Exhibit I

Implementing Solar Technologies at Airports

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Implementing Solar Technologies at Airports

A. Kandt and R. Romero

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Technical Report
NREL/TP-7A40-62349
July 2014

Contract No. DE-AC36-08GO28308

Implementing Solar Technologies at Airports

A. Kandt and R. Romero

Prepared under Task No. WFG4.1010

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List of Acronyms

AC	alternating current
ATCT	airport traffic control tower
ALP	airport layout plan
CNS	communication, navigation, and surveillance
CSP	concentrating solar power
DC	direct current
DIA	Denver International Airport
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
FAA	Federal Aviation Administration
HQ	headquarters
kW	kilowatt
kWh	kilowatt-hour
MHT	Manchester-Boston Regional Airport
MW	megawatt
NREL	National Renewable Energy Laboratory
NWRC	National Wildlife Research Center
PV	photovoltaics
REC	renewable energy certificate
SGHAT	Solar Glare Hazard Analysis Tool
SHW	solar hot water
SVP	solar ventilation preheat
USDA	U.S. Department of Agriculture
USFW	U.S. Fish and Wildlife Service
VALE	Voluntary Airport Low Emissions
W_p	(peak) watt

Executive Summary

Federal agencies, such as the Department of Defense and Department of Homeland Security, as well as numerous private entities are actively pursuing the installation of solar technologies to help reduce fossil fuel energy use and associated emissions, meet sustainability goals, and create more robust or reliable operations. One potential approach identified for siting solar technologies is the installation of solar energy technologies at airports and airfields, which present a significant opportunity for hosting solar technologies due to large amounts of open land. In particular, solar photovoltaics (PV) have a low profile and the potential to have low to no impact on flight operations.

This report focuses largely on the Federal Aviation Administration's (FAA's) policies toward siting solar technologies at airports. The FAA's policies cover fixed-axis, flat-plate solar technologies, including solar PV and solar thermal hot water systems. These policies apply to federally obligated airports. Private airports and land adjacent to airports are not covered under these policies, though the FAA encourages stakeholders of such lands who are interested in siting solar systems on those lands follow the FAA's policies. The FAA's policies outline how an airport sponsor can gain approval from FAA to amend an airport layout plan to add a solar system. The FAA also offers design resources to help to minimize glint and glare impacts.

With proper advanced planning and siting considerations, solar technologies can successfully be installed at airports with minimal or no impacts. This paper concludes with examples of solar installations at airports and highlights a case study where successful systems were installed at the Denver International Airport in Denver, Colorado.

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1 Introduction

1.1 Project Background

Many Federal agencies, such as the Department of Defense and Department of Homeland Security, as well as numerous private entities are actively pursuing the installation of solar technologies to help reduce fossil fuel energy use and associated emissions, meet sustainability goals, and create more robust or reliable operations. One potential approach identified for siting solar technologies is the installation of solar energy technologies at airports and airfields, which present a significant opportunity for hosting solar technologies due to large amounts of open land. In particular, solar photovoltaics (PV) have a low profile and the potential to have low to no impact on flight operations.

This study outlines the technical, economic, and operational implications of siting solar technologies at airports and airfields. This document can be used to inform project managers of existing requirements and to help influence future policies as they are being revised or developed. The document most directly supports staff considering solar projects at airports. The report outlines existing guidance for implementing solar technologies at airports and airfields, details best practices for siting solar at these locations, and highlights a successful case study where solar was installed at an airport.

1.2 Scale of Opportunity

A study conducted by the FAA, U.S. Department of Agriculture (USDA), and U.S. Fish and Wildlife Service (USFWS) stated that in 2010 there were approximately 15,000 public airports in the United States.[1] Of those, 2,915 airports were considered significant to national air transportation and are included in the National Plan of Integrated Airport Systems. The report's authors estimated there are approximately 3,306 square kilometers (816,930 acres) of grassland within the 2,915 significant airport properties in the contiguous United States.[2] The authors contend that grasslands are representative of idle lands at airports.

Assuming that 7 acres of grassland could host 1 megawatt (MW) of fixed-axis (non-tracking) photovoltaics (PV), there's potential for 116,704 MW of PV on idle lands at airports in the United States. These calculations do not include small or military airfields, and thus, can be considered conservative.

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[1] "The World Factbook." Central Intelligence Agency, 2010. Accessed Sept. 8, 2010: www.cia.gov/library/publications/the-world-factbook/geos/us.html.

[2] DeVault, T.; Belant, J.; Blackwell B.; Martin, J.; Schmidt, J.; Burger Jr., L.; Patterson Jr., J. "Airports Offer Unrealized Potential for Alternative Energy Production." *Environmental Management* (49), 2012; pp. 517-522. www.aphis.usda.gov/wildlife_damage/nwrc/publications/12pubs/devault123.pdf.

2 Solar Technology Overview

Solar energy technologies, such as solar PV, are mature, commercially available renewable energy technologies. The focus of this paper is PV, as it has the largest potential applicability for deployment at airports. Other solar technologies are briefly outlined in the Appendix, as they also may have some deployment potential at airports.

2.1 Solar Photovoltaics

Photovoltaic arrays convert sunlight to electricity. The systems require very little maintenance, make no noise, and operate without moving parts and without producing air pollution or greenhouse gases. Arrays can be mounted on buildings and structures (such as parking garages) or ground-mounted on supporting poles or racks. The arrays produce direct current (DC), which can be conditioned into grid-quality alternating current (AC) electricity or used to charge batteries. A typical PV cell converts approximately 14% of the solar energy striking its surface into usable electricity.[3]

The amount of electricity a system produces depends on the system type, orientation, and the available solar resource. The solar resource is the amount of the sun's energy reaching the earth's surface, which varies across the United States. A higher solar resource means more of the sun's energy is reaching the surface, which is optimal for PV system performance. The solar resource map in Figure 1 details the available solar resource throughout the country in kilowatt-hours per meter squared per day. Resources are highest in the southwest, and fairly high throughout the western states, Texas, and Florida.

[3] "Photovoltaics Resources and Technologies." U.S. Department of Energy, Office of Renewable Energy & Energy Efficiency, 2013. http://energy.gov/eere/femp/articles/photovoltaic-resources-and-technologies.

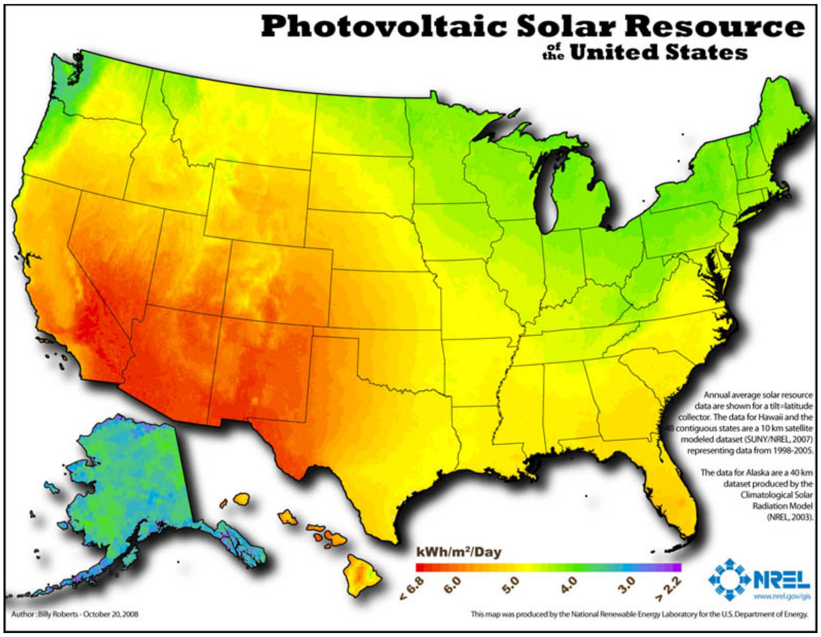

Figure 1. Geographic Information System map of U.S. solar PV resources

2.1.1 *Photovoltaics Economics*

The cost of PV-generated electricity has dropped 15- to 20-fold in the last 40 years. Grid-connected PV systems sell for between 20¢ per kilowatt-hour (kWh) and 32¢/kWh in 2011, or about \$5 per (peak) watt (W_p) to \$8/W_p, including support structures and power conditioning equipment. Peak-watt is the power rating that a PV system measures under standard test conditions, and under which a panel could be expected to deliver its peak output. An NREL study of 7,074 PV systems installed in 2007 reported a range of total capital costs averaging \$8.32/W_p for small systems less than 10 kilowatts (kW) and \$6.87/W_p for large systems greater than 100 kW; costs have dropped further since then. Costs reported for PV projects are decreasing rapidly, so a local solar installer may be the best source of current cost information. Operation and maintenance costs are reported at \$0.008/kWh produced, or at 0.17% of capital cost without tracking and 0.35% with tracking.[4] The systems are very reliable and last 20 years or longer.[5]

Siting PV systems at airports costs marginally more than systems sited in other locations. Additional costs could be incurred for project planning and coordination with FAA and related glare/glint studies.

A variety of financing mechanisms exist to help facilitate the installation of PV systems. Third-party financing, in which an entity finances, owns, and operates the system, is a mechanism for installing a PV system for little or no capital and is most often utilized for commercial- or utility-scale systems. These mechanisms include power purchase agreements, energy savings performance contracts, and utility energy services contracts.[6] In addition, the FAA operates the

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[4] Mortensen, J. *Factors Associated with Photovoltaic System Costs*. NREL/TP-620-29649. Golden, CO: National Renewable Energy Laboratory, 2001.
[5] Guey-Lee, L. "Forces Behind Wind Power." *Renewable Energy 2000*, (73), February 2001.
[6] "Project Funding." U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, undated. Accessed June 2011: http://energy.gov/eere/femp/project-funding.

Voluntary Airport Low Emissions (VALE) program, which helps airport sponsors meet their state-related air quality responsibilities under the Clean Air Act.[7] Through VALE, airport sponsors can be eligible for funds to help support the procurement and installation of PV systems. The Manchester-Boston Regional Airport (MHT) project, in the city of Manchester, New Hampshire, benefited from VALE funds that covered 95% of PV system costs. This system is detailed in Section 4.2 of this report.[8, 9]

[7] "Voluntary Airport Low Emissions Program (VALE): Airports." Federal Aviation Administration, 2014. www.faa.gov/airports/environmental/vale/.
[8] Hayward, M. "Airport controllers complain of solar panels' glare." *New Hampshire Union Leader*, Aug. 30, 2012. www.unionleader.com/article/20120830/NEWS02/708309966.
[9] "Solar Project." *Manchester-Boston Regional Airport newsletter*, Holiday 2012. www.flymanchester.com/newsletters/holiday-2012/solar-project.

3 Guidance

The most broadly known and utilized guidance is issued by FAA and is summarized below. The DOD recently issued a memorandum on glint and glare issues on or near DOD aviation operations; that memo is also summarized.

3.1 Federal Aviation Administration Policies

The FAA is the national aviation authority of the United States. It has authority to regulate and oversee all aspects of American civil aviation.[10] There are nine FAA regions and 21 FAA airport district offices that manage the FAA's day-to-day operations with the nation's airports. These operations include airport safety and standards, grant management, and compliance. The FAA Office of Airports in Washington D.C. (FAA Headquarters) develops national policies, standards, regulations, and guidance for the national system of airports and oversees federal funding, compliance, and airport environmental reviews. Generally, solar projects are reviewed at the regional level, with FAA Headquarters becoming involved only if a project requires additional resources or presents a complex problem.[11]

The FAA has an interest in solar energy for a multitude of reasons. The agency supports modernization and improved efficiency, and as such, supports appropriate solar projects. In some instances, the FAA is a PV operator, generally at remote or off-grid facilities. It works to ensure solar projects are sited properly and do not cause safety problems for aviation or otherwise interfere with aeronautical and airport activities. Specifically, the FAA wants to ensure solar systems do not create glint or glare conditions (glint is a momentary flash of bright light, and glare is a continuous source of bright light). The FAA has determined that glint and glare from typical ground-mounted solar energy systems could result in an ocular impact to pilots and/or air traffic control facilities and compromise the safety of the air transportation system. While the FAA supports solar energy systems on airports, the FAA seeks to ensure safety by eliminating the potential for ocular impact to pilots and/or air traffic control facilities due to glare from such projects.[12]

3.1.1 *Technical Guidance for Evaluating Selected Solar Technologies on Airports*

In November 2010, the FAA released a document titled *Technical Guidance for Evaluating Selected Solar Technologies on Airports*.[13] The FAA created this document to provide a readily usable reference for FAA technical staff who review proposed airport solar projects and for airport sponsors that may be considering a solar installation. It addresses a wide range of topics,

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[10] "Safety: The Foundation of Everything We Do." Federal Aviation Administration, 2014. www.faa.gov/about/safety_efficiency/.

[11] *Technical Guidance for Evaluating Selected Solar Technologies on Airports*. Washington, D.C.: Federal Aviation Administration, November 2010. www.faa.gov/airports/environmental/policy_guidance/media/airport_solar_guide_print.pdf.

[12] "Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports." *Federal Register*, Oct. 23, 2013. www.federalregister.gov/articles/2013/10/23/2013-24729/interim-policy-faa-review-of-solar-energy-system-projects-on-federally-obligated-airports.

[13] *Technical Guidance for Evaluating Selected Solar Technologies on Airports*. Washington, D.C.: Federal Aviation Administration, November 2010. www.faa.gov/airports/environmental/policy_guidance/media/airport_solar_guide_print.pdf.

including solar technology, electric grid infrastructure, FAA safety regulations, financing alternatives, incentives, and case studies.[14]

One of the case studies highlights an unsuccessful installation and details the associated implications. More information on this case study, including potential resolution to the installation issues, is provided in Section 4.2 of this report. This is currently the only existing publically available and federally issued guidance for installing solar technologies at airports and is a good reference document for all relevant stakeholders. Perhaps most useful for those parties interested in siting solar systems at airports, the report includes a checklist of FAA procedures to ensure the systems are safe and pose no risk to pilots, air traffic controllers, or airport operations.

There is a note on the initial page of the report stating:

> As of October 23, 2013, the FAA is reviewing multiple sections of the *Technical Guidance for Evaluating Selected Solar Technologies on Airports* based on new information and field experience, particularly with respect to compatibility and glare. All users of this guidance are hereby notified that significant content in this document may be subject to change, and the FAA cautions users against relying solely on this document at this time. Users should refer instead to the interim policy (http://federalregister.gov/a/2013-24729).

The interim policy is detailed below. This update to the technical guidance includes the standards for measuring glint and glare outlined in the interim policy. It also provides enhanced criteria to ensure the proper siting of a solar energy installation to eliminate the potential for harmful glare to pilots or air traffic control facilities.[15] A notice on the website states that, "The interim policy replaces the guidance for reflectivity found in Section 3.1.2 of the *Technical Guidance for Evaluating Selected Solar Technologies on Airports*."[16]

3.1.2 *Interim Policy, Federal Aviation Administration Review of Solar Energy System Projects on Federally Obligated Airports*

On Oct. 23, 2013, a notice was posted by the FAA on the Federal Register, titled *Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports*. The notice states that in 2012, the FAA partnered with the U.S. Department of Energy (DOE) "to establish a standard for measuring glint and glare, and clear thresholds for when glint and glare would impact aviation safety. The standards that this working group developed are set forth in this notice."[17] The notice also reads:

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[14] *Technical Guidance for Evaluating Selected Solar Technologies on Airports*. Washington, D.C.: Federal Aviation Administration, November 2010. www.faa.gov/airports/environmental/policy_guidance/media/airport_solar_guide_print.pdf.

[15] "Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports." *Federal Register*, Oct. 23, 2013. www.federalregister.gov/articles/2013/10/23/2013-24729/interim-policy-faa-review-of-solar-energy-system-projects-on-federally-obligated-airports.

[16] www.faa.gov/airports/environmental/

[17] "Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports." *Federal Register*, Oct. 23, 2013. www.federalregister.gov/articles/2013/10/23/2013-24729/interim-policy-faa-review-of-solar-energy-system-projects-on-federally-obligated-airports.

> The FAA is adopting an interim policy because it is in the public interest to enhance safety by clarifying and adding standards for measuring ocular impact of proposed solar energy systems. FAA will consider comments and make appropriate modifications before issuing a final policy in a future Federal Register Notice. The policy applies to any proposed solar energy system that has not received unconditional airport layout plan (ALP) approval or a "no objection" from the FAA on a filed 7460-1, Notice of Proposed Construction or Alteration. The FAA expects to continue to update these policies and procedures as part of an iterative process as new information and technologies become available.[18]

It should be noted that solar energy systems located on an airport that is not federally obligated or located outside the property of a federally obligated airport are not subject to this policy. Proponents of solar energy systems located off airport property or on nonfederally obligated airports are strongly encouraged to consider the requirements of this policy when siting such systems.

Considerations outlined in the notice include:

- A sponsor of a federally obligated airport must notify the FAA of its intent to construct *any* solar installation, including the intent to permit airport tenants, such as federal agencies, to build such installations.[19]
  - A sponsor of a federally obligated airport must request FAA review and approval to depict proposed solar installations that will either be ground-based installations or that are not ground-based but substantially change the footprint of a colocated building or structure (i.e., a roof-mounted system that increases the footprint of an existing building or structure) on its ALP, before construction begins.
  - Airport sponsors and project proponents must comply with the policies and procedures outlined in the Interim Policy in order to demonstrate to the FAA that a proposed solar energy system will not result in an ocular impact that compromises the safety of the air transportation system.[20]
  - The airport sponsor, in siting a proposed solar energy system, is responsible for limiting the potential for inference with communication, navigation, and surveillance (CNS) facilities by ensuring that solar energy systems remain clear of the critical areas surrounding CNS facilities.

Standards for Measuring Ocular Impact

The notice states the FAA prescribes the solar glare hazard analysis plot as the standard for measuring the potential ocular impact of any proposed solar energy system on a federally

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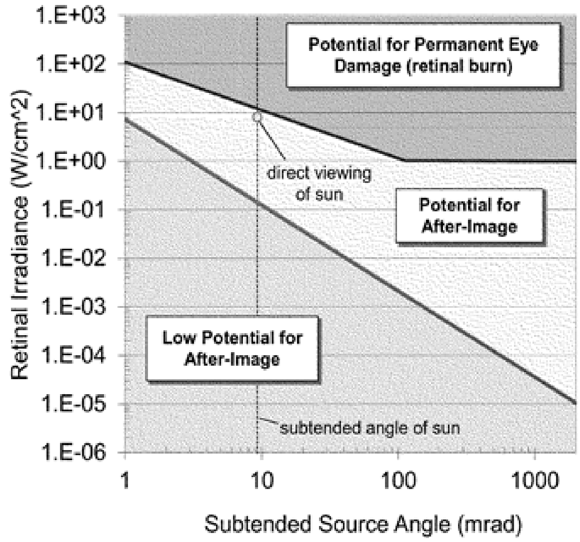
[18] "Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports." *Federal Register*, Oct. 23, 2013. www.federalregister.gov/articles/2013/10/23/2013-24729/interim-policy-faa-review-of-solar-energy-system-projects-on-federally-obligated-airports.

[19] The sponsor must notify FAA by filing FAA Form 7460-1, "Notice of Proposed Construction or Alteration," under 14 CFR Part 77 for a nonrulemaking case.

[20] This process enables the FAA to approve amendment of the ALP to depict certain solar energy projects or issue a "no objection" finding to a filed 7460-1 form.

obligated airport (see Figure 2). The airport sponsor must reference this plot and utilize the associated Solar Glare Hazard Analysis Tool (SGHAT)[21] to demonstrate the potential for glare and glint resulting from a proposed solar project. Non-federally obligated airports or solar systems adjacent to an airport are encouraged to utilize this tool as well, though are not required to. The FAA will consider the use of alternative tools or methods on a case-by-case basis. [22]



Solar Glare Ocular Hazard Plot: The potential ocular hazard from solar glare is a function of retinal irradiance and the subtended angle (size/distance) of the glare source. It should be noted that the ratio of spectrally weighted solar illuminance to solar irradiance at the earth's surface yields a conversion factor of ~100 lumens/W. Plot adapted from Ho et al., 2011.

Chart References: Ho, C.K., C.M. Ghanbari, and R.B. Diver, 2011, Methodology to Assess Potential Glint and Glare Hazards from Concentrating Solar Power Plants: Analytical Models and Experimental Validation, J. Solar Energy Engineering, August 2011, Vol. 133, 031021-1 – 031021-9.

Figure 2. Solar glare hazard analysis plot

Source: Federal Register

In order for an airport sponsor to obtain FAA approval to revise an airport layout plan to depict a solar installation and/or a "no objection" to a Notice of Proposed Construction Form 7460-1, the sponsor is required to demonstrate the proposed solar energy system meets the following standards:[23]

- No potential for glint or glare in the existing or planned airport traffic control tower (ATCT) cab
- No potential for glare or "low potential for after-image" along the final approach path for any existing landing threshold or future landing thresholds (including any planned

[21] The Solar Glare Hazard Analysis Tool is available at: https://share.sandia.gov/phlux.
[22] "Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports." *Federal Register*, Oct. 23, 2013. www.federalregister.gov/articles/2013/10/23/2013-24729/interim-policy-faa-review-of-solar-energy-system-projects-on-federally-obligated-airports.
[23] The standards are taken verbatim from the: "Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports." Federal Register, Oct. 23, 2013. www.federalregister.gov/articles/2013/10/23/2013-24729/interim-policy-faa-review-of-solar-energy-system-projects-on-federally-obligated-airports.

interim phases of the landing thresholds), as shown on the current FAA-approved ALP. The final approach path is defined as 2 miles from 50 feet above the landing threshold using a standard 3-degree glide path.

As part of the analysis, ocular impact must be examined over the entire calendar year in 1-minute intervals, from when the sun rises above the horizon until the sun sets below the horizon.[24]

SGHAT was designed to determine whether a proposed solar energy project would result in the potential for ocular impact as depicted in Figure 2. The tool was developed by the FAA and DOE's Sandia National Laboratory to provide a quantified assessment of (1) when and where glare will occur throughout the year for a prescribed solar installation and (2) potential effects on the human eye at locations where glare occurs.[25] It is a free, web-based tool that uses a Google map interface, but requires a user to first register to use the tool.

The user inputs the location of the proposed site, draws an outline of the proposed solar array, and provides additional information about the solar system, including height and reflectance. The user specifies observer locations (usually the ATCT) or flight paths. A screenshot of the input page is shown in Figure 3.

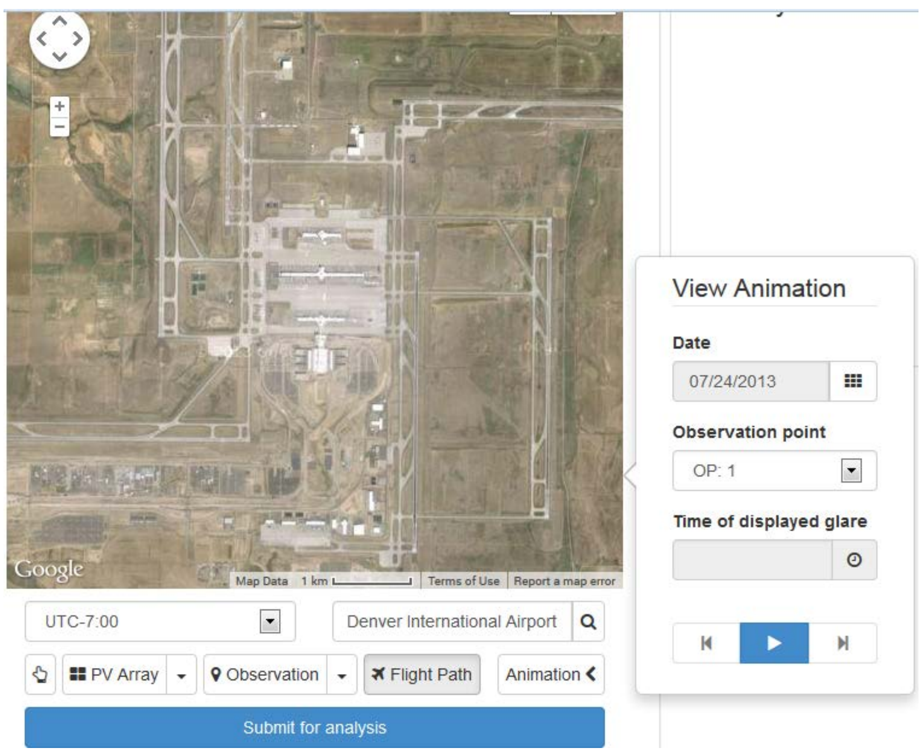


Figure 3. Input page of SGHAT

Source: SGHAT

[24] "Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports." Federal Register, Oct. 23, 2013. www.federalregister.gov/articles/2013/10/23/2013-24729/interim-policy-faa-review-of-solar-energy-system-projects-on-federally-obligated-airports.
[25] Ho, C. and Sims, C. *Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v2.0.* Albuquerque, NM: Sandia National Laboratories, Aug. 23, 2013. https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Users_Manual_v2-0_final.pdf.

If glare is found, the tool calculates the retinal irradiance and subtended angle (size/distance) of the glare source to predict potential ocular hazards ranging from temporary after-image to retinal burn. The results are presented in a plot that specifies when glare will occur throughout the year, with color codes indicating the potential ocular hazard (see Figure 4). The tool can also predict relative energy production while evaluating alternative designs, layouts, and locations to identify configurations that maximize energy production while mitigating the impacts of glare.[26]

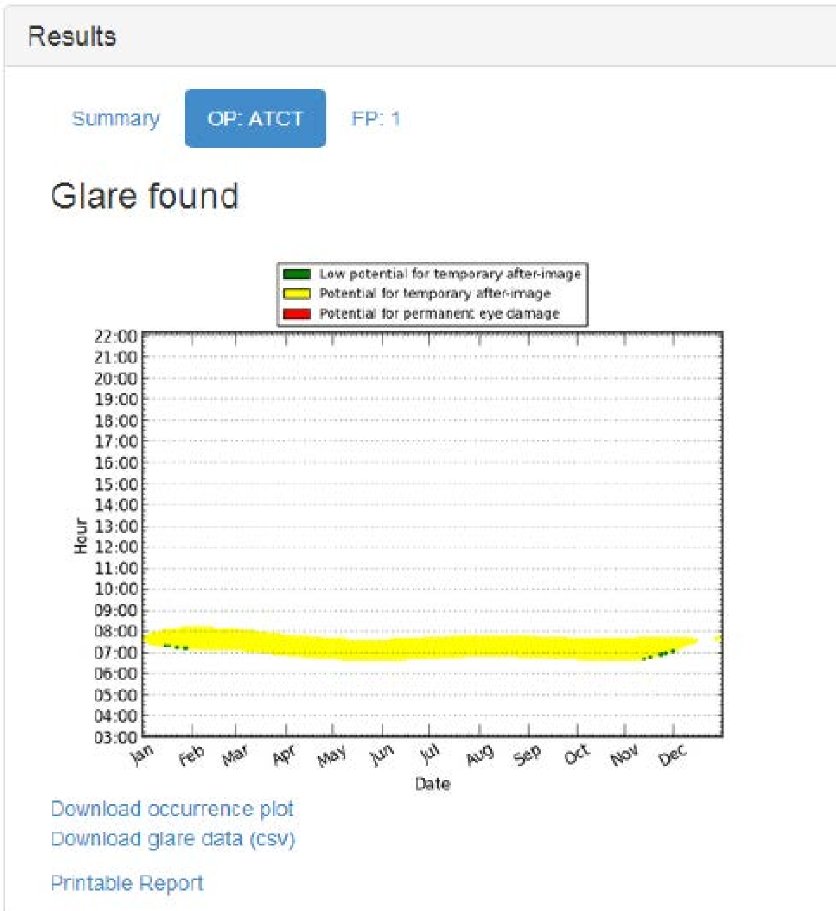


Figure 4. Results tab for observation point, with glare occurrence plot

Source: SGHAT

A user's manual is available for SGHAT, and it provides detailed information regarding the needed inputs, assumptions used in calculations, and interpreting outputs. Although much more detail is provided in the manual, a few important assumptions or limitations are outlined here:

- The software is only applicable to flat reflective surfaces. Focused mirrors, such as parabolic troughs or dishes, cannot be simulated in SGHAT.

[26] Ho, C. and Sims, C. *Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v2.0.* Albuquerque, NM: Sandia National Laboratories, Aug. 23, 2013. https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Users_Manual_v2-0_final.pdf.

