance ratings over this time period were fairly low. During the last 6 months of the study, however, there was an increase in the number of days where the daily L_{Cdn} approached 70 dB, and the annoyance responses seemed to track this trend. For example, the levels between March and April decreased, followed by an increase in levels through June.

At Installation C, there was little blast noise producing activities during the first few months (August through December). However, trends in the mean annoyance seemed to track daily noise levels. In Community C1, there was a slight decrease in both the levels and annoyance, and in Community C2 there was a slight increase in the levels and annoyance. Also, the annoyance in Community C2 seemed to peak in February, which coincided with several consecutive days in which the daily noise levels increased from just below to just above 60 dB L_{Cdn}. Community C1 experienced the same increase in level in February, but without the increase in annoyance. Further, in C1, there appeared to be many consecutive days of noise between February and July, yet the annoyance stayed fairly constant.

8.3 Most Disturbing Time of Day

The GCS survey asked the following question, "Is there a particular time of day when noises from your neighborhood are most disturbing?" There were a total of 948 respondents, across all three study sites (installations A, B, and C) that answered the question. The respondents reported time ranges (e.g., between 6 PM and 9 PM), and the results are summarized below. When all the results are combined, it can be seen that starting at 5AM the probability increases until around 10PM, where it steadily decreases. This, in essence, stands in contrast to the penalty used in standard L_{dn} calculations.

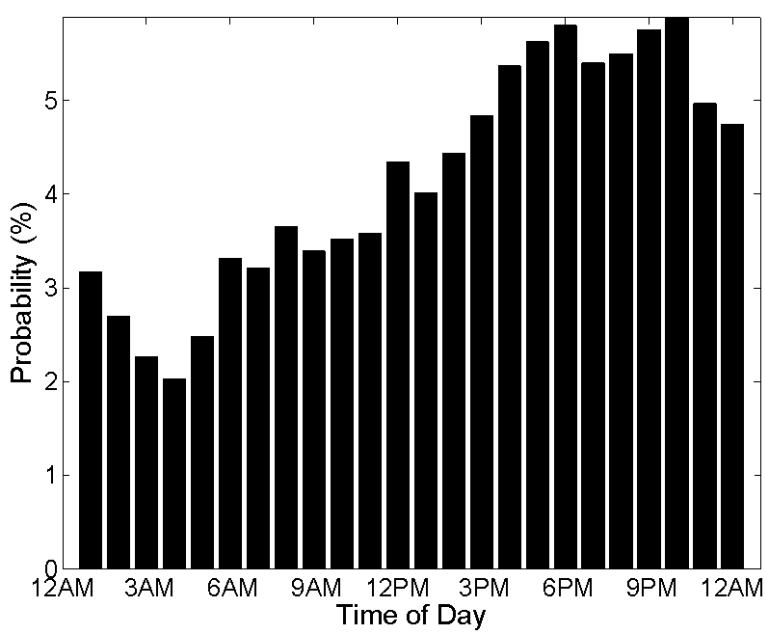


Figure 8-5. Probability density function of the time of day when noises from participants' neighborhood are most disturbing across all study sites (installations A, B, and C).

When the data is broken up by installation, it can be seen that each installation reports a different most disturbing time of day; this is perhaps more support of the community

tolerance hypothesis. Installation A (299 respondents, Figure 8-6 left), which typically does not make much noise after working hours, shows that the noise is most disturbing between 8AM and 5PM. Installation B (321 respondents) shows a marked increase between the hours 5PM to 10PM, and installation C (328 respondents) shows a slight increase around 10PM. It is also interesting that the least disturbing times at each installation are between 12AM to 5AM. These findings are consistent with an Army sleep disturbance study conducted in 2004, which found that blast noise was the least disturbing to sleep between the hours of 1AM to 2AM.[3] Again, this is inconsistent with the 10 dB nighttime penalty of the day-night level calculation.

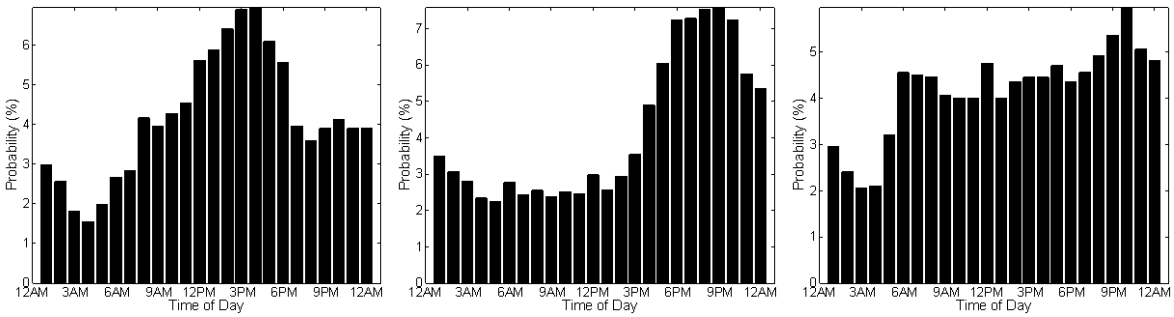


Figure 8-6. Probability density function of the time of day when noises from participants' neighborhood are most disturbing at each study sites: Installations A (left), B (middle), and C (right).

8.4 Summary and Conclusions

This section examined the variability in annoyance in response to a dynamic noise environment. The majority of panel participants did not show a change in annoyance even though noise environments were highly variable during the intervening time period. There was, however, a slight increase in the median change of annoyance as noise levels increased, but change in annoyance did not decrease much as levels decreased.

In addition, although each community was exposed to similar variability in noise levels, each responded in a different manner. Occasionally, annoyance increased with an increasing noise environment, but this was not a common occurrence. Some evidence was seen that when levels increased past 60 dB $L_{Cdn,24hr,}$ increases in annoyance were more common. In terms of whether there were specific times of the day in which respondents reported blasts to be most disturbing, again, this varied by installation; however, when all installations are pooled, blasts in the evening hours (6-10PM) seem to be most disturbing. This finding is in line with the result of the *in situ* study (Section 5) that interference of activities is the subjective variable most associated with annoyance to blast noise, as well as the statistical analysis of the GCS.

9 Recommendations and Conclusions

In this section, we summarize our findings in terms of the three project objectives (Sec. 1.2). In addition, we give recommendations on how to implement the findings, share our lessons learned, and suggest directions for future research.

9.1 Objective (i): Investigate Blast Noise Metrics Currently used by the US Army

The first project objective was to investigate the metrics currently used by the US military to assess blast noise and determine whether these metrics adequately account for the intermittent and impulsive nature of blasts. Recall that the metrics used in AR 200-1 are yearly averaged L_{Cdn} for assessing community annoyance and peak sound pressure level L_{Zpk} for predicting complaint risk.

We have found that the metrics in AR 200-1 do not adequately characterize blast noise environments. The L_{Cdn} – as calculated by measurements or predictions over a long time period (i.e., >= 250 days) – fails to capture the dynamic nature of the blast noise environment, which was measured during this project and examined in Section 8 (see Figure 8-2 and Figure 8-4). The maximum L_{Zpk} also fails to capture the dynamic nature of blast noise, and in this study we find that the $L_{Cdn,24hr}$ has better correlation to both complaints (Section 4) and annoyance (Section 5 and Section 6).

However, we find no evidence to abandon use of the L_{Cdn} when measured over short time periods. This project also examined the metrics used in the current ANSI[7] and ISO[8] standards, which converts the C-weighted events into A-weighted equivalent levels, along with a variety of other metrics that have been used to assess blast noise over the past 50 years (see Table 5-1), and we have found no strong justification to abandon using the L_{Cdn} as recommended in AR 200-1.

We recommend that the L_{Cdn} be calculated over a much shorter time window than the currently recommended yearly average. Preferably, L_{Cdn} would be calculated over the time period of a day when making short-term testing and training decisions. This time period is more consistent with the definition of the L_{Cdn} and can meaningfully characterize the variation in the dynamic testing and training environment. In terms of implementation, an installation could use a noise monitoring system to capture the noise environment and calculate this metric (see Sec. 9.5.1 for further discussion).

As an alternate solution, given that many installations do not currently have noise monitoring systems due to cost and reliability,[21] the noise environment could be calculated using propagation/prediction software that takes into account the current/actual meteorological conditions. Caution should be given to the use of propagation software, given that the accuracy of many propagation softwares over short time periods has not been established, there is difficulty in obtaining the inputs need to run the propagation model (i.e., source data, terrain/topography, and micro-

meteorological data), and the more detailed inputs that are given to the model, the longer the model takes to run.

In terms of noise impact assessments to guide long-term testing and training decisions, such as choosing the location of a new range and scheduling training activity on existing ranges, we recommend that the L_{Cdn} be calculated over successive time periods of a month (i.e., 4 weeks) rather than over the current 250-day or annual time period. The four-week time window represents the best available dose-response information and better captures the dynamic nature of the blast noise environment than does a larger time window. Though not reported in Section 7, the four-week community tolerance models (CT) showed superior fits in modeling community annoyance than the 12-month models. It should be noted that the choice of the four-week time frame does not result from some threshold in community behavior or individual psychology; rather, it represents a compromise. A shorter time period would more accurately characterize the intermittent nature of blast noise, and the resulting long-term assessments may give important details such as which time of year the new range/training activity is likely to have more or less impact on surrounding communities.

In terms of complaint management, we find evidence to discontinue use of the max L_{Zpk} for complaint risk prediction. Maximum levels do not take into account the number or timing of noise events, and we found little evidence that this metric is useful to predict either annoyance or complaints, largely because of the large variation in community tolerance (CT) described in Section 2.3. In place of the max L_{Zpk}, we recommend that $L_{Cdn,24hr}$ be used to predict complaint risk. In Section 4, we found that correlation between the $L_{Cdn,24hr}$ and blast noise complaints was larger than the max L_{Zpk}. In terms of implementation, an installation could correlate complaint records with noise monitor data to establish complaint risk relationships, as was done in Section 4 to predict regions where complaints are likely to occur (see Sec. 9.5.1 for further discussion). Noise impact assessment software tools such as the one found in the range manager's toolkit (RMTK, which uses the same algorithms in BNOISE2^{TM}) could also be used to calculate $L_{Cdn,24hr}$ values, albeit with much less accuracy for the reasons discussed above. Also, use of the $L_{Cdn,24hr}$ simplifies assessment procedures, since this is also the metric we recommend for predicting community annoyance.

9.2 Objective (ii): Examine Relationship between Individual Complaints and General Community Annoyance

The Complaint Survey (Section 3) specifically addressed Objective (ii). We found that the ***opinions of individual complainants do not represent the general community opinion of blast noise***. This suggests that installations should not immediately implement testing and training restrictions based upon the opinion of a few individuals, and also suggests that installations may be too overly restrictive with their local noise management policies. ***However, we are not suggesting that noise complaints be dismissed outright***. ***Rather, following the guidance of Luz et al. 1983, blast noise***

complaints should be dealt with in a timely manner in order to defuse the situation. Recall from Section 3 (Sec. 3.1.1), that those who file complaints about noise often have higher economic and social status, are members of environmental organizations, and are more likely to sign petitions and attend public meetings and demonstrations. While complaints may not be indicative of general community annoyance, ignoring these complaints will almost definitely result in more and potentially unnecessary testing/training restrictions.

9.3 Objective (iii): Recommend Criteria to Actively Manage Noise at an Installation so that the Sustainability of Testing and Training is Ensured

In this section, we make recommendations using the best information available from this project. Our recommendation is that military noise be managed using unique criteria for each installation rather than managing all installations with universal criteria. We recommend this until more data are gathered regarding how to integrate community specific variables into a universal dose-response model.

9.3.1 Recommendations for Managing Blast Noise at the Installation Level

We recommend that policy and decision makers move away from a universal dose-response curve for blast noise management, and instead move towards managing military noise on a community-by-community basis. The findings of this project support the community tolerance hypothesis: each community seems to have a unique tolerance to noise. The results from the complaint study (Section 4), *in situ* study (Section 5), community tolerance analysis (Section 7), and dynamic noise environment analysis (Section 8) all support this hypothesis. It is important to note that when non-acoustical factors are included in the annoyance model (GCS analysis Section 6), the community specific differences are less pronounced; a topic that warrants further research (see Sec. 9.5.1 for further discussion).

Management of military noise on a community-by-community basis can be accomplished by the use of intelligent noise monitoring technology, such as those developed in ESTCP WP-201117; however, a full implementation of a real-time, adaptive solution for noise management requires more research and development of current technologies (see below).

