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TERRAIN AND THE PHYSICAL ENVIRONMENT: FACTORS FOR CONSIDERATION IN NOISE MITIGATION

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TERRAIN AND THE PHYSICAL ENVIRONMENT: FACTORS FOR CONSIDERATION IN NOISE MITIGATION

1. Purpose

a. Army training involves live-fire and ordnance activities that generate high-amplitude sound and potential restrictions on training areas. Army installations are faced with new requirements and must rapidly adapt to control noise without impacting mission. In addition, high-amplitude sound can pose risks to soldier health, disturb wildlife, and provoke civil affairs issues with surrounding communities.

b. This Public Works Technical Bulletin (PWTB) offers assistance with these challenges by explaining both the physical effects of terrain on sound propagation and the use of digital terrain maps when preparing noise assessments. With the increasing availability of digital terrain maps, it is now possible to consider the role of terrain when preparing noise contours for military installations with live-fire training and demolition activities. It is difficult, however, to anticipate whether the terrain in the vicinity of an installation will be of benefit for noise shielding, and whether attention given to the question will change the noise assessment. Currently, the best practice is to try both scenarios when preparing noise contours (i.e., with terrain and without); doing so removes uncertainty. This PWTB helps to overcome this assessment dilemma by outlining steps to using terrain maps with noise analyses software.

c. The information in this PWTB is primarily for the graphical information system (GIS) specialist who may be tasked with preparing such an assessment. However, the material also provides general guidance on how to interpret noise contours that may be useful to urban planners, land managers, and others interested in knowing more about training range noise.

d. All PWTBs are available electronically at the National Institute of Building Sciences' Whole Building Design Guide webpage, which is accessible through this link:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability

a. This PWTB applies to all US Army facilities' engineering activities.

3. References

a. Army Regulation (AR) 200-1, "Environmental Protection and Enhancement," revised 13 December 2007.

b. "Noise Control Act of 1972," Public Law (PL) 92-574, 86 Statute 1234, 42 U.S.C. § 4901–42 U.S.C. § 4918, 27 October 1972.

c. "National Environmental Policy Act of 1969 (NEPA)," PL 91-190, 42 U.S.C. § 4321, § 4331-4335, 1 January 1970, as amended.

d. Department of Defense (DoD), Acquisition Technology and Logistics (AT&L), "Defense Noise Program," Department of Defense Instruction (DODI) 4715.13, 15 November 2005.

e. Department of Defense Noise Working Group (DNWG) Technical Bulletin, "An Overview of Blast Noise: Characteristics, Assessment, and Mitigation," 2013.

f. Departments of the Air Force, Army and Navy, "Environmental Protection for Planning in the Noise Environment," Air Force Manual (AFM) 19-10, Army Technical Manual (TM) 5-803-2, and Naval Facilities Engineering Command (NAVFAC) P-970, 15 June 1978.

4. Discussion

a. AR 200-1 contains noise metrics and thresholds used to prepare Noise Management Plans for Army installations. Land use planning promotes compliance with the Noise Control Act and helps to satisfy NEPA requirements.

b. The Noise Control Act of 1972 requires federal agencies to be responsible for noise they produce and to comply with all state laws and local ordinances pertaining to noise.

c. NEPA requires that major federal actions be preceded by Environmental Impact Statements (EIS), containing a description of the proposed action and its impacts and consideration of possible alternatives.

d. DODI 4715.13 established the Defense Noise Program and DNWG to reduce adverse effects from the noise associated with military test and training operations.

e. The DNWG Technical Bulletin provides relevant and basic notions of blast sound generation, propagation, and reception to better interpret noise assessments and devise noise mitigation strategies.

f. The tri-service document for planning in the noise environment was first published in 1978 and is now under revision. The document contains much information about characteristics and measurement of military noise, noise assessment, recommended noise levels, reducing noise conflict, and noise planning strategies.

g. Appendix A describes the physical effects of the environment on sound propagation for noise analyses and concludes with an example of terrain shielding of noise by the natural landscape.

h. Appendix B is an introduction to blast noise impact assessment software (BNOISE), which enables the preparation of long-term noise assessments for large- and medium-large caliber (20 mm and larger) and other impulsive sound sources including all grenades, bombs, rockets, and demolition charges.

i. Appendix C provides step-by-step instructions for preparing a terrain map appropriate for conducting noise analyses with BNOISE.

j. Appendix D contains a list of references, abbreviations and their meanings, and a glossary of terms used in this PWTB.

k. Software for conducting noise analyses with BNOISE and Small Arms Range Noise Assessment Model (SARNAM) can be obtained by contacting the technical POC listed below in item 5b.

5. Points of Contact

a. Headquarters, US Army Corps of Engineers (HQUSACE) is the proponent for this document. The point of contact (POC) at HQUSACE is Mr. Malcolm E. McLeod, CEMP-CEP, 202-761-5696, or e-mail: Malcolm.E.Mcleod@usace.army.mil.

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APPENDIX A: TERRAIN AND THE PHYSICAL ENVIRONMENT: FACTORS FOR CONSIDERATION IN NOISE MITIGATION

Introduction

Noise that reaches the community from Army installations can generate complaints. Unlike industrial noise, noise from military live-fire training and demolition is intermittent, very short in duration (*impulsive*[1]), and has significant low-frequency content. *Sound propagation* from these military sources is both transient and varies from shot to shot. Also, factors such as wind, temperature stratification, vegetation, ground surface, recent precipitation, hills, and built structures can significantly influence the received sound level. The interaction of sound with the surface features is the primary focus of this document.

Noise assessment can be accomplished through measurements in the field that use precision sound-level meters deployed at positions of concern (Schomer et al. 1988; Sachs et al. 1999). Because of great variability in received sound level, however, achieving statistical significance with this method can require many (i.e., dozens of) measurement positions and recording times that last for weeks or months (Schomer et al. 1976; Valente et al. 2012). Given the time and resources required for that type of measurement, noise monitoring has been favored for only a few critical noise assessments.

Software for Noise Assessment

All but the simplest noise analyses for military live-fire training must be conducted by computer software because of the complexity and tedium involved in doing the calculations by hand. Firing noise is typically assessed on and around installations with special-purpose software developed for the military, such as BNOISE version 2 (BNOISE2), SARNAM, or Range Managers Toolkit (RMTK).[2] The first two of these computer programs were developed for producing long-term noise assessments as required in AR 200-1 (US Army 2007). Output from these noise assessments

[1] Italicized terms through this document are further defined in the glossary located in Appendix D. Definitions were taken from ANSI S12.9/Part 1; ANSI S1.1; and Morfey 2000.

[2] Software discussed here, including BNOISE, SARNAM, and portions of RMTK/Noise Tool has been developed by ERDC-CERL.

may be used in public release documents, such as EIS and NEPA documentation. The third, RMTK/Noise Tool, is for short-term and rapid-response estimation. The RMTK Noise Tool was developed for the US Army Sustainable Range Program, to provide a tool for installations to use when assessing the risk of receiving a noise complaint due to training or testing operations. Output from the RMTK Noise Tool is not permitted in public release documents, due to its close integration with potentially sensitive range safety information.

All of these software packages accept information such as: firing and target positions; gun, bomb, or explosive source type; number of shots fired; time of day; weather conditions; and assessment duration. These software packages all produce output in the form of a map layer of noise levels appropriate for the noise assessment being performed. Each software package has a component that adjusts in some way for the interaction of sound with the surface or surface features, and that interaction with terrain is the main focus of this document.

Noise Zone Designations

As described in AR 200-1, impulsive noise from medium-large caliber guns and explosives (with charge weight above 20 g) is assessed separately from small-arms noise. For those larger caliber guns and explosions, AR-200-1 describes the *Land Use Planning Zone* (LUPZ) as including any area between *C-weighted day-night level* (CDNL) contours of 57 decibels (dB) and 62 dB. *Noise Zone* I areas apply to CDNL below 62 , Noise Zone II areas include values of CDNL 62-70 dB, and Noise Zone III applies to areas with CDNL exceeding 70 dB. These noise zones are used by the Army to manage actions for mitigation of noise impacts from larger impulsive noise sources. For example, noise-sensitive development areas such as housing and schools are normally not recommended to be located in Noise Zone II and not recommended ever to be placed in Noise Zone III.

Similar nomenclature is used (but with different metrics and threshold values) for assessing risk of complaint from small-arms ranges. Because proper noise management potentially affects the cost of operations, training quality, and community relations, it is important to base noise assessments on correct methodology. BNoise2 and SARNAM can produce *noise contours* corresponding to metrics and thresholds described in AR 200-1 (US Army 2007).

Under DODI 4715.13 section 4.4, the DoD noise program shall "Promote scientific research and the use of sound scientific methods and validated noise data as the basis for and the establishment of noise program guidance" (US DoD 2005). Therefore, research is ongoing at ERDC-CERL to refine the metrics to be used in noise assessments, and noise assessment models will be adjusted as needed to reflect best practice and applicable policy.