- SGHAT only simulates fixed systems; it does not currently apply to tracking systems.
- The software assumes the PV array is aligned with a plane defined by the total heights of the coordinates outlined in the Google map.
- SGHAT does not consider manmade or natural obstacles between the observation points and the prescribed solar installation that may obstruct observed glare, such as trees, hills, buildings, etc.
- The software currently uses a constant reflectance for the solar modules; this value is prescribed by the user. In actuality, the reflectance increases with increasing incidence angle.[27]

The manual also provides a case-study example of the Manchester-Boston Regional Airport, which is summarized in Section 4.2 of this paper. The case study provides an overview of a SGHAT analysis for the airport, as well as real-world examples from an installed PV system that caused glare at the air traffic control tower. The panels have since been temporarily covered to resolve the glare issue.

3.2 Department of Defense Memorandum

In June of 2014 the Office of the Under Secretary of Defense issued a memorandum for the Assistant Secretary of the Army, the Assistant Secretary of the Navy, and the Acting Assistant Secretary of the Air Force with the subject 'Glint/Glare Issues on or near DOD Aviation Operations'.[28] The memo outlines the FAA's conclusion that glint and glare from some solar systems could result in ocular impact to pilots and/or air traffic controllers. It references the FAA interim procedures and states that, "FAA's interim guidance should only be used as a guide for consideration."[29] The memo does encourage mission compatibility evaluations to include the potential impact of glint and glare from non-residential PV and glass-enclosed solar-hot water systems. It outlines in which instances the use of the SGHAT tool is required or recommended.

3.3 Siting Considerations for Airports

In addition to careful planning and assessment to ensure glare and glint are minimized or alleviated, as summarized in the FAA guidance highlighted above, other considerations need to be taken into account when siting solar systems at or near airports. In addition to those outlined here, systems should be placed an appropriate distance from the runway and should adhere to appropriate safety and fire measures.

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[27] Ho, C. and Sims, C. *Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v2.0.* Albuquerque, NM: Sandia National Laboratories, Aug. 23, 2013. https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Users_Manual_v2-0_final.pdf.

[28] http://www.acq.osd.mil/dodsc/library/Procedures_Memo_4_Glint%20Glare%20Issues%20on%20or%20near%20DoD%20Aviation%20Operations.pdf

[29] http://www.acq.osd.mil/dodsc/library/Procedures_Memo_4_Glint%20Glare%20Issues%20on%20or%20near%20DoD%20Aviation%20Operations.pdf

3.3.1 *System Performance*

An ideal solar installation would be situated in an unshaded, south-facing location with an optimum tilt angle (generally tilt equal to latitude; see third bullet below for more information). Not all sites are suitable for solar technologies. There are a few rules of thumb that are helpful in determining when solar technologies are appropriate for a site.

- It is important to identify an unshaded area for solar PV installation, particularly between the peak sun hours of 9 a.m.–3 p.m. Shade will reduce the output of a solar panel. Shade can be caused by trees, nearby buildings, and roof equipment or features (such as chimneys).
- It is best to orient fixed-mount panels due south in the northern hemisphere. Siting panels so they face east or west of due south will decrease energy production. However, that effect varies by location and could be minimal.
- In the area of Boulder, Colorado, for example, the losses due to orientation are about 4% for a panel facing 45° east of south and about 10% for one facing 45° west of south (due to the mountains to the west).[30] While an orientation east or west of south is not ideal because of the resulting reduction in energy production, it may be necessary due to land availability constraints or to minimize or alleviate glint or glare issues.
- For locations in latitudes less than 20º, the optimal tilt angle for achieving the highest performance from a fixed-mount PV panel is equal to the latitude of a location. At higher latitudes, the correlation is not valid. A previous study analyzed the annual solar resource data for different latitudes.[31] At a location of 40° north latitude, an optimal tilt varies from 30° to 35° to maximize the annual energy production. Fixed-mount solar panels can be flush- or tilt-mounted on roofs, pole mounted on the ground, or can be integrated into building materials, such as roofs, windows, and awnings. However, a tilt angle equal to latitude is not always feasible because of factors such as roof pitch, wind or snow loading considerations, or a need to minimize or alleviate glint and glare. It is possible to install panels at a different angle. The impact of a nonideal tilt angle varies by location and could be minimal. The energy production of PV systems at various orientation and tilt angles can be calculated by tools such as PVWatts.[32]

3.3.2 *Minimizing Glare and Glint*

Aside from the strategies previously discussed, there are physical methods to potentially reduce reflection from panels and the associated glare and glint. These include the application of antireflective coatings[33] and/or texturing[34] to the panels. Neither has discernable effects on system performance but could help minimize reflection.

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[30] Analysis in PVWatts makes the following assumptions: location = Boulder, CO; tilt = latitude (40°); DC to AC derate factor = 0.77. Analysis was performed in: Kandt, A. et al. *Implementing Solar PV Projects on Historic Buildings and in Historic Districts*. NREL/TP-7A40-51297. Golden, CO: National Renewable Energy Laboratory, 2011. www.nrel.gov/docs/fy11osti/51297.pdf.

[31] Christensen, C. and Barker, G. "Effects of Tilt and Azimuth on Annual Incident Solar Radiation for United States Locations." Presented at 2001 Solar Energy Forum, Washington, D.C., 2001.

[32] For more information, see: www.nrel.gov/rredc/pvwatts/.

[33] "Anti-Reflection Coatings." PVEducation.org, undated. http://pveducation.org/pvcdrom/design/anti-reflection-coatings.

3.3.3 *Wildlife Impact*

Very little information is available quantifying the potential impact of solar systems on wildlife, or of wildlife on solar system installations, at airports. The previously referenced study conducted by the FAA, USDA, and USFWS states "airports offer one of the few land uses where reductions in wildlife, abundance, and habitat quality are necessary and socially acceptable, due to risk of wildlife collisions with aircraft."[35] However, when siting solar systems at airports, it is important to mitigate against creating wildlife attractants, such as perches or shade. A study by the USDA National Wildlife Research Center (NWRC) aimed to evaluate the hazard level posed by PV facilities to aircraft, compare bird and mammal use of the two land cover types (PV or open land), and provide findings and guidance to the FAA.[36] Note that existing FAA guidance does not yet touch on wildlife impact or mitigation strategies.

The NWRC study compared open land with PV-covered land at airports in five locations across the country. The results indicated most observations at PV arrays were of perched birds. Birds do not present risk to aircraft when they are perched, either on or under panels. However, the study highlighted it is unclear if the PV arrays are drawing birds from outside the airport or if the observations were simply local birds that would be present regardless of the presence of PV. It concluded there is very little information available on the effects of solar energy development on wildlife, but such development is generally assumed to be negative due to habitat destruction and modification. This is in contrast to the FAA, USDA, and USFWS study, which indicated solar system development is compatible with airports due to the need to reduce wildlife abundance and habitat quality. The USDA NWRC study went on to say, though, that the observed low use of PV arrays by birds for perching or sheltering should facilitate solar development at airports, especially in regions where solar development is most promising. Furthermore, the study said "establishment of PV arrays could play a major role in efforts to design and operate "greener" airports."[37]

Strategies can be taken to minimize the potential for birds being drawn to the solar system for perching or sheltering. These could include the use of spikes or other such systems on top of each panel to limit the ability of birds to perch, and potential closures or barriers behind panels to decrease the ability of birds or wildlife to shelter there.

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[34] "Surface Texturing." PVEducation.org, undated. http://pveducation.org/pvcdrom/design/surface-texturing.
[35] DeVault, T.; Belant, J.; Blackwell B.; Martin, J.; Schmidt, J.;Burger Jr., L.; Patterson Jr., J. "Airports Offer Unrealized Potential for Alternative Energy Production." *Environmental Management* (49), 2012; pp. 517-522. www.aphis.usda.gov/wildlife_damage/nwrc/publications/12pubs/devault123.pdf.
[36] DeVault, T. et al. "Wildlife Use of Solar Facilities On and Near Airports." National Wildlife Research Center, undated. www.aaae.org/?e=showFile&l=HZMIYX.
[37] DeVault, T. et al. "Wildlife Use of Solar Facilities On and Near Airports." National Wildlife Research Center, undated. www.aaae.org/?e=showFile&l=HZMIYX.

4 Applications

While airport lands are a relatively new application of solar PV, there are dozens of installations worldwide where the technology has been implemented successfully. Here is a sampling of some installed PV systems:

- **Indianapolis International Airport in Indianapolis, Indiana:**[38] Operating as of 2013, the 12.5-MW system sits at the main airport exit.
- **Fresno Yosemite Airport in Fresno, California:**[39] The 2-MW system was constructed in 2008, and energy production meets approximately 60% of the airports energy demand.
- **Gatwick Airport in London, England:**[40] The 50-kW system was installed in 2012 just 150 meters from the main runway of the airport. The installation company spent about six months negotiating the siting with the United Kingdom National Air Traffic Service and the Civil Aviation Authority to ensure the solar panels were not disruptive to the airport.
- **Birmingham Airport in Birmingham, England:**[41] Installed in 2011, the 50-kW system was installed on the roof of the terminal.
- **Athens International in Athens, Greece:**[42] In October 2012, the Athens airport completed installation of an 8-MW system on the airport site. To ensure safe operation, a pilot PV unit was installed at the airport's train station in 2004 to provide data for the newest installation.
- **Ancona Falconara Airport in Falconara Marittima, Italy:**[43] The buildings surrounding the airport control tower have 45 kW of solar PV installed. Prior to the project, an analytic study was completed that looked at the sun and landing aircraft positions to ensure comfort of pilots and staff in the control tower.

4.1 Denver International Airport Solar Photovoltaics Case Study

Denver International Airport (DIA), located in Denver, Colorado, has installed approximately 8 MW of solar PV on its property. In 2012, DIA was the 11th busiest airport in the world as designated by passenger traffic, so the airport sees significant air traffic as well. The solar PV installed on the airport land meets approximately 6% of the annual electricity consumption of the airport overall.

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[38] "The Solar Farm." Telamon, Johnson Melloh Solutions and Brandrenew, 2013. http://indsolarfarm.com/the-solar-farm/.

[39] Mick, J. "Fresno-Yosemite International Leads Green Airport Movement." *Daily Tech*, July 21, 2008. www.dailytech.com/FresnoYosemite+International+Leads+Green+Airport+Movement/article12417.htm.

[40] "Gatwick solar system hailed a runway success." *BusinessGreen,* undated. www.businessgreen.com/bg/news/2156392/gatwick-solar-cleared.

[41] "Birmingham Airport Invests in Solar Power." Birmingham Airport, Feb. 6, 2012. www.birminghamairport.co.uk/meta/news/2012/02/solarpanels-news-article.aspx.

[42] "Athens International begins operation of the world's largest airport photovoltaic installation." GreenAir Online, Oct. 12, 2012. www.greenaironline.com/news.php?viewStory=1350.

[43] "Falconara Airport Photovoltaic System." Convert Italia, 2013. http://trj.convertitalia.com/en/su-copertura/impianto-fotovoltaico-aeroporto-di-falconara/.

Figure 5. Solar PV at DIA

Source: Denver International Airport

The airport installed the solar PV in three phases, as shown in Table 1.

Table 1. DIA Solar PV Installation Characteristics

	DIA I	DIA II	DIA III
Capacity	2 MW DC	1.6 MW DC	4.3 MW DC
Annual Production	3.5 M kWh	2.4 M kWh	6.9 M kWh
System	Flat single axis tracking	25 degree fixed tilt	25 degree fixed tilt
Total Panels	9,254 panels	7,250 Panels	18,980 panels

The project was completed via private-public partnerships, which were achieved through ground lease and power purchase agreements. Additionally, the interconnection agreements were put in place with the local utility provider. The solar PV system owner, which varies for each system, receives federal tax benefits, renewable energy certificate payments and solar rewards rebates from the local utility provider, and sells power to DIA.

DIA has learned what it takes to install solar PV on their site. Woods Allee, director of Technical Programs in the Planning and Development Office at DIA, said that prior to design and construction of the first solar PV system, panels were brought to the site and viewed from the air traffic control tower. The solar panels, as shown in Figure 6, were viewed from several positions and orientations to ensure the panels would not affect the view from the tower. His team looked for complimentary angles to the sun and pilots' eyes during approach and departure.

Mr. Allee said there was little to no impact to pilots or air traffic control during construction of the three DIA projects. Today, the tracking feature of DIA I ensures there are never glare or glint situations from the PV system, which is generated when there are complimentary angles between the line of site and the PV system. DIA I is the system closest to designated runway spaces.

Fixed-tilt systems DIA II and III are further from the actual runways, and no complaints of interference have been made.

Mr. Allee described the three parameters that cannot be interfered within the aviation mission space: air traffic control tower, pilots landing or taking off, and the navigation aids on the ground. For all the projects, standard panels were installed for the systems.

Figure 6. Location of solar PV at DIA

Source: Google Earth (edited by NREL)

Additionally, a car rental company at DIA recently added a 235 kW solar PV to its carport roof south of the airport, which is also parallel to an east-west runway. The main design requirement for the PV system was to complete the reflectivity study. At this time, there have not been any complications with the installation, and both DIA and the car rental company are pleased with the installation.

Overall, solar PV has been so successful that DIA PV IV is anticipated in the near future.

4.2 Manchester-Boston Regional Airport Solar Photovoltaics Case Study

The Manchester-Boston Regional Airport in the city of Manchester, New Hampshire, installed a solar PV system on the roof of an existing six-story parking garage in August 2012. At the time, the system detailed in Table 1 was the largest solar PV project in New Hampshire. The system was designed to save the airport approximately $100,000 in electric utility costs annually and more than $2,000,000 over the 25-year life of the project.[44] The $3.5 million project was funded under the FAA's VALE program, which covered 95% of the costs.[45,46]

Table 2. Manchester-Boston Regional Airport Solar PV Installation Characteristics

	MHT
Capacity	530 kW DC
Annual Production	650,000 kWh
System	20 degree fixed tilt
Total Panels	2,210 panels

Source: MHT (www.flymanchester.com/newsletters/holiday-2012/solar-project)

Within the first month of installation, air traffic controllers started complaining about glare from the solar PV system, as seen in Figure 7. The glare occurred for approximately 45 minutes each morning, as seen from the tower, which was located just west of the parking garage.[47] Neither aircraft pilots nor any airlines commented on glare issues. While the airport, contractor, FAA, and others sought a solution, approximately 25% of the system was covered with tarps.

[44] "Solar Project." *Manchester-Boston Regional Airport newsletter*, Holiday 2012. www.flymanchester.com/newsletters/holiday-2012/solar-project.
[45] Hayward, M. "Airport controllers complain of solar panels' glare." *New Hampshire Union Leader*, Aug. 30, 2012. www.unionleader.com/article/20120830/NEWS02/708309966.
[46] "Solar Project." *Manchester-Boston Regional Airport newsletter*, Holiday 2012. www.flymanchester.com/newsletters/holiday-2012/solar-project.
[47] Hayward, M. "Airport controllers complain of solar panels' glare." *New Hampshire Union Leader*, Aug. 30, 2012. www.unionleader.com/article/20120830/NEWS02/708309966.

Figure 7. Solar PV at MHT

Source: Sandia National Laboratory

Using the SGHAT tool, a study was conducted in 2012 by Clifford K. Ho, Cianan A. Sims, Julius E. Yellowhair from Sandia National Laboratories to investigate possible solutions, and the results were published in the *Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v. 2.0.*[48] The study recommended a less reflective PV panel would create a perceptible glare decrease. The report also recommended the panels be rotated 90° to the east, which would point away from the air traffic control tower. Additional possible solutions investigated for the south-facing problem panels included:

- Moving panels
- Altering the tilt
- Adding blinds to the tower.

Based on recommendations from Sandia National Laboratories and a separate study by the Massachusetts Institute of Technology and the Volpe Center, the array is currently being reconstructed at 90° rotation from the current position, facing the east, to eliminate the glare problems. The rotation solution was verified with the SGHAT tool. Completion of the solar PV array facing east is expected in summer 2014 with an estimated decrease in annual output by 10% for the new orientation.

Richard Fixler, the assistant director of Engineering and Planning at MHT, says since the original glare study was completed at the airport, tools for the solar glare analysis have improved and now provide results that are more accurate today. He also points to lessons learned from other solar PV installations at airports as experience for the whole industry.

[48] Ho, C. and Sims, C. *Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v2.0.* Albuquerque, NM: Sandia National Laboratories, Aug. 23, 2013. https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Users_Manual_v2-0_final.pdf.

4.3 Unique Airport Applications

There are several unique applications for solar at airports. Some examples include:

- **PV for runway deicing**: The University of Arkansas is developing a system that utilizes PV as the energy source for deicing runways instead of plowing or applying chemicals. In this application, the solar panels convert the sunlight into energy, which is then stored in a battery bank. Energy is then sent to electrodes imbedded in the cement to melt the ice to keep the slab above freezing temperatures. Because snow and ice removal requires expensive equipment, large quantities of energy, and a high number of personnel, the economics of solar PV for ice melt are promising.[49]
- **PV in building facades**: The Geneva airport recently installed solar PV in the balustrade in the main terminal. The solar panels are dye-sensitized solar cells encapsulated in glass, which were incorporated into the building façade of the terminal. This unique application not only generates electricity, but the new windows can improve the energy efficiency of the space over typical windows without sacrificing daylighting to the interior space.[50]
- **PV for airport lighting**: The DOD is utilizing solar-powered obstruction lights at forward-operating bases. The installation of these lights is fast and easy; trenching, wiring, and disruptions in aviation operations are unnecessary. Solar-powered lights can be used for approach, runway, and taxiway lights; wind cones; precision approach path indicators; approach lights; and elevated runway guard lights.[51]

[49] "Researchers Develop Runway Anti-Icing System." *Arkansas Newswire*. University of Arkansas, Nov. 15, 2011. http://newswire.uark.edu/articles/17228/researchers-develop-runway-anti-icing-system.

[50] "g2e launches first installation at Geneva International Airport." Glass 2 energy, April 4, 2013. http://g2e.ch/views/media_newsletter/pdf/cp_g2e_04_2013_en.pdf.

[51] "Obstruction Lighting Solutions." Carmanah, 2014. http://obstructionlights.com/news/us-dod-obstruction-lights/.

5 Conclusions

A multitude of Federal agencies and entities are proactively considering the opportunities and associated economic, technical, and operational implications associated with siting solar technologies at airports and airfields. Airports present a significant opportunity for hosting solar technologies due to large amounts of open land. In particular, solar PV has a low profile and the potential to have low to no impact on flight operations.

Solar systems have successfully been implemented at dozens of airports worldwide. There have also been less successful installations where inadequate planning and analysis led to insurmountable glint and glare issues. It is clear successful implementation of solar systems depends on detailed planning and siting studies, including considerations for glint and glare potential, wildlife impacts, system performance, and safety. With sufficient analysis in the planning stages, solar systems should continue to be able to be synergistic with airport operations.

Appendix

Other Solar Technologies

Concentrating Solar Power

Concentrating solar power (CSP) systems utilize mirrors or other reflectors to concentrate the sun's energy onto a focal point. This intense energy is used to heat a working fluid and to ultimately operate turbines and create electricity. There are three types of CSP systems:

- *Linear concentrator systems* collect the sun's energy using long rectangular, curved (U-shaped) mirrors. The mirrors are tilted toward the sun, focusing sunlight on tubes (or receivers) that run the length of the mirrors. The reflected sunlight heats a fluid flowing through the tubes. The hot fluid is then used to boil water in a conventional steam-turbine generator to produce electricity.
- *Dish/engines* use a mirrored dish similar to a very large satellite dish. The dish-shaped surface directs and concentrates sunlight onto a thermal receiver, which absorbs and collects the heat and transfers it to the engine generator, which is used to produce electricity.
- *Power towers* use a large field of flat, sun-tracking mirrors, known as heliostats, to focus and concentrate sunlight onto a receiver on the top of a tower. A heat-transfer fluid heated in the receiver is used to generate steam, which is then used in a conventional turbine generator to produce electricity.

These technologies are typically used to generate large amounts of electricity, and they require vast quantities of land. Also, these systems operate on direct beam radiation only, and for these reasons, they are therefore limited in their applicability. The concentrating solar resource map in Figure A-1 details the available concentrating solar resource throughout the country in kilowatt-hours per square meters per day. Resources are highest in the southwest, and this is currently the only location where this technology is technically and economically feasible.

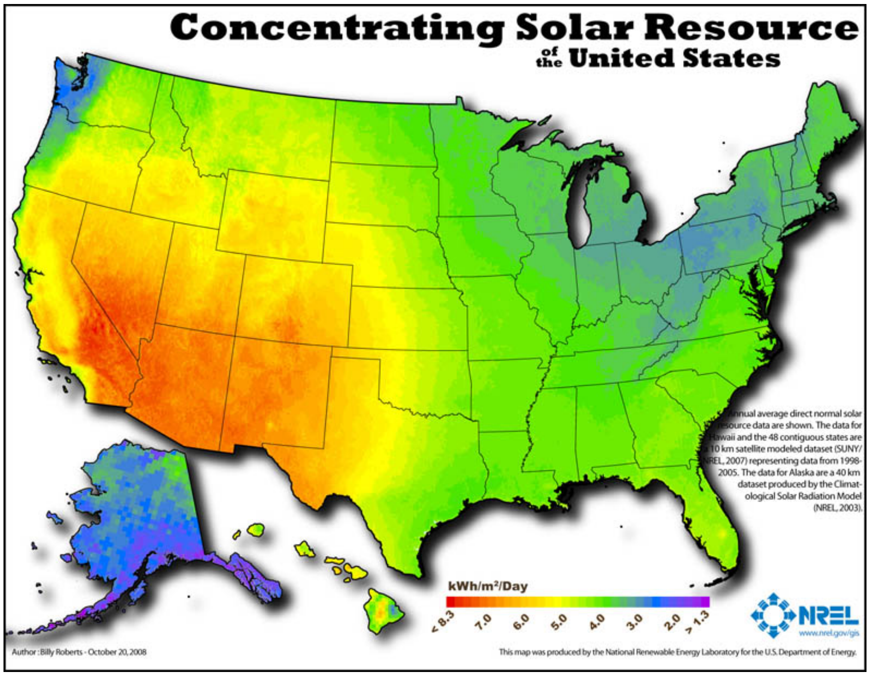

Figure A-1. Geographic Information System map of U.S. concentrating solar resources

Airports located in areas of high concentrating solar resource may be potentially suitable for CSP systems; however, at the time of publishing of this paper, no CSP systems have been installed at airports. The Federal Aviation Administration (FAA) notes CSP projects require enhanced coordination with the FAA due to unique issues with reflectivity, thermal plumes, radar interference, and airspace penetration.[52]

Solar Hot Water

A few types of solar hot water (SHW) systems exist, but the fundamental concept is a collector absorbs and transfers hear from the sun to the water, which is stored in a tank until needed.[53] Depending on application and climate, some systems utilize pumps, controls, and/or freeze protection.

Airports have relatively low hot water loads, comprised mostly of restroom hand washing, service dishwashing, and employee showers. But, if the U.S. Department of Homeland Security or other federal entities are building a new airport, SHW technologies should be considered. The Energy Independence and Security Act of 2007 requires 30% of hot water demand in new federal buildings and major renovations be met with SHW equipment, provided it is life cycle cost-effective.[54]

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[52] *Technical Guidance for Evaluating Selected Solar Technologies on Airports*. Washington, D.C.: Federal Aviation Administration, November 2010. www.faa.gov/airports/environmental/policy_guidance/media/airport_solar_guide_print.pdf.

[53] "Solar Hot Water Resources and Technologies." U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, 2013. http://energy.gov/eere/femp/articles/solar-hot-water-resources-and-technologies.

[54] "Energy Independence and Security Act." U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, 2013. http://energy.gov/eere/femp/articles/energy-independence-and-security-act.

Solar Ventilation Preheat

A solar ventilation preheat (SVP) system consists of a dark, perforated metal wall—a transpired collector—installed on the south-facing façade of a building, creating an approximately 6-inch gap between it and the building's structural wall. Because SVP systems consist of dark colored metal there are no glint or glare concerns. Outside air is drawn through the holes, and this air is heated by the wall's warmth. As air rises in the space between the wall and the collector, it is drawn into the building's air duct system, usually by means of a fan, to provided heated ventilation air into the building. Systems are approximately 75% efficient, making SVP the most efficient solar air-heating application available today.[55]

SVP systems are most cost-effective in applications that demand high heated ventilation air rates, such as vehicle maintenance facilities, chemical storage buildings, airport hangars, and factories. As such, they likely have minimal applicability in most airport terminals, but may have some deployment potential in airport hangars in climates requiring that ventilation air be heated in hangars.

[55] "Solar Ventilation Preheating Resources and Technologies." U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, 2013. http://energy.gov/eere/femp/articles/solar-ventilation-preheating-resources-and-technologies.

Exhibit J

FAA Solar Airport Guide

Research and Innovative Technology Administration

Aylward, Anne D.; Brecht-Clark, Jan M.; Farley, Audrey L.; Hu, Patricia S.; Ishihara, David S.; Johns, Robert C.; Lang, Steven R.; Partridge, Ellen L.; Schmitt, Rolf R.; Womack, Kevin C.

Saint Lawrence Seaway Development Corporation

Middlebrook, Craig H.; Pisani, Salvatore L.

[FR Doc. 2013–24813 Filed 10–22–13; 8:45 am]

BILLING CODE 4910–9X–P

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Notice of interim policy; opportunity to comment.

SUMMARY: This notice establishes interim FAA policy for proposals by sponsors of federally obligated airports to construct solar energy systems on airport property. FAA is adopting an interim policy because it is in the public interest to enhance safety by clarifying and adding standards for measuring ocular impact of proposed solar energy systems which are effective upon publication. FAA will consider comments and make appropriate modifications before issuing a final policy. The policy applies to any proposed on-airport solar energy system that has not received from the FAA either an unconditional airport layout plan approval or a ''no objection'' finding on a Notice of Proposed Construction or Alteration Form 7460–1.

DATES: The effective date of this interim policy is October 23, 2013.

Comments must be received by November 22, 2013.

ADDRESSES: You can get an electronic copy of the interim policy and the comment form on the FAA Airports Web site at *http://www.faa.gov/airports/environmental/.*

You can submit comments using the Comments Matrix, using any of the following methods:

Electronic Submittal to the FAA: Go to *http://www.faa.gov/airports/environmental/* and follow the instructions for sending your comments electronically.

Mail: FAA Office of Airports, Office of Airport Planning and Programming, Routing Symbol APP–400, 800 Independence Avenue SW., Room 615, Washington, DC 20591. Please send two copies.

Fax: 1–202–267–5302.

Hand Delivery: To FAA Office of Airports, Office of Airport Planning and Programming, Routing Symbol APP–400, 800 Independence Avenue SW., Room 615, Washington, DC 20591; between 9 a.m. and 4 p.m., Monday through Friday, except Federal holidays. Please provide two copies.

For more information on the notice and comment process, see the **SUPPLEMENTARY INFORMATION** section of this document.

Privacy: We will post all comments we receive, without change, to *http://www.faa.gov/airports/environmental/*, including any personal information you provide.

Comments Received: To read comments received, go to *http://www.faa.gov/airports/environmental/* at any time.

FOR FURTHER INFORMATION CONTACT: Ralph Thompson, Manager, Airport Planning and Environmental Division, APP–400, Federal Aviation Administration, 800 Independence Ave. SW., Washington, DC 20591, telephone (202) 267–3263; facsimile (202) 267–5257; email: *ralph.thompson@faa.gov*.

SUPPLEMENTARY INFORMATION: The FAA invites interested persons to join in this notice and comment process by filing written comments, data, or views. The most helpful comments reference a specific portion of the proposal, explain the reason for any recommended change, and include supporting data.

Availability of Documents

You can get an electronic copy of this interim policy by visiting the FAA's Airports Web page at *http://www.faa.gov/airports/environmental/*.

Authority for the Policy

This notice is published under the authority described in Subtitle VII, part B, chapter 471, section 47122 of title 49 United States Code.

Background

There is growing interest in installing solar photovoltaic (PV) and solar hot water (SHW) systems on airports. While solar PV or SHW systems (henceforth referred to as solar energy systems) are designed to absorb solar energy to maximize electrical energy production or the heating of water, in certain situations the glass surfaces of the solar energy systems can reflect sunlight and produce glint (a momentary flash of bright light) and glare (a continuous source of bright light). In conjunction with the United States Department of Energy (DOE), the FAA has determined that glint and glare from solar energy systems could result in an ocular impact to pilots and/or air traffic control (ATC) facilities and compromise the safety of the air transportation system. While the FAA supports solar energy systems on airports, the FAA seeks to ensure safety by eliminating the potential for ocular impact to pilots and/or air traffic control facilities due to glare from such projects.