9.3.2 Universal Criteria for Managing Blast Noise

Until a fully operational, automated, inexpensive, and adaptive noise management solution can be developed that enables installation-specific noise limit criteria, we realize that decision-makers may need/want criteria that can be used at *all* installations to make both short-term and long-term testing and training decisions. *We do not recommend this approach*. However, if one were to desire such a one-size-fits-all solution in terms of a

universal dose-response relationship such as the one originally given by the CHABA working group, we suggest using the data from Installation B fit to the 2-parameter model proposed by Wilson et al. The model has the following form:

$$p_{\mathrm{HA}} = 100e^{-26.17/m}, \tag{9.1}$$

where $m = (10^{(\mathrm{L_{Cdn}}/10)})^{0.25745}$ and the L_{Cdn} is calculated over a four week time period.

We suggest this model over those fit with data from Installations A, C, or the CHABA 1996 data for several reasons. Primarily, the noise data at Installation B was of superior quality in comparison to the other study sites. Recall that the true positive rate of the blast noise classifier used at Installation B was 97% when 2 monitors picked up the blast event and 99.7% when 3 monitors picked up the blast event. However, when the same blast noise classifier was applied to Installation C, the true positive rate was only 78% (Table 6-3 in Section 6). This discrepancy is likely due to the fact that the blast noise classifier was not trained using data from Installation C. Also, Installation C was windier than Installation B; wind signals have similar characteristics to blast signals and as a result often confound the blast noise classifier. Installation B also had significantly more blast events that were picked up by 3 or more monitors. Roughly 20% of the noise events that were classified as blast noise from Installation C may not have been true blast noise events, and the cumulative blast noise levels at Installation C could be significantly over-estimated. This topic is further discussed in the Sec. 9.4.3.

In addition, noise data from Installation A was measured using sound level meters that only recorded a few simple noise metrics and did not capture an audio recording of the triggered event. Also, an inferior blast noise classifier was used. Therefore, the noise data at Installation A suffers from many of the same accuracy problems as Installation C. Perhaps most importantly, the study area around Installation A was much larger than the communities studied at Installations B and C (i.e., 4096 km^2 vs. < 25 km^2). In fact, 75% of the GCS participants around Installation A mentioned that they did not hear blast noise very often.

Lastly, it is difficult to assess the data behind the CHABA 1996 curve, as the raw (un-binned) data are no longer available. Furthermore, in most cases, the noise environments were calculated using propagation/prediction software using operational range records from 1-year prior and following the survey. We do not feel that this is an accurate depiction of the noise environment around installations, and our research has suggested that L_{Cdn} measured over shorter time windows results in superior correlations with annoyance.

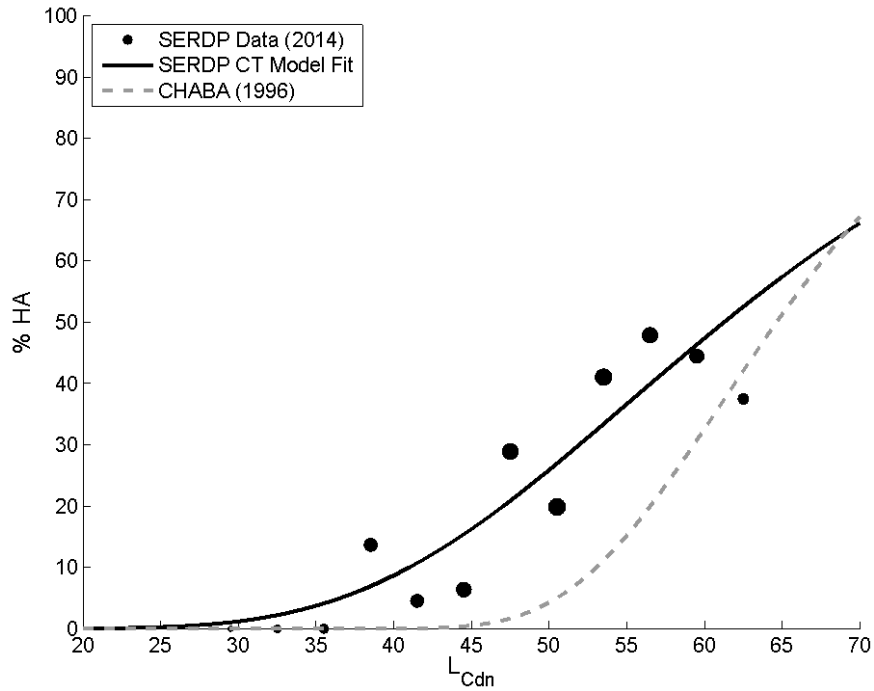


Figure 9-1. Dose-response curve (black line) based on data gathered at study site B (black dots), compared with the CHABA 1996 curve (dashed line). The size of the circle is proportional to the number of data points in that bin or the weight applied in the model.

Figure 9-1 shows the blast noise annoyance data from Installation B fit to the 2-parameter CT_{NL2} Wilson et al. model, in comparison to an early version of the Fidell et al. model suggested by CHABA 1996. Both curves asymptote to 100% high annoyance, but the figure is cut off to show only the range in which data was captured. It can be seen that the growth in annoyance starts at a lower level than the CHABA 1996 curve, and in general there is more annoyance at lower levels until around 70 dB where the two models converge. ***The Installation B curve is more conservative than the curve currently in use and policy makers will need to decide how to implement such a curve if they decide to go the route of implementing a universal criterion.***

It should be noted that this curve represents an amalgamation of the communities on and around Installation B. The Community Tolerance (CT) model suggests that this may *not* give an accurate estimate of the percentage of the population that might be annoyed to blast noise around another community. Secondly, the noise data we acquired only captures the range of 30 – 63 dB. While it may be useful and necessary to estimate the percent of the population highly annoyed at levels outside this range, caution should be used given that we do not have data for how communities respond to the levels outside this range. In fact, our analysis (Section 7) showed that a linear fit to these data was superior to the 1 and 2 parameter non-linear CT_{NL1} and CT_{NL2} models, in terms of model fit. Lastly, while there is historical precedence for basing policy on the percent of the population that is highly annoyed, it should be kept in mind that the definition of highly annoyed only includes two-fifths of the annoyance response categories. One

improvement to future policy could be the use of the full annoyance scale or the mean annoyance such as was done in Section 6.

In Table 9-1, the compatible use zones given in AR 200-1 are defined using the curve in Figure 9-1. ***NOTE: we are NOT recommending that Table 9-1 be used to re-define the current noise zones.*** Rather we include this table to illustrate the potential implications of adopting a new universal criteria based upon the best available from this project. In the end, policy makers will need to decide how to define the noise zones and it is recommended that the 15% and 39% HA markers which were adopted from military aircraft studies be reassessed.

Table 9-1. Land use zones using the dose-response curve in Figure 9-1 compared with the land use zones given in AR 200-1.

Noise Zone	% HA	LCdn (dB) AR 200-1 2007	LCdn (dB) SERDP 2014	Compatible for residential use (schools, housing, and medical)
Zone I	< 15%	< 62	< 45	Yes
Zone II	15 – 39%	62 – 70	45 – 56	Not normally recommended
Zone III	> 39%	> 70	> 56	Not recommended

In terms of the management of blast noise on a day-to-day basis, the findings from the *in situ* (Figure 5-4) and the dynamic noise environment (Figure 8-4) analyses, suggest that when the daily-averaged L_{Cdn} exceeds 60 dB and/or repeatedly exceeds 60 dB there appears to be an increase in annoyance. The results from Section 7 and Section 8 also suggest that there is a large percentage of the community that reports no annoyance, or small percentage that is highly annoyed when the L_{Cdn} is typically below 45 dB. These insights are in the line with the criteria given in Figure 9-1 and Table 9-1.

In addition, although it may seem obvious, we recommend that installations ensure that no community be exposed to blast events with peak levels ≥ 140 dB, which is the threshold for human hearing damage.[†††18,19] We measured several instances in which peak levels approached this threshold. ***We also recommend moving away from using/measuring the unweighted peak level (L_{Zpk}) and suggest replacing it with the C-***

[†††] The potential for hearing damage is not as simple as measuring the unweighted peak level. Hearing hazard depends on the shape of the impulse. For example, an impulsive noise from an M-16 rifle at 140 dB is more likely to cause hearing damage than an artillery blast at 140 dB because the spectral energy of the M-16 is more similar to the resonance frequencies of the cochlea, whereas the spectral energy for blasts occurs at much lower frequencies.

weighted Sound Exposure Level (CSEL or L_{CE}) since this single-event metric is used to calculate the cumulative event metric L_{Cdn}. For blast noise, the L_{Zpk} level and L_{CE} are highly correlated and their difference is 22 +/- 6 dB, 95% of the time.[‡‡‡] In this sense, ***we recommend that no single blast event should exceed a L_{CE} of 118 dB, and that caution be exercised if singe-event levels approach L_{CE} of 112 dB***.

9.4 Lessons Learned

There were many lessons learned over this lengthy 6-year project. In this section we share the three primary lessons that one should consider before attempting to emulate the studies described in this report.

9.4.1 Approvals

The first thing to consider before emulating the studies presented in this report is that many approvals will be needed before any data can be collected. The survey work required approval from the Office of Management and Budget (OMB), which took approximately one year to obtain, and setting up equipment in participants' homes required an Institutional Review Board (IRB) approval. Lastly, though not technically required, this project received approval from the Command Staff at each of the participating Installations. The participating Installations were appreciative and supportive of the project, and it is highly recommended that future research take the same approach.

9.4.2 Noise Data Collection

This project set out to measure each and every blast noise event over a 5-year time period: 3 years worth of data at Installation A, 1 year at Installation B, and 1 year at Installation C. The noise monitors and data recorders used in this project did not have built-in wind rejection or blast noise classifiers, and therefore every noise event that exceeded the 100 dB L_{Zpk} threshold was captured over the 5-year project. As a result, there were on the order of 10's of millions of noise events recorded on 20+ noise monitors, and several terabytes of noise recordings made over the course of the project. Managing and post-processing the noise data became a very time consuming and difficult challenge. The research team dealt with many hard drive failures and data storage issues. Future research that aspires to measure each and every noise event should utilize the wind rejection and military noise classifiers developed during this project and the sister

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[‡‡‡] This number comes from 54,705 noise events that have been human classified to be blast events.

ESTCP project (WP-201117), and should have a solid data storage and backup plan from the outset.

9.4.3 Quality and Accuracy of the Blast Noise Datasets

In attempting to collect every blast event over a 5-year period, there was no way to ensure that each noise event captured was actually a blast, beyond the labor-intensive task of listening to every noise recording. Therefore, any study that employs unattended noise monitors must rely on noise classification algorithms. While the approach taken in this research was an improvement over the blast noise studies conducted in the 1970's – 1990's, it was by no means perfect. During the course of the project, several different blast noise classification algorithms were developed using various human classified datasets, captured at many different locations. We have found that an improvement can be made to these classification algorithms if separate classifiers are built using data captured at *each* study location. For example, the same blast noise classifier was used to classify the noise events captured at both Installation B and C, and we saw a steep degradation in performance for events from Installation C. This was most likely due to the fact that the dataset used to train the classifier did not contain blast records from Installation C. No classifier is 100% accurate, and any results of this or future work should be interpreted in light of this. On the other hand, future advances in noise monitoring technologies and machine learning algorithms will likely result in much higher confidence of event classification.

9.5 Future Research

9.5.1 An Intelligent Noise Monitoring System to Manage Noise on a Community-By-Community Basis

Management of military noise on a community-by-community basis can be accomplished by the use of intelligent noise monitoring technology; however, a full implementation of a real-time, adaptive solution for management of military noise will require future research & development of current technologies. Some of the areas of future research include improving the current blast noise classifiers and expanding the classes of noise. Algorithms, such as the ones used in Section 6 to associate blast records into blast groups, estimate the source location, and to interpolate/extrapolate the blast noise records from the noise monitor locations to other locations of interest, will also need to be refined and automated.

Assuming that such improvements are made and integrated into an intelligent noise monitoring system, information about the real-time noise environment could be coupled with the findings of this research to predict which communities are likely to be impacted by the testing/training noise. Such a system would provide range mangers and decision-makers with the information they need to make informed decisions, such as whether to

proceed, postpone, or relocate a scheduled testing/training exercise. It would also provide them with the information they need to determine whether noise complaints and damage claims are legitimate. Further, such a system would show which regions have recently been exposed to an excessive amount of noise and the installation could provide outreach before noise issues (e.g., high annoyance, complaints, lawsuits, and loss of operational capability) occur.

Such an intelligent noise monitoring system could be further improved if installations coupled their complaint records into the system. For example, a simple algorithm like the one used in Section 4 could predict the risk of receiving blast noise complaints, and unlike the current set of universal criteria, a unique complaint risk criteria could be built for each community/region of interest.