The next section briefly covers some important effects that environment can have on sound propagation. The third section in this appendix illustrates the effect of terrain shielding and gives an example of noise assessment using the BNOISE software (see Appendix B for background of BNOISE software). Currently, of the three software packages previously mentioned, only BNOISE can accept and use a digital terrain map. The effects of terrain are important, because the shielding of noise by terrain could be used to advantage when deciding where to place ranges on Army installations.

Sound Propagation in the Environment

Sound is an oscillation of pressure that can propagate (travel) from a sound source along many paths, some of which may reach a receiver (listener). The received *sound pressure* decreases as the path distance is increased from the sound source. The sound velocity varies along each of the paths because of its sensitivity to both local temperature and wind. For example, the environmental temperature and wind are usually stratified (layered) and the sound is refracted (turned) either upward or downward, depending on those environmental conditions. For example, in downwind conditions, the concentration of sound waves (by downward refraction) tends to increase the received *sound pressure level* (SPL) and is called a *focus*. Sound waves that encounter an object undergo *reflection* if they reach a listener within the line-of-sight from the source; sound waves are said to undergo *diffraction* when they reach receivers located past the line-of-sight.

With these few concepts, we can consider many of the important effects of the environment on military noise. An expanded summary of these effects can be found in the DoD document that provides an overview of blast noise (US DoD 2013).

- **Distance** - Sound levels generally decrease with distance from the sound source. An obvious means of noise mitigation would be to increase the distance between a source and receiver. Unfortunately, the amount of area needed for a potential noise buffer can be quite large. As a general rule, the area needed for a noise control *buffer* increases according to the square of the distance separating the source and the nearest receiver. Depending on location, the resulting cost of the buffering distance could offset the potential noise mitigation benefit.

- **Source Directivity** – Sound levels can vary based on the direction of the receiver from the sound source. Most guns have a significant amount of *directivity*, such that the sound level is as much as 6-12 dB higher toward the front than in back of the gun. Exceptions such as recoilless guns usually have the opposite situation. Bombs, mines, and open detonations are nearly *omnidirectional*, meaning they emit the same amount of sound in any direction away from the charge.

- **Wind -** Downwind from an omnidirectional sound source, SPLs are usually higher than the received SPLs at the same distances upwind or crosswind from the same source. This effect is a consequence of downward refraction of sound, as the velocity of air within the wind is an increasing function of height. In upwind conditions away from the source, wind causes upward refraction of sound and lower received sound pressure levels.

- **Temperature -** Temperature layers (stratification) can cause refraction of sound and significantly affect sound transmission. Daytime *temperature lapse* (associated with a mildly sunny weather condition) can refract sound away from the warmer ground, and nighttime temperature inversion (having air temperature greater than that of the ground) contributes to sound refraction toward the ground.

- **Wind and temperature -** Often, wind and temperature act in a way to refract sound downward in some downwind directions, upward in some upwind directions, and perhaps also form an elevated duct in other directions. In such situations, it can be necessary to perform a detailed analysis of sound propagation to forecast the received SPL.

- **Atmospheric turbulence -** Fluctuations in wind (mechanical turbulence) and in temperature (thermal turbulence) in the lower atmosphere cause sound to scatter away from its path and cause some small delays reaching the receiver. Usually, turbulence makes the received levels slightly higher than they might have been in smoothly-layered wind, and *reverberation* (multiple arrivals of the sound) may be heard as well. While reverberation is typically not a concern for community annoyance to a noise, reverberation does increase the *sound exposure level* (SEL), which is the commonly used noise metric to predict community noise annoyance. Turbulence also contributes to shot-to-shot variability in sound levels, which may prevent listeners from becoming accustomed (habituated) to the noise.

- **Ground reflection -** Sound propagation along the ground may be *attenuated* (sound pressure reduced) due to sound absorption by the porous ground surface. The amount of attenuation depends on the types and condition of ground surfaces (Craddock and White 1992). Following a rain, the ground's water-filled pores reflect sound and tend to enhance the received sound level. The type and condition of the ground can work in concert with wind and temperature stratification, leading to multiple ground reflections on the way to the receiver. These multiple reflections can then combine in such a way that the received sound level can be not only higher or lower but also, difficult to predict.

- **Terrain shielding -** Variable terrain has two common effects on sound propagation: (1) production of echoes, and (2) diffraction from elevated surfaces (including hilltops, ridgelines, safety berms, noise barriers, etc.). At present, the reverberation due to hillside reflections is omitted from most models of impulsive noise because the effect is less important and the related computational run time is high. However, when the line-of-sight between source and receiver is obstructed by hills, noise barriers, or safety berms, the stronger noise signals arrive by diffraction. BNOISE is the only model that can use digital terrain maps to account for hills; SARNAM and RMTK use only manually-entered coordinates for analyzing diffraction by noise barriers and safety berms.

Research on practical applications of barrier walls for use in road traffic noise mitigation from the 1970s showed a diffraction index to be the key parameter for calculating the amount of sound reaching listeners by diffraction (Maekawa 1977; Kurze 1971). The diffraction index is ratio of the path length difference (paths around and through the diffracting object) and the sound wavelength. By supplying the diffraction index for a single object, the attenuation due to the object can be calculated using Maekawa’s model. Similar findings were obtained by the U.S. Army in research for shielding noise of artillery (Raspet and Lewis 1984) and of small-caliber guns (Pater et al. 1994). A central theme from these results is the dependence of attenuation, based on the ratio of the path length difference (over-distance minus through-distance) to the wavelength of sound. In BNOISE, the propagation over one or more hills is treated as attenuation by a single diffracting object. An early version of this idea was implemented for digital terrain in the Geographic Resources and Analysis Subsystem (GRASS) (Zhuang et al. 1993).

For each source-receiver pair, the shortest overland path (grazing only the fewest hilltops) is compared to the (obscured) line-of-sight path, and the difference in path lengths is used to calculate the diffraction index in BNOISE. Noise shielding by the terrain is evaluated in BNOISE by repeatedly performing these path length calculations between locations on a digital map. When making noise contours with BNOISE, receivers are placed in a large grid at coordinates with equal increments in universal transverse Mercator (UTM) *easting* and *northing* coordinates, covering the requested *map extents*. (*Northing* and *easting* values are the northward and eastward distances in meters from a *UTM zone* datum [single reference point].)Each source-to-receiver path is calculated to assess terrain shielding effects. Where terrain does not intercept the line-of-sight, no assessment of terrain shielding is formed.

Example of Terrain Shielding Using BNOISE Software

In the following example, we consider a hypothetical case of a single demolition noise source with 2500 kg net explosive weight to be fired on a demolition range at Fort Carson, Colorado. The terrain throughout and surrounding Fort Carson is famously mountainous and thus, it provides an opportunity to demonstrate terrain shielding of noise. The prepared noise contour shows the *C-weighted sound exposure levels* (CSEL) in decibels. The CSEL quantifies impulsive noise from individual shots because C-weighting includes more low-frequency energy of medium-large gun noise than does A-weighting. Calculations are made using BNOISE, with and without the effects of terrain; these results are displayed in Figure A-1. Height contours (i.e., constant-terrain-height curves as seen in traditional terrain contour maps) for the region are shown in Figure A-2. Directions for obtaining a terrain map are given in Appendix C, using the region for Fort Carson as an example. Note that in making the noise contour calculations, the demolition charge was assumed to be omnidirectional and refraction by wind was not accounted for.

In directions without strongly varying terrain heights (especially toward the east and north), the noise contours are almost circular and are unaffected by terrain (Figure A-1). By making use of the terrain map, some regions toward the west are shown as being partly shielded from exposure to noise. It should be emphasized that the shielding by terrain is never complete; lower sound levels reach points beyond the contours.