The FAA established a cross-organizational working group in 2012, to establish a standard for measuring glint and glare, and clear thresholds for when glint and glare would impact aviation safety. The standards that this working group developed are set forth in this notice.

A sponsor of a federally-obligated airport must request FAA review and approval to depict certain proposed solar installations (e.g., ground-based installations and collocated installations that increase the footprint of the collocated building or structure) on its airport layout plan (ALP), before construction begins.[1] A sponsor of a federally-obligated airport must notify the FAA of its intent to construct any solar installation[2] by filing FAA Form 7460–1, ''Notice of Proposed Construction or Alteration'' under 14 CFR Part 77 for a Non-Rulemaking case (NRA)[3][4]. This includes the intent to permit airport tenants, including Federal agencies, to build such

[1] FAA Technical Guidance for Evaluating Selected Solar Technologies on Airports, Section 2.3.5, states that ''solar installations of any size, located on an airport, that are not collocated on an existing structure (i.e., roof of an existing building) and require a new footprint, need to be shown on the Airport Layout Plan (ALP). Collocated solar installations need to be shown on the ALP only if these installations substantially change the footprint of the collocated building or structure. *Available at: http://www.faa.gov/airports/environmental/policy_guidance/media/airport_solar_guide_print.pdf.* Title 49 of the United States Code (USC), sec. 47107(a), requires, in part, a current ALP approved by the FAA prior to the approval of an airport development project. See Grant Assurance No. 29, AC No. 150/5070–6B, and FAA Order No. 5100.38.

[2] Any solar installation means any ground-based solar energy installation and those solar energy installations collocated with a building or structure (i.e., rooftop installations).

[3] FAA Technical Guidance for Evaluating Selected Solar Technologies on Airports Section 3.1 reads in part ''All solar projects at airports must submit to FAA a Notice of Proposed Construction Form 7460 . . .''. This section further states ''Even if the project will be roof mounted . . . the sponsor must still submit a case'' [i.e., file a Form 7460–1].

[4] The requirements of this policy are not mandatory for a proposed solar installation that is not on an airport and for which a form 7460–1 is filed under part 77 and is studied under the Obstruction Evaluation Program. However, the FAA urges proponents of off-airport solar-installations to voluntarily implement the provisions in this policy.

installations. The sponsor's obligation to obtain FAA review and approval to depict certain proposed solar energy installation projects at an airport is found in 49 U.S.C. 47107(a)(16) and Sponsor Grant Assurance 29, ''Airport Layout Plan.'' Under these latter provisions, the sponsor may not make or permit any changes or alterations in the airport or any of its facilities which are not in conformity with the ALP as approved by the FAA and which might, in the opinion of the FAA, adversely affect the safety, utility or efficiency of the airport.

Airport sponsors and project proponents must comply with the policies and procedures in this notice to demonstrate to the FAA that a proposed solar energy system will not result in an ocular impact that compromises the safety of the air transportation system. This process enables the FAA to approve amendment of the ALP to depict certain solar energy projects or issue a ''no objection'' finding to a filed 7460–1 form. The FAA expects to continue to update these policies and procedures as part of an iterative process as new information and technologies become available.

Solar energy systems located on an airport that is not federally-obligated or located outside the property of a federally-obligated airport are not subject to this policy. Proponents of solar energy systems located off-airport property or on non-federally-obligated airports are strongly encouraged to consider the requirements of this policy when siting such systems.

This interim policy clarifies and adds standards for measurement of glint or glare presented in the 2010 Technical Guidance document. Later this year the FAA plans to publish an update to the ''Technical Guidance for Evaluating Selected Solar Technologies on Airports,'' (hereinafter referred to as ''Technical Guidance'') dated November 2010. This update to the technical guidance will include the standards for measuring glint and glare outlined in this notice. It will also provide enhanced criteria to ensure the proper siting of a solar energy installation to eliminate the potential for harmful glare to pilots or air traffic control facilities.

In advance of the planned update, as part of this Notice, we are clarifying one aspect of the Technical Guidance relating to airport sponsor and FAA responsibilities for evaluating the potential for solar energy systems installed on airports to either block, reflect, or disrupt radar signals, NAVAIDS, and other equipment required for safe aviation operations. Section 3.1 of the Technical Guidance, entitled ''Airspace Review,'' correctly states that this role is exclusively the responsibility of FAA Technical Operations (Tech Ops). However subsection 3.1.3, ''System Interference,'' states: ''[s]tudies conducted during project siting should identify the location of radar transmission and receiving facilities and other NAVAIDS, and determine locations that would not be suitable for structures based on their potential to either block, reflect, or disrupt radar signals.''

Reading the two sections together, what is meant is that the airport sponsor, in siting a proposed solar energy system, is responsible for limiting the potential for inference with communication, navigation, and surveillance (CNS) facilities. The sponsor should do so by ensuring that solar energy systems remain clear of the critical areas surrounding CNS facilities. FAA Advisory Circular (AC) 5300–13, ''Airport Design,'' Chapter 6, defines the critical areas for common CNS facilities located on an airport. Sponsors may need to coordinate with FAA Technical Operations concerning CNS facilities not in AC 5300–13. As stated in Section 3.1, the FAA is responsible for evaluating if there are any impacts to CNS facilities. The FAA will conduct this review after the Form 7460–1 is filed for the construction of a new solar energy system installation on an airport. In summary, airport sponsors do not need to conduct studies on their own to determine impacts to CNS facilities when siting a solar energy system on airport. Section 3.1.3 will be revised accordingly in the next version of the Technical Guidance.

Interim Policy Statement

The following sets forth the standards for measuring ocular impact, the required analysis tool, and the obligations of the Airport Sponsor when a solar energy system is proposed for development on a federally-obligated airport.

The FAA is adopting an interim policy because it is in the public interest to enhance safety by clarifying and adding standards for measuring ocular impact of proposed solar energy systems. FAA will consider comments and make appropriate modifications before issuing a final policy in a future **Federal Register** Notice. The policy applies to any proposed solar energy system that has not received unconditional airport layout plan approval (ALP) or a ''no objection'' from the FAA on a filed 7460–1, Notice of Proposed Construction or Alteration.

Standard for Measuring Ocular Impact

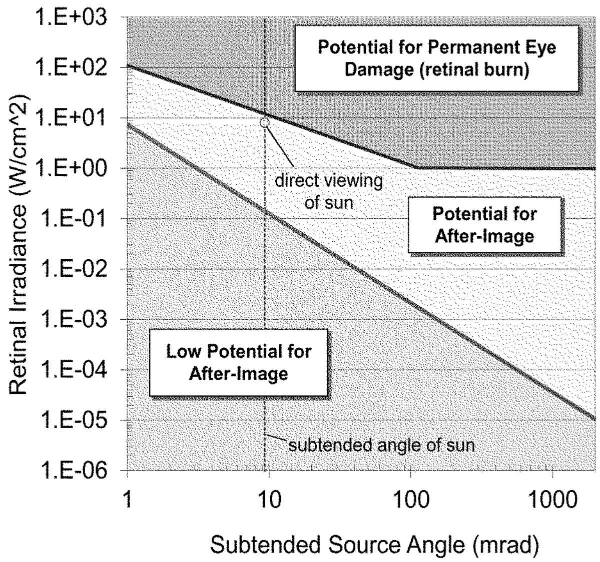
FAA adopts the *Solar Glare Hazard Analysis Plot* shown in Figure 1 below as the standard for measuring the ocular impact of any proposed solar energy system on a federally-obligated airport. To obtain FAA approval to revise an airport layout plan to depict a solar installation and/or a ''no objection'' to a Notice of Proposed Construction Form 7460–1, the airport sponsor will be required to demonstrate that the proposed solar energy system meets the following standards:

1. No potential for glint or glare in the existing or planned Airport Traffic Control Tower (ATCT) cab, and

2. No potential for glare or ''low potential for after-image'' (shown in green in Figure 1) along the final approach path for any existing landing threshold or future landing thresholds (including any planned interim phases of the landing thresholds) as shown on the current FAA-approved Airport Layout Plan (ALP). The final approach path is defined as two (2) miles from fifty (50) feet above the landing threshold using a standard three (3) degree glidepath.

Ocular impact must be analyzed over the entire calendar year in one (1) minute intervals from when the sun rises above the horizon until the sun sets below the horizon.

Figure 1



Solar Glare Ocular Hazard Plot: The potential ocular hazard from solar glare is a function of retinal irradiance and the subtended angle (size/distance) of the glare source. It should be noted that the ratio of spectrally weighted solar illuminance to solar irradiance at the earth's surface yields a conversion factor of ~100 lumens/W. Plot adapted from Ho et al., 2011.

Chart References: Ho, C.K., C.M. Ghanbari, and R.B. Diver, 2011, Methodology to Assess Potential Glint and Glare Hazards from Concentrating Solar Power Plants: Analytical Models and Experimental Validation, J. Solar Energy Engineering, August 2011, Vol. 133, 031021-1 – 031021-9.

Tool To Assess Ocular Impact

In cooperation with the DOE, the FAA is making available free-of-charge the *Solar Glare Hazard Analysis Tool* (SGHAT). The SGHAT was designed to determine whether a proposed solar energy project would result in the potential for ocular impact as depicted on the *Solar Glare Hazard Analysis Plot* shown above.

The SGHAT employs an interactive Google map where the user can quickly locate a site, draw an outline of the proposed solar energy system, and specify observer locations (Airport Traffic Control Tower cab) and final approach paths. Latitude, longitude, and elevation are automatically recorded through the Google interface, providing necessary information for sun position and vector calculations. Additional information regarding the orientation and tilt of the solar energy panels, reflectance, environment, and ocular factors are entered by the user.

If glare is found, the tool calculates the retinal irradiance and subtended source angle (size/distance) of the glare source to predict potential ocular hazards ranging from temporary after-image to retinal burn. The results are presented in a simple, easy-to-interpret plot that specifies when glare will occur throughout the year, with color codes indicating the potential ocular hazard. The tool can also predict relative energy production while evaluating alternative designs, layouts, and locations to identify configurations that maximize energy production while mitigating the impacts of glare.

Users must first register for the use of the tool at this web address: *www.sandia.gov/glare.*

Required Use of the SGHAT

As of the date of publication of this interim policy, the FAA requires the use of the SGHAT to demonstrate compliance with the standards for measuring ocular impact stated above for any proposed solar energy system located on a federally-obligated airport. The SGHAT is a validated tool specifically designed to measure glare according to the *Solar Glare Hazard Analysis Plot.* All sponsors of federally-obligated airports who propose to install or to permit others to install solar energy systems on the airport must attach the SGHAT report, outlining solar panel glare and ocular impact, for each point of measurement to the Notice of Proposed Construction Form 7460–1. The FAA will consider the use of alternative tools or methods on a case-by-case basis. However, the FAA must approve the use of an alternative tool or method prior to an airport sponsor seeking approval for any proposed on-airport solar energy system. The alternative tool or method must evaluate ocular impact in accordance with the *Solar Glare Hazard Analysis Plot.*

Please contact the Office of Airport Planning and Programming, Airport Planning and Environmental Division, APP–400, for more information on the validation process for alternative tools or methods.

Airport sponsor obligations have been discussed above under Background. We caution airport sponsors that under preexisting airport grant compliance policy, failure to seek FAA review of a solar installation prior to construction could trigger possible compliance action under 14 CFR Part 16, ''Rules of Practice for Federally-Assisted Airport Enforcement Proceedings.'' Moreover, if a solar installation creates glare that interferes with aviation safety, the FAA could require the airport to pay for the elimination of solar glare by removing or relocating the solar facility.

Issued in Washington, DC, on September 27, 2013.

Benito De Leon,

Director, Office of Airport Planning and Programming.

[FR Doc. 2013–24729 Filed 10–22–13; 8:45 am]

BILLING CODE 4910–13–P

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

Third Meeting: RTCA Tactical Operations Committee (TOC)

AGENCY: Federal Aviation Administration (FAA), U.S. Department of Transportation (DOT)

ACTION: Third Meeting Notice of RTCA Tactical Operations Committee.

SUMMARY: The FAA is issuing this notice to advise the public of the third meeting of the RTCA Tactical Operations Committee.

DATES: The meeting will be held November 7, 2013 from 9 a.m.–3 p.m.

ADDRESSES: The meeting will be held at RTCA Headquarters, 1150 18th Street NW., Suite 910, Washington, DC 20036.

FOR FURTHER INFORMATION CONTACT: The RTCA Secretariat, 1150 18th Street NW., Suite 910, Washington, DC 20036, or by telephone at (202) 833–9339, fax at (202) 833–9434, or Web site *http://www.rtca.org.* Andy Cebula, NAC Secretary can also be contacted at *acebula@rtca.org* or 202–330–0652.

SUPPLEMENTARY INFORMATION: Pursuant to section 10(a)(2) of the Federal Advisory Committee Act (Pub. L. No. 92–463, 5 U.S.C., App.), notice is hereby given for a meeting of the Tactical Operations Committee (TOC). The agenda will include the following:

November 19, 2013

- Opening of Meeting/Introduction of TOC Members
- Official Statement of Designated Federal Official
- Approval of July 23, 2013 Meeting Summary
- FAA Report
- Notice to Airmen (NOTAM) Activity Prioritization
- Regional Task Groups (RTGs)
- Reports on current activities underway by Regional Task Groups: Eastern, Central, Western
- VHF Omni-directional Range (VOR) Minimum Operating Network
- New Tasking: Obstacle Clearance
- Anticipated Issues for TOC consideration and action at the next meeting
- Other Business
- Adjourn

Attendance is open to the interested public but limited to space availability. With the approval of the chairman, members of the public may present oral statements at the meeting. Persons wishing to present statements or obtain information should contact the person listed in the **FOR FURTHER INFORMATION CONTACT** section. Members of the public may present a written statement to the committee at any time.

Issued in Washington, DC, on October 18, 2013.

Edith V. Parish,

Senior Advisor, Mission Support Services, Air Traffic Organization, Federal Aviation Administration.

[FR Doc. 2013–24968 Filed 10–22–13; 8:45 am]

BILLING CODE 4910–13–P

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

Public Notice for Waiver of Aeronautical Land-Use Assurance

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Notice of intent of waiver with respect to land; French Lick Airport; French Lick, Indiana.

SUMMARY: The FAA is considering a proposal to change a portion of airport land from aeronautical use to non-aeronautical use and to authorize the sale of airport property located at French Lick Airport, French Lick, Indiana. The aforementioned land is not needed for aeronautical use. The proposal consists of 18.606 acres located in the southern section of airport property which is not being used by the airport presently. The land is to be sold to Commissioners of Orange County for the construction of County Road CR 300 South/Airport Road to facilitate access to the airport.

DATES: Comments must be received on or before November 22, 2013.

ADDRESSES: Documents are available for review by appointment at the FAA Airports District Office, Azra Hussain, Program Manager, 2300 E. Devon Avenue, Des Plaines, Illinois 60018 Telephone: (847) 294–8252/Fax: (847) 294–7046 and Zachary D. Brown, French Lick Municipal Airport, 9764 West County Road 375 South, French Lick, Indiana, 47933.

Written comments on the Sponsor's request must be delivered or mailed to: Azra Hussain, Program Manager, Federal Aviation Administration, Airports District Office, 2300 E. Devon Avenue, Des Plaines, Illinois (847) 294–7046.

FOR FURTHER INFORMATION CONTACT: Azra Hussain, Program Manager, Federal Aviation Administration, Airports District Office, 2300 E. Devon Avenue, Des Plaines, Illinois 60018. Telephone Number: (847) 294–8252/FAX Number: (847) 294–7046.

SUPPLEMENTARY INFORMATION: In accordance with section 47107(h) of Title 49, United States Code, this notice is required to be published in the **Federal Register** 30 days before modifying the land-use assurance that requires the property to be used for an aeronautical purpose.

The subject land consists of two parcels. Parcel 1 (approx. 16.667 acres) was acquired through the Federal Aid to Airport Program dated July 28, 1963 and Parcel 2 (approx. 1.939 acres) was acquired by the sponsor as part of a larger parcel (approx. 9.97 acres) for the nominal sum of One Dollar and zero cents ($1.00) on April 19, 2010. The Commissioners of Orange County intend to purchase the property for a nominal sum of One Dollar and zero cents ($1.00) for the construction of County Road CR 300 South/Airport Road. Construction of the road will facilitate access to the airport. The aforementioned land is not needed for aeronautical use, as shown on the Airport Layout Plan. There are no impacts to the airport by allowing the airport to dispose of the property.

This notice announces that the FAA is considering the release of the subject airport property at French Lick Airport, French Lick, Indiana, subject to easements and covenants running with the land. Approval does not constitute a commitment by the FAA to financially assist in the disposal of the subject airport property nor a determination that all measures covered by the program are eligible for grant-in-aid funding from the FAA. The disposition of proceeds from the sale of the airport property will be in accordance with FAA's Policy and Procedures Concerning the Use of Airport Revenue, published in the **Federal Register** on February 16, 1999 (64 FR 7696).

Issued in Des Plaines, Illinois on September 30, 2013.

James Keefer,

Manager, Chicago Airports District Office, FAA, Great Lakes Region.

[FR Doc. 2013–24738 Filed 10–22–13; 8:45 am]

BILLING CODE 4910–13–P

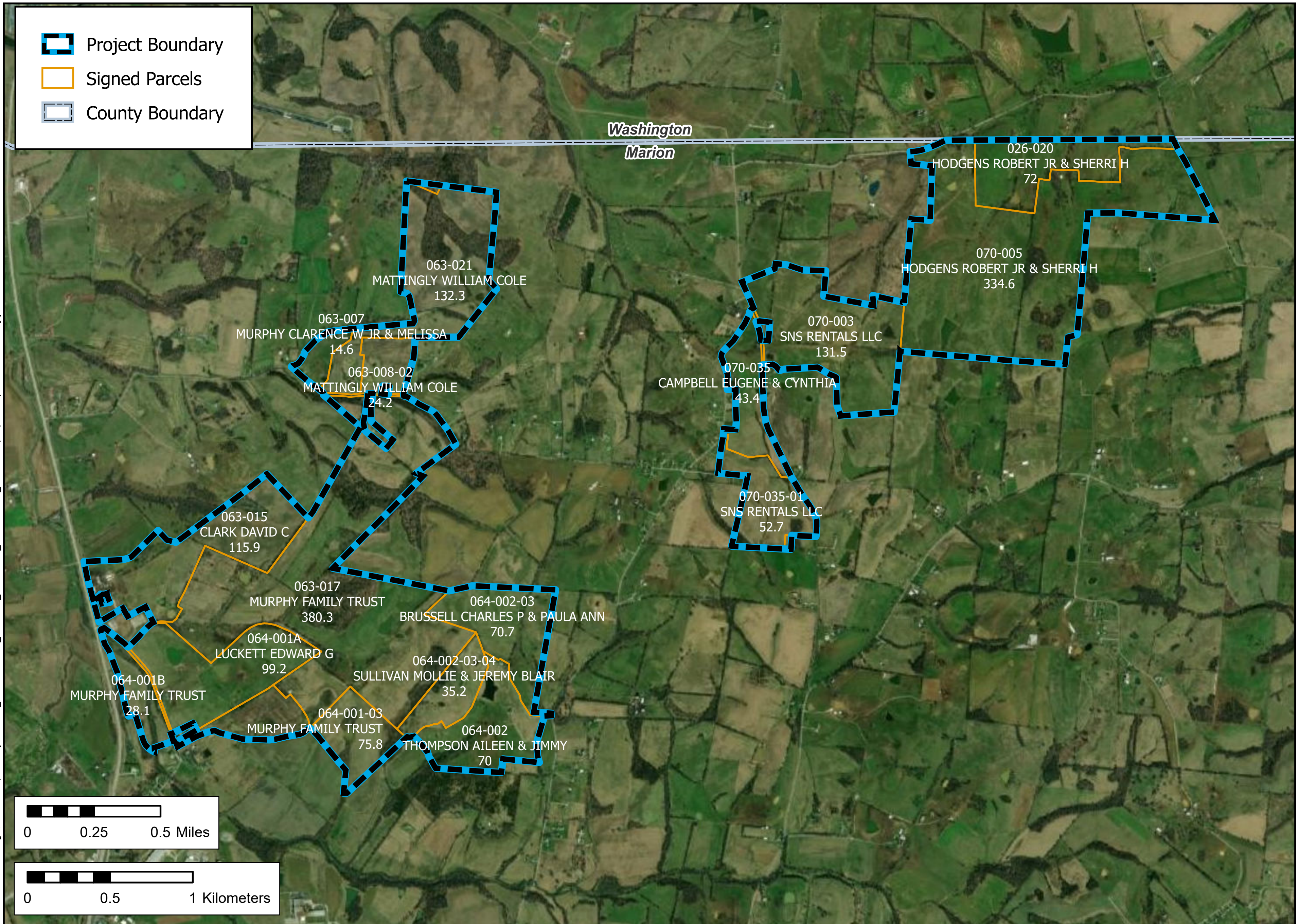
Exhibit K

Landowner Agreements

REDACTED IN ITS ENTIRETY

Exhibit L

Updated Land Control Map



Source: Esri, CoreLogic, EDF 2020 | G:\Projects\USA_North\Northern_Bobwhite_Geenex\05_GIS\Northern_Bobwhite.aprx | Last Updated 2/5/2021 by jessica.leonard

EDF renewables

LAND CONTROL

Northern Bobwhite Solar | Marion County, Kentucky

Exhibit M

Updated Kirkland Letter

Kirkland Appraisals

Richard C. Kirkland, Jr., MAI
9408 Northfield Court
Raleigh, North Carolina 27603
Phone (919) 414-8142
rkirkland2@gmail.com
www.kirklandappraisals.com

February 13, 2021

Ms. Kara Price
Geenex
7804-C Fairview Road, #257
Charlotte, NC 28226

RE: Northern Bobwhite Solar Impact Study, Lebanon, Marion County, KY

Ms. Price

The purpose of this letter is to address questions from the Public Service Commission related to the market impact analysis that I completed on this project on July 9, 2020. This letter relies on the information in the market study and supplemental information provided in this letter to answer the questions.

I was asked to provide information on property values around the proposed project. I have included a chart attached on the pages at the end of this letter to show the current assessed values of adjoining parcels as derived from the Marion County PVA. I note further that in the original study I noted on Page 92 that within a 1-mile radius of the project the average home value is $144,444 and that within a 3-mile radius of the project the average home value is $156,382.

The chart at the end of this letter is an update on the chart included in Pages 5 and 6 of the report to include the assessed values and the linear feet of adjoining property line with the project. Where the linear feet is noted in red, it is actually across a road right of way and I measured the adjoining distance from across the road.

The measurements for the distance from closest panel to closest point on an adjoining home is based on the KMZ data file and GoogleEarth measurements which provides a better basis than measuring off the Marion County GIS as I can rely on the location of the panels within the parcel as indicated by the KMZ file, which would not be possible using the Marion County GIS.

Where the distance is noted as N/A there is no home on that site for me to measure distance from home to panel. A lot is still classified as residential even if it is vacant.

There is a question about the difference between the 60 adjoining properties that I have identified and the 75 properties with borders within 300 feet of the proposed site. I presume that the difference is that there are 15 properties within 300 feet of the proposed site, but not adjoining. I have attempted to show the properties that likely fall within this range based on the GIS by updating the map with a red dot on parcels that appear to be within 300 feet of the property but are not adjoining. My report addresses impacts on adjoining properties as requested, but given a finding of no impact on adjoining properties, I would conclude that nearby properties 300 feet further away from the solar farm would likewise not be negatively impacted by the proposed solar farm.

On the chart I show a breakdown of adjoining uses based on the number of adjoining parcels and the number of adjoining acres. I show both methods of outlining the breakdown of adjoining uses as the two factors together give a better indication of what the surrounding area looks like. By number of adjoining parcels gives more weight to residential, while by number of adjoining acres gives more weight to the agricultural use. By considering both, I get a better model of the area. Most of the projects considered have residential as the most common adjoining use by parcel, and agricultural as the most common adjoining use by acreage. Consider the example of a single farm wrapping around 3 sides of a solar farm and 19 single family homes being located on the 4^{th} side. By parcel it would only show 5% agricultural in the area. That might be terribly misleading if it were a 981-acre farm and the homes were on 1-acre lots. By acre that scenario would then show 98% agricultural and only 2% residential. I find it best to use both methods to test for any unusual situations such as what is described above. However, by acre does typically provide a better indication of the two methods for describing the general area.

I have attached to the end of this letter an expanded summary chart including updated research on solar farms over 50 MW to best answer the question about a focus on larger solar farms. The data presented is very consistent with the solar farm data for all solar farms (those ranging from 5 MW and larger).

Furthermore, any impact from a solar farm is limited to the visual impacts based on all of the analysis and data included in the original report (see Pages 111-112). Essentially, if you can't see it, hear it, or smell it and there are no health impacts, then it doesn't matter how large that use might be. While solar farms often can be seen in bits and parts from adjoining properties, the adjoining homeowner is not able to see 2,000 adjoining acres either before or after the project. Adjoining a 20 MW facility with an appropriate landscaping buffer would offer the adjoining homeowner the same effective view as a 200 MW facility in most cases. It is for this reason that it is reasonable to compare these larger projects to those shown in the impact study. This is supported by the focus on the larger solar farms shown in comparison with the larger set with similar mixes of adjoining uses, similar distances to adjoining homes, and a similar range of impacts from matched pairs that fall mostly within +/- 5%.

This goes to the final question regarding landscaping. Landscaping is an important tool in maintaining a good visual buffer. It is not necessary for the solar farm to be invisible. There is no evidence found in the evaluation that indicates the visibility of solar panels or other solar infrastructure had a measurable negative impact on property values. Many of the matched pairs considered in the analysis can see solar farms. Specifically the solar farm in Crittenden in KY has a very unobstructed view of the solar farm adjoining those homes, but typically landscaping screens do provide more of a screen than seen at that location. However, the primary need for a landscaping screen is to obscure the up close view of panels near the ground. Distant views of solar panels can be found in many locations with panels peeking through trees or on hillsides with no particular or measurable negative impacts.

I further cite two studies completed by two different universities related to solar farms and impacts on property values. The first one specifically addresses larger solar farms over 100 MW.

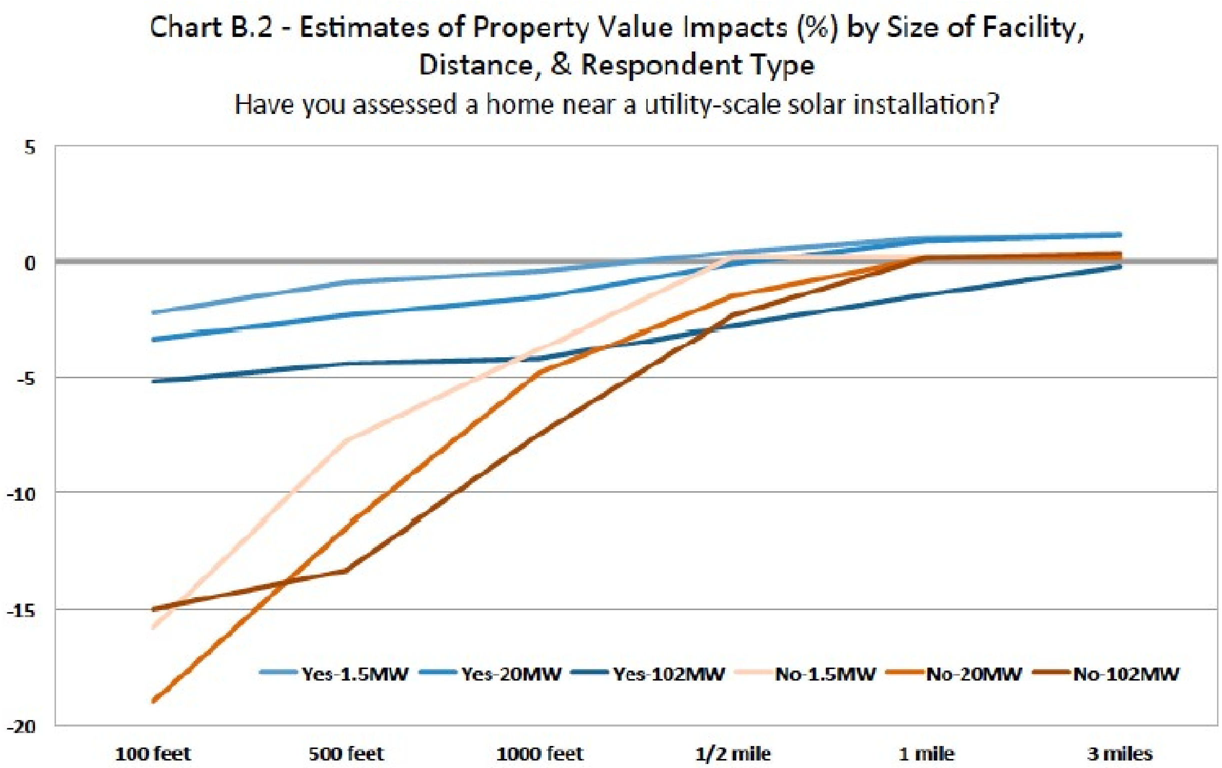
A. University of Texas at Austin, May 2018

An Exploration of Property-Value Impacts Near Utility-Scale Solar Installations

This study considers solar farms from two angles. First it looks at where solar farms are being located and concludes that they are being located primarily in low density residential areas where there are fewer homes than in urban or suburban areas.