Future research should also focus on uncovering community-specific factors (e.g., in terms of easily obtainable public information such as demographics) that can be used to predict a community's tolerance to noise *a priori*, which will allow each installation to estimate the appropriate parameters of the dose-response curve for the populations on and around their installation. Some parameters that should be included in the model include the non-acoustical variables that implicit to the community tolerances that were identified in the in situ (Section 5) and GCS studies (Section 6). The inclusion of other community variables such as demographics, output from semantic analysis of local newspaper and social media, and other variables such as the time of day, source location, and meteorological conditions at the time of the military noise events could put into the system could also be used to increase the accuracy of noise impact predictions.

9.5.2 Improvements in the Prediction of Annoyance to Blast Noise

In addition to focused efforts to develop improved real-time noise monitoring capabilities, a possible direction for future research could be identifying a blast noise metric that better predicts community response. As mentioned earlier, loudness-based metrics may be a step in the right direction. This project explored the utility of loudness-based metrics during the *in situ* study, and found some evidence that the Moore & Glasberg instantaneous loudness was a good predictor of single event annoyance.[82] In the end, inclusion of loudness-based metrics was dropped from the final list of project metrics due to the computational burden and realization that psychoacoustic loudness models have not been fully tested at the low-frequencies important for blast noise. Further, in order to fully utilize loudness-based metrics, future research must establish how to create cumulative loudness metrics. Once established, these measures could be compared to the response data captured in this project.

An improved annoyance prediction metric should further examine the 10 dB penalty to noise events that occur between 10PM and 7AM, which is implicit to the calculation of the L_{dn}. Examination of the GCS participants' responses to the most disturbing time of day (Sec. 8.3) finds that the least disturbing times at each installation is between 12AM

to 5AM. These findings are contrary to the L_{dn} penalty, but consistent with an Army sleep disturbance study conducted in 2004, which found that blast noise was the least disturbing to sleep between the hours of 12AM to 2AM.[3] Another improvement to predicting annoyance to blast noise could be the inclusion of the ambient or background level.

Future research should also look for additional metrics that capture the intermittency or dynamic nature of the blast noise environment. In our research, we found that there were many consecutive days or weeks in which no blast events occur, which may explain the low correlation between L_{Cdn} levels calculated over long time periods and community annoyance. However, we found that neither the mean time between events nor the standard deviation of time between events showed good correlation to annoyance. There are several additional ways intermittency could be included in an improved blast noise metric. Another approach would be to change the denominator in the L_{Cdn} calculation to only include the number of minutes, hours, or days in which the blast events actually occurred, or to establish a running blast noise environment metric. This metric could include a decay term to reduce the level during times of no blast noise and a growth factor that increased the level during active firing times. Separate factors to model the decay and growth of blast noise and associated annoyance are likely needed given the role that habituation and sensitization play in blast noise annoyance (see Luz and Nykaza 2009 for more details).[60]

The GCS analysis also found that how often subjects had heard the blast noise events was a strong contributor to annoyance. While estimating audibility of events *in situ* is a very difficult task, future metrics may benefit from an estimation of blast audibility. Such estimation may be achieved by a detailed examination of the distribution of transfer functions from a variety of different home construction types, as well as psychoacoustic laboratory studies examining how the activities in which the subjects are engaged at the time of the blast event influence the audibility of the blast.

However, one must ultimately question whether a better metric is necessary for community noise annoyance prediction and policy. To what end would a better metric be useful? At the outset of this project, the variability of human response to noise was of great concern (Figure 2-1). But what this project has demonstrated, and the story that seems to be emerging in community-response-to-noise literature, is that the day-night level is more than adequate to predict noise annoyance once community differences are taken into account. In fact, the relationship seen between %HA and L_{Cdn} in Figure 9-1 is quite direct; that is, for Installation B. When variability arises, this seems to be due to community-specific effects, but these effects can be modeled. It is likely more advantageous, then, to spend effort in developing prediction models for community tolerance than spending effort in finding a noise metric that presents less variability in the annoyance than the day-night level, assuming, of course, the day-night level is measured over an adequately short time period.

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A Supporting Studies

A.1 Personal Interview Study

A.1.1 Summary

This section gives a summary of the Personal Interview (PI) study, which was the first study conducted in SERDP Project WP-1546. Full details can be found in Hodgdon et al. 2009.[25] The PI was executed in the vicinity of three military installations between October 2008 and February 2009. The installations or study sites were spread across the US: NorthEast, South, and West. The objective of the PI was to identify the language/terminology that residents living near military installations use to describe their community, environment, and blast noise. These descriptors were then compared to the descriptors used in the other SERDP WP-1546 survey instruments.

The PI study found that the language participants used to define noise and their environment was similar to the language that was used in the other SERDP WP-1546 survey instruments. The qualitative PI findings also indicate that residents living near military installations are aware of the installation and the noise generated by the installation. Participants reported that they adapt to the basic noise environment over time and often do not notice smaller noise events, but do notice unusually large noise events or noise in conjunction with house vibrations. A number of participants reported that their current neighborhood is less noisy than other areas in which they have lived and is a better place to live. Several of the participants stated that they would not leave the area because of the noise, and almost all participants expressed that they are content with their neighborhood.

A.1.2 Sampling of Comments from PI Study Participants

Comments from Participants at Study Site A

Sampling of Comments from A201
Teenage boy with amplified base radio in his car ; can hear thump thump of radio; it vibrates the windows.
Would like Installation A to "put a muffler on their testing."
"Depending on the wind and how much testing they're doing they can vibrate the house."
Well, it’s annoying, but you get used to it. It’s like living next to railroad tracks, you know. After a while, you don’t really notice it.
We accept it. We would like it to be quieter so people that are getting cracks in their houses and things would like something done. But it’s always been here.
Sampling of Comments from A202

"The noise from Installation A is loud at times, but it, I get used to it. I don't even pay attention. I've been here so long. But you know, they keep putting off bombs and stuff."
Just a boom, just boom, like you hear booms going off. And every morning, they put one off between 7:30 and 8:00. That's the only thing I don't like. I don't want to wake up that early; can even hear it at 7:30am with the windows shut.
Well, one of my neighbors, just about a month ago, said, she said, did you hear that awful boom? I said, yes. And she said, well, it shook my house. And I said, it didn't shake mine. And she said, it didn't? She said, well, it shook mine. That was three doors up.
It's more loud, yes, when we have these severe thunderstorms.
Sampling of Comments from A203
In the five years we've been here, there's been one time where I'd stop and went, wow, did something hit the house? Because the vibration was so great. But that was about two years ago, I thought a tree fell down.
Local trailer park campground, their noise is mostly at nighttime, where during the day, which would be the, you know, when Installation A is doing their thing, it's kind of, I don't know if you're busy doing something and don't really notice Installation A as much as you would notice their noise.
You hear more in the winter than you do in the summer because there's no leaves on the trees, and we're pretty well wooded and insulated down here with the leaves on.
Sampling of Comments from A204
You can hear Installation A. When it goes off, you can hear them, the bomb, or whatever they're doing over there, the shooting or whatever. But you get used to it. You don't even notice it; can hear planes go over, but don't notice it anymore because I've lived in the area for 60 years.
The windows shake and rattle; can hear the vibration.
Kids that have the four-wheelers next door, riding them in a residential area.; have no respect for anybody else's property; that's my biggest complain about noise.
A great big boom. it's more than thunder.
Sampling of Comments from A301
You hear explosives from the Installation A occasionally, which, again, don't bother me because I'm used to them; don't notice simply because you're used to the sounds.
I like the whole area. I think it's great. It's not hustle and bustle like you find in the city. I'm very comfortable living out here as I do.
Sampling of Comments from A302
When the kids get out of high school, you know, it's vroom, vroom. That's for half an hour.
Installation A doesn't bother us, the planes, the firing. In fact, most of the people around here call it the sounds of freedom.
Even when they have a big boom and it shakes the frames on the thing, it doesn't bother us, yeah. It doesn't bother us at all. The only one it bothers is one of my dogs; the dog shivers and shakes, thinks it's a thunderstorm.
We have Harry the Hooter who just blows that train whistle unbelievable, and then we have, you know, other people who are quite gentle, especially during the night. It never wakes me up. Yeah, it's not bothersome.
Sampling of Comments from A303
Blasts at times shook house; feel it; booms; could feel testing from Installation A shaking house; house has shaken 2-3 times in two years.
Do you notice the trains? Of course I notice them. I mean, at first it bothered me. But now I'm kind of like, oh, there goes the train, you know. It's kind of second nature now.
I've just kind of gotten used to it. At first, like hearing stuff, you know, activity and stuff, I was like, what the heck, you know, at first. And after a while of being here, I'm just like, okay, you know, it's just there.
he one thing that does get my nerves up a little bit is when that siren goes off to like test it. …the boo-oop one, they have like this emergency alert system that they test every couple of months, and it does like this boo-oop, boo-oop, like it goes up, almost like an air raid siren, like what I could imagine what it would be. And it like goes aa-aa-aa at the end of it, and it just says, this is a test. If this had been an actual emergency, I'm like, okay.

Comments from Participants at Study Site D

Sampling of Comments from D102
Sometimes hear the canon and gunfire from Installation D, even though we're quite far, but I guess they've opened a new range that's not very far from here.
Sometimes when you go outside and it's real calm night, you know, that rat-a-tat-tat-tat, you can hear that, or you hear a boom and you'll ask yourself, was that thunder? I mean, you know, it's not constant, not like it keeps us up at night or anything like that.; hear rat-tat-tat-tat about once a month.
The one negative would probably be the recent trend to loud music coming from your car and all that thumping. Yes, and you can feel the, it will vibrate my eardrums, and it will hurt, and I get frustrated and angry, and I want to say something, but, you know, at this day and age, you have to be very careful if you're going to confront someone; wants to see change about the car noise; enforcement of radio noise rules.
I have noticed that if things go wrong in a community, they like to blame the military post. But if things are going good, you know, it's just, they don't, the benefit of the military there, they don't get the credit for bringing in jobs or, you know, anything good that's happening, even though the military community does a lot to, PR-wise, to make sure that the community knows that they're here to be a good neighbor. They're here to be positive in the community and stuff like that.
If it's a quiet night, I mean, you know, clear, crystal clear, cold, you can hear, it seems, travels a little bit better, the noise.
Sampling of Comments from D103
We have some teenagers run through here with their various loud cars, but that's teenagers. Only every once in a while you hear a car that's not actually an automobile but a musical instrument. A percussion instrument.
As I said, when we have firecrackers and stuff in the neighborhood or bad thunderstorms, these things aggravate you, or a dog barking over here that won't shut up, you know, that bothers you. But that I can hear in my bedroom, these kind of things bother me, but Installation D's guns never do. There's just never enough noise coming from there to bother me, at least here.
It's like a, it's like a rumble. Sort of like if you had to describe it naturally, you would say it's similar to a thunder from a very distant thunderstorm.
I'm sorry that we have to have Installation D. I'm sorry we have to have the military. I'm sorry we have to have war. And I'm sorry we have to practice for it. But I'm aware of the realities of the world and of life... But you know, it's, the military base is not, we really benefit from Installation D..... And so I have no problems with Installation D being here....
The only time you notice it differently is when it's overcast and the ceiling is low. It seems, and in fog. When, then you hear it way more than on a day like this. You almost hear it not at all on a day like this.
Economy is essentially dependent on Installation D
The school district, there was an article in the paper this morning again, constantly has not received from the federal government or from the State ...any benefits from all these students coming in. we are looking at having. . . 5,000 or 6,000 more students, no more buildings, no more teachers, no more anything. They will fund, you know, the military expansion, but they will not fund anything to help the community serve these people that are going to come here.
Sampling of Comments from D104
When they're having exercises at Installation D, particularly at times when the, I think it's when the humidity is up. There's some times that the sound seems to travel more. But it's sort of like they're really in the distance, and you hear the boom-booms and you know that they're doing their exercises. And our daughter said, when she lived here after college, that she thought they did the exercises the last two weeks of the month. It seemed like there was activity certain weeks and not others. But it's really not that disruptive. It's kind of interesting, because when you go outside, you can hear the noise from the highway; on clear nights can sometimes hear rat-a-tat-tat-tat or booms.
so there's noise out there, but there's nothing, you know, it's really not that, it's far enough away from us that I don't think it's a problem,
I don't feel like the ranges impinge upon our life here, about the noise level that we have, it doesn't. And I think, you know, it doesn't really, it's like I can't sleep, it's not one of those I can't sleep because they're