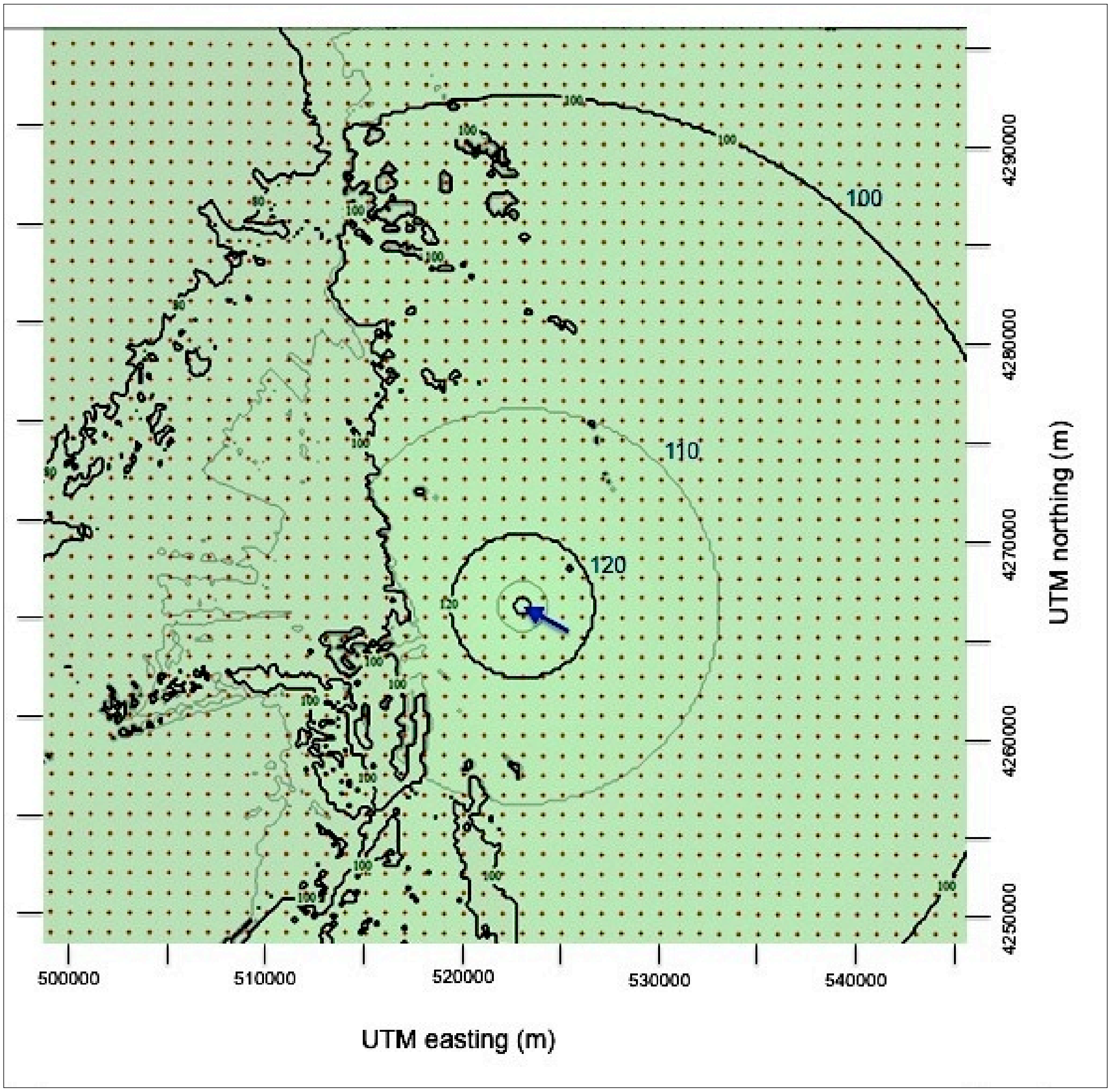

Figure A-1. Noise contours, as calculated by BNOISE using digital terrain, outlining constant values (dB) of C-weighted SEL in partially circular patterns, surrounding an explosion at coordinates UTM 13 523000E 4266500N (indicated by arrow). The TNT-equivalent weight of the explosive charge is 2,500 kg. The inward displacement of contours in the west indicates the modeled reduction of noise by terrain shielding.

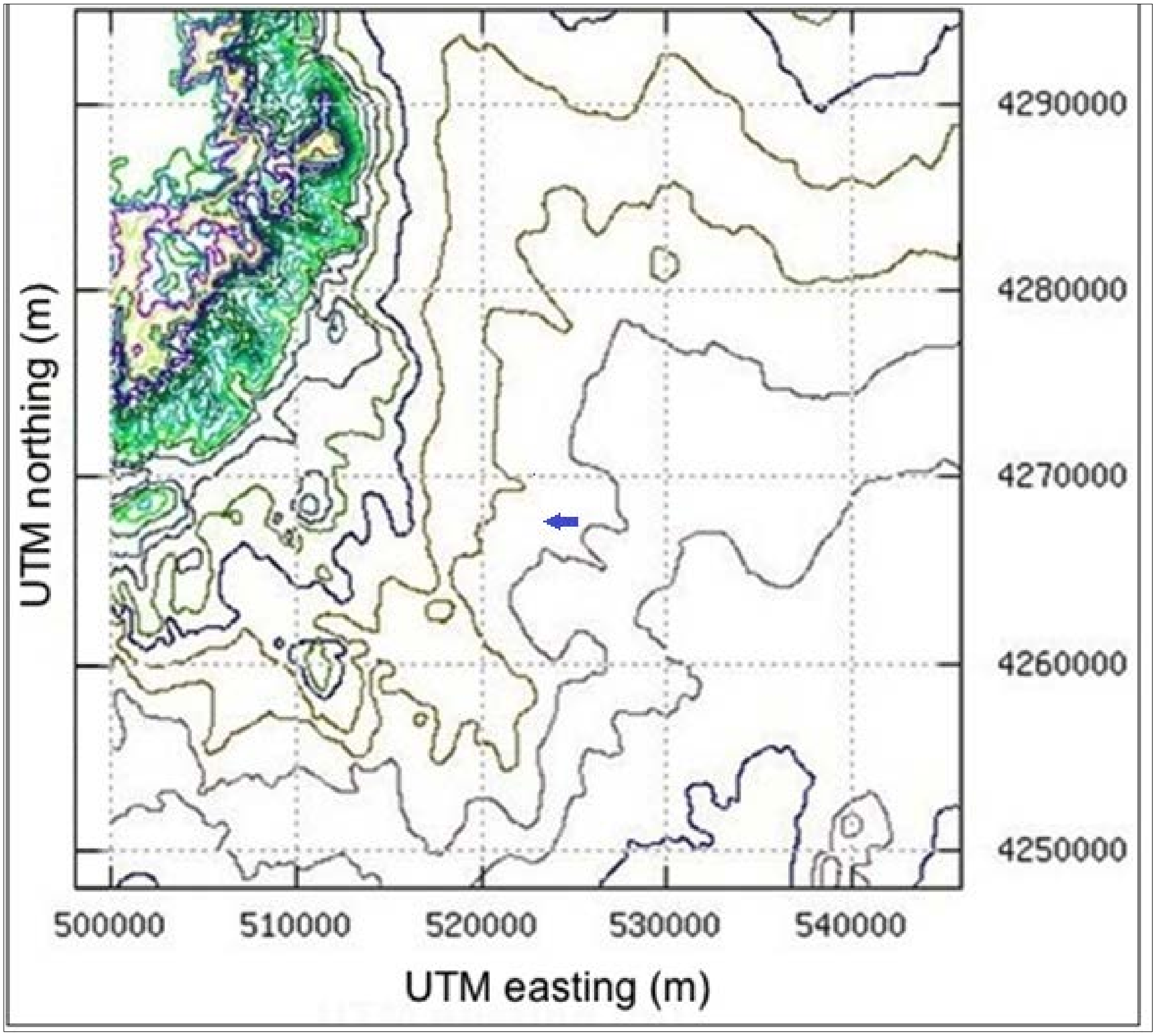

Figure A-2. Terrain elevation data. Regional 1-degree digital elevation model (DEM) for Pueblo-E from the US Geological Survey (USGS), showing height contours on 100-m increments. Map scale and explosion coordinates are as in Figure A-1 (also indicated here by blue arrow).

Discussion of Terrain-Shielding Example

The example above is idealized in several ways that deserve mention. On a busy installation, there are many noise sources and source locations. The noise sources, especially guns, can have strong directivity. Consequently, a detailed noise map should include these additional and directional noise sources; however, including the additional noise sources can make the result very complicated. Throughout changing weather conditions, the noise impact is likely to change considerably due to changing refraction conditions. Furthermore, the combined effect of refraction and terrain shielding is not routinely modeled in producing noise contours. However, much of the energy in sound waves received at positions on the ground originates from elevation angles within about 20 degrees from the horizon, so that the terrain-shielding analysis here remains meaningful.

Using noise software modeling tools such as BNOISE, SARNAM, and RMTK offers the planner and manager of range lands the ability to consider noise impacts according to planned land use and a way to evaluate the effects of terrain and physical environment on the noise footprint (summary of environmental effects on noise on pages A-3 t0 A-5). BNOISE and SARNAM are available from US Army ERDC-CERL.[3] RMTK is available to the US Army and approved contractors through the Army Sustainable Range Program (SRP) website[4].

[3] Refer to ERDC-CERL POC information on page 4 of this document.

[4] The Army SRP website is at: https://srp.army.mil/. The ERDC-CERL POC may also be able to assist.

APPENDIX B

INTRODUCTION TO BNOISE SOFTWARE

BNOISE is software that enables the preparation of noise assessments for large- and medium-large impulsive sound sources. These impulse sound sources include the 20 mm and larger caliber guns, and mortars and explosions of 50 g and larger net equivalent weight of TNT. With BNOISE, the user can calculate, display, and print noise contours of the C-weighted day-night SELs around a busy military installation conducting live-fire training exercises. Noise assessment typically takes into account the timeframe of study, production of sound by noise sources, transmission of sound through the environment, and reception of sound by listeners in the area.