The second part is more applicable in that they conducted a survey of appraisers/assessors on their opinions of the possible impacts of proximity to a solar farm. They consider the question in terms of size of the adjoining solar farm and how close the adjoining home is to the solar farm. I am very familiar with this part of the study as I was interviewed by the researchers multiple times as they were developing this. One very important question that they ask within the survey is very illustrative. They asked if the appraiser being surveyed had ever appraised a property next to a solar farm. There is a very noticeable divide in the answers provided by appraisers who have experience appraising property next to a solar farm versus appraisers who self-identify as having no experience or knowledge related to that use.

On Page 16 of that study they have a chart showing the responses from appraisers related to proximity to a facility and size of the facility, but they separate the answers as shown below with appraisers with experience in appraising properties next to a solar farm shown in blue and those inexperienced shown in brown. Even within 100 feet of a 102 MW facility the response from experienced appraisers were -5% at most on impact. While inexperienced appraisers came up with significantly higher impacts. This chart clearly shows that an uninformed response widely diverges from the sales data available on this subject.



Furthermore, the question cited above does not consider any mitigating factors such as landscaping buffers or screens which would presumably reduce the minor impacts noted by experienced appraisers on this subject.

The conclusion of the researchers is shown on Page 23 indicated that "Results from our survey of residential home assessors show that the majority of respondents believe that proximity to a solar installation has either no impact or a positive impact on home values."

This analysis supports the conclusion of this report that the data supports no impact on adjoining property values.

B. University of Rhode Island, September 2020

Property Value Impacts of Commercial-Scale Solar Energy in Massachusetts and Rhode Island

The University of Rhode Island published a study entitled **Property Value Impacts of Commercial-Scale Solar Energy in Massachusetts and Rhode Island** on September 29, 2020 with lead researchers being Vasundhara Gaur and Corey Lang. I have read that study and interviewed Mr. Corey Lang related to that study. This study is often cited by opponents of solar farms but the findings of that study have some very specific caveats according to the report itself as well as Mr. Lang from the interview.

While that study does state in the Abstract that they found depreciation of homes within 1-mile of a solar farm, that impact is limited to non-rural locations. On Pages 16-18 of that study under Section 5.3 Heterogeneity in treatment effect they indicate that the impact that they found was limited to non-rural locations with the impact in rural locations effectively being zero. For the study they defined "rural" as a municipality/township with less than 850 population per square mile.

They further tested the robustness of that finding and even in areas up to 2,000 population per square mile they found no statistically significant data to suggest a negative impact. They have not specifically defined a point at which they found negative impacts to begin, as the sensitivity study stopped checking at the 2,000 population dataset.

Where they did find negative impacts was in high population density areas that was largely a factor of running the study in Massachusetts and Rhode Island which the study specifically cites as being the 2nd and 3rd most population dense states in the USA. Mr. Lang in conversation as well as in recorded presentations has indicated that the impact in these heavily populated areas may reflect a loss in value due to the scarce greenery in those areas and not specifically related to the solar farm itself. In other words, any development of that site might have a similar impact on property value.

So based on this study I have checked the population for the Lebanon CCD of Marion County, which has a population of 10,784 based on STDB 2020 population estimates and a total area of 95.1 square miles for a population density of 113 people per square mile. I also looked at cesnsusreporter.org which gave an estimated population in 2020 of 10,843 for a population density of 114 people per square mile. This is well below the threshold indicated by the Rhode Island Study.

Lebanon CCD, Marion County, KY

County Subdivision in: Marion County, KY, Kentucky, United States

10,843
Population

95.1 square miles

114 people per square mile

Census data: ACS 2019 5-year unless noted

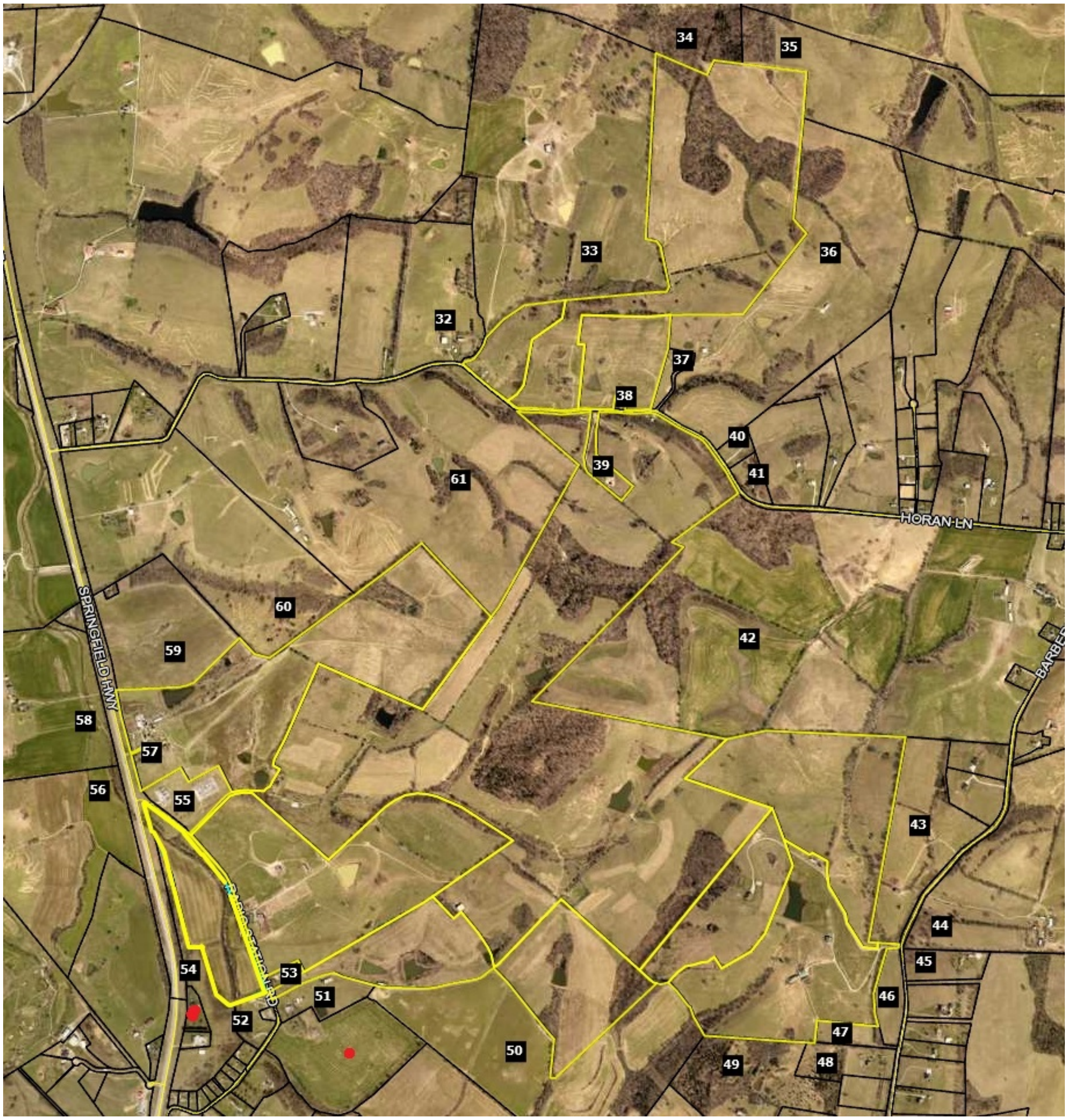
I therefore conclude that the Rhode Island Study supports the indication of no impact on adjoining properties for the proposed solar farm project.

If you have any further questions please call me any time.

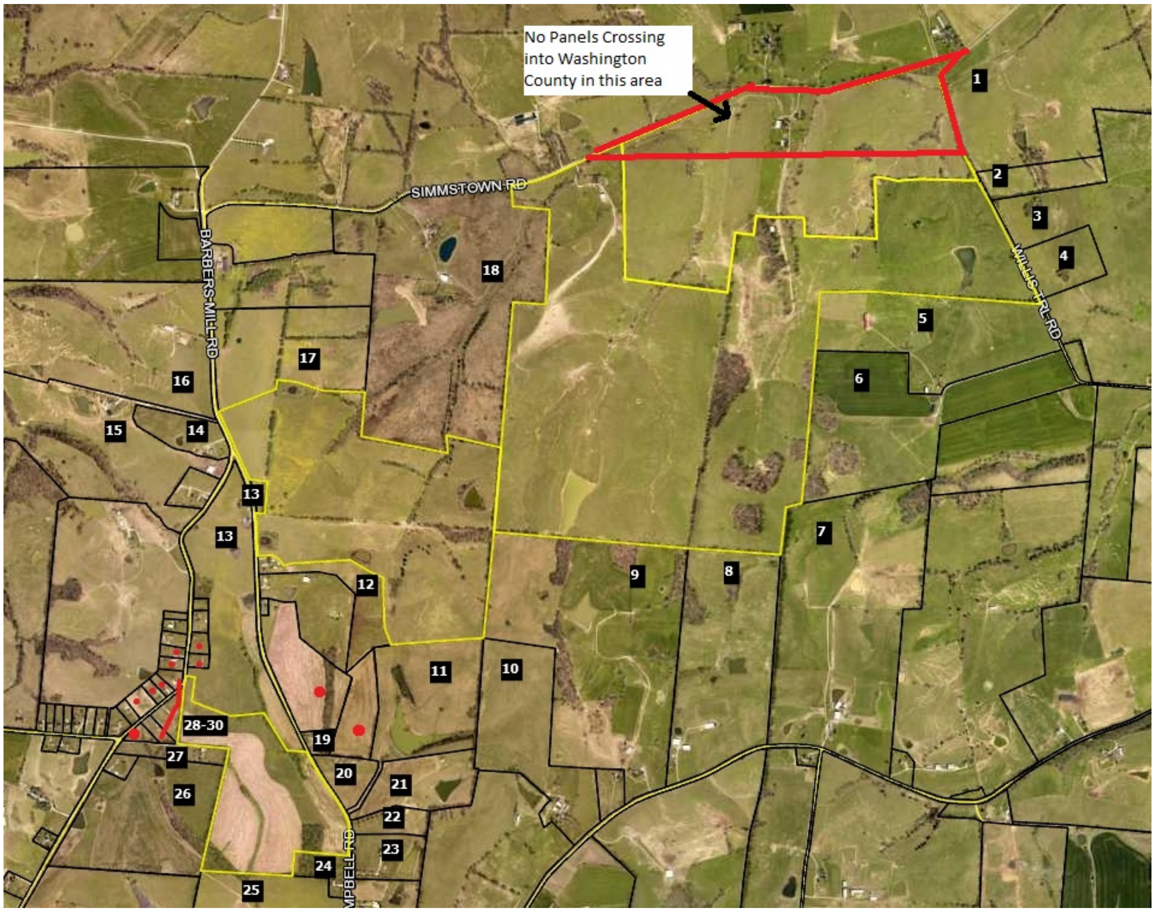
Sincerely,

Richard C. Kirkland, Jr., MAI
Kirkland Appraisals, LLC

A. Updated Adjoining Parcel Data



On the two updated maps I have placed red dots on parcels that are within 300 feet of a boundary line of the project, but not adjoining.



Surrounding Uses

#	MAP ID	Owner	GIS Data Acres	Present Use	Distance (ft) Home/ Note	L.F. Adjoining	Assessed Value
1	Washington County Property		0.00	Unknown	N/A	1,456	N/A
2	Washington County Property		0.00	Unknown	N/A	352	N/A
3	077-003	Hays	117.00	Agri/Res	2,540	664	$480,000
4	077-003-01	Glasscock	11.02	Residential	N/A	602	$30,000
5	077-001-08	Hamilton	48.73	Agri/Res	1,035	3,182	$175,000
6	077-001	Lawson	64.23	Agricultural	N/A	1,739	$100,000
7	077-015	Wright	104.00	Agri/Res	2,405	749	$300,000
8	070-024	Johnson	125.00	Agri/Res	2,620	1,020	$275,000
9	070-033	Clark	110.00	Agri/Res	2,680	3,369	$350,000
10	070-023	Harmon	34.00	Agri/Res	2,455	29	$250,000
11	070-017-06	Robinson	35.99	Agricultural	N/A	1,020	$140,750
12	070-017-01	Tracey	12.76	Residential	300	2,286	$148,000
13	070-035	Cambell	50.24	Agri/Res	215	1,395	$250,000
14	070-007-02	Abell	8.79	Residential	365	415	$195,000
15	070-007	Clark	93.43	Agri/Res	1,515	48	$450,000
16	070-001	Grubbs	119.70	Agricultural	N/A	74	$250,000

#	MAP ID	Owner	GIS Data Acres	Present Use	Distance (ft) Home/Note		
17	070-003-03	Sabdusky	40.98	Agricultural	N/A	1,814	$163,920
18	070-004	Kutter	121.96	Agri/Res	1,340	5,955	$450,000
19	070-030A	Hunt	2.00	Residential	425	34	$110,000
20	070-018-01	Pittman	6.06	Residential	710	735	$215,000
21	070-018	Leake	16.74	Residential	N/A	70	$32,500
22	070-018-08	Leake	5.42	Residential	1,055	151	$175,000
23	070-018-02	Ballinger	10.06	Residential	920	242	$275,000
24	070-034	Leake	5.00	Residential	455	870	$116,000
25	070-011	Hardin	42.00	Agricultural	N/A	1,025	$100,000
26	070-015	Hardin	46.60	Agricultural	N/A	1,236	$150,000
27	070-010-01	Mattingly	5.49	Residential	355	782	$140,000
28	070-010-03	Tucker	1.34	Residential	885	3	$70,000
29	070-010-04	Cook	2.60	Residential	780	680	$55,000
30	070-008-14	Gootee	1.15	Residential	1,035	87	$122,000
31	063-005	Routin	61.29	Agri/Res	505	457	$300,000
32	063-006	Mattingly	163.35	Agricultural	N/A	5,227	$325,000
33	070-002-01	Marion Co	37.00	Agricultural	N/A	1,187	$190,000
34	070-001	Grubbs	119.70	Agricultural	N/A	1,288	$250,000
35	063-008	Parkers	122.37	Agricultural	N/A	4,330	$300,000
36	063-008-01	Brown	2.90	Residential	290	755	$90,000
37	063-022	MLM	0.50	Residential	200	576	$80,000
38	063-011-02	Robbins	4.50	Residential	205	2,642	$240,000
39	063-008-03	Dedman	2.50	Residential	980	252	$50,000
40	063-008-02-02	Deering	3.10	Residential	820	328	$140,000
41	063-010	Tatum	309.00	Agri/Res	4,230	8,124	$600,000
42	070-012	Bradshaw	36.01	Agri/Res	1,045	2,810	$400,000
43	070-013	Montgomery	147.75	Agricultural	N/A	62	$300,000
44	071-001A	Bradshaw	7.81	Residential	1,875	2	$135,000
45	064-002-01	Bradshaw	6.92	Residential	N/A	933	$24,725
46	064-002-06	Mcmicael	6.00	Residential	290	969	$8,000
47	064-003-02	Mullins	10.04	Residential	755	104	$300,000
48	064-003	Bradshaw	110.78	Agri/Res	805	1,200	$400,000
49	054-001	Goodwin	118.76	Agricultural	N/A	5,656	$300,000
50	064-001-01	Begley	8.65	Residential	965	1,273	$150,000
51	064-006A-01	Murphy	1.76	Residential	1,065	540	$25,000
52	064-041	Murphy	1.50	Residential	780	2,427	$185,000
53	062-042B	Cook	17.70	Residential	N/A	2,440	$50,000
54	063-016	Unknown	10.05	Substation	N/A	2,720	N/A
55	055-052	Mattlingly	78.20	Agricultural	N/A	589	$250,000
56	063-015-02	Farmer	0.71	Residential	950	939	$5,000
57	055-006	Gootee	147.00	Agri/Res	2,510	864	$1,000,000
58	063-015-01	Clark	40.84	Agricultural	N/A	1,667	$120,000
59	063-014	Averitt	107.70	Agri/Res	2,680	1,665	$400,000
60	063-002-02	Beams Abell	172.79	Agri/Res	1,450	3,267	$1,385,000
		Total	**3099.469**		1,192	1,456	$238,086

Adjoining linear feet noted in red are located across a right of way from the solar farm parcel.

N/A for Distance from Home/Panel indicates a vacant parcel.

B. Larger Solar Farms

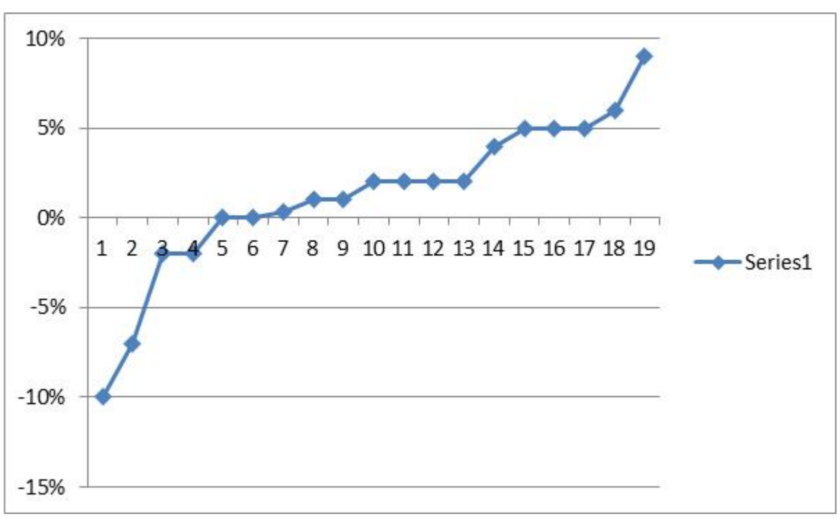
I have also considered larger solar farms to address impacts related to larger projects. Projects have been increasing in size and most of the projects between 100 and 1000 MW are newer with little time for adjoining sales. I have included a breakdown of solar farms with 50 MW to 80 MW facilities adjoining and I will discuss applicability of these solar farms to larger scale projects in the conclusion. This includes data from the original report as well as additional solar farm data compiled since that date.

Matched Pair Summary							Adj. Uses By Acreage				1 mile Radius (2010-2020 Data)		
						Topo						Med.	Avg. Housing
Name	City	State	Acres	MW		Shift	Res	Ag	Ag/Res	Com/Ind	Population	Income	Unit
8 Summit	Moyock	NC	2,034	80.00		4	4%	0%	94%	2%	382	$79,114	$281,731
9 Manatee	Parrish	FL	1,180	75.00		20	2%	97%	1%	0%	48	$75,000	$291,667
10 McBride	Midland	NC	627	75.00		140	12%	10%	78%	0%	398	$63,678	$256,306
13 Innov 46	Hope Mills	NC	532	78.50		0	17%	83%	0%	0%	2,247	$58,688	$183,435
14 Innov 42	Fayetteville	NC	414	71.00		0	41%	59%	0%	0%	568	$60,037	$276,347
47 Barefoot Bay	Barefoot Bay	FL	504	74.50		0	11%	87%	0%	3%	2,446	$36,737	$143,320
48 Miami-Dade	Miami	FL	347	74.50		0	26%	74%	0%	0%	127	$90,909	$403,571
Average			805	76		23	16%	59%	25%	1%	888	$66,309	$262,340
Median			532	75		0	12%	74%	0%	0%	398	$63,678	$276,347
High			2,034	80		140	41%	97%	94%	3%	2,446	$90,909	$403,571
Low			347	71		0	2%	0%	0%	0%	48	$36,737	$143,320

The breakdown of adjoining uses, population density, median income and housing prices for these projects are very similar to those of the larger set. The matched pairs for each of these were considered earlier and support a finding of no negative impact on the adjoining home values.

The matched pairs are shown for these 7 solar farms on the next page. I was able to pull 19 matched pairs from these solar farms. The summary chart below illustrates that most of these findings are between -2% and +5% with two findings suggesting a positive impact over +5% and two findings suggesting a negative impact over -5%. This data very much tracks with a similar range as the impacts noted for the larger set of solar farms showing no impact on value.

The closest adjoining home to a solar farm from these 19 solar farms is 275 feet from home to panel.



Residential Dwelling Matched Pairs Adjoining Solar Farms

Pair	Solar Farm	City	State	Area	MW	Approx Distance	Tax ID/Address	Sale Date	Sale Price	Adj. Sale Price	% Diff
1	Summit	Moyock	NC	Suburban	80	1,060	129 Pinto	Apr-16	$170,000		
							102 Timber	Apr-16	$175,500	$169,451	0%
2	Summit	Moyock	NC	Suburban	80	2,020	105 Pinto	Dec-16	$206,000		
							127 Ranchland	Jun-15	$219,900	$194,278	6%
3	Manatee	Parrish	FL	Rural	75	1180	13670 Highland	Aug-18	$255,000		
							13851 Highland	Sep-18	$240,000	$255,825	0%
4	McBride Place	Midland	NC	Rural	75	275	4380 Joyner	Nov-17	$325,000		
							3870 Elkwood	Aug-16	$250,000	$317,523	2%
5	McBride Place	Midland	NC	Rural	75	505	5811 Kristi	Mar-20	$530,000		
							3915 Tania	Dec-19	$495,000	$504,657	5%
6	Summit	Moyock	NC	Suburban	80	570	318 Green View	Sep-19	$357,000		
							336 Green View	Jan-19	$365,000	$340,286	5%
7	Summit	Moyock	NC	Suburban	80	440	164 Ranchland	Apr-19	$169,000		
							105 Longhorn	Oct-17	$184,500	$186,616	-10%
8	Summit	Moyock	NC	Suburban	80	635	358 Oxford	Sep-19	$478,000		
							176 Providence	Sep-19	$425,000	$456,623	4%
9	Summit	Moyock	NC	Suburban	80	970	343 Oxford	Mar-17	$490,000		
							218 Oxford	Apr-17	$525,000	$484,064	1%
10	Innov 46	Hope Mills	NC	Suburban	78.5	435	6849 Roslin Farm	Feb-19	$155,000		
							109 Bledsoe	Jan-19	$150,000	$147,558	5%
11	Innov 42	Fayetteville	NC	Suburban	71	340	2923 County Line	Feb-19	$385,000		
							2109 John McMillan	Apr-18	$320,000	$379,156	2%
12	Innov 42	Fayetteville	NC	Suburban	71	330	2935 County Line	Jun-19	$266,000		
							7031 Glynn Mill	May-18	$255,000	$264,422	1%
13	Barefoot Bay	Barefoot Bay	FL	Suburban	74.5	765	465 Papaya	Jul-19	$155,000		
							1132 Waterway	Jul-20	$129,000	$141,618	9%
14	Barefoot Bay	Barefoot Bay	FL	Suburban	74.5	750	455 Papaya	Sep-20	$183,500		
							904 Fir	Sep-20	$192,500	$186,697	-2%
15	Barefoot Bay	Barefoot Bay	FL	Suburban	74.5	690	419 Papaya	Jul-19	$127,500		
							865 Tamarind	Feb-19	$133,900	$124,613	2%
16	Barefoot Bay	Barefoot Bay	FL	Suburban	74.5	690	413 Papaya	Jul-20	$130,000		
							1367 Barefoot	Jan-21	$130,500	$139,507	-7%
17	Barefoot Bay	Barefoot Bay	FL	Suburban	74.5	690	343 Papaya	Dec-19	$145,000		
							865 Tamarind	Feb-19	$133,900	$142,403	2%
18	Barefoot Bay	Barefoot Bay	FL	Suburban	74.5	710	335 Papaya	Apr-18	$110,000		
							865 Tamarind	Feb-19	$133,900	$110,517	0%
19	Miami-Dade	Miami	FL	Suburban	74.5	1390	13600 SW 182nd	Nov-20	$1,684,000		
							17950 SW 158th	Oct-20	$1,730,000	$1,713,199	-2%

	MW	Avg. Distance
Average	76.16	760
Median	75.00	690
High	80.00	2,020
Low	71.00	275

	Indicated Impact
Average	1%
Median	2%
High	9%
Low	-10%

On the following page I show 81 projects ranging in size from 50 MW up to 1,000 MW with an average size of 111.80 MW and a median of 80 MW. The average closest distance for an adjoining home is 263 feet, while the median distance is 188 feet. The closest distance is 57 feet. The mix of adjoining uses is similar with most of the adjoining uses remaining residential or agricultural in nature. This is the list of solar farms that I have researched for possible matched pairs and not a complete list of larger solar farms in those states.