shooting the guns at Installation D, and I hope it never becomes that way.
We hear it, but it's just sort of like you know what it is. And sometimes, there will be a big boom and, you know, you kind of feel like the house shakes a little bit. But usually, I guess we know what it is so we don't think too much about it, because it's not that loud.
Sampling of Comments from D105
Sometimes I can hear, and I don't even know how often it is. Sometimes I can hear a little shooting, but not very often. I couldn't tell you whether it's been two or three times or not, because I keep my TV on and I'm not outside a lot; might hear it if outside; knew Installation D was out there when we built.
Installation D is a wonderful place, and so I would rather it be there than something else.
Sampling of Comments D201
"Not that heavy environment as far as noise-wise"; tank doesn't make as much noise as you would think
They train all around this area. They do a lot of airdrops, the Rangers does. It's just like anywhere you go. When you're first there, you know, the least little thing wakes you up, you know. But then you get used to it, you pay no attention to it.; to me it's not loud.
But overall, we wouldn't have our freedom if it weren't for the military bases and troops out there.
Sampling of Comments from D203
They (windows) had been actually shook, the rattling of the windows. They were wooden windows and they, over the years, had rattled so much that we actually had no choice but to replace them, because they were certainly inefficient because they had been compromised with the noise and the continuous shaking.
At one time we had shelves over this window and the kitchen window, and I collect plates, old plates, and those plates, I've even had something fall off and break, you know, because I didn't catch it in time…It didn't happen from any one blast, though. I want to make that clear. It didn't happen from any one thing. It was an accumulation over time.
Certain degree we've gotten used to it. There are times when it's louder than others. And of course, no matter how long you've been here, you're very aware of it.
Sometimes it's, in fact, if you've got young children here, sometimes it scares them and you have a problem with that.
As it is now, most of the time it's bearable, but we would certainly not want to see them extend the boundaries of Installation D range. It would be very intrusive in our lives.
Sampling of Comments from D205
I got used to it in the background. I don't hear. I don't hear too much . . . disturb me of anything. The airplanes is mostly, when the airplanes are low, flying low, that's the biggest noise we hear. This is kind of quiet . . .
Sampling of Comments from D206
Some days it has been annoying. It's, at times, the time that they're doing it, you know, like if you're trying to sleep or whatever; like you get woke up with one of those machineguns or whatever it is that makes that, you know.
I can hear it if they're firing or anything. I can hear that. …And sometimes we have thought it was like bad weather coming on.
We'll be like, hey, do you hear that? Is it thunder? And you know, then all of a sudden, we know that they're having training or something.
I wouldn't leave because of it,...I mean, I like my location, I definitely do.
Sampling of Comments from D207
We hear sirens going by in the middle of the night. We hear people with their radios so loud it'll wake you up.
You're talking about the shooting of the M16s. How would you describe it? Rat-tat-tat-tat-tat. Rat-tat-tat-tat-tat.
Neighbors over there, they turn their music up real loud.
Sampling of Comments from D208
Stopping the noise at night would be nice-it's startling and annoying.

So do you hear the installation at all? All the time. It's probably unstoppable, I believe, you know. We hear it all hours of the night, also during the day.; gotten used to the noise.
You hear it all the time, the machine, the machine guns going off, the jets flying over. I mean, it's went to the point of knocking pictures off the walls and breaking things. Did it ever break anything or? Oh, yeah. Oh, yeah. I mean, it knocks the pictures off the walls and it vibrates . . .
We're settled there. We're happy there. I mean, you know, yes, it's a pain sometimes, but I don't think it's going to run us off, you know.
Sampling of Comments from D210
Yeah. Boom, boom, boom sometimes, but mostly, you know, it sounds like that. Or the guns, you know... like those, what is it, those guns that they shoot; hear different types of noises once or twice a month.
And like the flares goes up, they go [sound effect]. And then you just hear like the rat-a-tat type noise? Yeah, like the guns, machine guns [sound effect], you know. I sit out there and enjoy it. it starts at 9:00. I'll be out there watching it.
I guess I'm so used to it, it don't bother me. . .mean, you know, the military needs training, and they, you know, I don't think they should change anything about, you know.

Comments from Participants at Installation E

Sampling of Comments from E101
I was a civilian in Israel when Saddam Hussein was bombing Tel Aviv. So this is fairly loud. it certainly takes me back, . . .Yeah. I'm used to it now, but, at first, it was kind of unnerving, I have to say. Sometimes they're so loud, in fact, that it's hard to distinguish whether you just live near something or it's that close where it kind of, you know, feels uncomfortable, . . .we moved here, sight unseen. My husband moved here for work, and so did I. And then, we started hearing the noises. And then, we realized we were that close.
Just gets you on the deeper level that, you know, it's not just a noise, it's not just an annoyance, the fact that it's a noise. It's the fact that it's military exercises that are very, you know, they're carrying them out with real weapons. This is not just, you know, kids playing in the backyard. This is the real deal, so that part of it, for sure, is uncomfortable.
And for some people, this may bring a level of comfort, that there is a, you know, a government installation with weapons that could possibly protect them. You know, maybe there is a level of comfort. I don't know. That might be something to consider. But, yeah, for me, it just, it's been uncomfortable.
The booms and the bangs, they actually shake the windows on the apartment. And I'm going to say the night before last; I had trouble falling asleep, because I could hear the bangs and the loud booms. All the sound was traveling, probably way past midnight.
A lot of helicopters that are flying really low. You can see a lot of detail on these large Army helicopters. And it's pretty scary, because they fly low, like I said. And they're so large and noisy that we're not quite sure what they're doing above this peaceful, little corner, you know.
It's a general vibrating feeling on the building. On the larger booms that come in, the building, you can sort of feel the walls, as well as the windows. But some of the, you know, not so impactful noises that come through, you just hear them, you know, ricochet by the windows, the sound.
It's almost like somebody is doing target practice. It's like, boom, boom, bang, and then it will stop. And then, there's, you know, there are almost like, like a family of noises that follow each other, you know. And then, there are loud, through the hills here, so they continue all the way into the buildings, and you can hear them. And neighbors that I have, actually friends of mine, have heard, late into the night, they've heard actually voices and exercises being carried out into the hills.
A cluster of sounds, different sounds. Some are deeper, some are not. Some have more of a kickback to them, you know.
Sampling of Comments from E102

I heard what sounded like hammering. And I was going, what in the world is, who's building something at 9:00 at night? And you could hear it. It was like, pound, pound, pound, pound, pound. I was like, amazing. Pound, pound, pound, pound, pound. I couldn't fathom how someone could be pounding that late at night. And I went, oh, those are 50 caliber machine guns. And then I realized that subsequent sounds were probably Howitzers on tanks. But that's only happened one time . . . I heard howitzer 4.5 years ago
Periodically, late at night, (the boy in the apartment downstairs) has anger management problems, so he will slam the doors in the apartment, two, three, four, five, six, eight times at night at 12:00, 1:00, 2:00 in the morning. Wakes me up, wakes my son up. When that happens, sometimes my son is real, he's very calm, but sometimes, he gets really mad about it.
Other than neighbors that periodically get kind of strange, it's pretty quiet. You can hear children playing and screaming, and skateboards. They're not supposed to ride them here, but they do. And they call it grinding, where you ride it into the curb and the board will go, slam, and it makes that real wood sound. You can hear that.
Sampling of Comments from E201
It's not too terribly bad. The artillery fire is frequent. It does boom on occasion, particularly if it's foggy and weather-dependent, but it's not intrusive or overpowering. Very rarely do the windows rattle or anything like that, so . . . we had a lightening storm, of all things, not too long ago, and that bothered the dog more than anything. So he's gotten used to the artillery. So if the dog doesn't start, it's not bad.
It's not a rattling, but you can kind of feel the pressure wave occasionally, you know. But I guess you could, you know, like when you have the bass on a radio turned up and you kind of feel the vibration of the sound wave itself? Every now and then, you get a small one like that, but it's not bad. And it's usually when there's overcast clouds and stuff like that that echoes it down or something. It just feels more, something like that.
It's a lower section where the fog comes in more frequently….Pressure, yeah. But it's very mild. It's not even affecting us. It's enough that you kind of know the thumps are happening, but it's not overbearing, it's not dangerous. It's not, I mean, I used to live in Lennox, which is right underneath the flight path of LAX, and that was more intrusive than this is.
I don't really pay much attention to it anymore, because I've kind of muted it out of my brain. That's a weird phrase. But I would say it happens every couple of weeks, you know. Not the fog boom part, but the actual artillery launching every couple of weeks. For sure, once a month, maybe every other week, you know.
Artillery doesn't sound like thunder. To me, no. You know, it sounds like they're doing training, you know. And they're firing off 10, 15 rounds, waiting a half hour, firing off 10, 15 rounds. You know, that kind of thing? It's not like small arms fire or even automatic weapons or anything like that. It's just in intervals of 30 seconds, a minute apart. You know, it's not very, it's not intrusive, to be honest, you know. No.
Sampling of Comments from E203
Except my only complaint is from the (installation). And between 4:00 and 10:00, almost every day, there's huge planes that come over here. And you have to even turn the TV louder or talk louder . . . that's really a bad, bad thing….. Big passenger planes, transfer planes from different bases....Jumbo jets.
Some pictures, and some baskets,… some more items, …. they fall off all the time… see that picture is crooked? …. Over there. And they broke a picture over here. The frame is busted, because it popped off the wall… Airplane, yeah. It's the aircraft, mostly
No, it's just annoying . . . some of those bombs really send the glass, send the windows rambling too. And the percussion of them is really surprising, as if there's an actual war going there. I mean, sometimes with the aircraft, the . . . get sometimes . . . really feel them.
Yeah, the artillery is just in booms. And there are some big booms, I'll tell you…so before you might actually hear the aircraft itself, the windows would shake? Jiggle.
Well, I'm annoyed. That's a pretty, we were really annoyed. I don't get mad, I just get, it's like helplessly annoyed, because there's nothing I can do about it. It's like . . . busy when they have to be, you know.
I saw a little gazebo area in the center. Yeah. where people are out, getting . . . at any rate . . . well, the argument goes on. Did you feel that earthquake last night? That wasn't no earthquake. That was just (the installation), you know. . . .You know, it rattled my bones . . .
Sampling of Comments from E204
We've heard this guy across the street say something, but it seems like it just comes up at us, like we're in an

amphitheater.
The loudest thing that happens here is the sound of freedom, as I explained to the gentleman that called to set up the appointment.
With the artillery…. You can feel the thump, you know. It's on a much lower frequency, so it moves things a little bit more for sound attenuation. But, I mean, dishes don't rattle or anything like that. ….You kind of maybe almost feel it, more than hear it.
Helicopter flyovers…. have to be doing it at least weekly basis, Do you hear any artillery noise. . Yes.Yep, yep. We can hear that other sound of freedom. Faintly inside, yeah.
In terms of describing the noise, I asked, you know, is it annoying? From Installation E? Minimal.... it's not like it's scary or bothersome or anything…It's more of a vague kind of . . . oh, they must be doing some exercise or something over at Installation E. It's not offensive, it's not annoying.
Sampling of Comments from E301
You hear the avenues and a lot of traffic going by, you know. Yeah.
Sometimes, you know, we hear the helicopters, you know, and the planes going by. But those, they don't bother us, you know, because we know. We've been hearing those since I was here, so.
Sampling of Comments from E401
Retirement community . . .So it's very quiet because we're all retired . . .And so, we don't even see anything, much less hear anything. The only sound we have is what we call the sound of freedom, and. …That doesn't bother us at all. You hardly think about it, unless there's a real good boom that shakes the house, you know. And they usually tell you in the paper that that's going to happen.
We can go days and days with; you hear nothing but booms and guns. And then, you don't hear anything for a long time. So, you know, you get used to it. It's kind of like living on the ocean, where you don't hear the breakers anymore. But nobody, I've never heard a complaint.
Sometimes we feel it, you know, if they shoot off some really big guns. At first, I come from earthquake country, and the first time it happened, I just stopped in my tracks and thought, boy, I've got to get out of here.
Our windows and doors are open all the time.
It's really just a distant boom, sometimes a rat-tat-tat. But it's distant.
It's not an annoyance. It doesn't annoy me at all. They could even be louder and it wouldn't annoy me, because it's not in my face. It's not restricting me from doing anything. It's a distant, I also hear the Amtrak, you know. That doesn't annoy me either.
Sampling of Comments from E402
When they have their maneuvers, sometime in August there, you hear a few banging and moving, you know. But overall, I mean, I always consider them a good neighbor. I mean, they have to do what they have to do. And the noise that they have is, you know, it's acceptable. No problem.; for two weeks, start banging away with some big boom, boom boom; most the time peaceful and quiet.
It sounds like a baby earthquake, you know, but it isn't. It's just a big boom of some sort, you know, and everything shakes a little bit. It's just one boom and that's it. And you say, oh, boy, they're practicing again, and you go back to whatever you're doing.
They have these, you know, maneuvers there, usually in the summertime. It's about two weeks there, they start banging away with some big boom, boom, boom. But, you know, like I say, you hear it, you know what they're doing, and it's over in a few days, and you're back to normal again. But like I say, most of the time, it's quiet and peaceful, and there's no problem.