BNOISE was originally developed by the US Army ERDC-CERL for making long-term noise assessments at Army installations engaged in live-fire training and testing (Pawlowska and Little 1979; Little et al. 1981; Schomer et al. 1981). The source sound levels and directivities of large- and medium-caliber guns were measured and published in a series of supplements (Schomer et al. 1979; Schomer 1982; Schomer and Raspet 1984; Schomer and Goebel 1985, Schomer 1986). The software was ported from mainframe computers to the personal computer (Hottman et al. 1986). Most of these sound source levels, source directivity information, and propagation curves for CSEL are summarized in ANSI S12.17.

Approximately a decade following the initial development of BNOISE, changes were made in stages. In order to distinguish the new model from the original development, the updated software was distributed as BNOISE2 (Pater et al. 2001). The changes made are briefly outlined here.

- Sound propagation algorithms of BNOISE were converted to use 1/3-octave spectra, improving calculations for such things as:
    - ground reflection effect;
    - atmospheric absorption of sound; and
    - atmospheric refraction of sound.
- *Ballistic shock* was added for including effects of supersonic projectiles and rockets:

  - o choice of trajectory arcs or lines; and
  - o initial velocity and cross-sectional area.

- Diffraction effects of terrain were included.
- A graphical user interface was implemented.
- A Structured Query Language (SQL)-based database was added for storing noise data items and easing user data entry, such as:
  - o noise energy production and directivity of many explosives, guns, bombs, rockets, and other noise sources;
  - o named firing and target point coordinates, noise source, source height, target height (or depth);
  - o daytime and nighttime shot counts; and
  - o weather and ground surface conditions.

For making accurate calculations with BNOISE, the user should prepare some information in advance about the locations, receiver grid, activities, and timeframe, as described below.

- **Locations -** The locations of all *firing areas*, *firing points*, *target areas*, and *target points* are assigned names in BNOISE by the user. It is helpful to enter these data in UTM northing and easting coordinates, and preferably by associating them with any pre-existing range identifiers found on the installation map. Once the locations are defined in BNOISE, they can be referenced as firing or target locations in activities.
- **Receiver grid -** A *receiver grid* for BNOISE is a square lattice of point locations that has a rectangular border aligned with the UTM grid. A study area can often be 10-15 km or larger on each side. BNOISE requires the southwest corner UTM northing and easting coordinates, overall east-west distance (m), overall north-south distance (m), and the grid spacing (m). A reasonable first choice for the receiver grid is 200 m, but the grid spacing should be decreased whenever the noise contours contain sharp turns. (Note that halving the grid spacing approximately quadruples the computation time.) If the noise contours intercept the edge of the receiver grid, the overall size of the grid

should be increased to accommodate the entire contour loop. An illustration of this problem and its solution is given in Figure B-1.

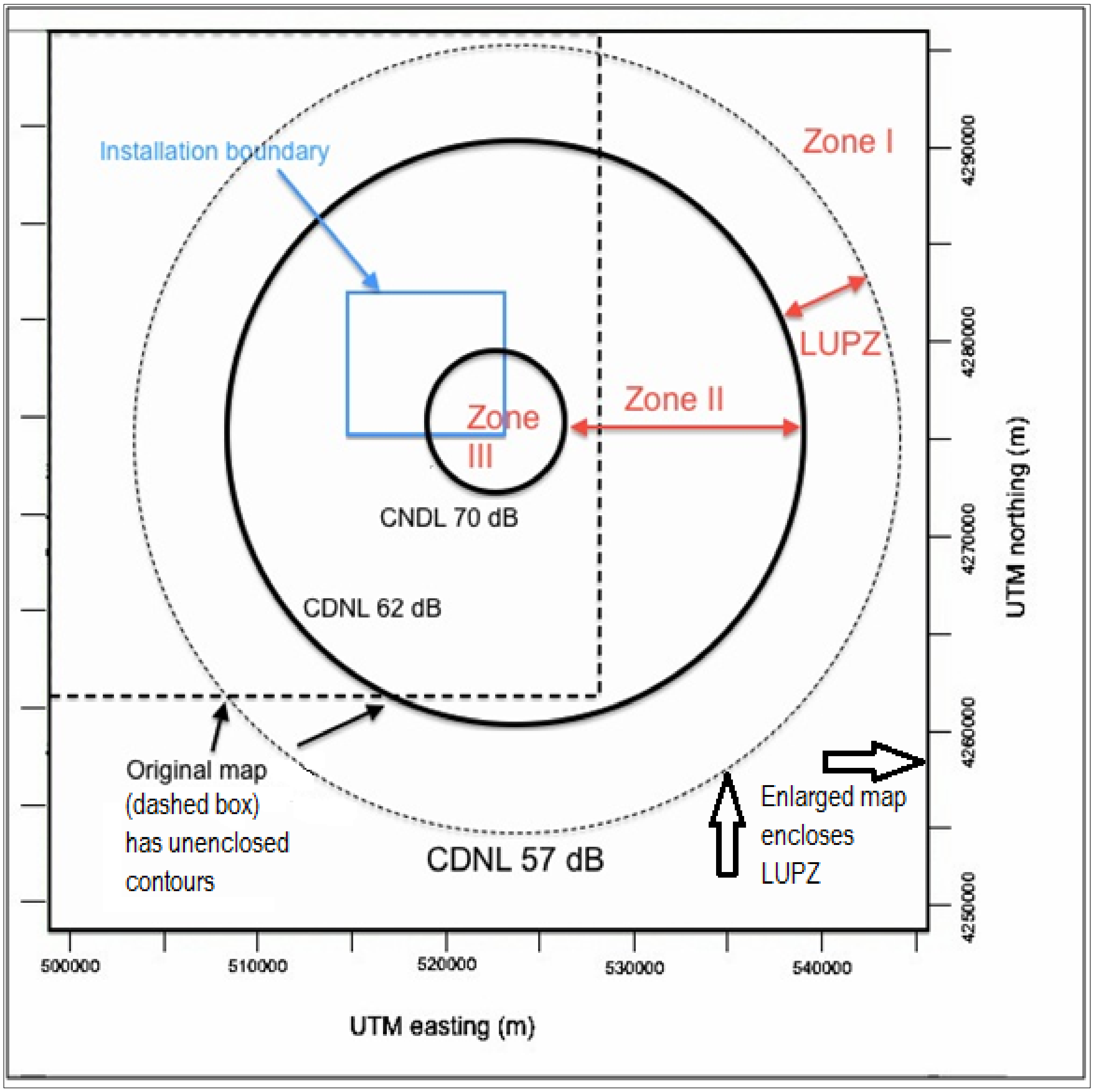

Figure B-1. The solid rectangular outline in the figure illustrates enlargement of the installation's original noise contour map boundary (dotted rectangular line); to notice the size of this expansion, refer to pair of small arrows and pair of larger arrows. When determining the noise boundary, the extents of both the receiver grid and the terrain map should contain all noise contours of interest including the LUPZ outer contour (represented here by dotted outer circle). This example makes it clear that the original noise boundary was not sufficient to contain all contours.

- **Terrain map –** BNOISE allows the user to select a terrain map from a file entry window and automatically adds the selected terrain map file name to the case input file. (Preparation of the terrain map file is described in Appendix C.) If a terrain map selection is not made, BNOISE assumes that all receivers are within direct line-of-sight from all sound sources.

- **Activities -** Activities consist of a noise source type and ammunition type, firing location name, target location name, and number of daytime and nighttime shots within the assessment timeframe. Some noise sources (such as bombs, mines, grenades, or demolitions) may need only a firing location or a target location. Guns (artillery, mortars, Howitzers, cannons, and tank main guns) need user specification of gun type, propelling charge (zone), and projectile dimensions. Because the projectile may be detonating or inert, user specification is also needed of the target charge type and amount. Some demolitions, bombs, or target charges may be detonated below the surface; for those activities, the burial depth is needed.

- **Timeframe -** The assessment timeframe is the calendar time spanning all activities included in the noise assessment. The timeframe is used in BNOISE to form a time average of the accumulated sound exposure. The time should be chosen to span a longer term (e.g., one month, three months, or one year), so that noise level averages are meaningful for land-use planning with respect to noise in the community.

The initial portion of BNOISE operation is devoted to user input of the information just described. Because of the level of detail needed in the input data, the initial preparation can take a few hours. It is always possible to inspect and modify this *activity* data whenever operations change or if corrections are needed. Each scenario can be archived and recalled as needed.

After entering data in BNOISE, the user can select "Calculate," and BNOISE will calculate the average noise level at every point in the receiver grid. These computer runs can take some time, so BNOISE displays an estimate of the time remaining. It is common with lengthy calculations, such as those with fine resolutions or large receiver grids, to run them overnight. When a run is complete, a noise contour can be displayed of the resulting noise levels by using NMPlot.[5] To operate with computer-aided design (CAD) and geographical information systems (GIS), NMPlot can export AutoCAD-type data exchange format (.DXF) files[6].

[5] NMPlot is a Microsoft Windows application by Wasmer Consulting of Gainesville, FL, that is used for viewing and editing sets of georeferenced data points. A copy of the NMPlot software is provided with BNOISE, and NMPLOT also is available separately from the developer's website (http://wasmerconsulting.com/nmplot.htm).