Parcel #	State	City	Name	Output (MW)	Total Acres	Used Acres	Avg. Dist to home	Closest Home	Adjoining Use by Acre Res	Agri	Ag/R	Com
78	NC	Moyock	Summit/Ranchland	80	2034		674	360	4%	94%	0%	2%
133	MS	Hattiesburg	Hattiesburg	50	1129	479.6	650	315	35%	65%	0%	0%
179	SC	Ridgeland	Jasper	140	1600	1000	461	108	2%	85%	13%	0%
211	NC	Enfield	Chestnut	75	1428.1		1,429	210	4%	96%	0%	0%
222	VA	Chase City	Grasshopper	80	946.25				6%	87%	5%	1%
226	VA	Louisa	Belcher	88	1238.1			150	19%	53%	28%	0%
305	FL	Dade City	Mountain View	55	347.12		510	175	32%	39%	21%	8%
319	FL	Jasper	Hamilton	74.9	1268.9	537	3,596	240	5%	67%	28%	0%
336	FL	Parrish	Manatee	74.5	1180.4		1,079	625	2%	50%	1%	47%
337	FL	Arcadia	Citrus	74.5	640				0%	0%	100%	0%
338	FL	Port Charlotte	Babcock	74.5	422.61				0%	0%	100%	0%
353	VA	Oak Hall	Amazon East(ern sh	80	1000		645	135	8%	75%	17%	0%
364	VA	Stevensburg	Greenwood	100	2266.6	1800	788	200	8%	62%	29%	0%
368	NC	Warsaw	Warsaw	87.5	585.97	499	526	130	11%	66%	21%	3%
390	NC	Ellerbe	Innovative Solar 34	50	385.24	226	N/A	N/A	1%	99%	0%	0%
399	NC	Midland	McBride	74.9	974.59	627	1,425	140	12%	78%	9%	0%
400	FL	Mulberry	Alafia	51	420.35		490	105	7%	90%	3%	0%
406	VA	Clover	Foxhound	91	1311.8		885	185	5%	61%	17%	18%
410	FL	Trenton	Trenton	74.5	480		2,193	775	0%	26%	55%	19%
411	NC	Battleboro	Fern	100	1235.4	960.71	1,494	220	5%	76%	19%	0%
412	MD	Goldsboro	Cherrywood	202	1722.9	1073.7	429	200	10%	76%	13%	0%
434	NC	Conetoe	Conetoe	80	1389.9	910.6	1,152	120	5%	78%	17%	0%
440	FL	Debary	Debary	74.5	844.63		654	190	3%	27%	0%	70%
441	FL	Hawthorne	Horizon	74.5	684				3%	81%	16%	0%
484	VA	Newsoms	Southampton	100	3243.9		-	-	3%	78%	17%	3%
486	VA	Stuarts Draft	Augusta	125	3197.4	1147	588	165	16%	61%	16%	7%
491	NC	Misenheimer	Misenheimer 2018	80	740.2	687.2	504	130	11%	40%	22%	27%
494	VA	Shacklefords	Walnut	110	1700	1173	641	165	14%	72%	13%	1%
496	VA	Clover	Piney Creek	80	776.18	422	523	195	15%	62%	24%	0%
511	NC	Scotland Neck	American Beech	160	3255.2	1807.8	1,262	205	2%	58%	38%	3%
514	NC	Reidsville	Williamsburg	80	802.6	507	734	200	25%	12%	63%	0%
517	VA	Luray	Cape	100	566.53	461	519	110	42%	12%	46%	0%
518	VA	Emporia	Fountain Creek	80	798.3	595	862	300	6%	23%	71%	0%
525	NC	Plymouth	Macadamia	484	5578.7	4813.5	1,513	275	1%	90%	9%	0%
526	NC	Mooresboro	Broad River	50	759.8	365	419	70	29%	55%	16%	0%
555	FL	Mulberry	Durrance	74.5	463.57	324.65	438	140	3%	97%	0%	0%
560	NC	Yadkinville	Sugar	60	477	357	382	65	19%	39%	20%	22%
561	NC	Enfield	Halifax 80mw 2019	80	1007.6	1007.6	672	190	8%	73%	19%	0%
577	VA	Windsor	Windsor	85	564.1	564.1	572	160	9%	67%	24%	0%
579	VA	Paytes	Spotsylvania	500	6412	3500			9%	52%	11%	27%
582	NC	Salisbury	China Grove	65	428.66	324.26	438	85	58%	4%	38%	0%
583	NC	Walnut Cove	Lick Creek	50	1424	185.11	410	65	20%	64%	11%	5%
584	NC	Enfield	Sweetleaf	94	1956.3	1250	968	160	5%	63%	32%	0%
586	VA	Aylett	Sweet Sue	77	1262	576	1,617	680	7%	68%	25%	0%
593	NC	Windsor	Sumac	120	3360.6	1257.9	876	160	4%	90%	6%	0%
599	TN	Somerville	Yum Yum	147	4000	1500	1,862	330	3%	32%	64%	1%
602	GA	Waynesboro	White Oak	76.5	516.7	516.7	2,995	1,790	1%	34%	65%	0%
603	GA	Butler	Butler GA	103	2395.1	2395.1	1,534	255	2%	73%	23%	2%
604	GA	Butler	White Pine	101.2	505.94	505.94	1,044	100	1%	51%	48%	1%
605	GA	Metter	Live Oak	51	417.84	417.84	910	235	4%	72%	23%	0%
606	GA	Hazelhurst	Hazelhurst II	52.5	947.15	490.42	2,114	105	9%	64%	27%	0%
607	GA	Bainbridge	Decatur Parkway	80	781.5	781.5	1,123	450	2%	27%	22%	49%
608	GA	Leslie-DeSoto	Americus	1000	9661.2	4437	5,210	510	1%	63%	36%	0%
616	FL	Fort White	Fort White	74.5	570.5	457.2	828	220	12%	71%	17%	0%
621	VA	Spring Grove	Loblolly	150	2181.9	1000	1,860	110	7%	62%	31%	0%
622	VA	Scottsville	Woodridge	138	2260.9	1000	1,094	170	9%	63%	28%	0%
625	NC	Middlesex	Phobos	80	754.52	734	356	57	14%	75%	10%	0%
628	MI	Deerfield	Carroll Road	200	1694.8	1694.8	343	190	12%	86%	0%	2%
633	VA	Emporia	Brunswick	150.2	2076.4	1387.3	1,091	240	4%	85%	11%	0%
634	NC	Elkin	Partin	50	429.4	257.64	945	155	30%	25%	15%	30%

Parcel #	State	City	Name	Output (MW)	Total Acres	Used Acres	Avg. Dist to home	Closest Home	Adjoining Use by Acre Res	Agri	Ag/R	Com
638	GA	Dry Branch	Twiggs	200	2132.7	2132.7	-	-	10%	55%	35%	0%
639	NC	Hope Mills	Innovative Solar 46	78.5	531.87	531.87	423	125	17%	83%	0%	0%
640	NC	Hope Mills	Innovative Solar 42	71	413.99	413.99	375	135	41%	59%	0%	0%
645	NC	Stanley	Hornet	75	1499.5	858.4	663	110	30%	40%	23%	6%
650	NC	Grifton	Grifton 2	56	681.59	297.6	363	235	1%	99%	0%	0%
651	NC	Grifton	Buckleberry	52.1	367.67	361.67	913	180	5%	54%	41%	0%
657	KY	Greensburg	Horseshoe Bend	60	585.65	395	1,394	63	3%	36%	61%	0%
658	KY	Campbellsville	Flat Run	55	429.76	429.76	408	115	13%	52%	35%	0%
666	FL	Archer	Archer	74.9	636.94	636.94	638	200	43%	57%	0%	0%
667	FL	New Smyrna Bea	Pioneer Trail	74.5	1202.8	900	1,162	225	14%	61%	21%	4%
668	FL	Lake City	Sunshine Gateway	74.5	904.29	472	1,233	890	11%	80%	8%	0%
669	FL	Florahome	Coral Farms	74.5	666.54	580	1,614	765	19%	75%	7%	0%
672	VA	Appomattox	Spout Spring	60	881.12	673.37	836	335	16%	30%	46%	8%
676	TX	Stamford	Alamo 7	106.4	1663.1	1050	-	-	6%	83%	0%	11%
677	TX	Fort Stockton	RE Roserock	160	1738.2	1500	-	-	0%	100%	0%	0%
678	TX	Lamesa	Lamesa	102	914.5	655	921	170	4%	41%	11%	44%
679	TX	Lamesa	Ivory	50	706	570	716	460	0%	87%	2%	12%
680	TX	Uvalde	Alamo 5	95	830.35	800	925	740	1%	93%	6%	0%
684	NC	Waco	Brookcliff	50	671.03	671.03	560	150	7%	21%	15%	57%
689	AZ	Arlington	Mesquite	320.8	3774.5	2617	1,670	525	8%	92%	0%	0%
692	AZ	Tucson	Avalon	51	479.21	352	-	-	0%	100%	0%	0%
				81								
			Average	111.80	1422.4	968.4	1031	263	10%	62%	22%	6%
			Median	80.00	914.5	646.0	836	188	7%	64%	17%	0%
			High	1000.00	9661.2	4813.5	5210	1790	58%	100%	100%	70%
			Low	50.00	347.1	185.1	343	57	0%	0%	0%	0%

Parcel #	State	County	City	Name	Output (MW)	Total Acres	Used Acres	Avg. Dist to home	Closest Home	Adjoining Use by Acre			
										Res	Agri	Agri/Res	Com
78	NC	Currituck	Moyock	Summit/Ranchland	80	2034		674	360	4%	94%	0%	2%
133	MS	Forrest	Hattiesburg	Hattiesburg	50	1129	479.6	650	315	35%	65%	0%	0%
179	SC	Jasper	Ridgeland	Jasper	140	1600	1000	461	108	2%	85%	13%	0%
211	NC	Halifax	Enfield	Chestnut	75	1428.1		1,429	210	4%	96%	0%	0%
222	VA	Mecklenburg	Chase City	Grasshopper	80	946.25				6%	87%	5%	1%
226	VA	Louisa	Louisa	Belcher	88	1238.1			150	19%	53%	28%	0%
305	FL	Pasco	Dade City	Mountain View	55	347.12		510	175	32%	39%	21%	8%
319	FL	Hamilton	Jasper	Hamilton	74.9	1268.9	537	3,596	240	5%	67%	28%	0%
336	FL	Manatee	Parrish	Manatee	74.5	1180.4		1,079	625	2%	50%	1%	47%
337	FL	DeSoto	Arcadia	Citrus	74.5	640				0%	0%	100%	0%
338	FL	Charlotte	Port Charlotte	Babcock	74.5	422.61				0%	0%	100%	0%
353	VA	Accomack	Oak Hall	Amazon East(ern shore)	80	1000		645	135	8%	75%	17%	0%
364	VA	Culpepper	Stevensburg	Greenwood	100	2266.6	1800	788	200	8%	62%	29%	0%
368	NC	Duplin	Warsaw	Warsaw	87.5	585.97	499	526	130	11%	66%	21%	3%
390	NC	Richmond	Ellerbe	Innovative Solar 34	50	385.24	226	N/A	N/A	1%	99%	0%	0%
399	NC	Cabarrus	Midland	McBride	74.9	974.59	627	1,425	140	12%	78%	9%	0%
400	FL	Polk	Mulberry	Alafia	51	420.35		490	105	7%	90%	3%	0%
406	VA	Halifax	Clover	Foxhound	91	1311.8		885	185	5%	61%	17%	18%
410	FL	Gilchrist	Trenton	Trenton	74.5	480		2,193	775	0%	26%	55%	19%
411	NC	Edgecombe	Battleboro	Fern	100	1235.4	960.71	1,494	220	5%	76%	19%	0%
412	MD	Caroline	Goldsboro	Cherrywood	202	1722.9	1073.7	429	200	10%	76%	13%	0%
434	NC	Edgecombe	Conetoe	Conetoe	80	1389.9	910.6	1,152	120	5%	78%	17%	0%
440	FL	Volusia	Debary	Debary	74.5	844.63		654	190	3%	27%	0%	70%
441	FL	Alachua & Pu	Hawthorne	Horizon	74.5	684				3%	81%	16%	0%
484	VA	Southampton	Newsoms	Southampton	100	3243.9		-	-	3%	78%	17%	3%
486	VA	Augusta	Stuarts Draft	Augusta	125	3197.4	1147	588	165	16%	61%	16%	7%
491	NC	Stanly	Misenheimer	Misenheimer 2018	80	740.2	687.2	504	130	11%	40%	22%	27%
494	VA	King and Que	Shacklefords	Walnut	110	1700	1173	641	165	14%	72%	13%	1%
496	VA	Halifax	Clover	Piney Creek	80	776.18	422	523	195	15%	62%	24%	0%
511	NC	Halifax	Scotland Neck	American Beech	160	3255.2	1807.8	1,262	205	2%	58%	38%	3%
514	NC	Rockingham	Reidsville	Williamsburg	80	802.6	507	734	200	25%	12%	63%	0%
517	VA	Page	Luray	Cape	100	566.53	461	519	110	42%	12%	46%	0%
518	VA	Greensville	Emporia	Fountain Creek	80	798.3	595	862	300	6%	23%	71%	0%
525	NC	Washington	Plymouth	Macadamia	484	5578.7	4813.5	1,513	275	1%	90%	9%	0%
526	NC	Cleveland	Mooresboro	Broad River	50	759.8	365	419	70	29%	55%	16%	0%
555	FL	Polk	Mulberry	Durrance	74.5	463.57	324.65	438	140	3%	97%	0%	0%
560	NC	Yadkin	Yadkinville	Sugar	60	477	357	382	65	19%	39%	20%	22%
561	NC	Halifax	Enfield	Halifax 80mw 2019	80	1007.6	1007.6	672	190	8%	73%	19%	0%
577	VA	Isle of Wight	Windsor	Windsor	85	564.1	564.1	572	160	9%	67%	24%	0%
579	VA	Spotsylvania	Paytes	Spotsylvania	500	6412	3500			9%	52%	11%	27%
582	NC	Rowan	Salisbury	China Grove	65	428.66	324.26	438	85	58%	4%	38%	0%
583	NC	Stokes	Walnut Cove	Lick Creek	50	1424	185.11	410	65	20%	64%	11%	5%
584	NC	Halifax	Enfield	Sweetleaf	94	1956.3	1250	968	160	5%	63%	32%	0%
586	VA	King William	Aylett	Sweet Sue	77	1262	576	1,617	680	7%	68%	25%	0%
593	NC	Bertie	Windsor	Sumac	120	3360.6	1257.9	876	160	4%	90%	6%	0%
599	TN	Fayette	Somerville	Yum Yum	147	4000	1500	1,862	330	3%	32%	64%	1%
602	GA	Burke	Waynesboro	White Oak	76.5	516.7	516.7	2,995	1,790	1%	34%	65%	0%
603	GA	Taylor	Butler	Butler GA	103	2395.1	2395.1	1,534	255	2%	73%	23%	2%
604	GA	Taylor	Butler	White Pine	101.2	505.94	505.94	1,044	100	1%	51%	48%	1%
605	GA	Candler	Metter	Live Oak	51	417.84	417.84	910	235	4%	72%	23%	0%
606	GA	Jeff Davis	Hazelhurst	Hazelhurst II	52.5	947.15	490.42	2,114	105	9%	64%	27%	0%
607	GA	Decatur	Bainbridge	Decatur Parkway	80	781.5	781.5	1,123	450	2%	27%	22%	49%
608	GA	Sumter	Leslie-DeSoto	Americus	1000	9661.2	4437	5,210	510	1%	63%	36%	0%
616	FL	Colombia	Fort White	Fort White	74.5	570.5	457.2	828	220	12%	71%	17%	0%
621	VA	Surry	Spring Grove	Loblolly	150	2181.9	1000	1,860	110	7%	62%	31%	0%
622	VA	Albemarle	Scottsville	Woodridge	138	2260.9	1000	1,094	170	9%	63%	28%	0%
625	NC	Nash	Middlesex	Phobos	80	754.52	734	356	57	14%	75%	10%	0%
628	MI	Lenawee	Deerfield	Carroll Road	200	1694.8	1694.8	343	190	12%	86%	0%	2%
633	VA	Greensville	Emporia	Brunswick	150.2	2076.4	1387.3	1,091	240	4%	85%	11%	0%
634	NC	Surry	Elkin	Partin	50	429.4	257.64	945	155	30%	25%	15%	30%
638	GA	Twiggs	Dry Branch	Twiggs	200	2132.7	2132.7	-	-	10%	55%	35%	0%
639	NC	Cumberland	Hope Mills	Innovative Solar 46	78.5	531.87	531.87	423	125	17%	83%	0%	0%
640	NC	Cumberland	Hope Mills	Innovative Solar 42	71	413.99	413.99	375	135	41%	59%	0%	0%
		Total Number of Solar Farms			63								
				Average	118.48	1533.1	1043.6	1058	241	11%	60%	24%	6%
				Median	80.00	1000.0	657.1	808	175	7%	64%	19%	0%
				High	1000.00	9661.2	4813.5	5210	1790	58%	99%	100%	70%
				Low	50.00	347.1	185.1	343	57	0%	0%	0%	0%

Exhibit N

Map of Primary Roads

NOTE:
AERIAL PHOTOGRAPHY FROM GOOGLE EARTH
IMAGERY DATE: 4/12/2017

TRAFFIC

Smith Management Group
a division of ALL4

PRIMARY ROADS

NORTHERN BOBWHITE SOLAR
LEBANON, KENTUCKY

SCALE: AS SHOWN	JOB NO. 2020-6869	FIGURE 1
DATE: 2/8/21		
PREPARED BY: KAF		
CHECKED BY: KMC		

Exhibit O

Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety

550/9-74-004

INFORMATION ON LEVELS OF ENVIRONMENTAL NOISE REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE WITH AN ADEQUATE MARGIN OF SAFETY

MARCH 1974

PREPARED BY
THE U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF NOISE ABATEMENT AND CONTROL

This document has been approved for general availability. It does not constitute a standard, specification, or regulation.

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FOREWORD

The Congress included among the requirements of the Noise Control Act of 1972 a directive that the Administrator of the Environmental Protection Agency "...develop and publish criteria with respect to noise..." and then "publish information on the levels of environmental noise the attainment and maintenance of which in defined areas under various conditions are requisite to protect the public health and welfare with an adequate margin of safety."

Not all of the scientific work that is required for basing such levels of environmental noise on precise objective factors has been completed. Some investigations are currently underway, and the need for others has been identified. These involve both special studies on various aspects of effects of noise on humans and the accumulation of additional epidemiological data. In some cases, a considerable period of time must elapse before the results will be meaningful, due to the long-term nature of the investigations involved. Nonetheless, there is information available from which extrapolations are possible and about which reasoned judgments can be made.

Given the foregoing, EPA has sought to provide information on the levels of noise requisite to protect public health and welfare with an adequate margin of safety. The information presented is based on analyses, extrapolations and evaluations of the present state of scientific knowledge. This approach is not unusual or different from that used for other environmental stressors and pollutants. As pointed out in "Air Quality Criteria"-Staff Report, Subcommittee on Air and Water Pollution, Committee on Public Works, U-S. Senate, July, 1968,

> The protection of public health is required action based upon best evidence of causation available. Sir E. B. Hill, 1962 appropriately expressed this philosophy, when he wrote: "All scientific work is incomplete-whether it be observational or experimental. All scientific work is liable to be upset or modified by advancing knowledge. That does not confer upon us freedom to lower the knowledge we already have, or to postpone the action that it appears to demand at a given time. The lessons of the past in general health and safety practices are easy to read. They are characterized by empirical decisions, by eternally persistent reappraisal of public health standards against available knowledge of causation, by consistently giving the public the benefit of the doubt, and by ever striving for improved environmental quality with the accompanying reduction in disease morbidity and mortality. The day of precise quantitative

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> measurement of health and welfare effects has not yet arrived. Until such measurement is possible, action must be based upon limited knowledge, guided by the principal of the enhancement of the quality of human life. Such action is based on a philosophy of preventive medicine."

The foregoing represents the approach taken by EPA in the preparation of this present document on noise. As the fund of knowledge is expanded, improved and refined, revisions of this document will occur.

The incorporation of a margin of safety in the identification of non-hazardous levels is not new. In most cases, a statistical determination is made of the lowest level at which harmful effects could occur, and then an additional correction is applied as a margin of safety. In the case of noise, the margin of safety has been developed through the application of a conservative approach at each stage of the data analysis. The cumulation of these results thus provides for the adequate margin of safety.

It should be borne in mind that this document is published to present information required by the Noise Control Act, Section 5(a)(2), and that its contents do not constitute Agency regulations or standards. Its statistical generalizations should not be applied to a particular individual. Moreover, States and localities will approach this information according to their individual needs and situations.

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ABBREVIATIONS

AAOO American Academy of Ophthalmology and Otolaryngology

AFR	Air Force Regulation
AI	Articulation Index
AMA	American Medical Association
ANSI	American National Standards Institute (formerly USASI)
ASHA	American Speech and Hearing Association
CHABA	Committee on Hearing and Bio-Acoustics
dBA	A-weighted decibel (decibels). Also written dB(A).
EPA	Environmental Protection Agency
IEC	International Electrotechnical Commission
ISO	Intentional Organization for Standardization
NIOSH	National Institute for Occupational Safety and Health
NIPTS	Noise-Induced Permanent Threshold Shift
NITTS	Noise-Induced Temporary Threshold Shift
NPL	Noise Pollution Level (also National Physical Laboratory in England)
NR	Noise Rating
OSHA	Occupational Safety and Health Act
RMS	Root Mean Square
SIL	Speech Interference Level
SPL	Sound Pressure Level
TTS	Temporary Threshold Shift

Abbreviations-1

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TTS_2	TTS determined 2 minutes after cessation of exposure
$L_{(t)}$	Time-varying noise level
L_A	A-weighted sound level
L_b	"Background" or "residual" sound level, A-weighted
L_d	Daytime equivalent A-weighted sound level between the hours of 0700 and 2200
L_e	Sound exposure level-the level of sound accumulated during a given event.
L_{dn}	Day-night average sound level-the 24 hour A-weighted equivalent sound level, with a 10 decibel penalty applied to nighttime levels
L_{eq}	Equivalent A-weighted sound level over a given time interval
$L_{eq(8)}$	Equivalent A-weighted sound level over eight hours
$L_{eq(24)}$	Equivalent A-weighted sound level over 24 hours
L_h	Hourly equivalent A-weighted sound level
L_n	Nighttime equivalent A-weighted sound level between the hours of 2200 and 0700
L_{max}	Maximum A-weighted sound level for a given time interval or event
L_x	X-percent sound level, the A-weighted sound level equaled or exceeded x% of time

Abbreviations-2

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Section 1

INTRODUCTION

The Noise Control Act of 1972 established by statutory mandate a national policy "to promote an environment for all Americans free from noise that jeopardizes their public health and welfare". The Act provides for a division of powers between the Federal and state and local governments, in which the primary Federal responsibility is for noise source emission control, with the states and other political subdivisions retaining rights and authorities for primary responsibility to control the use of noise sources and the levels of noise to be permitted in their environment.

In order to provide adequately for the Federal emission control requirement and to insure Federal assistance and guidance to the state and localities, the Congress has established two separate but related requirements with regard to scientific information about health and welfare effects of noise. First, the Environmental Protection Agency was called upon to publish descriptive data on the effect of noise which might be expected from various levels and exposure situations. Such "criteria" statements are typical of other environmental regulatory schemes. Secondly, the Agency is required to publish "information" as to the levels of noise "requisite to protect the public health and welfare with an adequate margin of safety".

SUMMARY

The first requirement was completed in July, 1973, when the document "Public Health and Welfare Criteria for Noise" was published. The present document represents the second step. Much of the scientific material on which this document is based was drawn from the earlier "criteria document", while additional material was gathered from scientific publications and other sources, both from the U.S. and abroad. In addition, two review meetings were held which were attended by representatives of the Federal agencies as well as distinguished members of the professional community and representatives from industrial and environmental associations. The reviewers' suggestions, both oral and written, have received thoughtful attention, and their comments incorporated to the extent feasible and appropriate.

After a great deal of analysis and deliberation, levels were identified to protect public health and welfare for a large number of situations. These levels are subject to the

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definitions and qualifications contained in the Foreword. They are summarized in Table I according to the public health and welfare effect to be protected against, the requisite sound level, and the areas which are appropriate for such protection.

In order to identify these levels, a number of considerations and hypotheses were necessary, which are listed below with reference to the appropriate appendices where they are discussed in detail.

1. In order to describe the effects of environmental noise in a simple, uniform and appropriate way, the best descriptors are the long-term equivalent A-weighted sound level (L_{eq}) and a variation with a nighttime weighting, the day-night sound level (L_{dn}) (see Appendix A).

2. To protect against hearing impairment (see Appendix C):

a. The human ear, when damaged by noise, is typically affected first at the audiometric frequency of 4000 Hz.

b. Changes in hearing level of less than 5 dB are generally not considered noticeable or significant.

c. One cannot be damaged by sounds considered normally audible, which one cannot hear.

d. Protecting the population up to a critical percentile (ranked according to decreasing ability to hear) will also protect those above that percentile, (in view of consideration 2c above) thereby protecting virtually the entire population.

3. To correct for intermittence and duration in identifying the appropriate level to protect against hearing loss (also, see Appendix C):

a. The Equal Energy Hypothesis

b. The TTS Hypothesis

4. To identify levels requisite to protect against activity interference (see Appendix D):

a. Annoyance due to noise, as measured by community surveys, is the consequence of activity interference.

b. Of the various kinds of activity interference, speech interference is the one that is most readily quantifiable.

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Table 1

SUMMARY OF NOISE LEVELS IDENTIFIED AS REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE WITH AN ADEQUATE MARGIN OF SAFETY

(see Table 4 for a detailed description)

EFFECT	LEVEL	AREA
Hearing Loss	$L_{eq(24)}$ =< 70 dB	All areas
Outdoor activity interference and annoyance	L_{dn} =< 55 dB	Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use
	$L_{eq(24)}$ =< 55 dB	Outdoor areas where people spend limited amounts of time, such as school yards, playgrounds, etc.
Indoor activity interference and annoyance	L_{dn} =< 45 dB	Indoor residential areas
		Other indoor areas with human

	$L_{eq(24)}$ =< 45 dB	activities such as schools, etc.

Explanation of Table 1:

1. Detailed discussions of the terms L_{dn} and L_{eq} appear later in the document. Briefly, $L_{eq(24)}$ represents the sound energy averaged over a 24-hour period while L_{dn} represents the L_{eq} with a 10 dB nighttime weighting.

2. The hearing loss level identified here represents annual averages of the daily level over a period of forty years. (These are energy averages, not to be confused with arithmetic averages.)

3. Relationship of an $L_{eq(24)}$ of 70 dB to higher exposure levels.

EPA has determined that for purposes of hearing conservation alone, a level which is protective of that segment of the population at or below the 96th percentile will protect virtually the entire population. This level has been calculated to be an L_{eq} of 70 dB over a 24-hour day.

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Given this quantity, it is possible to calculate levels which, when averaged over given durations shorter than 24 hours, result in equivalent amounts of energy. For example, the energy contained in an 8-hour exposure to 75 dB is equivalent to the energy contained in a 24-hour exposure to 70 dB. For practical purposes, the former exposure is only equivalent to the latter when the average level of the remaining 16 hours per day is negligible (I.e., no more than about 60 dB* for this case).

Since 8 hours is the typical daily work period, an $L_{eq(8)}$ of 75 is considered an appropriate level for this particular duration. In addition, the 24-hour exposure level was derived from data on 8-hour daily exposures over a 40-year working life. In planning community noise abatement activities, local governments should bear in mind the special needs of those residents who experience levels higher than
$L_{eq(8)}$ at 70 on their jobs.

These levels are not to be construed as standards as they do not take into account cost or feasibility. Nor should they be thought of as discrete numbers, since they are described in terms of energy equivalents. As specified in this document, it is EPA's judgment that the maintenance of levels of environmental noise at or below those specified above are requisite to protect the public from adverse health and welfare effects. Thus, as an individual moves from a relatively quiet home, through the transportation cycle, to a somewhat noisier occupational situation, and then back home again, his hearing will not be impaired if the daily equivalent of sound energy in his environment is no more than 70 decibels. Likewise, undue interference with activity and annoyance will not occur if outdoor levels are maintained at an energy equivalent of 55 dB and indoor levels at 45 dB. However, it is always assumed throughout that environmental levels will fluctuate, even though the identified energy equivalent is not exceeded. Likewise, human exposure to noise will vary during the day, even though the daily "dose" may correspond well to the identified levels.

Before progressing further, it would be helpful to differentiate between the terms "levels", "exposure" and "dose". As used in this document, the word "level" refers to the magnitude of sound in its physical dimension, whether or not there are humans present to hear it. "Exposure" is used to mean those sound levels which are transmitted to the human ear, and "dose" is the summed exposure over a period of time.

> * This is not to imply that 60 dB is a negligible exposure level in terms of health and welfare considerations, but rather that levels of 60 dB make a negligible contribution to the energy average of L_{eq} = 70 dB when an 8-hour exposure of 75 dB is included.

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LEGISLATIVE HISTORY

Pursuant to Section 5(a)(1), EPA developed and published on July 27, 1973, criteria

reflecting:

> ...the scientific knowledge most useful in indicating the kind and extent of all identifiable effects on the public health or welfare which may be expected from differing quantities and qualities of noise.

Under Section 5(a)(1), EPA was required to provide scientific data that, in its judgement, was most appropriate to characterize noise effects.

The present "levels information" document is required by Section 5(a)(2), which calls for EPA to publish,

> ...information on the levels of environmental noise the attainment and maintenance of which in defined areas under various conditions are requisite to protect the public health and welfare with an adequate margin of safety.

The present document, and its approach to identifying noise levels based on cumulative noise exposure is in response to the expressed intent of the Congress that the Agency develop such a methodology. The EPA Report to the President and Congress, under Title IV, PL 91-604, contained considerable material on the various schemes for measuring and -evaluating community noise response, and it contained a recommendation that the Federal government should make an assessment of the large number of varying systems, with a goal of "standardization, simplification, and interchangeability of data".

The need for such action was the subject of considerable Congressional interest in the hearings on the various noise control bills, which finally resulted in enactment of the

Noise Control Act of 1972. The concept underlying this present document can be better appreciated from the following pertinent elements of the legislative history of the Act.

In the course of the hearings before the Subcommittee on Public Health and Environment of the Committee on Interstate and Foreign Commerce, House of Representatives ("Noise Control" HR Serial 92-30), the subject of the relation of physical noise measurements to human response was given considerable attention. The Committee, in reporting the bill (House of Representatives Report No. 92-842, Noise Control Act of 1972), stated the following on this matter:

> The Committee notes that most of the information relating to noise exposures was concerned with specific sources, rather than typical

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> cumulative exposures to which urban and suburban dwellers are commonly exposed. There is a need for much greater effort to determine the magnitude and extent of such exposures and the Committee expects the EPA to promote studies on this subject and consider development of methods of uniform measurement of the impact of noise on communities.