A.2 General Community Survey (Installation A)

In this section, the procedure that was used to estimate blast noise levels at participants' homes is given, along with a summary of the survey findings. Full details can be found in Nykaza et al. 2012.[83] As mention in Section 6, the GCS at Installation A served as a pilot study for the GCS studies conducted at study sites B and C. The general community survey (GCS) at Installation A began 1 June 2009 and was completed 3 February 2010.

A.2.1 Noise Data Processing

Blast noise was recorded using a set of thirty-seven Larson Davis 870 sound level meter noise monitors located on and around the installation (Figure A-1).[10] These monitors recorded every event that exceeded an unweighted peak threshold of 105 dB over the entire 9-month period that the general community survey was being administered. The threshold value for several monitors was set lower than 105 dB at various times throughout the experiment by installation personnel, presumably due to institutional needs to compensate for such things as increased numbers of wind triggers or event densities related to fluctuations in training schedules.

[10] It should be noted that the installation map is purposely left vague to protect the identity of the installation in this report. The on-post monitors are left on this map, despite the fact that they were not used in this study to better show the reader the approximate location of the installation.

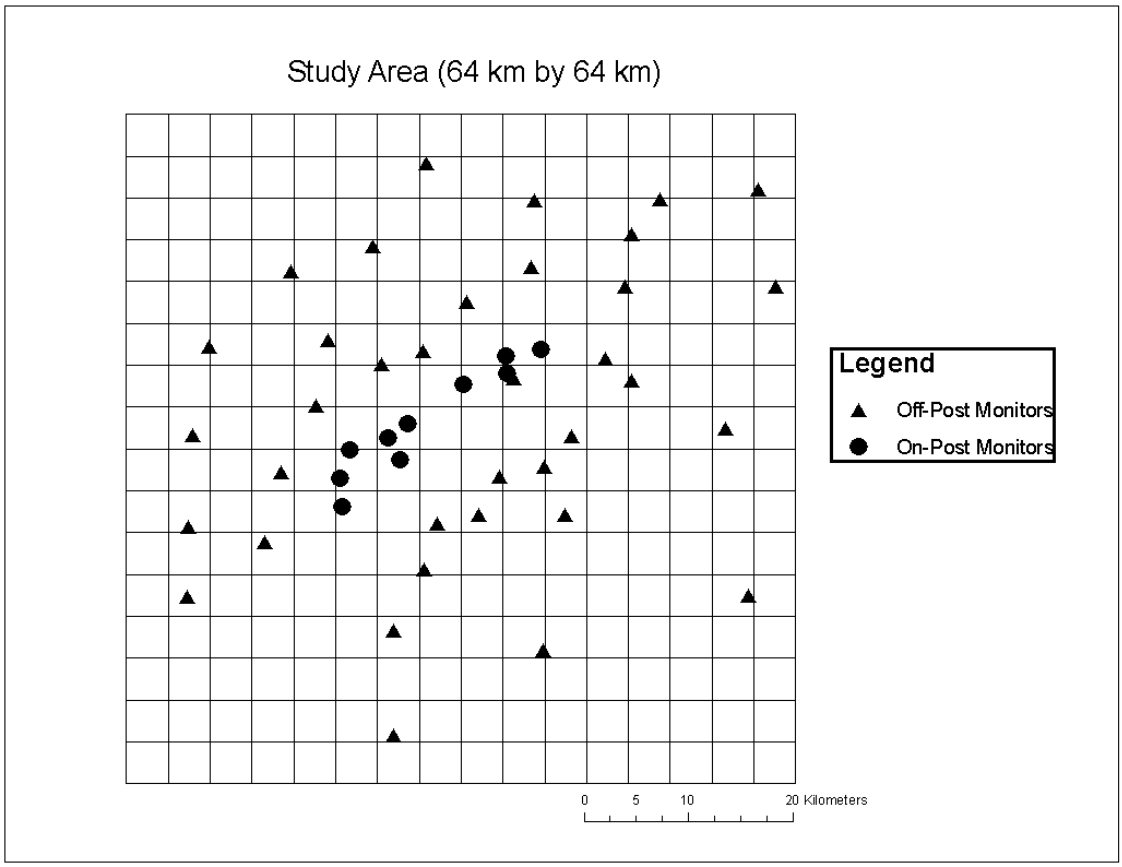

Figure A-1. Location of noise monitors at study site 1. Triangle markers represent the noise monitors used for this study.

It should also be noted that the noise monitoring equipment (sound level meters) used for the GCS Installation A is different than the equipment (16-bit data recorders) that were used for Installations B and C. At Installation A, the research team utilized noise monitors that the participating installation already had in place and running. These monitors, demarcated by triangles in Figure A-1, were located on the perimeter of the installation and in surrounding communities. Unfortunately, there were several issues with these monitors that resulted in a less than perfect collection of blast noise data. For example, the noise monitoring equipment did not have any built in detection or classification software, nor did it record the entire pressure time series for captured noise events. The equipment only output traditional sound pressure level measurements (e.g., the peak level and sound exposure level), and did not have the capability to calculate additional metrics during the post-processing.

Range Data Processing

The installation made range records available, which contained information such as the locations of active ranges, times of active firing windows, types of weapons, intended number of shots from guns and explosive weights from detonations. Because this study was interested solely in large arms and large explosions, entries for small or medium arms or small detonations were excluded from the records. Small detonations and medium arms were defined respectively as

explosive weights less than one pound or guns of size less than 75 mm. Also, if the firing site was an indoor range or a range that fired only small arms, these intervals were excluded. Further, if the time window included midnight (suggesting that the firing window was a placeholder and not an actual firing time) or reported zero fired rounds, it was excluded. Ranges with more than one weapon in use in the same time period had the information from all relevant weapons (large arms or detonations) combined into a single entry. The qualified range records were placed in chronological order by end time first and then by start time and any duplicate firing windows were eliminated. This procedure resulted in a list of large arms training intervals, their locations and the weapons active at each place and time.

Noise Monitor Data

Of the thirty-seven monitors that recorded data, two were excluded because of calibration problems. The on-post monitors were also excluded because of an increased uncertainty of identifying the true source location of nearby loud noise events. Ambiguity in source location could potentially lead to large errors in extrapolated levels if the monitor was much closer than expected to the source. In the end, the outputs from thirty-two noise monitors were included in the analysis.

Every event triggered on the monitors was not necessarily a blast. Based on preliminary blast noise classifier work that eventually led to the Cvengros et al. classifier, events were classified as a blast if the difference between the maximum exponentially fast-averaged C-weighted sound pressure level and the C-weighted sound exposure level (L_{CE}) was greater than 4.8 dB. This classification scheme was originally found to have an accuracy of 90%, but later found to have an accuracy of 87% with a true positive rate of 83% and false positive rate of 10%. Because some of the monitors had lower thresholds throughout the course of the experiment, the 105 dB threshold was enforced at all monitors via post processing, excluding all events below this level from analysis. Also, in an isolated case, a monitor appeared to be triggering on a different metric than others—for example, L_{CE} instead of L_{Zpk}. The shifting trigger levels or settings may have led to some inconsistency in reported numbers of events at the lower levels (which might be selectively excluded at some sites and not others). This should not, however, affect the accumulated peak levels or numbers of higher-level events.

For the higher-level events (those which when extrapolated from the assumed source position to the average monitor distance are greater than 135 dB), a corroboration stage was employed in which a blast had to be registered at more than one site within a one minute time range of the recorded event in order to be accepted. This was the result of seeing unusual numbers of what were deemed unrealistically loud events at only certain sites, with little corroboration at others. Distributions of events received at each monitor were examined in an effort to identify any groups of abnormal events. Most monitor specific event levels followed a roughly exponential distribution of occurrence with the maximum at the approximate threshold value and decreasing prevalence as level increased.

Extrapolation of Blast Noise Levels

The Universal Transverse Mercator (UTM) coordinates of the home of each of the participants in the survey were used to determine which monitors were within ten kilometers. In order to

increase specificity and accuracy of noise assessment, only these monitors were employed in the procedure to extrapolate blast levels. The date of the survey was used to determine which events had taken place within the past four weeks and within the past twelve months. Events were assumed to originate from the active range nearest to the receiving monitor. If no ranges were active at that time, then the event was assumed to be falsely classified as a blast and was eliminated. To compensate for the possibility of multiple monitors receiving a blast, each event received at a monitor in range of a subject's house within a minute of an event received at another such monitor was processed in order to eliminate duplicate reporting to the extent possible. The level at the closest monitor was chosen as the most representative. Notwithstanding this process, predictions of individual blast exposure typically included greater numbers of received events if there were more monitors in range.

The metrics evaluated in this study were all level-type metrics and so could be reasonably extrapolated or interpolated from the monitor to subject homes using the following equation:

$$L_h = L_m + 20 \log_{10} R_{ms}/R_{hs}.$$

In this formula L_h is the predicted level at the subject's home, L_m is the level at the monitor, R_{ms} is the distance from the monitor to the source location and R_{hs} is the distance from the subjects house to the source location. This equation accounts for spherical spreading, but clearly does not account for potential atmospheric effects. This is an important reason for only allowing input from nearby monitors rather than including all monitors for all events.

After processing, two main outputs were produced: (1) a subject-specific record of all of the unique blast events recorded by monitors with 10 km of the subject's house, and (2) cumulative metrics, which were based on the values of the individual events for that subject's location over the past 4 weeks and 12 months. These were incorporated into a summary record that contained summary metric information from all subjects as well as survey identification numbers so that it interfaced with the survey data.

A.2.2 Summary

The majority of respondents had generally positive things to say about their neighborhood. Most respondents reported that their neighborhood was a good or excellent place to live and that their general noise environment was either quiet or about average. In regards to respondents' awareness of the installation, most report that they were aware of the installation noise before they moved into the neighborhood, and that the installation was important for the economic health of the area. On the other hand, blast noise was the most annoying source around Installation A. Blast noise was also the second most frequently heard noise source of the 8 noise sources surveyed in this study; however, 74% of respondents report that they did not hear blast events that often, which may be a consequence of having such a large study area (64 km by 64 km).

In terms of factors that contributed to annoyance, it was found that speech interference did not contribute to annoyance, but habituation and vibration/rattle did contribute to annoyance. Respondents that self-report being able to habituate to noise had less overall annoyance than

those who self-report not being able to habituate to noise. In addition to habituation, 62% of respondents reported that they had experienced vibration or rattle from blast noise. When the respondents were divided up into geographical regions it was found that those who experienced rattle or vibration live in areas that are approximately 15-20 kilometers from the perimeter of the installation.

In terms of traditional blast noise assessment metrics (e.g. L_{Cdn} and L_{ZPk}), blast noise was weakly correlated with annoyance, there was high annoyance at relatively low LCdn levels, and a large number of events over a L_{ZPk} of 115 and 130 dB, yet the yearly average metrics (i.e., L_{Cdn}) were quite low. These findings are likely attributed to the sporadic nature of blast events distributed throughout a year, and support the current hypothesis that current or traditional blast noise assessment metrics do not properly account for the number and level nor the spatial and temporal variation of blast events.

A.3 In Situ Single and Series Event Survey Statistical Analysis

Because the single and series surveys assessed annoyance to noise on similar time scales, these data were analyzed together. At Installation B, 641 single/series surveys were completed , 391 of which could be matched with corresponding noise data. In these 391 records, 32 participants were represented, each individual having completed anywhere from 1 to 54 surveys. For Installation C, 654 single/series surveys were completed, 268 of which had corresponding noise data. These 268 records came from 17 participants, each individual having completed anywhere from 1 to 52 surveys. Therefore, across both installations, a total of 49 participants were represented in the 659 completed series / single event surveys. All single/series event analyses were performed using the SAS statistical software.

A.3.1 Model Exploration

A primary goal of this research was to assess which noise metric best captured individuals' annoyance to noise, in addition to which additional factors contributed to noise annoyance. To decide on a general model, a detailed investigation of the possible modeling strategies was first undertaken on the single/series survey data. This investigation examined the use of transformations, the inclusion of repeated measures for raters, and the inclusion of a random effect for the community of the rater. Six models, each having the same set of fixed effects were examined.