[6] The Data Exchange Format type of file was developed by Autodesk, a softrware developer headquartered in San Rafael, CA. The format is used for computer-aided design vector image files, such as AutoCAD documents.

APPENDIX C: PREPARING A TERRAIN MAP FOR NOISE ASSESSMENTS

Terrain can be incorporated into a noise assessment by using a digital terrain map. In BNOISE, it is important to choose maps with relatively coarse resolution (approximately 30-m spacing), because finer resolution offers only small increases in accuracy for much greater increases in run time. Maps with adequate resolution for noise assessments can be prepared by following the steps given below.

The main idea is that a single digital terrain map can be freely obtained to encompass a desired region of interest and at adequate resolution for preparing good-quality noise assessments. For best results, map resolution should be 30 m, and map extents should be 10 mi (16 km) beyond the installation boundaries. Note that in the following steps, the user should be alert to possible changes in the functions provided by the mentioned websites from the details described below.

1. Finding the Location

First, find the coordinates of the general region of interest. The objective of this step is to obtain the approximate coordinates in decimal degrees of latitude and longitude, for use as reference within next few steps. For this example, the area of interest is Fort Carson, Colorado. Note that in following this example, you will use the USGS web tool, “EarthExplorer.”

- Locate <http://earthexplorer.usgs.gov> by using an Internet browser. The browser window will open “EarthExplorer,” display a North America map graphic, with the “Search Criteria” tab selected and showing “1. Enter Search Criteria” to left of graphic.

- We want only the coordinates of Fort Carson. Select the “Address/Place” sub-tab and enter “Fort Carson, CO, USA” within its text box.

- Click “Show” and the result should appear as: “Address: Ft. Carson, Pueblo, CO, USA” with “Latitude: 38.7375” and “Longitude: -104.7889.” (See Figure C-1.)

- Make a note of these coordinates for the next task.

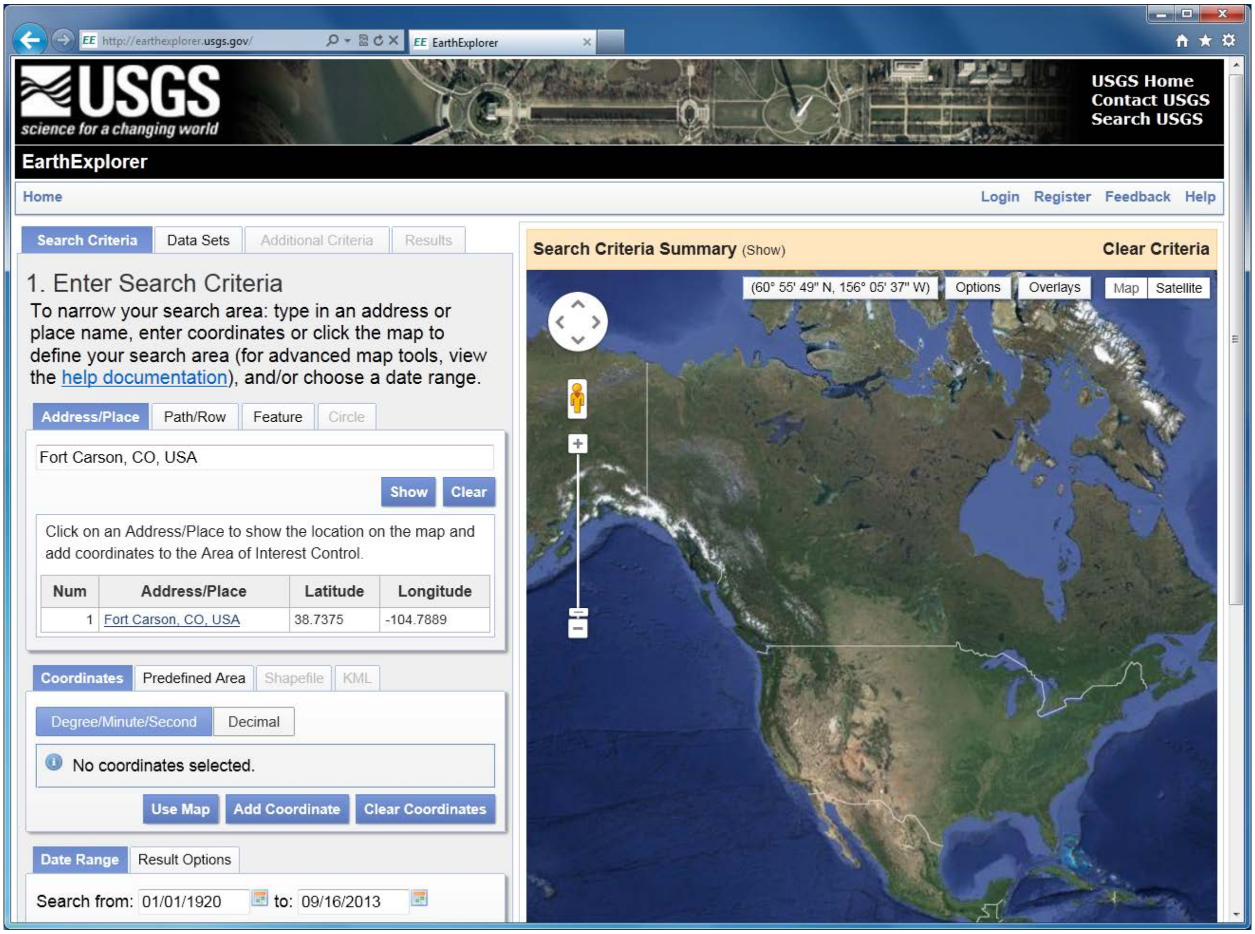

Figure C-1. Example of finding coordinates for a location when using the EarthExplorer web tool.

2. Obtaining Digital Elevation Data

Digital elevation data at resolutions finer than 30 m are freely available from another website of the USGS. The data are provided in a "seamless" format as one or more 1-degree-square tiles. The following steps show how to manage downloading the desired elevation data for Fort Carson Military Reservation.

2.1 Identifying the Installation Boundaries[7]

The objective of this step is to locate the installation boundaries, to ensure that the acquired terrain map will include the

[7] Changes in the user interface for the national map viewer cannot be anticipated. As a consequence, some adaptation of the steps below may be necessary to exactly reproduce the example.

installation. (An additional buffer beyond the installation boundaries will be needed, and that topic will be coming up in later steps.)

- Navigate to <http://nationalmap.gov/viewer.html> using any browser. Click the link to go to the USGS website for “The National Map and Download Platform.”

- Enter the longitude and latitude saved from the previous task, “38.7375, -104.7889,” in the Search text box and click “Search.”

- Click the “Zoom To” link. The map will zoom to a pin marking the selected coordinates.

- Click the “Overlays” tab, to show “Base Data Layers” subtab.

- Click the box to expand “Governmental Unit Boundaries.”

- Click “zoom out” (down-pointing triangle) four times. The map scale should be approximately 1:1,000,000 and Fort Carson should appear as a shaded trapezoid in the center of the map (Figure C-2).