The Committee went on in the Report to assign responsibility to the Administrator to coordinate all Federal noise programs, with a specific expression of concern over the "different systems of noise measurement" in use by the various Agencies. The following is especially important with respect to the purposes of this document:

> The Committee gave some consideration to the establishment of a Federal ambient noise standard, but rejected the concept. Establishment of a Federal ambient standard would in effect put the Federal Government in the position of establishing land use zoning requirements on the basis of noise. . . It is the Committee's view that this function is one more properly of the states and their political subdivisions, and that the Federal Government should provide guidance and leadership in undertaking that effort.

The need for EPA action on this subject under the legislative authority of the Act was presented in Agency testimony before the Subcommittee on Air and Water Pollution, Committee on Public Works, U. S. Senate. The following portion is important (Noise Pollution Serial 92-H35 U. S. Senate):

> A variety of specialized schemes have been evolved over the past years to quantify the relationship between these various conditions and their effects on humans. . . . Suffice it to say that no simplistic single number system can adequately provide for a uniform acceptable national ambient noise level value. This, however, does not preclude the undertaking of a noise abatement strategy involving the proper use of the available scientific data on the part of the Federal Government in conjunction with the state and local governments. . . . The complex nature of the considerations we have outlined above in our judgment require that the Federal Government undertake to provide the necessary information upon which to base judgments. . . .

Taking both the specific language of the Act, cited above, and the legislative history discussed in the foregoing, EPA interprets Section 5(a)(2) as directing the Agency to identify levels based only on health and welfare effects and not on technical feasibility or economic costs

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Throughout this report, the words "identified level" are used to express the result of the inquiry mandated by Section 5(a)(2). The words "goals", "standards", or "recommended levels" are not used since they are not appropriate. Neither Congress nor the Environmental Protection Agency has reached the conclusion that these identified levels should be adopted by states and localities. This is a decision which the Noise Control Act clearly leaves to the states and localities themselves.

Certain of the statutory phrases in Section 5(a)(2) need further definition and discussion in order to make clear the purpose of this document. Congress required that EPA "publish information on environmental noise" levels. This mandate is basically one of "description". Such description is to be made in the specific context of "defined areas" and "under various conditions". The phrase "in defined areas under various conditions" is used in both a geographical and an activity sense, for example, indoors in a school classroom or outdoors adjacent to an urban freeway. It also requires consideration not only of the human activity involved, but also of the nature of the noise impact.

The next and last statutory phrase in Section 5(a)(2) is most important. It is that the noise levels are to be discussed on the basis of what is requisite to protect "the public health and welfare with an adequate margin of safety". The use of the words "public health" requires a statistical approach to determine the order of magnitude of the population affected by a given level of noise. The concept of a margin of safety implies that every sector of the population which would reasonably be exposed to adverse noise levels should be included by the specifically described levels.

The phrase "health and welfare" as used herein is defined as "complete physical, mental and social well-being and not merely the absence of disease and infirmity". This definition would take into account sub-clinical and subjective responses (e.g., annoyance or other adverse psychological reactions) of the individual and the public. As will be discussed below, the available data demonstrate that the most serious clinical health and welfare effect caused

by noise is interference with the ability to hear. Thus, as used in this document, the phrase "health and welfare" will necessarily apply to those levels of noise that have been shown to interfere with the ability to hear.

The phrase "health and welfare" also includes personal comfort and well-being and the absence of mental anguish and annoyance.. In fact, a considerable portion of the data available on the "health and welfare" effects of noise is expressed in terms of annoyance. However, "annoyance" is a description of the human reaction to what is described as noise "interference"; and though annoyance appears to be statistically quantifiable, it is a subjective reaction to interference with some desired human activity. From a legal standpoint, annoyance per se is not a legal concept. Annoyance expresses the human response or results, not its cause. For this reason, the common law has never recognized annoyance as being a

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compensable injury, in the absence of interference with a personal or property right. Of the many community surveys on noise which have been conducted, speech interference emerges as the most tangible component of annoyance, whereas sleep and other kinds of activity interference are important, but less well-defined contributors. Thus, although it is important to understand the importance of annoyance as a concept, it is the actual interference with activity on which the levels identified in this document are based.

There was a great deal of concern during the preparation of this document that the levels identified would be mistakenly interpreted as Federal noise standards. The information contained in this document should not be so interpreted. The general purpose of this document is rather to discuss environmental noise levels requisite for the protection of public health and welfare without consideration of those elements necessary to an actual

rule-making Those elements not considered in this document include economic and technological feasibility and attitudes about the desirability of undertaking an activity which produces interference effects. Instead, the levels identified here will provide State and local governments as well as the Federal Government and the private sector with an informational point of departure for the purpose of decision-making.

An even more important, but related point must be kept in mind when this document is read. The data on which the informational levels in this document are based are not "short run" or single event noises. Rather, they represent energy equivalent noise levels over a long period. For example, the exposure period which results in no more than 5 dB hearing loss at the identified level in Tables 1 and 4 is a period of forty years.

The definition of "environmental noise" is provided in Section 3(11) of the Noise Control Act of 1972. "The term 'environmental noise' means the intensity, duration, and the character of sounds from all sources." As discussed earlier, it is the intent of Congress that a simple, uniform measure of noise be developed. Not all information contained in the noise environment can be easily considered and analyzed. Instead, for practical purposes, it needs to be condensed to result in one indicator of the environmental quantity and quality of noise, which correlates with the overall long-term effects of noise on public health and welfare.

Many noise rating and evaluation procedures are available in the literature,[2,3] in voluntary national and international standards, and in commonly used engineering practices (see Appendix A). These methods and practices are well established, and it is not the purpose of this document to list them, elaborate on them, or imply a restriction of their use. Instead, the purpose is to discuss levels of environmental noise using a measure which correlates with other measures and can be applied to most situations. Based on the concept of the cumulative human exposure to environmental noise associated with the various life styles of the population, maximum long-term exposures for individuals and the corresponding environmental noise levels at various places can be identified. It is important to keep in mind that

the selected indicator of environment noise does not correlate uniquely with any specific effect on human health or performance. Admittedly, there are uncertainties with respect to effects in individual cases and situations. Such effects cannot be completely accounted for; thus, the necessity to employ a statistical approach.

Section 2 of the report addresses the details of characterizing and measuring human exposure to environmental noise. The equivalent sound level (L_{eq}) and a variation weighted for nighttime exposure
(L_{dn}) has been selected as the uniform descriptor. The relationship of
L_{eq} and L_{dn} to other measures in use is analyzed in Appendix A. Section 2 and Appendix B further detail the various human exposure patterns and give simplified examples of individual exposure patterns. The problem of separating occupational exposure from the balance of environmental exposure and the statutory responsibility for controlling occupational exposure is analyzed in Appendix F.

In Section 3, cause and effect relationships are summarized and presented as the basis and justification for the environmental noise levels identified in Section 4. Specifically, Section 3 develops conclusions with regard to levels at which hearing impairment and activity interference take place. These are discussed in terms of situational variation and the respective appropriateness of L_{eq} and L_{dn}. The factors providing for an adequate margin of safety and special types of noises are discussed. This section makes reference to material in Appendices C (on hearing loss), D (annoyance and activity interference) and G (special noises), which in turn rely upon material presented in EPA's document, Public Health and Welfare Criteria for Noise,[2] to which the reader is referred for more detailed information.

Section 4 discusses the levels of environmental noise requisite to protect public health and welfare for various indoor and outdoor areas in the public and private domain in terms of L_{eq} and L_{dn}. The summary table is supplemented by short explanations.

It is obvious that the practical application of the levels to the various purposes outlined earlier requires considerations of factors not discussed here. Although some guidance in this respect is included in Section 4, not all problems can be anticipated and some of these questions can only be resolved as the information contained in this report is considered and applied. Such practical experiences combined with results of further research will guide EPA in revising and updating the levels identified. In this regard, it should be recognized that certain of the levels herein might well be subject to revision when additional data are developed.

Section 2

ENVIRONMENTAL NOISE EXPOSURE

A complete physical description of a sound must describe its magnitude, its frequency spectrum, and the variations of both of these parameters in time. However, one must choose between the ultimate refinement in measurement techniques and a practical approach that is no more complicated than necessary to predict the impact of noise on people. The Environmental Protection Agency's choice for the measurement of environmental noise is based on the following considerations:

1. The measure should be applicable to the evaluation of pervasive long-term noise in various defined areas and under various conditions over long periods of time.
2. The measure should correlate well with known effects of the noise environment on the individual and the public.
3. The measure should be simple, practical and accurate. In principle, it should be useful for planning as well as for enforcement or monitoring purposes.
4. The required measurement equipment, with standardized characteristics, should be commercially available.
5. The measure should be closely related to existing methods currently in use.
6. The single measure of noise at a given location should be predictable, within an acceptable tolerance, from knowledge of the physical events producing the noise.
7. The measure should lend itself to small, simple monitors which can be left unattended in public areas for long periods of time.

These considerations, when coupled with the physical attributes of sound that influence human response, lead EPA to the conclusion that the magnitude of sound is of most importance insofar as cumulative noise effects are concerned. Long-term average sound level, henceforth referred to as equivalent sound level (L_{eq}), is considered the best measure for the magnitude of environmental noise to fulfill the above seven requirements. Several versions of equivalent sound level will be used for identifying levels of sound in

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specific places requisite to protect public health and welfare. These versions differ from each other primarily in the time intervals over which the sound levels are of interest, and the correction factor employed.

Equivalent A-weighted sound level is the constant sound level that, in a given situation and time period, conveys the same sound energy as the actual time-varying A-weighted sound.* The basic unit of equivalent sound levels is the decibel (see Appendix A), and the symbol for equivalent sound level is L_{eq}. Two sounds, one of which contains twice as much energy but lasts only half as long as the other, would be characterized by the same equivalent sound level; so would a sound with four times the energy lasting one fourth as long. The relation is often called the equal-energy rule. A more complete discussion of the computation of equivalent sound level, its evolution and application to environmental noise problems, and its relationship to other measures used to characterize environmental noise is provided in Appendix A.

The following caution is called to the attention of those who may prescribe levels: It should be noted that the use of equivalent sound level in measuring environmental noise will not directly exclude the existence of very high noise levels of short duration. For example, an equivalent sound level of 60 dB over a twenty-four hour day would permit sound levels of 1 10 dB but would limit them to less than one-second duration in the twenty-four hour period. Comparable relationships between maximum sound levels and their permissible durations can easily be obtained for any combination, relative to any equivalent sound level (see the charts provided in Appendix A).

Three basic situations are used in this document for the purpose of identifying levels of environmental noise:

1. Defined areas and conditions in which people are exposed to environmental noise for periods of time which are usually less than twenty-four hours, such as school classrooms, or occupational settings.
2. Defined areas and conditions in which people are exposed to environmental noise for extended periods of time, such as dwellings.
3. Total noise exposure of an individual, irrespective of area or condition.

*See Glossary for a detailed definition of terms. Note that when the term "sound level" is used throughout this document, it always implies the use of the A-weighting for frequency.

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Three versions of equivalent sound level are used in this document in order to accommodate the various modes of noise exposure that occur in these situations. They are distinguished by the periods of time over which they are averaged and the way in which the averaging is done.

1. L_{eq} for an 8-hour period ($L_{eq(8)}$): This is the equivalent A-weighted sound level (in decibels relative to 20 micropascals) computed over any continuous time period of eight hours identified with the typical occupational exposure. As will be shown in later sections of this document, $L_{eq(8)}$ serves as a basis for identifying environmental noise which causes damage to hearing.
2. L_{eq} for 24-hour weighted for nighttime exposure (L_{dn}): This formula of equivalent level is used here to relate noise in residential environments to chronic annoyance by speech interference and in some part by sleep and activity interference. For these situations, where people are affected by environmental noise for extended periods of time, the natural choice of duration is the 24-hour day. Most noise environments are characterized by repetitive behavior from day to day, with some variation imposed by differences between weekday and weekend activity, as well as some seasonal variation. To account for these variations, it has been found useful to measure environmental noise in terms of the long-term yearly average of the daily levels.

In determining the daily measure of environmental noise, it is important to account for the difference in response of people in residential areas to noises that occur during sleeping hours as compared to waking hours. -During nighttime, exterior background ' noises generally drop in level from daytime values. Further, the activity of most households decreases at night, lowering the internally generated noise levels. Thus, noise events become more intrusive at night, since the increase in noise levels of the event over background noise is greater than it is during the daytime.

Methods for accounting for these differences between daytime and nighttime exposures have been developed in a number of different noise assessment methods employed around the world, (see Appendix A). In general, the method used is to characterize nighttime noise as more severe than corresponding daytime events; that is, to apply a weighting factor to noise that increases the numbers commensurate with their severity. Two approaches to identifying time periods have been employed: one divides the 24-hour day into two periods, the waking and sleeping hours, while the other divides the 24 hours into three periods--day, evening, and night. The weighting applied to the non-daytime periods differs slightly among the different countries, but most of them weight nighttime activities by about 10 dB. The evening weighting, if used, is 5 dB.

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An examination of the numerical values obtained by using two periods versus three periods per day shows that for any reasonable distribution of environmental noise levels, the two-period day and the three-period day are essentially identical; i.e., the 24-hour equivalent sound levels are equal within a few tenths of a decibel. Therefore, the simpler two-period day is used in this document, with daytime extending from 7 a.m. to 10 p.m. and nighttime extending from 10 p.m. to 7 a.m. The symbol for the 15-hour daytime equivalent sound level is L_d, the symbol for the 9-hour nighttime equivalent sound level is L_n, and the day-night weighted measure is symbolized as L_{dn}.

The L_{dn} is defined as the A-weighted average sound level in decibels (re 20 micropascals) during a 24-hour period with a 10 dB weighting applied to nighttime sound levels. Examples of the outdoor present day (1973) day-night noise level at typical locations are given in Figure 1.

3. L_{eq} for the 24-hour average sound level to which an individual is exposed ($L_{eq\ (24)}$): This situation is related to the cumulative noise exposure experienced by an individual irrespective of where, or under what situation, this exposure is received. The long-term health and welfare effects of noise on an individual are related to the cumulative noise exposure he receives over a lifetime.

Relatively little is known concerning the total effect of such lifetime exposures, but dose-effect relations have been studied for two selected situations:

a. The average long-term exposure to noise primarily in residential areas leading to annoyance reactions and complaints.

b. The long-term effects of occupational noise on hearing, with the daily exposure dose based on an eight-hour workday.

An ideal approach to identifying environmental noise levels in terms of their effect on public health and welfare would be to start by identifying the maximum noise not to be exceeded by individuals. However, the noise dose that an individual receives is a function of lifestyle. For example, exposure patterns of office workers, factory workers, housewives, and school children are quite different. Within each group the exposures will vary widely as a function of the working, recreational, and sleeping patterns of the individual. Thus, two individuals working in the same office will probably accumulate different total noise doses if they use different modes of transportation, live in different areas, and have different TV habits. Examples of these variations in noise dose for several typical life styles are provided in Appendix B. However, detailed statistical information on the distribution of actual noise doses and the relationship of these doses to long-term health and welfare effects is still missing. Therefore, a realistic approach to this problem is to identify appropriate noise levels for

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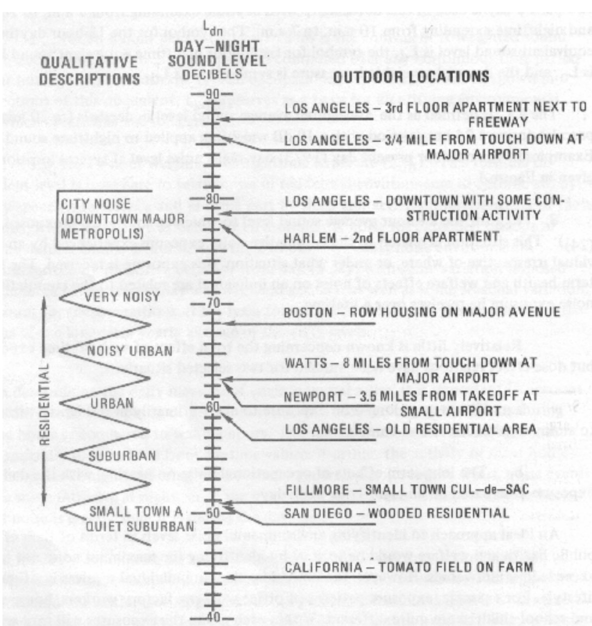

Figure 1. Outdoor Day-Night Sound Level in dB (re 20 micropascals) at Various Locations[4]

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places occupied by people as a function of the activity in which they are engaged, including a gross estimate of typical average exposure times.

From a practical viewpoint, it is necessary to utilize the wealth of data relating to occupational noise exposure, some of it, albeit, subject to interpretation, in order to arrive at extrapolations upon which the identification of safe levels for daily (24-hour) exposures can be based.

in the following sections of this report, the various modes of exposure to noise and the human responses elicited will be discussed, leading to the identification of appropriate noise exposure levels. In order to assist the reader in associating these levels with numerical values of noise for familiar situations, typical noise levels encountered at various locations are fisted in Table 2. For further assistance, Figure 2 provides an estimate of outdoor noise levels for different residential areas.

Table 2

EQUIVALENT SOUND LEVELS IN DECIBELS NORMALLY OCCURRING INSIDE VARIOUS PLACES[6]

SPACE	L_{eq}(+)
Small Store (1-5 clerks)	60
Large Store (more than 5 clerks)	65
Small Office (1-2 desks)	58
Medium Office (3-10 desks)	63
Large Office (more than 10 desks)	67
Miscellaneous Business	63
Residences: Typical movement of people-no TV or radio Speech at 10 feet, normal voice TV listening at 10 feet, no other activity Stereo music	 40-45 55 55-60 50-70

(+) These measurements were taken over durations typical of the operation of these facilities.

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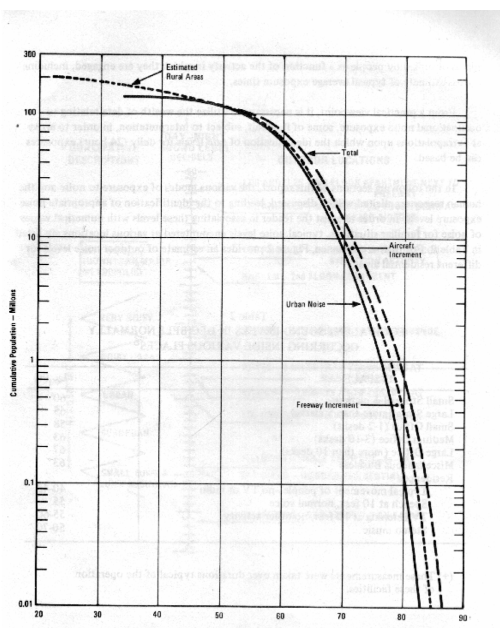

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Section 3

RATIONALE FOR IDENTIFICATION OF LEVELS OF ENVIRONMENTAL NOISE REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE

BASIS FOR IDENTIFYING LEVELS

For the identification of levels to protect against the direct, disease-producing effects of noise, protection against hearing loss is the guiding consideration. At this time, there is insufficient scientific evidence that non-auditory diseases are caused by noise levels lower than those that cause noise-induced hearing loss. In the event that future research renders this conclusion invalid, this document will be revised accordingly (see Appendix E). in addition to direct disease-producing health effects, interference by noise with various human activities, such as speech-perception, sleep, and thought can lead to annoyance and indirect effects on well-being. All of these direct and indirect effects are considered here as effects on public health and welfare. It is important to note, however, the distinction between voluntary and involuntary exposures. Exposures to high levels of environmental noise are often produced or sought by the individual. For example, voluntary exposures to loud music are common. Consequently, the concept of total individual noise dose with regard to annoyance, must be applied only to involuntary exposure, although, of course, this argument does not apply to the effects of noise on hearing.

A further consideration is the physical setting in which the exposure takes place. Although there are no data to justify the assumption, it is judged here that, whereas a small amount of speech interference in most outdoor places is not detrimental to public health and welfare, the same is not true for most indoor environments. Based on this reasoning, adequate protection of the public against involuntary exposure to environmental noise requires special consideration of physical setting and the communication needs associated with each.

In the next subsection, the above rationale is applied to identify the maximum noise level consistent with an adequate margin of safety for the general classes of sound found most often in the environment. Certain special classes of sound, such as infrasound, ultrasound, and impulsive sounds are discussed in the final subsection.

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IDENTIFICATION OF MAXIMUM EXPOSURE LEVELS TO AVOID SIGNIFICANT ADVERSE EFFECTS

Hearing

Basic Considerations

The following considerations have been applied in identifying the environmental noise levels requisite to protect the hearing of the general population. For detailed derivation, justification and references, (see Appendix C).

1. The human ear, when damaged by noise, is typically affected at the 4000 Hz frequency first, and, therefore, this frequency can be considered the most noise-sensitive frequency. The averaged frequencies of 500 Hz, 1000 Hz and 2000 Hz have traditionally been employed in hearing conservation criteria because of their importance to the hearing of speech sounds. Since there is considerable evidence that frequencies above 2000 Hz are critical to the understanding of speech in lifelike situations, and since 4000 Hz is considered the most sensitive frequency, 4000 Hz has been selected as the most important frequency to be protected in this document.
2. Changes in hearing level of less than 5 dB are generally not considered noticeable or significant.
3. As individuals approach the high end of the distribution and their hearing levels are decreased, they become less affected by noise exposure. In other words, there comes a point where one cannot be damaged by sounds, which one cannot hear.
4. The noise level chosen protects against hearing loss up to and including the 96th percentile of the population, ranked according to decreasing ability to hear at 4000 Hz. Since the percentiles beyond that point are also protected (see consideration number 3), virtually the entire population is protected against incurring more than a 5 dB noise-induced permanent threshold shift (NIPTS).

Explanation of Identified Level for Hearing Loss

Taking into account the assumptions and considerations mentioned above, the 8-hour exposure level, which protects virtually the entire population from greater than 5 dB NIPTS is 73 dB, (see Figure 3). Before this value of 73 dB for 8-hour exposures can be applied to the environmental situation, however, certain correction or conversion factors must be considered. These correction factors are:

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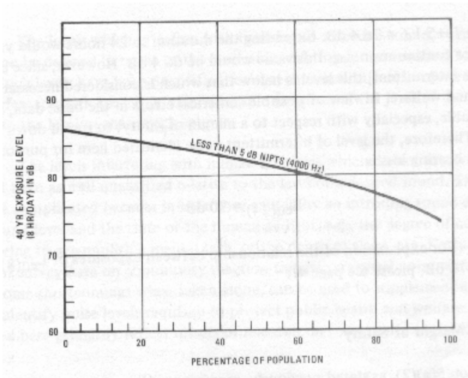

Figure 3. Percentage of Exposed Population That Will Incur No More Than 5 dB NIPTS Shown as a Function of Exposure Level. Population Ranked by Decreasing Ability to Hear at 4000 Hz. (See Appendix C for Rationale).

1. Intermittency: allows the exposure level to be 5 dB higher. This correction factor is required because most environmental noise is intermittent (not at a steady level, but below 65 dBA more than 10% of any one-hour period) and intermittent noise has been shown less damaging than continuous noise of the same L_{eq}. This correction should normally be applied except in situations that do not meet this criterion for intermittency.

2. Correction to yearly dose (250 to 365 days): requires reduction of the exposure level by 1.6 dB. All data used as the basis of Figure 3 come from occupational exposures which are only 250 days per year, whereas, this document must consider all 365 days in a year.

3. Correction to twenty-four hour day: the identified level of 73 dB is based on 8-hour daily exposures. Conversion to a 24-hour period using the equal-energy rule requires reduction of this level by 5 dB. This means that continuous sounds of a 24-hour duration must be 5 dB less intense than higher level sounds of only 8 hours duration, with the remaining 16 hours considered quiet.

Using the above corrections and conversions implies that the average 8-hour daily dose (based on a yearly average and assuming intermittent noise) should be no greater

than $L_{eq(8)}$ = 73+5-1.6 = 76.4 dB. Extending the duration to 24 hours would yield a value of 71.4 dB. For continuous noise, this value would be 66.4 dB. However, since environmental noise is intermittent, this level is below that which is considered necessary to protect public health and welfare. In view of possible statistical errors in the basic data, it is considered reasonable, especially with respect to a margin of safety, to round down from 71.4 dB to 70 dB. Therefore, the level of intermittent noise identified here for purposes of protection against hearing loss is:

$$L_{eq(24)} = 70 \text{ dB}$$

(For explanation of the relationship between exposures of $L_{eq(8)}$ = 75 dB and $L_{eq(24)}$ = 70 dB, please see page 4.)

Adequate Margin of Safety

Section 5(a)(2), as stated previously, requires an adequate margin of safety. The level identified to protect against hearing loss, is based on three margins of safety considerations

1. The level protects at the frequency where the ear is most sensitive (4,000 Hz).

2. It protects virtually the whole population from exceeding 5 dB NIPTS.

3. It rounds off in the direction of hearing conservation (downward) to provide in part for uncertainties in analyzing the data.

Activity Interference/Annoyance

Basic Considerations

The levels of environmental noise which interfere with human activity (see Appendix D for detailed dicussion) depend upon the activity and its contextual frame of reference; I.e., they depend upon "defined areas under various conditions". The effect of activity interference is often described in terms of annoyance. However, various non-level related factors, such as attitude towards the noise source and local conditions, may influence an individual's reaction to activity interferences.

The levels which interfere with listening to a desired sound, such as speech or music, can be defined in terms of the level of interfering sound required to mask the desired sound. Such levels have been quantified for speech communication by directly measuring the interference with speech intelligibility as a function of the level of the intruding sound, relative to the level of the speech sounds.

The levels interfering with human activities which do not involve active listening have not been as well quantified relative to the level of a desired sound. These relationships are more complicated because interference caused by an intruding sound depends upon the background level and the state of the human auditor; e.g., the degree of concentration when endeavoring to accomplish a mental task, or the depth of sleep, etc. Fortunately, there is a wealth of survey data on community reaction to environmental noise which, although subject to some shortcomings when taken alone, can be used to supplement activity interference data to identify noise levels requisite to protect public health and welfare. Thus, the levels identified here primarily reflect results of research on community reaction and speech masking.

Identified Levels for Interference

The level identified for the protection of speech communication is an L_{eq} of 45 dB within the home in order to provide for 100% intelligibility of speech sounds. Allowing for the 15 dB reduction in sound level between outdoors and indoors (which is an average amount of sound attenuation that assumes partly-open windows), this level becomes an outdoor L_{eq} of 60 dB for residential areas. For outdoor voice communication, the outdoor L_{eq} of 60 dB allows normal conversation at distances up to 2 meters with 95% sentence intelligibility.

Although speech-interference has been identified as the primary interference of noise with human activities and is one of the primary reasons for adverse community reactions to noise and long-term annoyance, the 10 dB nighttime weighting (and, hence, the term L_{dn}) is applied to give adequate weight to all of the other adverse effects on activity interference. For the same reason, a 5 dB margin of safety/ is applied to the identified outdoor level. Therefore, the outdoor L_{dn} identified for residential areas is 5 5 dB. (See Appendix E for relationship of L_{eq} to L_{dn}.)

The associated interior day-night sound level within a typical home which results from outdoors is 15 dB less, or 40 dB due to the attenuation of the structure. The expected indoor daytime level for a typical neighborhood which has an outdoor L_{dn} of 55 dB is approximately 40 dB, whereas the nighttime level is approximately 32 dB (see Figure A-7). This latter value is consistent with the limited available sleep criteria [D-5]. Additionally,

these indoor levels of 40 dB during the day and approximately 32 dB at night are consistent with the background levels inside the home which have been recommended by acoustical consultants as acceptable for many years, (see Table D-10).

The effects associated with an outdoor day-night sound level of 55 dB are summarized in Table 3. The summary shows that satisfactory outdoor average sentence intelligibility may be expected for normal voice conversations over distances of up to 3.5 meters; that depending on attitude and other non-level related factors, the average expected community reaction is none, although 1% may complain and 17% indicate "highly annoyed" when responding to social survey questions; and that noise is the least important factor governing attitude towards the area.

Identification of a level which is 5 dB higher than the 55 dB identified above would significantly increase the severity of the average community reaction, as well as the expected percentage of complaints and annoyance. Conversely, identification of a level 5 dB lower than the 55 dB identified above would reduce the indoor levels resulting from outdoor noise well below the typical background indoors (see Table 3) and probably make little change in annoyance since at levels below the identified level, individual attitude and life style, as well as local conditions, seem to be more important factors in controlling the resulting magnitude of annoyance or community reaction than is the absolute magnitude of the level of the intruding noise.