For this exploration, a single noise metric was included in the model in addition to several categorical explanatory variables. Because the tests for which metric best described annoyance were to be performed once the general model structure had been selected, the exact acoustic metric used in this stage was not entirely important, especially since all acoustic metrics were highly correlated. In this stage, the maximum A-weighted peak level was used as the noise metric of interest. The categorical explanatory variables were: a weekend/weekday variable (events ending Monday morning through 5:00 PM Friday were considered weekday events); a variable denoting whether a survey was of the single or series type; and a variable was used to denote whether participants were indoors or outdoors at the time of the event. In an effort to

compare both installations, a factor was also used to denote whether the participant was located at Installation B or Installation C. Finally, participant ID was used to model the dependence of multiple ratings from the same rater, and a Community variable was used as a random effect to model the dependence of raters from the same communities (e.g., B1, B2 and B3 for Installation B, and C1 and C2 for Installation C).

The Bayesian Information Criterion (BIC) was used to compare the modeling strategies. Three of the models transformed the annoyance using the natural logarithm of the annoyance ratings (where a constant of 1 was added to annoyance to avoid log-of-zero errors). Two models included neither repeated measures nor random community effects, two models included only repeated measures but not random community effects, and the final two included both repeated measures and random community effects. The fixed effects predictors for these models included the factors described above (weekend, type, installation, community), the maxApeak metric, and all factor by covariate interactions.

Examination of residual plots suggested that the log transformation improved the normality of the residuals, as well as homoscedasticity. Furthermore, the BIC values suggested that the best model was one that the random community effect and accounted for the repeated measures structure (BIC = 918, compared to BIC = 923 for repeated measures only, and BIC = 1527 with neither repeated measures nor community effects). The effect of community was less pronounced, but was still considered in the final model.

A.3.2 Relationship to Noise Metrics

Given the model structure resulting from the exploratory analysis above, the relationship between annoyance and noise was assessed by fitting this model using each noise metric individually. In total, 39 noise metrics were examined. The goal of this analysis was to find the noise metric that most accurately captured annoyance to blast noise. The models were first fit using maximum likelihood (ML) estimation, as this allowed direct comparison of the fit statistics (e.g., BIC) between models with different fixed effects structures. Models for the best metrics, in terms of BIC, were then refit using the restricted maximum likelihood (REML) estimation to obtain the actual model estimates relating annoyance to the metric values.

A.3.3 Series/Single Events Results

The BIC values estimated by maximum likelihood for the top 4 metrics found in the analysis of the single/series event data are seen in Table A.1. **Top 4 Maximum Likelihood estimates of the BIC for the models using noise metrics. All top metrics were day-night level metrics.**. The top four metrics were all Day-Night Level metrics, with the A-weighted L_{dn} displaying the best model fit. The difference in BIC between these top four metrics, however, is not very large, which is not surprising due to the very high correlation (> 0.8) between these metrics. Due to the small number of participants in the study and large variability in annoyance response, this likely does not present enough evidence to suggest that the L_{Cdn} currently used for blast noise policy be replaced with the L_{Adn}. Therefore, only the results for the relationship of annoyance with LCdn will be presented in the following.

Metric	ML BIC
L_{Adn}	701.9
L_{Cdn}	705.3
L_{Ndn}	711.6
L_{Zdn}	714.4

Table A.1. Top 4 Maximum Likelihood estimates of the BIC for the models using noise metrics. All top metrics were day-night level metrics.

The significant effects in this model were the LCdn, the weekend/weekday indicator, the installation, and their three-way interaction. Figure A-2 shows the result of the model fits for Installation B and C, back-transformed to the original annoyance scale. For Installation B, the relationship between annoyance and LCdn has a larger rate of increase on the weekend than it does during the week; that is, people will become annoyed more easily on the weekend (a cutoff of 104.3 dB on the weekday compared to 80.7 dB for the weekend). Note that the data, however, are not tightly clustered around the fitted lines, implying that the fitted models do not explain much of the variability in the annoyance ratings. As a result, the point estimates for cutoffs at which we can expect an annoyance of 8 are quite variable and have large standard errors, and if we were to repeat this experiment with a different sample of raters, we may well get a substantially different answer.

The results for Installation C are somewhat different. At this installation, only three events were reported on the weekend for the entire duration of the study, and several participants reported on a large number of blasts, yet did not rate any blasts higher than a 1 on the annoyance scale. This heavily biased the annoyance results at Installation C towards zero. Therefore, the model fits seen in Figure A-2 for the estimated annoyances at Installation C are incredibly flat, and fall almost uniformly between zero and one, as do the vast majority of the observations, regardless of the metric value, and regardless of whether we look at log- or original scale data.

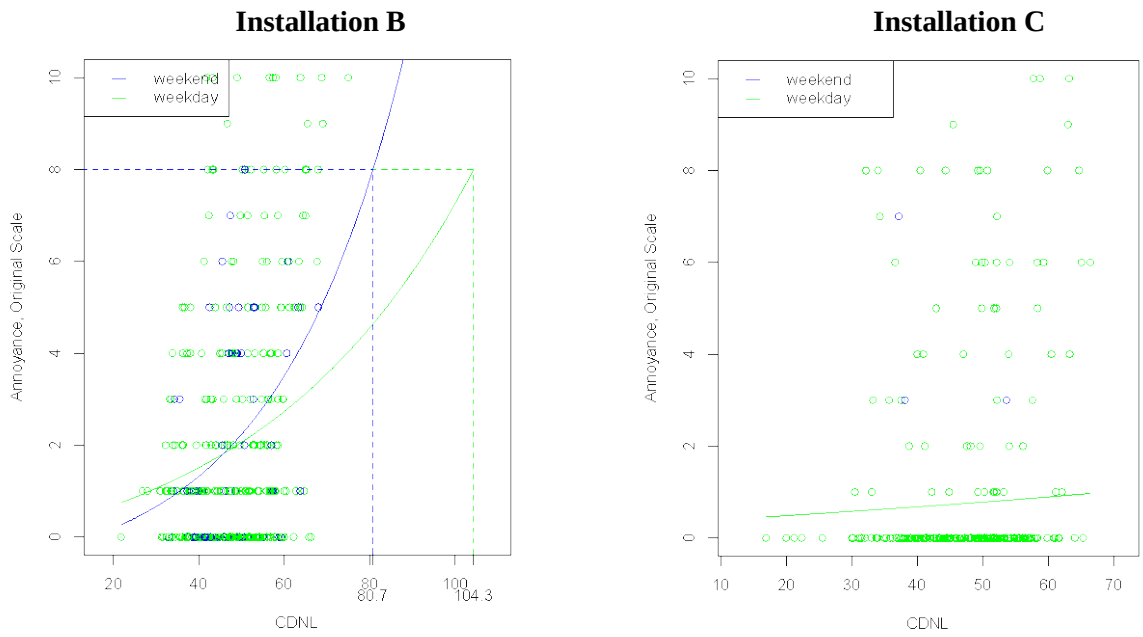

Figure A-2. Annoyance as a function of LCdn for weekday events (green circles) and weekend events (blue circles), with corresponding model fits. The high-annoyance cutoffs are shown as dotted lines on the Installation B plot. Due to the preponderance of low annoyance at Installation C, high-annoyance cutoffs could not be calculated.

B List of Scientific/Technical Publications

B.1 Peer-Reviewed Journal Articles

Nykaza, E. T., Hodgdon, K. K., Gaugler, T., Krecker, P. & Luz, G. A. On the relationship between blast noise complaints and community annoyance. *The Journal of the Acoustical Society of America* **133**, 2690-2698 (2013).

Valente, D., Nykaza, E. T., Swift, H. S. & Luz, G. Evolution of Metrics Used to Assess Community Response to Blast Noise. *Military Operations Research* **18**, 39-59 (2013).

Wilson, D. K., Valente, D., Nykaza, E. T. & Pettit, C. L. Information-criterion based selection of models for community noise annoyance. *The Journal of the Acoustical Society of America* **133**, EL195-EL201 (2013).

Wilson, D. K. *et al.* Sound Outdoors and Noise Pollution in *Handbook of Environmental Fluid Dynamics, Volume Two: Systems, Pollution, Modeling, and Measurements* (ed H.J. Fernando) (Taylor & Francis Group, 2012).

Valente, D. *et al.* Blast noise characteristics as a function of distance for temperate and desert climates. *The Journal of the Acoustical Society of America* **132**, 216-227 (2012).

Shelton, C. M., Vipperman, J. S., Nykaza, E. T. & Valente, D. Six noise type military sound classifier, in *ASME NCAD and INTER-NOISE Congress and Conference Proceedings.* 1886-1895 (Institute of Noise Control Engineering, 2012).

Cvengros, R. M., Valente, D., Nykaza, E. T. & Vipperman, J. S. Blast noise classification with common sound level meter metrics. *The Journal of the Acoustical Society of America* **132**, 822-831 (2012).

Nykaza, E. T., Pater, L. L., Melton, R. H. & Luz, G. A. Minimizing sleep disturbance from blast noise producing training activities for residents living near a military installation. *The Journal of the Acoustical Society of America* **125**, 175-184 (2009).

Nykaza, E. T., Pater, L. L. & Luz, G. A. Improved procedure for correlating blast noise events with complaint logs at U.S. Army installations. *Noise Control Engineering Journal* **56**, 451-459 (2008).

Luz, G., Nykaza, E. T., Stewart, C. & Pater, L. Use of actimeters to determine awakenings by sounds of large guns. *Noise Control Engineering Journal* **56**, 211-217 (2008).

B.2 Non-Peer-Reviewed Reports & Presentations

Wilson, D. K., Valente, D. & Nykaza, E. T. Assessment of the community tolerance level as a model for the prevalence of noise annoyance. *INTER-NOISE and NOISE-CON Congress and Conference Proceedings* **2012**, 1080-1093 (2012).

Nykaza, E. T. *et al.* An Investigation of Community Attitudes Toward Blast Noise: General Community Survey, Study Site 1. Report No. TR-12-9, (ERDC-CERL TR-12-9, 2012).

Nykaza, E. T. *et al.* An Investigation of Community Attitudes Toward Blast Noise: Complaint Survey Protocol. Report No. TR-12-8, (ERDC-CERL TR-12-8, 2012).

Valente, D. *et al.* Assessing the impact of blast noise on communities near U.S. Army installations in *11th International Congress on Noise as a Public Health Problem (ICBEN)* (London, UK, 2011).

Swift, S. H., Valente, D., Nykaza, E. T. & Hodgdon, K. Indoor human response to blast noise measured in situ. *The Journal of the Acoustical Society of America* **129**, 2378-2378 (2011).

Luz, G. A. & Nykaza, E. T. The Role of Habituation and Sensitization in Understanding the Annoyance of Community Exposures to Impulsive Noise. Report No. TR-9-14, (ERDC-CERL, 2009).

Hodgdon, K., Nykaza, E. T., Gaugler, T., Krecker, P. & Luz, G. Personal Interview Protocol Report. Report No. TR 09-005, (Applied Research Laboratory TR 09-005, State College, PA, 2009).

Nykaza, E. T., Luz, G. & Pater, L. Field research on the assessment of community impacts from large weapons noise in *ICBEN* (Foxwoods, CT, 2008).

Pater, L. L. *et al.* An Investigation of Community Attitudes Toward Blast Noise: Methodology. Report No. SR-07-24, (ERDC-CERL SR-07-24, 2007).

C Survey Instruments

C.1 General Community Survey Instrument

Part A: General Community Questions

The following questions in Part A are intended for use in the General Community Survey at all Installations. The specific questions and the order may vary between Installations. The specific questions to be included at each Installation will be determined in consultation with representatives from each Installation.

INTERVIEW ID: _____ _____
(house) (person)

INTERVIEW DATE: ____ /____/_____
(mo)/(day)/(year)

INTERVIEW TIME: ____:____ AM or PM (survey is to be conducted between 9 AM and 8 PM)

INTERVIEWER ID: ____

OMB No.: 0710-0015
OMB Expires: 31 May 2011

Agency Disclosure Notice

The public report burden for this information collection is estimated to average 30 - 45 minutes for the interview, including the time for reviewing instructions, searching existing data sources, gathering and maintaining data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this data collection, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Executive Services Directorate, Information Management Division, (0710-0015), 1155 Defense Pentagon, Washington DC, 20301-1155, and the Office of Information and Regulatory Affairs, Office of Management and Budget, Washington, D.C. 20503, Attn.: Desk Officer for U.S. Army Corps of Engineers.

Respondents should be aware that not withstanding any other provision of law, an agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number. PLEASE DO NOT RETURN YOUR SURVEY TO THE ABOVE ADDRESSES.

Introduction (Implied Consent)

Good morning/afternoon/evening. My name is _____ and I am calling on behalf of the U.S. Army Corps of Engineers and Pennsylvania State University. We are conducting a research study about residents' attitudes about their community. It is important that we talk to different types of people and your household is one of a small number randomly selected from this community.