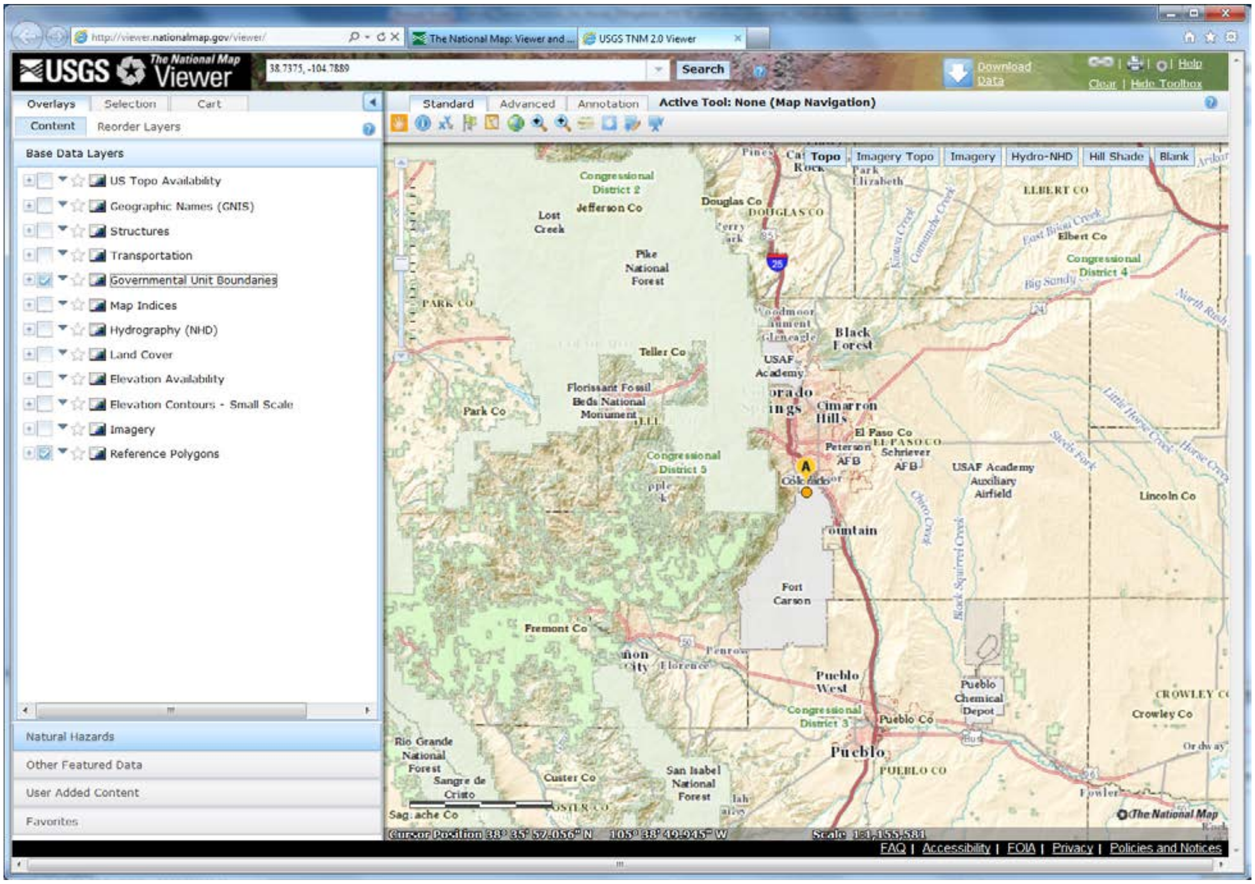

Figure C-2. Identifying the installation boundaries using the USGS National Map Viewer software, showing Fort Carson Military Reservation as an example.

2.3 Adding a Buffer Beyond the Installation Boundaries

The objective of this step is to identify a rectangular region enclosing the installation boundaries, with a buffering distance beyond the boundaries. In most noise assessments, a 10 mi (16 km) buffer on each side of the installation boundary is sufficient. Note that in some cases, a 10-mi buffer beyond the installation boundaries is not sufficient buffering for noise assessments. The buffer is insufficiently sized when the outermost LUPZ noise contour fails to “close” because it exits a map edge. In that case, the receiver grid and associated terrain map need to be enlarged until the LUPZ noise contour does close. See Appendix B (Figure B-1) for an example of contour closure.

Follow the steps outlined below to achieve the coordinates of the installation boundary plus buffer region.

- Click the "Options" gear in the upper right-hand corner (visible in Figure C-2). In the Options window, under Coordinate Display, select "Decimal Degrees," and click "Save." Note that the cursor coordinates then change to read decimal degrees.

- Select the Advanced tab, and then click the "Measure Distance" ruler icon. A message will attach to the arrow cursor, reading "Click to start drawing."

- Click the southwest corner of Fort Carson's boundary.

- Move from the selected point to find a location 22.6 km (14.1 mi) toward the southwest, and click again. This point will mark one corner of the selection region (see Figure C-3). Make a note of the point's coordinates. When we followed this procedure, the coordinates of the southwest corner were approximately (38.283 N, -105.156 E).

  Note 1 - At this step it is not necessary to locate the corner to great accuracy (e.g., better than 0.5 km; distances between 22.1 km and 23.1 km will be adequate).

  Note 2 - The Measure Distance tool can sometimes be difficult to use. A misplaced click can be cleared by pressing the "Esc" key. Two clicks on Measure Distance tool icon will clear the accumulated distance. Occasionally, it is useful to pan and zoom in for better placement of the Measure Distance ruler.

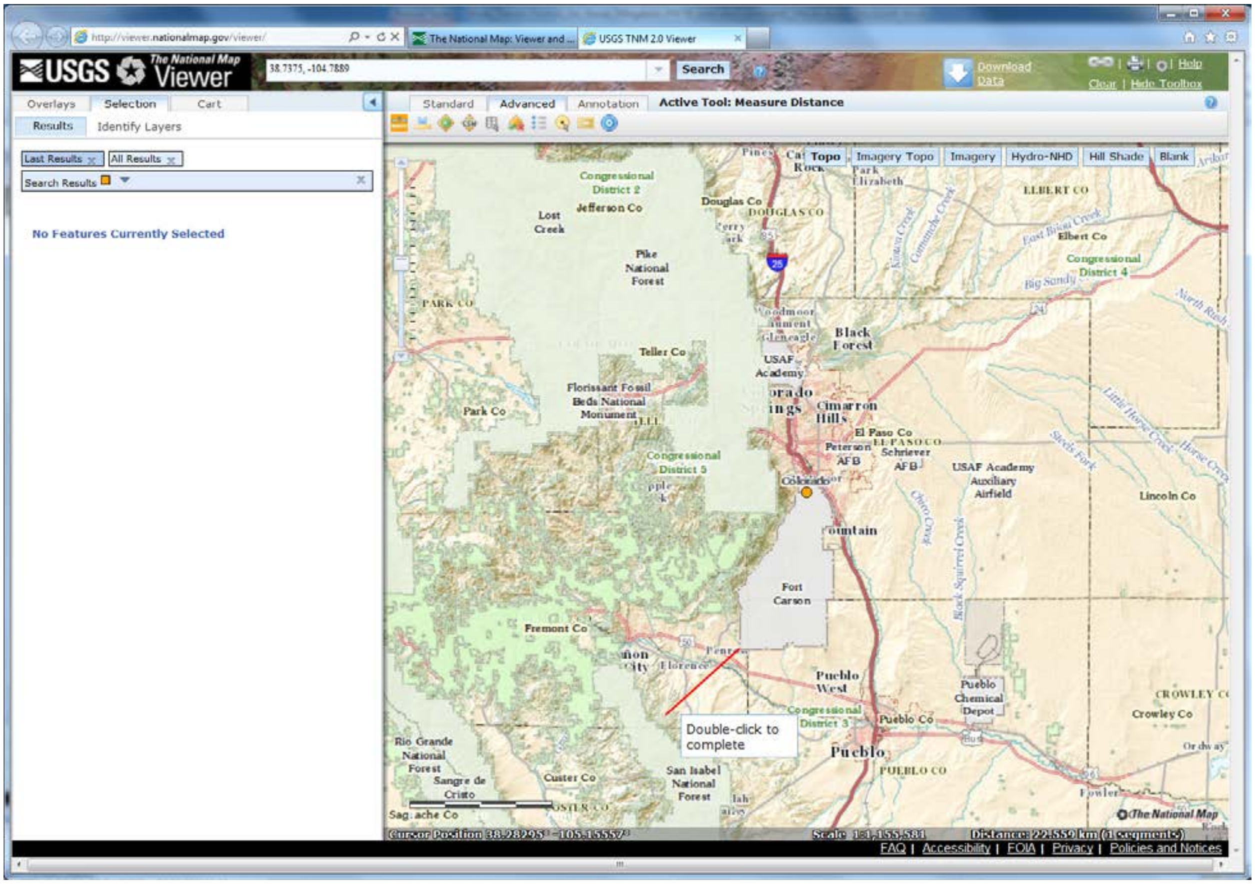

Figure C-3. Example for locating map extents in USGS National Map Viewer, using Fort Carson as an example and supplying a 10-mi buffer region on the south and the west (see red diagonal line in lower center, and note “Distance: 22,559 km” near lower right when compared to Figure C-2).

- Clear the distance accumulator (and the ruler) by clicking the Measure Distance icon twice.

- Repeat the above procedure to find the northeast corner of the map extent, by starting from the northeast corner of the installation and measuring 22.6 km toward the north-east. When we followed this procedure, the coordinates of the northeast corner were approximately (38.888N, -104.581E).

2.4 Selecting Map Layer and Extents

The objective of this step is to designate the desired region for downloading. For this, we may choose one of four download options, including “Click here to download by coordinate input.” or “Choose a reference area, then click on the map.”

The National Map server has recently changed its formatting of download data, so that maps are provided as a set of one or more large tiles (chunks) for individual downloading, rather than as the former single downloadable entity. To easily manage the data, it is preferred that the selection fits within a single tile. In situations where the download data cannot fit within a single tile, then two or more tiles must be combined in an extra step.[8]

2.5 Downloading the Terrain Mapset

- Click the “+” to open Elevation Availability, click “+” to open “Best Available NED Resolution,” and select “NED 1 (~30 m) – Staged.”
- Click “Download Data.”
- Within Download options choose the pull-down (triangle) to choose “Index 1X1 Deg.”
- Click within the “Fort Carson reserve.” The entire “Pueblo E” map will show highlighting (diagonal green stripes). On the left panel, Pueblo E will be listed as a “1X1 degree Index,” along with a download link (Figure C-4).

[8] Combining multiple tiles is made possible by using the DGAL software mentioned below in Section C.4, but documenting that task is beyond the scope of this PWTB.