Accordingly, L_{dn} of 45 dB indoors and of 55 dB outdoors in residential areas are identified as the maximum levels below which no effects on public health and welfare occur due to interference with speech or other activity. These levels would also protect the vast majority of the population under most conditions against annoyance, in the absence of intrusive noises with particularly aversive content.

Adequate Margin of Safety

The outdoor environmental noise level identified in Table 3 provides a 5 dB margin of safety with respect to protecting speech communication. This is considered desirable for the indoor situation to provide for homes with less than average noise reduction or for persons speaking with less than average voice level. A higher margin of safety would be ineffective most of the time due to normal indoor activity background levels.

The 5 dB margin of safety is particularly desirable to protect the population against long-term annoyance with a higher probability than would be provided by the levels protecting indoor and outdoor speech communication capability alone. The 5 dB margin clearly shifts community response as well as subjective annoyance rating into the next lower

Table 3

SUMMARY OF HUMAN EFFECTS IN TERMS OF SPEECH COMMUNICATION, COMMUNITY REACTIONS, ANNOYANCE AND ATTITUDE TOWARD AREA ASSOCIATED WITH AN OUTDOOR DAY/NIGHT SOUND LEVEL OF 55 dB re 20 MICROPASCALS

TYPE OF EFFECT	MAGNITUDE OF EFFECT

Speech - Indoors	100% sentence intelligibility (average) with a 5 dB margin of safety
Speech - Outdoors	100% sentence intelligibility (average) at 0.35 meters
	99% sentence intelligibility (average) at 1.0 meters
	95% sentence intelligibility (average) at 3.5 meters
Average Community Reaction	None evident; 7 dB below level of significant "complaints and threats of legal action" and at least 16 dB below "vigorous action" (attitudes and other non-level related factors may affect this result)
Complaints	1% dependent on attitude and other non-level related factors
Annoyance	1% dependent on attitude and other non-level related factors
Attitudes Towards Area	Noise essentially the least important of various factors

(Derived from Appendix D)

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response category than would be observed for the maximum level identified with respect to speech communication alone. According to present data, this margin of safety protects the vast majority of the population against long-term annoyance by noise. It would reduce environmental noise to a level where it is least important among environmental factors that influence the population's attitude toward the environment. To define an environment that eliminates any potential annoyance by noise occasionally to some part of the population appears not possible at the present state of knowledge.

MAXIMUM EXPOSURES TO SPECIAL NOISES

Inaudible Sounds

The following sounds may occur occasionally but are rarely found at levels high enough to warrant consideration in most environments, which the public occupies. For a more detailed discussion, see Appendix G.

Infrasound

Frequencies below 16 Hz are referred to as infrasonic frequencies and are not audible. Complaints associated with extremely high levels of infrasound can resemble a mild stress reaction and bizarre auditory sensations, such as pulsating and fluttering. Exposure to high levels of infrasound is rare for most individuals. Nevertheless, on the basis of existing data[2,7], the threshold of these effects is approximately 120 dB SPL (I -16 Hz). Since little information exists with respect to duration of exposure and its effects, and also since many of the data are derived from research in which audible frequencies were present in some amount, these results should be interpreted with caution.

Ultrasound

Ultrasonic frequencies are those above 20,000 Hz and are also generally inaudible. The effects of exposure to high intensity ultrasound is reported by some to be a general stress response. Exposure to high levels of ultrasound does not occur frequently. The threshold of any effects for ultrasound is 105 dB SPL[2]. Again, many of these data may include frequencies within the audible range, and results are, therefore, to be interpreted cautiously.

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Impulse Noise

It is difficult to identify a single-number limit requisite to protect against adverse effects from impulse noise because it is essential to take into account the circumstances of exposure, the type of impulse, the effective duration, and the number of daily exposures, (see Appendix G),

Hearing

Review of temporary threshold shift data leads to the conclusion that the impulse noise limit requisite to prevent more than a 5 dB permanent hearing loss at 4000 Hz after 10 years of daily exposure is a peak sound pressure level (SPL) of 145 dB. This level applies in the case of isolated events, irrespective of the type, duration, or incidence at the ear. However, for duration of 25 microseconds or less, a peak level of 167 dB SPL would produce the same effect, (see Figure 4).

1. Duration Correction: When the duration of the impulse is less than 25

micro-seconds, no correction for duration is necessary. For durations exceeding 25 microseconds, the level should be reduced in accordance with the "modified CHABA limit" shown in Figure 4 and Figure G-I of Appendix G.

2. Correction for Number of Impulses:

(More detailed information is provided in Figure 4.)

Furthermore, if the average interval between repeated impulses is between 1 and 10 seconds, a third correction factor of -5 dB is applied. Thus, to prevent hearing loss due to impulse noise, the identified level is 145 dB SPL, or 167 dB peak SPL for impulses less than 25 microseconds, for one impulse daily. For longer durations or more frequent exposures, the equivalent levels are as shown in Figure 4.

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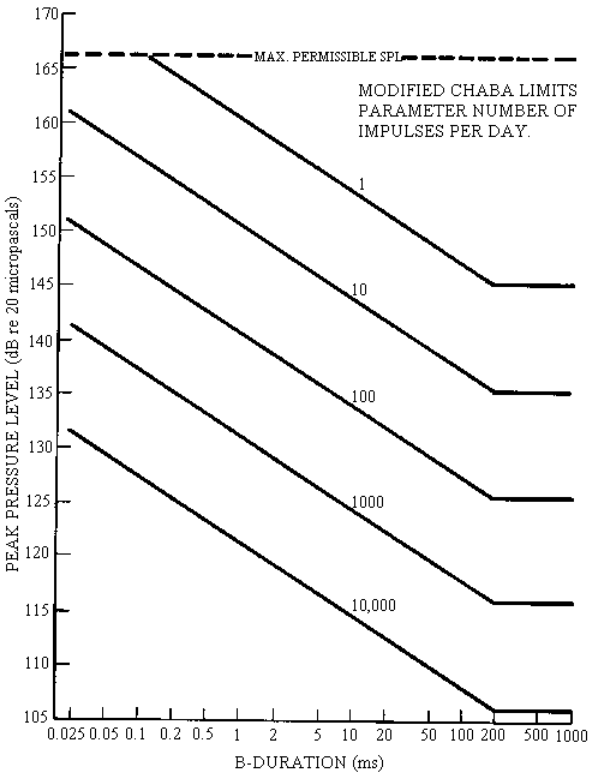

Figure 4. Set of Modified CHABA Limits for Daily Exposure to Impulse Noises Having B-Duration in the Range 25Microseconds to 1 Second. (Parameter: number (N) of impulses per daily exposure. Criterion: NIPTS not to exceed 5 dB at 4 kHz in more than 10% people.)

(Derived from Appendix G)

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Non-Auditory Effects of Impulsive Sound

Impulses exceeding the background noise by more than about 10 dB are potentially startling or sleep-disturbing- If repeated, impulsive noises can be disturbing to some individuals if heard at all (they Tray be at levels below the average noise levels). However, no threshold level can be identified at this time ; nor is there any clear evidence or documentation of any permanent effect on public health and welfare.

Sonic Booms

Little or no public annoyance is expected to result from one sonic boom during the daytime below the level of 35.91 pascals (0.75 pounds per square foot) as measured on the ground (see Appendix G). The same low probability of annoyance is expected to occur for more than one boom per day if the peak level of each boom is no greater than :

$$\text{Peak Level} = \frac{35.91}{\sqrt{N}} \text{ pascals}$$

Where N is the number of booms. This value is in agreement with the equal energy concept.

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Section 4

IDENTIFIED LEVELS OF ENVIRONMENTAL NOISE IN DEFINED AREAS

IDENTIFIED LEVELS

Table 4 identifies the levels requisite to protect public health and welfare with an adequate margin of safety for both activity interference and hearing loss. The table classifies the vyrious areas according to the primary activities that are most likely to occur in each. The following is a brief description of each classification and a discussion of the basis for the identified levels in Table 4. For a more detailed discussion of hearing loss and activity interference, see Appendices C and D.

1.Residential areas are areas where human beings live, including apartments, seasonal residences, and mobile homes, as well as year-round residences. A quiet environment is necessary in both urban and rural residential areas in order to prevent activity interference and annoyance, and to permit the hearing mechanism to recuperate if it is exposed to higher levels of noise during other periods of the day.

An indoor L_{dn} of 45 dB will permit speech communication in the home, while an outdoor L_{dn} not exceeding 55 dB will permit normal speech communication at approximately three meters. Maintenance of this identified outdoor level will provide an indoor L_{dn} of approximately 40 dB with windows partly open for ventilation. The nighttime portion of this L_{dn} will be approximately 32 dB, which should in most cases, protect against sleep interference. An $L_{eq(24)}$ of 70 dB is identified as protecting against damage to hearing.

Although there is a separate category for commercial areas, commercial living accommodations such as hotels, motels, cottages, and inns should be included in the residential category since these are places where people sleep and sometimes spend extended periods of time.

2. Commercial areas include retail and financial service facilities, offices, and miscellaneous commercial services. They do not include warehouses, manufacturing plants, and other industrial facilities, which are included in the industrial classification. Although a level for activity interference has not been identified here (see footnote a), suggestions for such levels will be found in Table D-10 of Appendix D. On the other hand, a level of $L_{eq(24)}$ of 70 dB has been identified to protect against hearing loss.

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Table 4

YEARLY AVERAGE* EQUIVALENT SOUND LEVELS IDENTIFIED AS REQUISITE TO PROTECT THE PUBLIC HEALTH AND WELFARE WITH AN ADEQUATE MARGIN OF SAFETY

	Measure	Indoor			Outdoor		
		Activity Interference	Hearing Loss Consideration	To Protect Against Both Effects (b)	Activity Interference	Hearing Loss Consideration	To Protect Against Both Effects (b)
Residential with Outside Space and Farm Residences	L_{dn}	45	-	45	55	-	55
	$L_{eq(24)}$	-	70	-	-	70	-
Residential with No Outside Space	L_{dn}	45	-	45	-	-	-
	$L_{eq(24)}$	-	70	-	-	-	-
Commercial	$L_{eq(24)}$	(a)	70	70(c)	(a)	70	70(c)
Inside Transportation	$L_{eq(24)}$	(a)	70	(a)	-	-	-
Industrial	$L_{eq(24)(d)}$	(a)	70	70(c)	(a)	70	70(c)
Hospitals	L_{dn}	45		45	55	-	55
	$L_{eq(24)}$	-	70	-	-	70	
Educational	$L_{eq(24)}$	45	-	45	55	-	55
	$L_{eq(24)(d)}$	-	70	-	-	70	
Recreational Areas	$L_{eq(24)}$	(a)	70	70(c)	(a)	70	70(c)
Farm Land and General Unpopulated Land	$L_{eq(24)}$	-	-	-	(a)	70	70(c)

Code:

a. Since different types of activities appear to be associated with different levels, identification of a maximum level for activity interference may be difficult except in those circumstances where speech communication is a critical activity. (See Figure D-2 for noise levels as a function of distance which allow satisfactory communication.)

b. Based on lowest level.

c. Based only on hearing loss.

d. An $L_{eq(8)}$ of 75 dB may be identified in these situations so long as the exposure over the remaining 16 hours per day is low enough to result in a negligible contribution to the 24-hour average, i.e., no greater than an L_{eq} of 60 dB.

Note: Explanation of identified level for hearing loss: The exposure period which results in hearing loss at the identified level is a period of 40 years.

*Refers to energy rather than arithmetic averages.

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3. Transportation facilities are included so as to protect individuals using public and private transportation. Included within this classification are commercial and private transportation vehicles. Identification of a level to protect against hearing loss is the only criterion used at this time, although levels lower than a L_{eq} of 70 dB are often desirable for effective speech communication. However, because of the great variety of conditions inside transportation vehicles, and because of the desirability of speech privacy in certain situations, a level based on activity interference cannot be identified for all modes of transportation at this time.

4. Industrial areas include such facilities as manufacturing plants, warehouses, storage areas, distribution facilities, and mining operations. Only a level for hearing loss is identified due to the lack of data with respect to annoyance and activity interference. Where the noise exposure is intermittent, a $L_{eq(24)}$ of 70 dB is identified as the maximum level for protection of hearing from industrial exposure to intermittent noise. For 8-hour exposures, an $L_{eq(8)}$ of 75 dB is considered appropriate so long as the exposure over the remaining 16 hours per day is low enough to result in a negligible contribution to the 24-hour average.

5. Hospital areas include the immediate neighborhood of the hospital as well as its interior. A quiet environment is required in hospital areas because of the importance of sleep and adequate rest to the recovery of patients. The maintenance of a noise level not exceeding a L_{dn} of 45 dB in the indoor hospital environment is deemed adequate to prevent activity interference and annoyance. An outdoor L_{dn} of 55 dB should be adequate to protect patients who spend some time outside, as well as insuring an adequately protective indoor level. A $L_{eq(24)}$ of 70 dB is identified to prevent hearing loss.

6. Educational areas include classrooms, auditoriums, and schools in general, and those grounds not used for athletics. The principal consideration in the education environment is the prevention of interference with activities, particularly speech communication. An indoor noise level not exceeding $L_{eq(24)}$ of 45 dB is identified as adequate to facilitate thought and communication. Since teaching is occasionally conducted outside the classroom, an outdoor $L_{eq(24)}$ of 55 dB is identified as the maximum level to prevent activity interference. To protect against hearing loss a $L_{eq(24)}$ of 70 dB is identified for both indoor and outdoor environments. As in the industrial situation, eight hours is generally the amount of time spent in educational facilities. Therefore an $L_{eq(8)}$ of 75 dB is considered appropriate to protect against hearing loss, so long as the exposure over the remaining 16 hours is low enough to result in a negligible contribution to the 24-hour average.

7. Recreational areas include facilities where noise exposure is voluntary. Included within this classification are nightclubs, theaters, stadiums, racetracks, beaches, amusement parks, and athletic fields. Since sound exposure in such areas is usually voluntary, there is seldom any interference with the desired activity. Consequently, the chief consideration is

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the protection of hearing. An $L_{eq(24)}$ of 70 dB is therefore identified for intermittent noise in order to prevent hearing damage.

8. Farm and general unpopulated land primarily includes agricultural property used for the production of crops or livestock. For such areas, the primary considerations are the protection of human hearing and the prevention of adverse effects on domestic and wild animals. Protection of hearing requires that an individual's exposure to intermittent noise does not exceed $L_{eq(24)}$ of 70 dB. A separate level for the exposure of animals is not identified due to the lack of data indicating that hearing damage risk for animals is substantially different from that of humans. The unpopulated areas include wilderness areas, parks, game refuges, and other areas that are set aside to provide enjoyment of the outdoors. Although quiet is not always of paramount importance in such areas, many individuals enjoy the special qualities of serenity and tranquility found in natural areas. At this time it is not possible to identify an appropriate level to prevent activity interference and annoyance. However, when it becomes possible to set such a level, a clear distinction should be made between natural and man-made noise.

USE OF IDENTIFIED ENVIRONMENTAL NOISE LEVELS

One of the purposes of this document is to provide a basis for judgment by states and local governments as a basis for setting standards. In doing so the information contained in this document must be utilized along with other relevant factors. These factors include the balance between costs and benefits associated with setting standards at particular noise levels, the nature of the existing or projected noise problems in any particular area, the local aspirations and the means available to control environmental noise.

In order to bring these factors together, states, local governments and the public will need to evaluate in a systematic manner the following:

1. The magnitude of existing or projected noise environments in defined areas as compared with the various levels identified in this document.

2. The community expectations for noise abatement with respect to existing or projected conditions.

3. The affected elements of the public and the degree of impact of present or projected environmental noise levels.

4. The noise sources not controlled by Federal regulations that cause local noise problems.

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5. Methods available to attack environmental noise problems (use limitations, source control through noise emission standards, compatible land use planning, etc.).

6. The costs inherent in reducing noise to certain levels and benefits achieved by doing so.

7. The availability of technology to achieve the desired noise reduction.

The levels of environmental noise identified in this report provide the basis for assessing the effectiveness of any noise abatement program. These noise levels are identified irrespective of the nature of any individual noise source. One of the primary purposes of identifying environmental noise levels is to provide a basis by which noise source emission regulations, human exposure standards, land use planning, zoning, and building codes may be assessed, as to the degree with which they protect the public health and welfare with respect to noise. Such regulatory action must consider technical feasibility and economic reasonableness, the scale of time over which results can be expected, and the specific problems of enforcement. In the process of balancing these conflicting elements, the public health and welfare consequence of any specific decision can be determined by comparing the resultant noise environment against the environmental noise levels identified in this report.

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GLOSSARY

AUDIBLE RANGE (OF FREQUENCY) (AUDIO-FREQUENCY RANGE). The frequency range 16 Hz to 20,000 Hz (20 kHz). Note.- This is conventionally taken to be the normal frequency range of human hearing.

AUDIOMETER. An instrument for measuring the threshold or sensitivity of hearing.

AUDIOMETRY. The measurement of hearing.

BROAD-BAND NOISE. Noise whose energy is distributed over a broad range of frequency (generally speaking, more than one octave).

CONTINUOUS NOISE. On-going noise whose intensity remains at a measurable level (which may vary) without interruption over an indefinite period or a specified period of time.

DEAFNESS. 100 percent impairment of hearing associated with an organic condition.

Note: This is defined for medical and cognate purposes as the hearing threshold level for speech or the average hearing threshold level for pure tones of 500, 1000 and 2000 Hz in excess of 92 dB.

EQUIVALENT SOUND LEVEL. The level of a constant sound which, in a given situation and time period, has the same sound energy as does a time-varying sound. Technically, equivalent sound level is the level of the time-weighted, mean square, A-weighted sound pressure. The time interval over which the measurement is taken should always be specified.

ENVIRONMENTAL NOISE. By Sec 3(11) of the Noise Control Act of 1972, the term "environmental noise" means the intensity, duration, and character of sounds from all sources.

HEARING LEVEL. The difference in sound pressure level between the threshold sound for a person (or the median value or the average for a group) and the reference sound pressure level defining the ASA standard audiometric threshold (ASA: 1951).

Note: The term is now commonly used to mean hearing threshold level (qv). Units: decibels.

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HEARING LOSS. Impairment of auditory sensitivity: an elevation of a hearing threshold level. 1

HEARING THRESHOLD LEVEL. The amount by which the threshold of hearing for an ear (or the average for a group) exceeds the standard audiometric reference zero (ISO, 1964; ANSI, 1969). Units: decibels.

IMPULSE NOISE (IMPULSIVE NOISE). Noise of short duration (typically, less than one second) especially of high intensity, abrupt onset and rapid decay, and often rapidly changing spectral composition. Note.- Impulse noise is characteristically associated with such sources as explosions, impacts, the discharge of firearms, the passage of super-sonic aircraft (sonic boom) and many industrial processes.

INFRASONIC. Having a frequency below the audible range for man (customarily deemed to cut off at 16 Hz).

INTERMITTENT NOISE. Fluctuating noise whose level falls once or more times to low or unmeasurable values during an exposure. In this document intermittent noise will mean noise that is below 65 dBA at least 10% of any I hour period.

NOISE EXPOSURE. The cumulative acoustic stimulation reaching the ear of the person over a specified period of time (e.g., a work shift, a day, a working life, or a lifetime).

NOISE HAZARD (HAZARDOUS NOISE). Acoustic stimulation of the ear which is likely to produce noise-induced permanent threshold shift in some of a population.

NOISE-INDUCED PERMANENT THRESHOLD SHIFT (NIPTS). Permanent threshold shift caused by noise exposure, corrected for the effect of aging (presbyacusis).

NOISE-INDUCED TEMPORARY THRESHOLD SHIFT (NITTS). Temporary threshold shift caused by noise exposure.

NON-VOLUNTARY EXPOSURE TO ENVIRONMENTAL NOISE. The exposure of an individual to sound which (1) the individual cannot avoid or (2) the sound serves no useful purpose (e.g., the exposure to traffic noise or exposure to noise from a lawn mower).

OCCUPATIONAL EXPOSURE TO ENVIRONMENTAL NOISE. The noise exposure of an individual defined under Pi. 91-596, Occupational Safety and Health Act of 1970.

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OTOLOGICALLY NORMAL. Enjoying normal health and freedom from all clinical manifestations and' history of ear disease or injury; and having a patent (wax-free) external auditory meatus.

PEAK SOUND PRESSURE. The absolute maximum value (magnitude) of the instantaneous sound pressure occurring in a specified period of time. PRESBYACUSIS (PRESBYCUSIS). Hearing loss, chiefly involving the higher audiometric frequencies above 3000 Hz, ascribed to advancing age. RISK. That percentage of a population whose hearing level, as a result of a given influence, exceeds the specified value, minus that percentage whose hearing level would have exceeded the specified value in the absence of that influence, other factors remaining the same. Note.- The influence may be noise, age, disease, or a combination of factors.

SOUND LEVEL. The quantity in decibels measured by a sound level meter satisfying the requirements of American National Standards Specification for Sound Level Meters Sl.4-1971. Sound level is the frequency-weighted sound pressure level obtained with the standardized dynamic characteristic "fast" or "slow" and weighting A, B, or C; unless indicated otherwise, the A-weighting is understood. The unit of any sound level is the decibel, having the unit symbol dB.

SOUND EXPOSURE LEVEL. The level of sound accumulated over a given time interval or event. Technically, the sound exposure level is the level of the time-integrated mean square A-weighted sound for a stated time interval or event, with a reference time of one second.

SOUND PRESSURE LEVEL. In decibels, 20 times the logarithm to the base ten of the ratio of a sound pressure to the reference sound pressure of 20 micropascals (20 micronewtons per square meter). In the absence of any modifier, the level is understood to be that of a mean-square pressure.

SPEECH DISCRIMINATION. The ability to distinguish and understand speech signals.

TEMPORARY THRESHOLD SHIFT (TTS). That component of threshold shift which shows a progressive reduction with the passage of time after the apparent cause has been removed.

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THRESHOLD OF HEARING (AUDIBILITY). The minimum effective sound pressure level of an acoustic signal capable of exciting the sensation of hearing in a specified proportion of trials in prescribed conditions of listening. ULTRASONIC. Having a frequency above the audible range for man (conventionally deemed to cut off at 20,000 Hz).

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APPENDIX A

EQUIVALENT SOUND LEVEL AND ITS RELATIONSHIP TO OTHER NOISE MEASURES

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Appendix A

EQUIVALENT SOUND LEVEL AND ITS RELATIONSHIP TO OTHER NOISE MEASURES

DEVELOPMENT OF EQUIVALENT SOUND LEVEL

The accumulated evidence of research on human response to sound indicates clearly that the magnitude of sound as a function of frequency and time are basic indicators of human response to sound. These factors are reviewed here, and it is concluded that it is not necessary to invent a new concept for the purpose of identifying levels of environmental noise.

Magnitude

Sound is a pressure fluctuation in the air; the magnitude of the sound describes the physical sound in the air; (loudness, on the other hand, refers to how people judge the sound when they hear it). Magnitude is stated in terms of the amplitude of the pressure fluctuation. The range of magnitude between the faintest audible sound and the loudest sound the ear can withstand is so enormous (a ratio of about 1,000,000 to I) that it would be very awkward to express sound pressure fluctuations directly in pressure units. Instead, this range is "compressed" by expressing the sound pressure on a logarithmic scale. Thus, sound is described in terms of the sound pressure level (SPL), which is ten times the common logarithm of the ratio of the square of the sound pressure in question to the square of a (stated or understood) reference sound pressure, almost always 20 micropascals. * Or, in mathematical terms, sound pressure level L expressed in decibels is:

$$L = 10 \log \left(\frac{p^2}{p_o^2}\right)$$

where p is the pressure fluctuation and p_o is the reference pressure.

*One pascal = one newton per square meter.

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Frequency Characteristics of Noise

The response of human beings to sound depends strongly on the frequency of sound. In general, people are less sensitive to sounds of low frequency, such as 100 hertz (Hz)*, than to sounds at 1000 Hz; also at high frequencies such as 8000 Hz, sensitivity decreases. Two basic approaches to compensate for this difference in response to different frequencies are (1) to segment the sound pressure spectrum into a series of contiguous frequency bands by electrical filters so as to display the distribution of sound energy over the frequency range; or (2) to apply a weighting to the overall spectrum in such a way that the sounds at various frequencies are weighted in much the same way as the human ear hears them.

In the first approach a sound is segmented into sound pressure levels in 24 different frequency bands, which may be used to calculate an estimate of the "loudness" or "noisiness" sensation which the sound may be expected to cause. This form of analysis into bands is usually employed when detailed engineering studies of noise sources are required. It is much too complicated for monitoring noise exposure.

To perform such analysis, especially for time-varying sounds, requires a very complex set of equipment. Fortunately, much of this complication can be avoided by using approach 2, i.e., by the use of a special electrical weighting network in the measurement system. This network weights the contributions of sounds of different frequency so that the response of the average human ear is simulated. Each frequency of the noise then contributes to the total reading by an amount approximately proportional to the subjective response associated with that frequency. Measurement of the overall noise with a sound level meter incorporating such a weighting network yields a single number, such as the A-weighted Sound Level, or simply A-level, in decibels. For zoning and monitoring purposes, this marks an enormous simplification. For this reason, the A-level has been adopted in large-scale surveys of city noise coming from a variety of sources. It is widely accepted as an adequate way to deal with the ear's differing sensitivity to sounds of different frequency, including assessment of noise with respect to its potential for causing hearing loss. Despite the fact that more detailed analysis is frequently required for engineering noise control, the results of such noise control are adequately described by the simple measure of sound level.

One difficulty in the use of a weighted sound level is that psychoacoustic judgment data indicate that effects of tonal components are sometimes not adequately accounted for by a simple sound level. Some current ratings attempt to correct for tonal components;

*Hertz is the international standard unit of frequency, until recently called cycles per second; it refers to the number of pressure fluctuations per second in the sound wave.

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for example, in the present aircraft noise certification procedures, "Noise Standards: Aircraft Type Certification," FAR Part 36, the presence of tones is identified by a complex frequency analysis procedure. If the tones protrude above the adjacent random noise spectrum, a penalty is applied beyond the direct calculation of perceived noise level alone. However, the complexities involved in accounting for tones exceed practicable limits for monitoring noise in the community or other defined areas. Consequently, EPA concludes that, where appropriate, standards for new products will address the problem of tones in such a way that manufacturers will be encouraged to minimize them and, thus, ultimately they will not be a significant factor in environmental noise.

With respect to both simplicity and adequacy for characterizing human response, a frequency-weighted sound level should be used for the evaluation of environmental noise. Several frequency weightings have been proposed for general use in the assessment of response to noise, differing primarily in the way sounds at frequencies between 1000 and 4000 Hz are evaluated. The A-weighting, standardized in current sound level meter specifications, has been widely used for transportation and community noise description. [A-1] For many noises the A-weighted sound level has been found to correlate as well with human response as more complex measures, such as the calculated perceived noise level or the loudness level derived from spectral analysis. [A-2] However, psychoacoustic research indicates that, at least for some noise signals, a different frequency weighting which increases the sensitivity to the 1000-4000 Hz region is more reliable. [A-3] various forms of this alternative weighting function have been proposed; they will be referred to here as the type "D-weightings". None of these alternative weightings has progressed in acceptance to the point where a standard has been approved for commercially available instrumentation.

It is concluded that a frequency-weighted sound pressure level is the most reasonable choice for describing the magnitude of environmental noise. In order to use available standardized instrumentation for direct measurement, the A frequency weighting is the only suitable choice at this time. * The indication that a type D-weighting might ultimately be more suitable than the A-weighting for evaluating the integrated effects of noise on people suggests that at such time as a type D-weighting becomes standardized and available in commercial instrumentation, its value as the weighting for environmental noise should be considered to determine if a change from the A-weighting is warranted.

Time Characteristics Of Noise

The dominant characteristic of environmental noise is that it is not steady-at any particular location the noise usually fluctuates considerably, from quiet at one instant to loud
*All sound levels in this report are A-weighted sound pressure levels in decibels with reference to 20 micropascals.

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the next. Thus, one cannot simply say that the noise level at a given location or that experienced by a person at that location is "so many decibels" unless a suitable method is used to average the time-varying levels. To describe the noise completely requires a statistical approach. Consequently, one should consider the noise *exposure*, which is received by an individual moving through different noisy spaces. This exposure is related to the whole time-varying pattern of sound levels. Such a noise exposure can be described by the cumulative distribution of sound levels, showing exactly what percent of the whole observation period each level was exceeded.