To make sure that our study represents people who live in your community and are able to answer our questions, I need to speak with an adult that lives at this residence. Would that be you?

1 YES (repeat intro)
2 NO (THANK AND EXIT)

I would like to verify your location. Do you live at [address]?

1 YES (CONTINUE)
2 NO (THANK AND EXIT)

CONF: Before we begin, I need to tell you a few things.

Your response is voluntary, you can quit at any time, and you may choose not to answer certain questions. The results of this study will be summarized so that the answers you provide cannot be associated with you or anyone in your household. The length of the interview varies from person to person, but most interviews last about 30 minutes. You must be 18 years of age or older to consent to take part in this research study. Responding to the survey questions implies your consent to participate in the survey. If you have any questions about the survey, you can contact Kathleen K. Hodgdon at (814) 865-2447 or (kkh2@psu.edu) at the Pennsylvania State University or Peg Krecker at (608) 443-2700 at PA Consulting Group

Do you have any questions before we begin?

Household Size and General Neighborhood Characteristics

A1. First, including yourself, how many people live in your household?

1
2
3
4
5
6
7
8
-8 Don’t know
-9 Refused

A2. Do any children under age 6 live in your household?

1 Yes
2 No
-9 Don’t know

A3. Including yourself, how many adults age 18 or older live in your household?

1
2
3
4
5
8
-9 Refused

A4. Have you heard about this survey before my call today?

1 Yes
2 No
-8 Refused

A5. How would you rate your neighborhood overall as a place to live? Would you say terrible, poor, average, good, or excellent?

1 Terrible
2 Poor
3 Average
4 Good
5 Excellent
-8 Don't know

A6. What are some of the things you LIKE most about living in your neighborhood?

_____

A7. What are some of the things you DISLIKE most about living in your neighborhood?

_____

A8. While we are interested in all neighborhood conditions, we are particularly interested in the various kinds of noises that people hear in this area. Do you think your neighborhood is quiet or noisy or about average?

1 Quiet
2 Average
3 Noisy
-8 Don't know
-9 Refused

A9.Can you tell me more about why you feel that way?

_____

I am going to read a list of neighborhood noises. During the **last 12 months** when you were at home, how much did noise from each of these sources bother, disturb, or annoy you?

B1. Barking dogs

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely

B2. Thunder

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely
-8 Don’t know
-9 Refused

B3. Street traffic

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely

B4. Commercial aircraft

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely
-8 Don’t know

B5. Military aircraft, including military helicopters, jets, and prop planes.

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely
-8 Don’t know

B6. Military ground vehicles

1 Not at all
2 Slightly
3 Moderately
4 Very

B7. Small military gunfire

1
1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely
-8 Don’t know

B8. Large military guns, bombs, or explosions

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely
-8 Don’t know
-9 Refused

I am going to read the same list of neighborhood noises but now I’d like you to think about the last 4 weeks. During the last **4 weeks** when you were at home, how much did noise from each of these sources bother, disturb, or annoy you?

B9. Barking dogs

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely
-9 Refused

B10. Thunder

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely
-8 Don’t know

B11. Street traffic

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely

B12. Commercial aircraft

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely

B13. Military aircraft, including military helicopters, jets, and prop planes.

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely
-8 Don’t know

B14. Military ground vehicles

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely
-8 Don’t know

B15. Small military gunfire

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely
-8 Don’t know

B16. Large military guns, bombs, or explosions

1 Not at all
2 Slightly
3 Moderately
4 Very
5 Extremely
-8 Don’t know

During the last **4 weeks** when you were at home, how often did you hear each of the following noises – not at all, only occasionally, moderately often, frequently, or very often?

B17. Street traffic

1 Not at all
2 Only occasionally
3 Moderately often
4 Frequently
5 Very often
-8 Don’t know
-9 Refused

B18. Commercial aircraft

1 Not at all
2 Only occasionally
3 Moderately often
4 Frequently
5 Very often
-8 Don’t know

B19. Military aircraft, including military helicopters, jets, and prop planes

1 Not at all
2 Only occasionally
3 Moderately often
4 Frequently
5 Very often
-8 Don’t know

B20. Military ground vehicles

1 Not at all
2 Only occasionally
3 Moderately often
4 Frequently
5 Very often
-8 Don’t know

B21. Small military gunfire

1 Not at all
2 Only occasionally
3 Moderately often
4 Frequently
5 Very often
-8 Don’t know

B22. Large military guns, bombs, or explosions

1 Not at all
2 Only occasionally
3 Moderately often
4 Frequently
5 Very often
-8 Don’t know

B23. Is there a particular time of day when noises from your neighborhood are most disturbing?

1 Yes
2 No
-8 Don't Know

B24. [If B23=1] What times of day are the noises from your neighborhood most disturbing?

___:___ AM/PM TO ___:___ AM/PM
___:___ AM/PM TO ___:___ AM/PM
___:___ AM/PM TO ___:___ AM/PM

Rattle and Vibration

The next questions are about vibration and rattles.

C1. Vibration is a motion. The motion may be seen, felt or heard. Rattle is a type of noise that can occur when objects move due to a vibration. Have you ever experienced rattle or vibration in your home from large military guns, bombs or explosions?

1 Yes
2 No (Skip to C7)
-8 Don't know (Skip to C7)

C2. What structures in your home rattled or vibrated?

Windows

0 Not mentioned
1 Mentioned
-7 Not applicable
-8 Don't know
-9 Refused

Walls

0 Not mentioned
1 Mentioned
-7 Not applicable
-8 Don't know
-9 Refused

Shelves

0 Not mentioned
1 Mentioned
-7 Not applicable
-8 Don't know
-9 Refused

China

0 Not mentioned
1 Mentioned
-7 Not applicable
-8 Don't know
-9 Refused

Small decorative items

0 Not mentioned
1 Mentioned
-7 Not applicable
-8 Don’t know
-9 Refused

Floors

0 Not mentioned
1 Mentioned
-7 Not applicable
-8 Don’t know
-9 Refused

Garage door

0 Not mentioned
1 Mentioned
-7 Not applicable
-8 Don’t know
-9 Refused

Other

0 Not mentioned
1 Mentioned
-7 Not applicable
-8 Don’t know
-9 Refused

Entire house

0 Not mentioned
1 Mentioned
-7 Not applicable
-8 Don’t know
-9 Refused

Pictures

0 Not mentioned
1 Mentioned
-7 Not applicable
-8 Don’t know
-9 Refused

Chandelier

0 Not mentioned
1 Mentioned
-7 Not applicable
-8 Don't know
-9 Refused

Doors

0 Not mentioned
1 Mentioned
-7 Not applicable
-8 Don't know
-9 Refused

Lights

0 Not mentioned
1 Mentioned
-7 Not applicable
-8 Don't know
-9 Refused

C3. During the last **4 weeks**, has the noise or rattle from military gunfire, bombs or explosions interfered with your ability to talk with others or hear conversations INSIDE your home?

1 Yes
2 No
-7 Not applicable
-8 Don't know

C4. During the last **4 weeks**, has the noise or rattle from military gunfire, bombs or explosions interfered with your ability to talk with others or hear conversations OUTSIDE your home?

1 Yes
2 No
-7 Not applicable
-8 Don't know

C5. During the last **4 weeks**, has noise or rattle from military gunfire, bombs or explosions disturbed or disrupted your other activities INSIDE your home?

1 Yes
2 No
-7 Not applicable
-8 Don't know

C6. During the last **4 weeks**, has noise or rattle from military gunfire, bombs or explosions disturbed or disrupted your other activities OUTSIDE your home?

1 Yes
2 No
-7 Not applicable
-8 Don't know

C7. Since you have been living at your current address, have you ever been awakened by noises coming from outside your home?

1 Yes
2 No
-8 Don't know

C8. What was the source of the noise that awakened you?

_____

C9. During the last 12 months, how often do you recall having been awakened by noise from [C8]?

1 Not at all
2 Only occasionally
3 Moderately often
4 Frequently
5 Very often
-7 Not applicable

C10. Has this happened to you in the last **4 weeks**?

1 Yes
2 No
-7 Not applicable
-8 Don't know

Thinking about the last 12 months, when you are at home, how often does noise in your neighborhood affect you in the following ways.

D1. First, how often does the noise (in your neighborhood) startle you or make you jump? Would you say not at all, only occasionally, moderately often, frequently, or very often?

1 Not at all
2 Only occasionally
3 Moderately often
4 Frequently
5 Very often
-8 Don't know
-9 Refused

D2. How often does the noise frighten you?

1 Not at all
2 Only occasionally
3 Moderately often
4 Frequently
5 Very often
-8 Don't know

D3. How often does the noise cause you to feel irritable or edgy?

1 Not at all
2 Only occasionally
3 Moderately often
4 Frequently
5 Very often

D4. How often does the noise make you become tense or nervous?

1 Not at all
2 Only occasionally
3 Moderately often
4 Frequently
5 Very often
-8 Don't know

E1. I'm going to read several statements. For each statement, please tell me if you strongly disagree, moderately disagree, neither agree nor disagree, moderately agree or strongly agree.

I believe that people have a hard time getting used to noise.

1 Strongly disagree
2 Moderately disagree
3 Neither agree nor disagree
4 Moderately agree
5 Strongly agree
-8 Don't know

E2. I believe that people get used to road traffic noise.

1 Strongly disagree
2 Moderately disagree
3 Neither agree nor disagree
4 Moderately agree
5 Strongly agree
-8 Don't know
-9 Refused

E3. I believe that with time most people adapt to noise.

1 Strongly disagree
2 Moderately disagree
3 Neither agree nor disagree
4 Moderately agree
5 Strongly agree
-8 Don't know
-9 Refused

E4. I believe that with time I can adapt to noise.

1 Strongly disagree
2 Moderately disagree
3 Neither agree nor disagree
4 Moderately agree
5 Strongly agree
-8 Don't know
-9 Refused

E5. I believe that with time I can get used to even the loudest noise.

1 Strongly disagree
2 Moderately disagree
3 Neither agree nor disagree
4 Moderately agree
5 Strongly agree
-8 Don't know
-9 Refused

Part B: Installation-Specific Questions

These next questions are about [NAME OF INSTALLATION] and how you feel about living close to it.

F1. Do any members of your household currently work for the military installation?

1 Yes
2 No
-8 Don't know

F2. Have any members of your household ever served in the Armed Services?

1 Yes
2 No
-8 Don't know

F3. Do any members of your household currently receive retirement or disability income as a result of military or civilian service in the Department of Defense?

1 Yes
2 No
-8 Don't know

F4. How would you rate the importance of [NAME OF INSTALLATION] for the economic health of your town and county? Please select from one of the following [READ RESPONSES]

1 Not at all important
2 Slightly important
3 Moderately important
4 Very important
5 Extremely important
6 Other *(SPECIFY)*
-8 Don't know
-9 Refused

F5. How would you rate the importance of Federal funding to your local school district from the [NAME OF INSTALLATION]?

1 Not at all important
2 Slightly important
3 Moderately important
4 Very important
5 Extremely important
6 Other
-8 Don't know
-9 Refused

The next questions ask about the time you personally are at home. Remember that this information will be kept confidential and will only be used to help us better understand your answers to the questions. The times that you provide will allow us to understand your answers with regard to likely noise sources in the community.

G1. On a typical weekday, about what time do you usually wake up?

____:____ AM or PM
-8 Don't know
-9 Refused

G2.On a typical weekday, about what time do you usually fall asleep?

____:____ AM or PM
-8 Don't know
-9 Refused

G3. On a typical weekday, how many hours are you usually at home in the morning between the hours of 6 AM and 8 AM? [IF NEEDED, REMIND THAT THIS IS A 2-HOUR PERIOD]

__ hours
-8 Don't know
-9 Refused

G4. On a typical weekday, how many hours are you at home during the day? That is between the hours of 8 AM and 6 PM? [IF NEEDED, REMIND THAT THIS IS A 10-HOUR PERIOD]

__ hours
-8 Don't know
-9 Refused

G5. On a typical weekday, how many hours are you at home in the evening between the hours of 6 PM and 10 PM? [IF NEEDED, REMIND THAT THIS IS A 4-HOUR PERIOD]

__ hours
-8 Don't know
-9 Refused

G6. On a typical weekday, how many hours are you at home during sleeping hours? That is between the hours of 10 PM and 6 AM? [IF NEEDED, REMIND THAT THIS IS AN 8-HOUR PERIOD]

__ hours
-8 Don't know
-9 Refused

H1. How long have you lived at your current address? [READ LIST]

1 Less than one year
2 1-5 years
3 6-10 years
4 More than 10 years
-8 Don't know

H2. Do you rent or own your home?