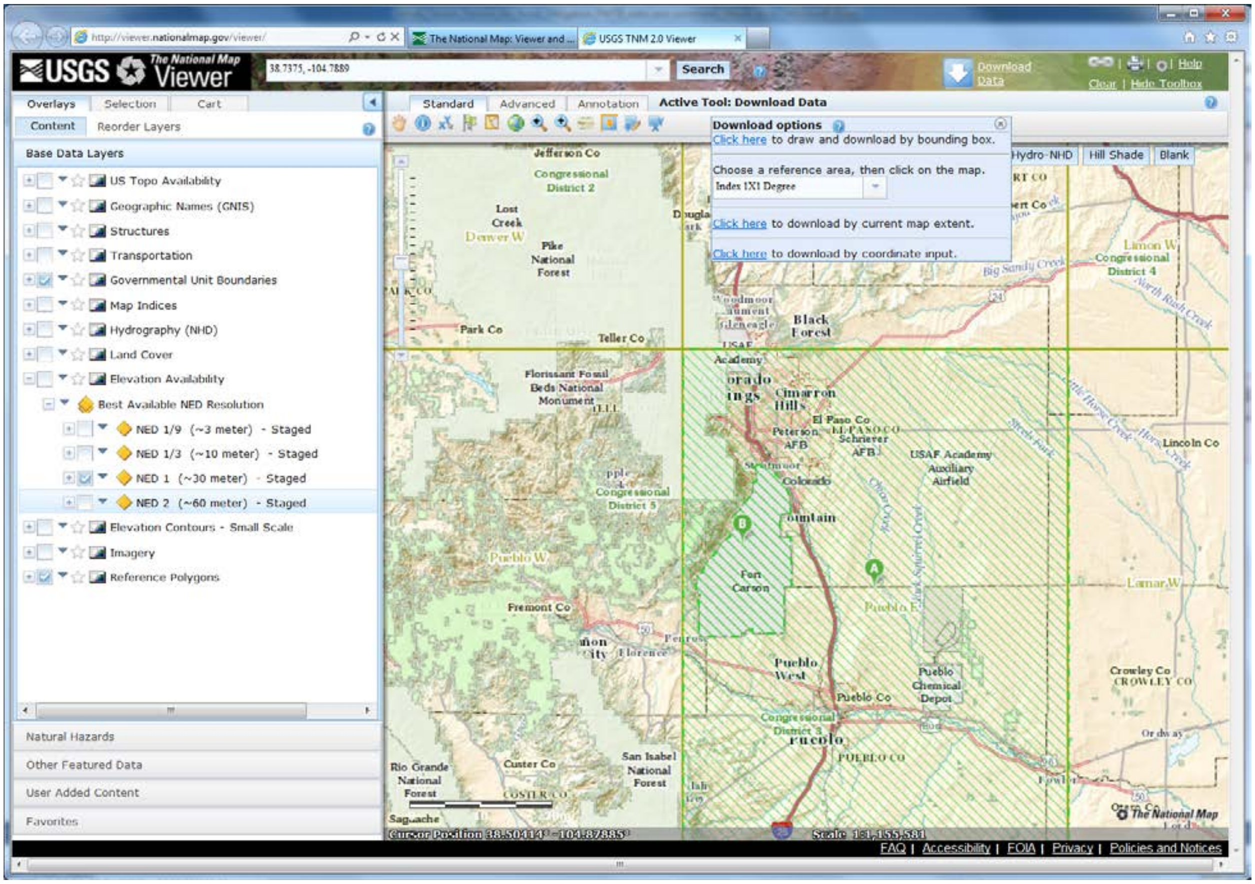

Figure C-4. Example for selecting Elevation Availability as “NED 1 (~30 m) – Staged” and choosing the reference area as “Index 1X1 Degree.”

- Click the download link to retrieve the download bundle. A file download window will appear.
- Under USGS Available data for download, select the checkbox “by Elevation.” Click the “Next” button.
- Select the checkbox next to “National Elevation Data (1 arc second)” in the “GridFloat” format (see Figure C-5).

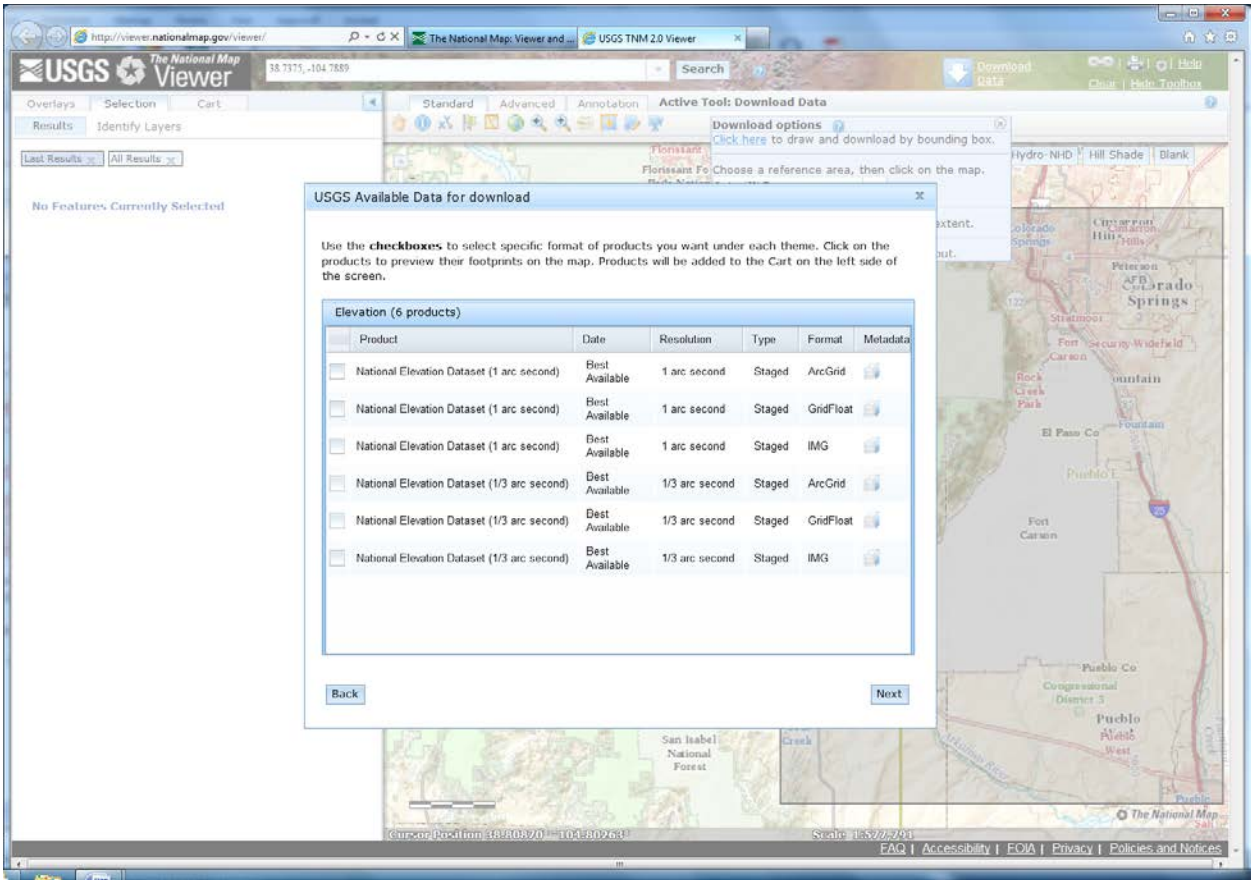

Figure C-5. Example for selecting among download data products to choose "National Elevation Dataset (1 arc second) Staged GridFloat" (the second item in the list above).

- Under "Cart," click "Checkout." Complete the requested information to receive an email with a link to the file in zip format.
- Save the download file in a known folder.
- Use a file extractor such as WinZip or 7-Zip to extract the contents to a location of your choice.

3. Installing GDAL Utilities

The terrain files must be processed so that they can be read for use in noise assessments. The processing can be done in Windows by using the Geospatial Data Abstraction Library (GDAL)[9] utilities. The following steps describe acquiring and installing the GDAL utilities.

- Follow steps to acquire the GDAL utilities.
  - o Visit webpage <*http://www.gdal.org/*>
  - o Click “Downloads - ready to use binaries (executables)”
  - o Select <*http://download.osgeo.org/gdal/win32/1.5/*>
  - o Choose *gdalwin32exe150.zip*
  - o Use a file extractor (e.g., WinZip or 7-Zip) to extract the folder, “gdalwin32-1.5” into a known local folder (e.g., “C:\bin\gdalwin32-1.5”).
- Follow instructions for installing the GDAL utilities.
  - o Open the “Control Panel, System, Advanced” tab.
  - o Click “Environment Variables”
  - o Select the “Path” variable.
  - o Edit and append the folder name (e.g., C:\bin\gdalwin32-1.5).
  - o While in the “Environment Variables” window, under user variables, click “New,” to add the variable named “GDAL_DATA,” to point to the data subfolder (e.g., *C:\bin\gdalwin32-1.5\data*).

4. Processing the Map

After obtaining the terrain map set and installing GDAL utilities, the map can be processed for use in the noise assessment.

- Open the “Command” prompt, or click “Start,” then “Run.”

[9] The GDAL software was developed by the Open Source Geospatial Foundation and is freely available from its website (http://www.gdal.org).