1 Rent
2 Own
3 Other
-8 Don't know
-9 Refused

H3. About how old is your home?

1 0-10 years
2 11-20 years
3 21-30 years
4 31-40 years
5 More than 40 years
-8 Don't know

H4. How old are most of the windows in your home?
[Interviewer prompt if necessary: Are they the original or replacement windows?]

1 0-10 years
2 11-20 years
3 21-30 years
4 31-40 years
5 More than 40 years
6 Other
-8 Don't know
-9 Refused

H5. Are most of the windows in your home single-frame, double-frame, single-paned, or double-paned?

1 Single frame
2 Double frame
3 Single paned
4 Double paned (Insulated or storm windows in place)
5 Other
-8 Don't know
-9 Refused

H6. What is the type of construction of your home?

1 Stone
2 Brick
3 Aluminum siding
4 Vinyl siding
5 Stucco
6 Wood frame
7 Modular unit
8 Concrete block
9 Other
10 Brick and vinyl
-8 Don't know
-9 Refused

H7. Which of the following best describes the type of home in which you live? [READ LIST]

1 Single-family detached [no common walls]
2 Single-family attached [at least one common wall with the surrounding dwellings]
3 Multi-family home [more than one common wall]
4 A mobile home or trailer
5 Other
-8 Don't know
-9 Refused

H8. (If H7=1) What is the style of the house?

1 Two story
2 Two story with basement
3 Ranch on concrete slab
4 Ranch with basement
5 Bi-level
6 Other style *(SPECIFY)*
7 Ranch on blocks
-7 Not applicable
-8 Don't know
-9 Refused

H9. Have you ever considered moving to another community because of the noise in your area?

1 Yes
2 No

H9a. [H9=1] Can you tell me more about that?

H9b. Were you aware that activities at [NAME OF INSTALLATION] may create noise before you first moved to your current neighborhood?

1 Yes
2 No
-8 Don't know
-9 Refused

H10. To the best of your knowledge is your hearing normal?

1 Yes
2 No
-8 Don't know

H11. [If H10=2] Do you use a hearing aid?

1 Yes
2 No
-7 Not applicable

END1. One of my supervisors may contact you in the next week or so. It will only take a few minutes. The supervisor will want to make sure that all of your questions were addressed and that the interview was conducted properly.

ENDPHONE. What is the best telephone number where a supervisor could reach you? [INCLUDE AREA CODE]

ENDTIME. What is the best time of day for them to call? [IF NECESSARY: It would only take a few minutes.]

ENDNAME. And, what is your name?

END2. Thank you very much. We appreciate your help with this study.

H12. [INTERVIEWER]: Did the Respondent's hearing capacity seem to be:

1 Normal
2 Somewhat Diminished -→ DESCRIBE EXTENT OF PROBLEM BELOW
3 Severely Diminished -→ DESCRIBE EXTENT OF PROBLEM BELOW

H13. [If H12=2,3] Describe extent of hearing problem.

_____

C.2 In situ Survey Instrument

Instructions for daily response surveys

Please fill out these surveys twice a day (once in the morning when you wake up and once in the evening before you go to bed). Please fill out these surveys even if you did not hear any blast noise events.

Header Questions:

Please enter the time period you are reporting on.

For the nighttime survey: Please fill out the nighttime survey when you get up in the morning. Please enter the approximate time you went to bed and approximate time you woke up in the morning.

For the daytime survey: Please fill out the daytime survey before you go to bed at night. If you were home for the entire day, please enter the approximate time you got out of bed in the morning as the start time and the approximate time you are filling out this survey as the end time. If you were gone for a significant portion of the day (more than a couple of hours), please report on the time you were home. For example, if you were away from your home in the morning and back at 1PM then you would fill out 1PM as your start time and the time you are filling out this survey as your end time. Also, in complicated cases where you are in and out of the house several times for different time periods, report on the time period that you where home for a significant portion of the day. For example, if you were gone from 8-9AM, 11AM-1PM, and 3PM-5PM report on the entire day and put a short note in the comments section that you were gone several times during the day.

Please enter the number of blast events you heard over this time period. For daily surveys **only report on blast events**. That is, the noise from large military guns, bombs, or explosions. If you would like to give us feedback on other noises you are welcome, but not required, to report that information in the individual surveys. **Note:** If you did not hear any blast events over the time period please enter 0 blast events and remember to submit the survey.

Questions 1-6:

Please respond to all 5 questions in regards to the time period and number of events you are reporting on. If you miss a question the computer will ask you to answer that question before allowing you to submit the survey.

Question 6 (extra comments) is optional. This question is provided in the case you have additional information about the time period and events you are reporting for this survey. These questions/comments will not be looked at until the data is collected.

If you have general comments and concerns please call or email the study team. A phone number and email option is included on the main menu of the survey.

Instructions for individual or series of event surveys:

Header Questions:

Please enter the time of the single event or series of noise events to the best of your ability. For example, if you heard a blast event at 7:16, you would enter the start time as 7:15 and the end time as 7:20. This way we know that event occurred between 7:15 and 7:20 and will be able to look at the noise data to identify the noise(s) you were reporting on. Or, if you heard 6 blast events between 8:17 and 9:43 you would enter 8:15 as the start time and 9:45 as the end time.

Please enter the type of noise you are reporting on. This study is looking to get your opinion of blast noise; that is, the noise from large military guns, bombs, or explosions. However, if you wish to report on other noises please check all of the noises that you are reporting on below. You can check more than one box. Reporting on the other noises besides large military guns, bombs, and explosions is not required.

Please enter the number of noise events that you heard over the time period you entered above. The more feedback you can give us about individual events the better; however, we understand that it may not be feasible to fill out a survey every few minutes and have included the option of reporting on a series of consecutive noise events. For example, if 6 blast noise events occur every 15 minutes you can fill out one survey to cover all 6 noise events rather than filling out 6 individual noise events.

Questions 1-9:

Please respond to all 8 questions in regards to the time period and number of events you are reporting on. If you miss a question the computer will ask you to answer that question before allowing you to submit the survey.

Question 9 (extra comments) is optional. This question is provided in the case you have additional information about the time period and events you are reporting for this survey. These questions/comments will not be looked at until the data is collected.

If you have general comments and concerns please call or email the study team. A phone number and email option is included on the main menu of the survey.

Here is the checklist to be added to the individual or series of individual event survey:

Please check the boxes for the noises you are reporting on. Noise from:

- ☐ Large military guns, bombs, or explosions
- ☐ Small military gunfire
- ☐ Military ground vehicles
- ☐ Military aircraft, including military helicopters, jets, and prop planes
- ☐ Other (please describe the “other noise” in the comment section.)

Single & Series Survey Instrument

Subject #_____

Enter the time of the single event or series of blast noise events:

Start Date/Time:__/__/__ __:__ AM or PM
mm/dd/yy hh:mm (circle one)

End Date/Time:__/__/__ __:__ AM or PM
mm/dd/yy hh:mm (circle one)

Approximate number of blasts in time period given above: _____

1) Next is a zero to ten opinion scale for how much blast noise bothers or annoys you when you are here at home. If you are not at all annoyed choose zero, if you are extremely annoyed choose ten, if you are somewhere in between choose a number between zero and ten. Thinking about the event that you just heard, what number from zero to ten best shows how much you are bothered or annoyed by blast noise?

(Not at all) 0 1 2 3 4 5 6 7 8 9 10 (Extremely)

2) Where you inside or outside of your home when the blast noise event occurred? Circle One: Inside Outside

3) Thinking about what you were doing when the blast noise occurred, use a zero to ten-opinion scale to rate how loud that activity noise was. For example, if you were doing a quiet activity, such as napping or reading, you might rate the activity noise as not at all loud. If you were doing a loud activity such as using a power tool or mowing the lawn, you might rate it extremely loud.

(Not at all) 0 1 2 3 4 5 6 7 8 9 10 (Extremely)

4) Use a zero to ten-opinion scale to rate how loud the blast noise sounds when you are here at home. If the blast noise was not at all loud choose zero, if the blast noise was extremely loud choose ten, if you are somewhere in between choose a number between zero and ten. Thinking about the event that you just heard, what number from zero to ten best shows how loud the blast noise was?

(Not at all) 0 1 2 3 4 5 6 7 8 9 10 (Extremely)

5) Did the blast noise you heard interfere with your activity? Use a zero to ten opinion scale to rate how intrusive the blast noise sounds when you are here at home. If the blast noise was not at all intrusive choose zero, if the blast noise was extremely intrusive choose ten, if you are somewhere in between choose a number between zero and ten. Thinking about the event that you just heard, what number from zero to ten best shows how intrusive the blast noise was?

(Not at all) 0 1 2 3 4 5 6 7 8 9 10 (Extremely)

6) Did the blast noise startle you or make you jump? If you were not at all startled choose zero, if you were extremely startled choose ten, if you were somewhere in between choose a number between zero and ten. Thinking about the event that you just heard, what number from zero to ten best shows how much you are startled by blast noise?

(Not at all) 0 1 2 3 4 5 6 7 8 9 10 (Extremely)

7) Vibration is a motion. The motion may be seen, felt or heard. For this question, we mean how much vibration did you notice that you could see or feel. If the blast noise caused no vibration that you noticed choose zero, if the blast noise caused a great deal of vibration choose ten, if the vibration was somewhere in between choose a number between zero and ten. Thinking about the event that you just heard, what number from zero to ten best shows how much vibration you noticed as a result of the blast noise?

(None) 0 1 2 3 4 5 6 7 8 9 10 (A great deal)

8) Rattle is a type of noise that can occur when objects move due to a vibration. For this question, how much rattle did you notice? If the blast noise caused no rattle that you noticed choose zero, if the blast noise caused a great deal of rattle choose ten, if the rattle was somewhere in between choose a number between zero and ten. Thinking about the event that you just heard, what number from zero to ten best shows how much rattle did you notice as a result of the blast noise?

(None) 0 1 2 3 4 5 6 7 8 9 10 (A great deal)

9) Extra Comments? -

_____

Summary Survey Instrument

Subject #_____

What time period are you reporting? Circle One: Daytime Survey Nighttime Survey

Fill out Daytime Survey before you go to bed.

Fill out Nighttime Survey when you get up in the morning.

Enter the time period you are reporting:

Start Date/Time:__/__/__ __:__ AM or PM End Date/Time:__/__/__ __:__ AM or PM
mm/dd/yy hh:mm (circle one) mm/dd/yy hh:mm (circle one)

1) How many blast events do you recall hearing today (or last night) while at home? _____
If 0 skip questions 2-6.

2) Next is a zero to ten opinion scale for how much blast noise bothers or annoys you when you are here at home. If you are not at all annoyed choose zero, if you are extremely annoyed choose ten, if you are somewhere in between choose a number between zero and ten. Thinking about the last 12 hours what number from zero to ten best shows how much you are bothered or annoyed by blast noise?

(Not at all) 0 1 2 3 4 5 6 7 8 9 10 (Extremely)

3) Use a zero to ten opinion scale to rate how loud the blast noise sounds when you are here at home. If the blast noise was not at all loud choose zero, if the blast noise was extremely loud choose ten, if you are somewhere in between choose a number between zero and ten. Thinking about the last 12 hours, what number from zero to ten best shows how loud the blast noise was?

(Not at all) 0 1 2 3 4 5 6 7 8 9 10 (Extremely)

4) Did the blast noise you heard interfere with your activities? Use a zero to ten opinion scale to rate how intrusive the blast noise sounds when you are here at home. If the blast noise was not at all intrusive choose zero, if the blast noise was extremely intrusive choose ten, if you are somewhere in between choose a number between zero and ten. Thinking about the last 12 hours, what number from zero to ten best shows how intrusive the blast noise was?

(Not at all) 0 1 2 3 4 5 6 7 8 9 10 (Extremely)

5) Vibration is a motion. The motion may be seen, felt or heard. For this question, we mean how much vibration did you notice that you could see or feel. If the blast noise caused no vibration that you noticed choose zero, if the blast noise caused a great deal of vibration choose ten, if the vibration was somewhere in between choose a number between zero and ten. Thinking about the last 12 hours, what number from zero to ten best shows how much vibration you noticed as a result of the blast noise?

(None) 0 1 2 3 4 5 6 7 8 9 10 (A great deal)

6) Rattle is a type of noise that can occur when objects move due to a vibration. For this question, how much rattle did you notice? If the blast noise caused no rattle that you noticed choose zero, if the blast noise caused a great deal of rattle choose ten, if the rattle was somewhere in between choose a number between zero and ten. Thinking about the last 12 hours, what number from zero to ten best shows how much rattle did you notice as a result of the blast noise?

(None) 0 1 2 3 4 5 6 7 8 9 10 (A great deal)

7) Extra Comments? -

_____