- Use the “gdal_translate” command with option “-of USGSDEM” to translate the map to USGSDEM format, with one continuous command line (e.g., *C:\gdalwin32-1.5\bin\gdal_translate -of USGSDEM c:\maps\FtCarson\NED_96308791\ned_96308791\hdr.adf C:\maps\ftcarson.dem).*

- Note that a message should appear, “Input file size is 1974, 2472.” (This pair of numbers is the number of rows and columns in the digital map.)

When following this example, the downloaded file has a size of 30,321,664 bytes, and it will be ready for use as a DEM map in BNOISE.

**APPENDIX D:
REFERENCES, GLOSSARY, AND ABBREVIATIONS**

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Glossary of Terms

A-weighting. The audio frequency filtering most commonly used for determining perception of noise. It has an emphasis on bands 1000-7000 Hz and attenuation of other bands; usually applied to audio signals.

activity. Live-fire training action leading to production of one or more impulsive noise events. Example: firing a Howitzer with a live warhead is an activity producing a firing noise event, a target noise event, and perhaps a ballistic shock noise event depending on the speed of the projectile.

attenuation. Reduction of sound pressure (and of its associated sound pressure level).

Note: The attenuation of sound pressure level is expressed in decibels (dB).

ballistic shock. Impulsive sound event for receivers within the footprint of the Mach cone associated with an object moving faster than the sound speed.

buffer, noise control. Additional distance (standoff) used to decrease the exposure of noise-sensitive receivers to noise sources. The buffering distance may include noise absorbent treatments such as additional vegetation.

C-weighting. Type of audio frequency filtering with emphasis on bands 200-1100 Hz and attenuation of other bands, usually applied to audio signals for determining annoyance of impulsive sounds. Similar to A-weighting.

C-weighted day-night level (CDNL). Combination of *C-weighting* and *day-night level*.

C-weighted sound exposure level (CSEL). Combination of *C-weighting* and *sound exposure level*.

day-night level (DNL). Ten times the logarithm base 10 in decibels, of the time-average sound exposure referred to 4×10^{-10} Pa^2s, including a ten-fold emphasis of the sound exposure within the nighttime hours from 2200-0700.

datum, UTM Zone. Coordinate reference point such that the western edge of the zone *easting* is assigned to 500000, and equator *northing* assigned to 5000000.

diffraction. Process by which sound waves commonly travel *around* objects to reach receivers beyond the line-of-sight.

digital elevation map (DEM). Type of digital map in which the terrain heights relative to average sea level are given in a sequence of raster scans, in a format prescribed by the USGS (USGS 1997).

directivity, sound. Variation of sound pressure as a function of angle about the sound source.

easting, UTM. Distance (m) toward the east from a horizontal datum, with the western edge of the datum assigned to 500000.

event, impulsive sound. Single burst, having both sudden onset and brief duration. The duration of an impulsive sound event may be as small as a few milliseconds, ranging up to a few seconds.

firing area. Collection of point locations representing an area distribution of firing points.

firing point. Coordinate locations (including height) for sources of firing sound (guns and rockets) or detonation sound (bombs, grenades, and demolition charges).

focus, sound. Concentrated region of higher sound level, often occurring due to downward refraction of sound outdoors.

land-use planning zone (LUPZ). Region in which noise sensitive development (e.g., housing, schools, and medical facilities) may react to days of higher-than-average operations.

Note: The LUPZ occupies the uppermost 5 dB of Zone I; for the impulsive noise LUPZ, the CDNL range is 57-62 dB (see also noise zone and CDNL). (See AR 200-1).

Mach cone. Geometric (conical) surface attached at the apex to projectile in supersonic motion. The surface of the Mach cone contains a mechanical shock wave, or sonic boom, and its reception pattern on the ground is sometimes called its noise “footprint.”

map extent. Extreme highest (or lowest) UTM easting (or northing) specifying one of four map edges as required by BNOISE.

Note - For purposes of this PWTB, map edges are aligned with UTM coordinate lines.

noise zone. Region demarcated by noise contours of given levels as prescribed by AR 200-1 for land use planning.

Notes – Zone I is acceptable for noise sensitive use, Zone II is normally not acceptable for noise sensitive development, and Zone III is not acceptable for noise sensitive use (see also Land-Use Planning Zone). (See AR 200-1.)

noise contour. Closed curve drawn onto a map through locations having a constant, specified, sound level.

northing, UTM. Distance (m) toward the north from a horizontal datum, with the equator assigned to 5000000.

omnidirectional. Property of a sound source having zero directivity. The sound pressure level is the same in all directions at a fixed distance from an omnidirectional source. (See *directivity*).

receiver grid. Lattice of point locations for calculating sound level. In BNOISE, these points are placed on equal-length segments (a square grid) at the standard measurement height for measuring outdoor noise, i.e. 1.2-1.5 m above ground.

reflection. Interaction of a sound wave with a surface, in which some portion of the wave (or all of it) is redirected back into the air.

refraction. Turning of a sound wave toward regions of lower sound speed. Outdoors, air commonly forms into layers, or strata, with each layer having a constant temperature. Because the speed of sound is faster in higher-temperature layers, sound tends to turn away from these layers, and that sound is said to be refracted. (See *reflection*.)

reverberation. Echoing sound, perhaps indistinct from the initial, direct arrival of sound.

sound exposure. Time-integrated square of the sound pressure (Pa^2s). Sound exposure is an indication of the dose of received sound due to an event or activity.

sound exposure level (SEL). In decibels (dB), ten times the logarithm of the time-integrated square of the sound pressure, referred to $4x10^{-10}$ Pa^2s.

sound pressure. In decibels (dB), ten times the logarithm of the time-integrated square of the sound pressure, referred to $4x10^{-10}$ Pa.

sound pressure level (SPL). In decibels (dB), ten times the logarithm of the square of the frequency-filtered sound pressure, referred to $20x10^{-6}$ Pa. (See *A-weighting* and *C-weighting*.) In addition to frequency filtering, time averaging may be applied. (See *time-averaging*.)

sound propagation. Physical processes by which sound spreads from a sound source to distant regions, while incurring transformations in amplitude and frequency spectrum. (See *attenuation*.)

target area. Collection of point locations representing an area distribution of targets. In the case of inert, smoke, or illumination round, target area serves to properly orient the firing noise and placement of any ballistic shock.

target point. Coordinate locations (*easting*, *northing* and height), for sources of warhead detonation sound. In the case of inert, smoke, or illumination round, target area serves to properly orient the firing noise and placement of any ballistic shock.

temperature lapse. Atmospheric condition in which the temperature decreases with increasing height (e.g., the usual condition near the warmed ground surface on a sunny day). Far above the ground, the temperature is usually in lapse.

temperature inversion. Atmospheric condition in which the temperature increases with increasing height (e.g., occurring near a cooled ground surface on a clear night with open sky).

time-averaging. Running average weighted root-mean-square sound pressure, taken such that the weighting function is an exponentially decreasing function of prior time. Examples include *fast* and *slow*.

UTM (Universal transverse Mercator). Geographic system for identifying any location on the Earth's surface, combining a numeric *zone* with an *easting* and a *northing*.

zone, noise. (see *noise zone*)

zone, UTM. Any one of 60 adjoining regions, having 6 degrees of longitude each, ranging from zone 01 with its western edge on longitude 180°, to zone 60 with its eastern edge on longitude 180°.

Zone I, II, and III. (see *noise zone*)

Abbreviations used in text

Abbreviation	**Spelled-Out Term**
AFM	Air Force Manual
AR	Army Regulation
AT&L	Acquisition Technology and Logistics (DoD)
BNOISE	blast noise impact assessment software
CAD	computer aided design
CDNL	C-weighted day-night level
CECW	Directorate of Civil Works, US Army Corps of Engineers
CEMP	Directorate of Military Programs, US Army Corps of Engineers
CERL	Construction Engineering Research Laboratory
CSEL	C-weighted sound exposure level
dB	decibel
DEM	digital elevation model
DNL	day-night level
DNWG	Defense Noise Working Group
DoD	Department of Defense
DoDI	Department of Defense Instruction

Abbreviation	**Spelled-Out Term**
DXF	data exchange format
EIS	Environmental Impact Statements
ERDC	Engineer Research and Development Center
GDAL	Geospatial Data and Abstraction Library
GIS	graphical information system
GRASS	Geographic Resources and Analysis Subsystem
HQUSACE	Headquarters, US Army Corps of Engineers
Hz	hertz
LUPZ	Land use planning zone
NAVFAC	Naval Facilities Engineering Command
NEPA	National Environmental Protection Act
POC	point of contact
PL	Public Law
PWTB	Public Works Technical Bulletin
RMTK	Range Managers Toolkit
SARNAM	Small Arms Range Noise Assessment Model
SEL	sound exposure level
SPL	sound pressure level
SQL	Structured Query Language (database)
SRP	Sustainable Range Program (Army)
TM	Technical Manual (Army)
U.S.C.	United States Code
USGS	US Geological Survey
UTM	Universal Transverse Mercator