A complete description of the noise exposure would distinguish between daytime, evening and nighttime, and between weekday and weekend noise level distributions. It would also give distributions to show the difference between winter and summer, fair weather and foul.

The practical difficulty with the statistical methodology is that it yields a large number of statistical parameters for each measuring location; and even if these were averaged over more or less homogeneous neighborhoods, it still would require a large set of numbers to characterize the noise exposure in that neighborhood. It is literally impossible for any such array of numbers to be effectively used either in an enforcement context or to map existing noise exposure baselines.

It is essential, therefore, to look further for a suitable single-number measure of noise exposure. Note that the ultimate goal is to characterize with reasonable accuracy the noise exposure of whole neighborhoods (within which there may actually exist a fairly wide range of noise levels), so as to prevent extremes of noise exposure at any given time, and to detect unfavorable trends in the future noise climate. For these purposes, pinpoint accuracy and masses of data for each location are not required, and may even be a hindrance, since one could fail to see the forest for the trees.

A number of methodologies for combining the noise from both individual events and quasi-steady state sources into measures of cumulative noise exposure have been developed in this country and in other developed nations, e.g., Noise Exposure Forecast, Composite Noise Rating, Community Noise Equivalent Level, Noise and Number Index, and Noise Pollution Level. Many of these methodologies, while differing in technical detail (primarily in the unit of measure for individual noise events), are conceptually similar and correlate fairly well with each other. Further, using any one of these methodologies, the relationships between cumulative noise exposure and community annoyance[A-4,A-5] also correlate fairly well. It is therefore unnecessary to invent a new concept for the purpose of identifying levels of environmental noise. Rather, it is possible to select a consistent measure that is based on existing scientific and practical experience and methodology and which meets the criteria presented in Section 2 of the body of this document. Accordingly, the Environmental Protection Agency has selected the Equivalent Sound Level (L_{eq}) for the purpose of identifying levels of environmental noise.

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Equivalent Sound Level is formulated in terms of the equivalent *steady* noise level which in a stated period of time would contain the same noise energy as the time-varying noise during the same time period.

The mathematical definition of L_{eq} for an interval defined as occupying the period between two points in time t_1 and t_2 is:

$$L_{eq} = 10 \log \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p^2(t)}{p_o^2} \, dt \right]$$

where p(t) is the time varying sound pressure and p_o is a reference pressure taken as 20 micropascals.

The concept of Equivalent Sound Level was developed in both the United States and Germany over a period of years. Equivalent level was used in the 1957 original Air Force Planning Guide for noise from aircraft operations, [A-6] as well as in the 1955 report [A-7] on criteria for short-time exposure of personnel to high intensity jet aircraft noise, which was the forerunner of the 1956 Air Force Regulation [A-8] on "Hazardous Noise Exposure". A more recent application is the development of CNEL (Community Noise Equivalent Level) measure for describing the noise environment of airports. This measure, contained in the Noise Standards, Title 4, Subchapter 6, of the California Administrative Code (1970) is based upon a summation of L_{eq} over a 24-hour period with weightings for exposure during evening and night periods

The Equivalent Noise Level was introduced in 1965 in Germany as a rating specifically to evaluate the impact of aircraft noise upon the neighbors of airports. [A-9] It was almost immediately recognized in Austria as appropriate for evaluating the impact of street traffic noise in dwellings [A-10] and in schoolrooms. [A-11] It has been embodied in the National Test Standards of both East Germany [A-12] and West Germany [A-13] for rating the subjective effects of fluctuating noises of all kinds, such as from street and road traffic, rail traffic, canal and river ship traffic, aircraft, industrial operations (including the noise from individual machines), sports stadiums, playgrounds, etc. It is the rating used in both the East German [A-14] and West German [A-15] standard guidelines for city planning. It was the rating that proved to correlate best with subjective response in the large Swedish traffic noise survey of 1966-67. It has come into such general use in Sweden for rating noise exposure that commercial instrumentation is currently available for measuring L_{eq} directly; the lightweight unit is small enough to be held in one hand and can be operated either from batteries or an electrical outlet. [A-16]

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The concept of representing a fluctuating noise level in terms of a steady noise having the same energy content is widespread in recent research, as shown in the EPA report on Public Health and Welfare Criteria for Noise (1973). There is evidence that it accurately describes the onset and progress of permanent noise-induced hearing loss, [A-17] and substantial evidence to show that it applies to annoyance in various circumstances. [A-18] The concept is borne out by Pearsons' experiments [A-19] on the trade-off of level and duration of a noisy event and by numerous investigations of the trade-off between number of events and noise level in aircraft flyovers. [A-20] Indeed, the Composite Noise Rating [A-21] is a formulation of L_{eq}, modified by corrections for day vs. night operations. The concept is embodied in several recommendations of the International Standards Organization, for assessing the noise from aircraft,[A-22] industrial noise as it affects residences,[A-23] and hearing conservation in factories.[A-24]

COMPUTATION OF EQUIVALENT SOUND LEVEL

In many applications, it is useful to have analytic expressions for the equivalent sound level L_{eq} in terms of simple parameters of the time-varying noise signal so that the integral does not have to be computed. It is often sufficiently accurate to approximate a complicated time-varying noise level with simple time patterns. For example, industrial noise can often be considered in terms of a specified noise level that is either on or off as a function of time. Similarly, individual aircraft or motor vehicle noise events can be considered to exhibit triangular time patterns that occur intermittently during a period of observation. (Assuming an aircraft flyover time pattern to be triangular in shape instead of shaped like a "normal distribution function" introduces an error of, at worst, 0.8 dB). Other noise histories can often be approximated with trapezoidal time pattern shapes.

The following sections provide explicit analytic expressions for estimating the equivalent sound level in terms of such time patterns, and graphic design charts are presented for easy application to practical problems. Most of the design charts are expressed in terms of the amount that the level (L) of the new noise source exceeds an existing background noise level, L_b. This background noise may be considered as the equivalent sound level that existed before the introduction of the new noise, provided that its fluctuation is small relative to the maximum value of the new noise level.

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Constant Level Noise - Steady or Intermittent

The L_{eq} for a continuous noise having a constant value of L_{max} is

$L_{eq} = L_{max}$, which is derived from

$$L_{eq} = 10 \log \frac{1}{T} \int_{0}^{T} 10^{\left(\frac{L_{max}}{10}\right)} dt = L_{max} \quad \text{(dB)} \quad \text{(Eq. A-3)}$$

When L_{max} is intermittently on during the period T for a fraction x of the total time, with a background noise level L_b present for the time fraction (1-x), L_{eq} is given by:

$$L_{eq} = L_b + 10 \log \left[(1-x) + x \left(10^{\frac{\Delta L}{10}} \right) \right] \quad \text{(dB)} \quad \text{(Eq. A-4)}$$

Where $\Delta L = L_{max} - L_b$. This pattern is illustrated and the expression is plotted in Figure A-1 for various values of L and x. For values of L_{max} that are 10dB or more higher than L_b, L_{eq} is approximated quite accurately by:

$L_{eq} = L_{max} + 10 \log x$ (dB) (Eq. A-5)

Except in extreme cases as noted on the graph. An hourly equivalent sound level (L_h) can be computed from the last equation with the integration time (T) equal to 3600 seconds (1 hour). An example of the relationship between L_h and L_{max} as a function of pulse duration t for $L_{max} - L_b$ greater than 10 is given in Figure A-2. These results may be described by:

$L_h = L_{max} + 10 \log t - 35.6$ (dB) (Eq. A-6)

for $(L_{max} - L_b) > 10$

Triangular Time Patterns

The equivalent sound level for a single triangular time pattern having a maximum value of L_{max} and rising from a background level of L_b is given by:

$$L_{eq} = L_b + 10 \log \left[\frac{10}{2.3 \Delta L} \left(10^{\frac{\Delta L}{10}} - 1 \right) \right] \quad \text{(dB)} \quad \text{(Eq. A-7)}$$

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where again $\Delta L = L_{max} - L_b$. When ΔL is greater than 10 dB, the following approximation for L_{eq} is quite accurate:

$$L_{eq} = L_{max} - 10 \log \frac{2.3 \Delta L}{10} \quad \text{(dB)} \quad \text{(Eq. A-8)}$$

Except in extreme cases as noted on the graph. The value of L_{eq} for a series on n identical triangular time patterns having maximum levels of L_{max} is given by:

$$L_{eq} = L_b + 10 \log \left[1 + \frac{n\tau}{T} \left(\frac{10^{\frac{\Delta L}{10}} - 1}{2.3} - \frac{\Delta L}{10} \right) \right] \quad \text{(dB)} \quad \text{(Eq. A-9)}$$

Where the duration between (L_{max} - 10 dB) points* is τ seconds, the background level is L_b, and the total time period is T. (See Figure A-3). A design chart for determining L_{eq} for different values of (DELTA)L as a function of N*t* per hour is provided in Figure A-3.

*The duration for which the noise level is within 10 dB of L_{max}; also called the "10 dB down" duration.

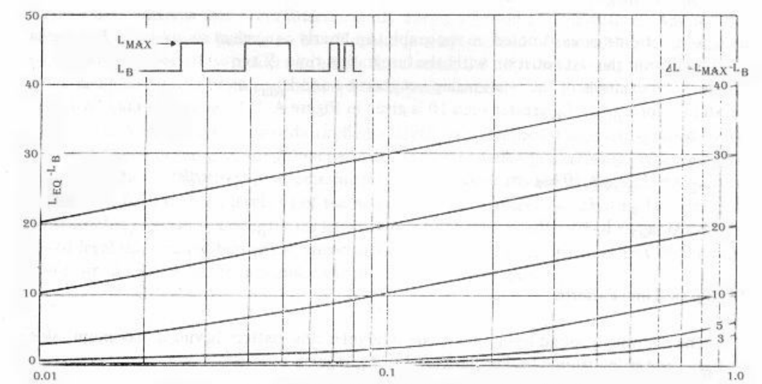

FIGURE A-1. L_{EQ} FOR INTERMITTENT L_{MAX} ADDED TO L_B A-25

Figure A-1. L_{eq} for Intermittent L_{max} Added to L_b A-25

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Figure A-2. Hourly Equivalent Sound Level as a Function of Pulse Duration and Maximum Sou

nd Level for One Pulse per Hour of a Succession of n Shorter Pulses Having a Total of the Indicated Duration During One Hour. (Background sound level less than 30 dB). (Derived from Equation A-5).

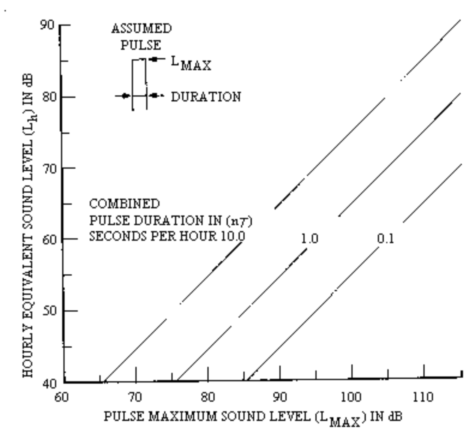
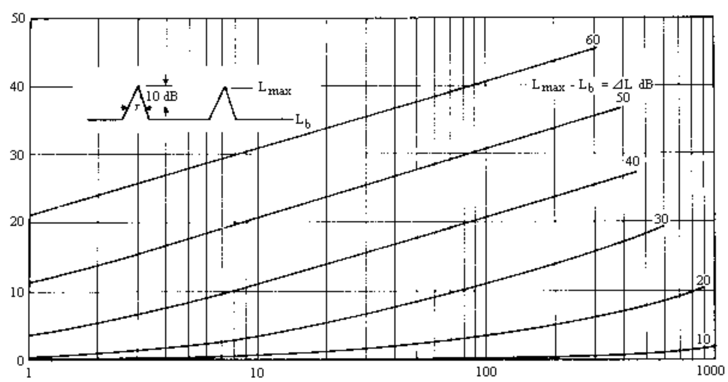


Figure A-3. L_{eq} for a Repeated Series of n Triangular Signals Overlaid on a Background Level of L_b, dB and τ= Duration at (L_{max}-10) dB in Seconds.A-25 (See Equation A-9).



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An approximation to equation (A-9) for cases where L is greater than 10 dB is given by:

$$L_{eq} = L_{max} + 10 \log \frac{n\tau}{2.3T}$$

This equation yields fairly good results except in extreme cases as can be seen in the graph.

Trapezoidal Time Patterns

The equivalent sound level, Leq, for a trapezoidal time pattern having maximum level of L_{max}, background level L_b, duration between (L_{max} -10 dB) points of τ and duration at L_{max} of § is given by

$$L_{eq} = 10 \log \left(\frac{1}{\frac{(\tau - \xi)\,\Delta L}{10} + \frac{\xi}{2}} \right) \left[10^{\frac{L_b}{10}} \left(\frac{\tau - \xi}{2.3} \right) \left(10^{\frac{\Delta L}{10}} - 1 \right) + 10^{\frac{L_{max}}{10}} \left(\frac{\xi}{2} \right) \right] \quad \text{(dB)} \quad \text{(Eq. A-11)}$$

The approximation to L_{eq} when (DELTA)L is greater than 10 dB, for § small compared to τ, is:

$$L_{eq} = L_{max} - \frac{2.3\ \Delta L}{10} + 10 \log \xi \quad \text{(dB)} \quad \text{(Eq. A-12)}$$

This equation yields adequate results except in extreme cases as noted on the graph. Noting the similarity between equations (A-5) (A-8), and (A-12), one can approximate L_{eq} for a series of trapezoidal pulses by suitably combining design data from Figure A-1 and A-3. That is, the approximate L_{eq} for a series of n trapezoidal pulses is obtained by the Leq value for triangular pulses plus an additional term equal to 10 log n, e.g.,

$$L_{eq} = L_{max} + 10 \log \frac{n\tau}{2.3T} + 10 \log\ n\xi \quad \text{(dB)} \quad \text{(Eq. A-13)}$$

Time Patterns of Noise Having a Normal Statistical Distribution

Many cases of noise exposures in communities have a noise level distribution that may be closely approximated by a normal statistical distribution. The equivalent sound level for the distribution can be described simply in terms of its mean value, which for a normal

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distributions is L_{50}, and the standard deviation (s) of the noise level distribution:

$L_{eq} = L_{50} + 0.115\ s^2$ (dB) (Eq. A-14)

A design chart showing the difference between L_{eq} and L_{50} as a function of the standard deviation is provided in Figure A-4.

It is often of interest to know which percentile level of a normal distribution is equal in magnitude to the Leq value for the distribution. A chart providing this relationship as a function of the standard deviation of the distribution is provided in Figure A-5.

Various noise criteria in use for highway noise are expressed in terms of the L_{10} value. For a normal distribution, the L_{10} value is specified in terms of the median and the standard deviation by the expression $L_{10} = L_{50} + 1.28$ s. The difference between L_{10} and L_{eq} is given by L_{10}-L_{eq} = 1.28 s- 0.115 s^2. This expression is plotted as a function of s in Figure A-6.

It should be noted that traffic noise does not always yield a normal distribution of noise levels, so caution should be used in determining exact differences between L_{eq} and L_{10}.

RELATIONSHIPS BETWEEN DAYTIME AND NIGHTTIME EQUIVALENT SOUND LEVELS

The day-night sound level (L_{dn}) was defined as the equivalent A-weighted sound level during a 24-hour time period with a 10 decibel weighting applied to the equivalent sound level during the nighttime hours of 10 p.m. to 7 a.m. This may be expressed by the equation:

$$L_{dn} = 10 \log \frac{1}{24}\left[15\left(10^{L_d/10}\right) + 9\left(10^{\frac{L_n+10}{10}}\right)\right] \quad \text{(dB)} \qquad \text{(Eq. A-15)}$$

where

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

and

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

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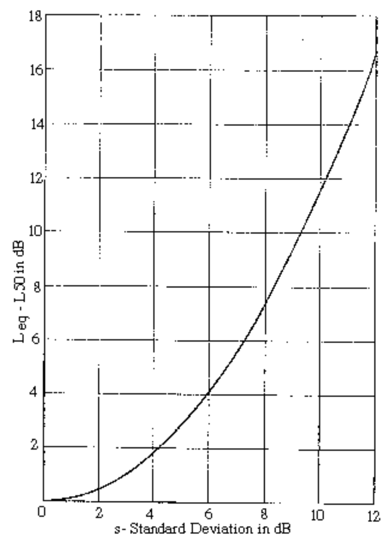

Figure A-4. Difference Between L_{eq} and L_{50} for a Normal Distributions Having Standard Deviation of s.[A-25] (See Equation A-14).

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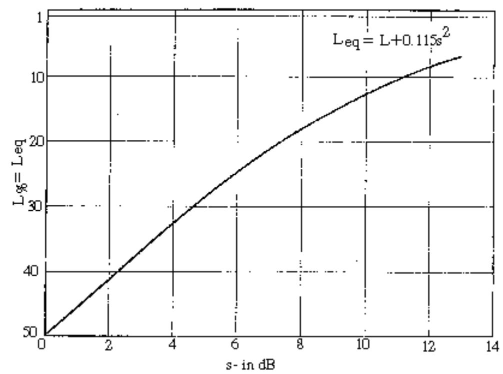

Figure A-5. Percentile of a Normal Distribution that is Equal to L_{eq}[A-25] (See Equation A-14 and Probability Function).

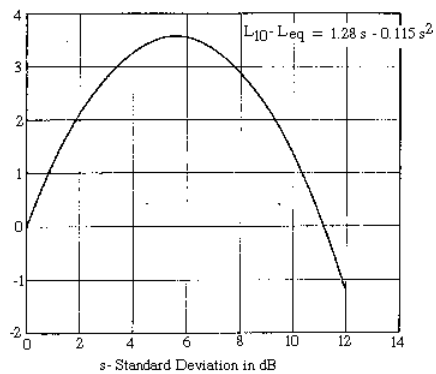

Figure A-6. Difference Between L_{10} and L_{eq} for a Normal Distribution[A-25]

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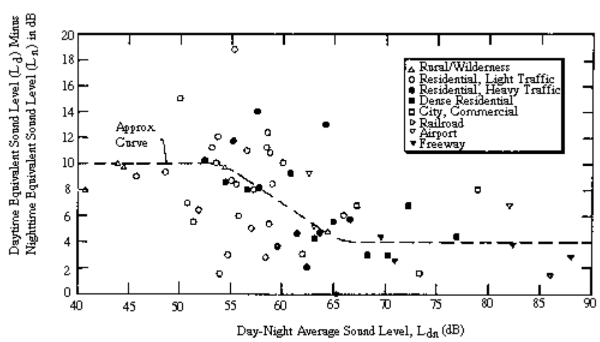

Figure A-7. Comparison of the Difference Between Day and Night Values of the Equivalent Sound Level with the Day-Night Average Sound Level, L_{dn} [A-25]

The effect of the weighting may perhaps be more clearly visualized if it is thought of as a method that makes all levels measured at night 10 dB higher than they actually are. Thus, as an example, if the noise level is a constant 70 dB all day and a constant 60 dB all night, L_{dn} would be 70 dB.

Methods for accounting for the differences in interference or annoyance between daytime/nighttime exposures have been employed in a number of different noise assessment methods around the world. [A-5] The weightings applied to the nondaytime periods differ slightly among the different countries but most of them weight night activities on the order of 10 dB; [A-24] the evening weighting if used is 5 dB. The choice of 10 dB for the nighttime weighting made in Section 2 was predicated on its extensive prior usage, together with an examination of the diurnal variation in environmental noise. This variation is best illustrated by comparing the difference between L_d and L_n as a function of L_{dn} over the range of environmental noise situations.

Data from 63 sets of measurements were available in sufficient detail that such a comparison could be made. These data are plotted in Figure A-7. The data span noise environments ranging from the quiet of a wilderness area to the noisiest of airport and highway environments. It can be seen that, at the lowest levels (L_{dn} around 40-55 dB), A-14

L_d is the controlling element in determining L_{dn}, because the nighttime noise level is so much lower than that in the daytime. At higher L_{dn} levels (65-90 dB), the values of L_n are not much lower than those for L_d; thus, because of the 10 dB nighttime weighting, L_n will control the value of L_{dn}.

The choice of the 10 dB nighttime weighting in the computation of L_{dn} has the following effect: In low noise level environments below L_{dn} of approximately 55 dB, the natural drop in L_n values is approximately 10 dB, so that L_d and L_n contribute about equally to L_{dn}. However, in high noise environments, the night noise levels drop relatively little from their daytime values. In these environments, the nighttime weighting applies pressure towards a round-the-clock reduction in noise levels if the noise criteria are to be met.

The effect of a nighttime weighting can also be studied indirectly by examining the correlation between noise measure and observed community response in the 55 community reaction cases presented in the EPA report to Congress of 1971.A-1 The data have a standard deviation of 3.3 dB when a 10 dB nighttime penalty is applied, but the correlation worsens (std, dev. = 4.0 dB) when no nighttime penalty is applied. However, little difference was observed among values of the weighting ranging between 8 and 12 dB. Consequently, the community reaction data support a weighting of the order of 10 dB but they cannot be utilized for determining a finer gradation. Neither do the data support "three-period" in preference to "two-period" days in assigning nondaytime noise penalties.

COMPARISON OF DAY-NIGHT SOUND LEVEL WITH OTHER MEASURES OF NOISE USED BY FEDERAL AGENCIES

The following subsections compare the day-night sound level with three measures utilized for airport noise, CNR, NEF, and CNEL, the HUD Guideline Interim Standards and the Federal Highway Administration standards:

Comparison of L_{dn} with Composite Noise Rating (CNR), Noise Exposure Forecast (NEF), and Community Noise Equivalent Level (CNEL)

CNR, NEF, and CNEL are all currently used expressions for weighted, accumulated noise exposure. Each is intended to sum a series of noise while weighting the sound pressure level for frequency and then adding appropriate nighttime weightings. The older ratings, CNR and NEF, are expressed in terms of maximum Perceived Noise Level and Effective Perceived Noise Level, respectively; each considers a day-night period identical to L_{dn}.

A-15

The measure CNEL itself is essentially the same as L_{dn} except for the method of treating nighttime noises. In CNEL, the 24-hour period is broken into three periods: day (0700-1900), evening (1900-2200), and night (2200-0700). Weightings of 5 dB are applied to the evening period and 10 dB to the night period. For most time distributions of aircraft noise around airports, the numerical difference between a two-period and three-period day are not significant, being of the order of several tenths of a decibel at most.

One additional difference between these four similar measures is the method of applying the nighttime weighting and the magnitude of the weighting. The original CNR concept, carried forward in the NEF, weighted the nighttime exposure by 10 dB. Because of the difference in total duration of the day and night periods, 15 and 9 hours respectively, a specific noise level at night receives a weighting of 10 + 10 log (15/9), or approximately 12 dB in a reckoning of total exposure. Given the choice of weighting either exposure or level, it is simpler to weight level directly, particularly when actual noise monitoring is eventually considered.

The following paragraphs describe the method utilized to calculate CNR, NEF, and CNEL, as applied principally to aircraft sounds, together with the analogous method for calculating L_{dn}:

Composite Noise Rating Method (CNR)

The original method for evaluating land use around civil airports is the composite noise rating (CNR). It is still in wide use by the Federal Aviation Administration and the Department of Defense for evaluating land use around airfields (Civil Engineering Planning and Programming, "Land Use Planning with Respect to Aircraft Noise," AFM 86-5, TM 5-365, NAVDOCKS P-98, October 1, 1964). This noise exposure scale may be expressed as follows:

$$CNR = \overline{PNL}_{max} + 10 \log N_f - 12 \quad \text{(Eq. A-16)}$$

The single event noise level is expressed (without a duration or tone correction) as simply the maximum perceived noise level (PNL_{max}) in PNdB.

The noise exposure in a community is specified in terms of the composite noise rating (CNR), which can be expressed approximately as follows:

$\overline{PNL}$ = approximate energy mean maximum perceived noise level (PNL) at a given point

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$N_f = (N_d + 16.7\ N_n)$, where N_d and N_f the numbers of daytime and nighttime events, respectively.

The constant (-12) is an arbitrary constant, and the factor 16.7 is used to weight the nighttime exposure in the 9-hour night period on a 10 to 1 basis with the daytime exposure in the 15-hour daytime period.

Noise Exposure Forecast (NEF)

This method, currently in wide use, for making noise exposure forecasts utilizes a perceived noise level scale with additional corrections for the presence of pure tones. Two time periods are used to weight the number of flights (Galloway, W.J. and Bishop, D.E., "Noise Exposure Forecasts: Evolution Evaluation, Extensions and Land Use Interpretations," FAA-NO-70-9, August 1970.

The single event noise level is defined in terms of effective perceived noise level (EPNL) which can be specified approximately by:

$$EPNL = PNL_{max} + \log \frac{\Delta t_{10}}{20} + F, \text{ (EPNdB)} \quad \text{(Eq. A-17)}$$

where

PNL_{max} = maximum perceived noise level during flyover, in PNdB,

Δt_{10} = "10 dB down" duration of the perceived noise level time history, in seconds,

and

F = pure tone correction. Typically, F = 0 to + 3 dB

Community noise exposure is then specified by the Noise Exposure Forecast (NEF). For a given runway and one or two dominant aircraft types, the total NEF for both daytime and nighttime operations can be expressed approximately as:

$$NEF = \overline{EPNL} + 10 \log N_f - 88.0 \quad \text{(Eq. A-18)}$$

where

$\overline{EPNL}$ = energy mean value of EPNL for each single event at the point in question

N_f = same as defined for CNR

Community Noise Equivalent Level (CNEL)

The following simplified expressions are derived from the exact definitions in the report, "Supporting Information for the Adopted Noise Regulations for California Airports." They can be used to estimate values of CNEL where one type of aircraft and one flight path dominate the noise exposure level.

Single event noise is specified by the single event noise exposure level (SENEL) in dB and can be closely approximated by:

$SENEL = NL_{max} + 10 \log_{10} \tau/2$ (dB) (Eq. A-19)

where

NL_{max} = maximum noise level as observed on the A scale of a standard sound level meter

and

τ = duration measured between the points of $(L_{max} - 10)$ in seconds. The effective duration is equal to the "energy" of the integrated noise level (NL), divided by the maximum noise level, NL_{max}, when both are expressed in terms of antilogs. It is approximately 1/2 of the 10 dB down duration.

A measure of the average integrated noise level over one hour is also utilized in the proposed standard. This is the hourly noise level (in dB), defined as:

$$HNL = \overline{SENEL} + 10 \log n - 35.6$$

= (dB) Eq. A-20)

where

SENEL = energy mean value of SENEL for each single event,

and

n = number of flights per hour

The total noise exposure for a day is specified by the community noise equivalent level (CNEL) in dB, and may be expressed as:

$$CNEL = \overline{SENEL} + 10 \log N_c - 49.4$$

= (dB) (Eq. A-21)

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where

$Nc = (N_d + 3N_e + 10\ N_n)$

or

$$= (12\bar{n}_d + 9\bar{n}_e + 90\bar{n}_n)$$

$N_d, \bar{n}_d$ = total number and average number per hour, respectively, of flights during the period 0700 to 1900

$N_e, \bar{n}_e$ = total number and average number per hour, respectively, of flights during the period 1900 to 2200

and

$N_n, \bar{n}_n$ = total number and average number per hour, respectively, of flights during the period 2200 to 0700

Day-Night Sound Level (L_{dn})

The following simplified expressions are useful for estimating the value of L_{dn} for a series of single event noises which are of sufficient magnitude relative to the background noise that they control L_{dn}:

Single event noise is specified by the sound exposure level (L_{ex}) measured during a single event. It can be closely approximated by:

$$L_{ex} \cong L_{max} + 10 \log_{10} \tau/2$$

(dB) (Eq. A-22)

Where

L_{max} = maximum sound level as observed on the A scale of a standard sound level meter on the slow time characteristic

and

τ = duration measured between the points of (L_{max} - 10) in seconds

The day-night sound level may be estimated by:

$$L_{dn} = \overline{L_{ex}} + 10 \log N - 49.4$$

(dB) (Eq. A-23)

where

$\overline{L_{ex}}$ = the energy mean value of the single event L_{ex} values

$N = (N_d + 10N_n)$

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or

N_d = total number of events during the period 0700 to 2200

and

Nn = total number of events during the period 2200 to 0700

There is no fixed relationship between L_{dn} or CNEL and CNR or NEF because of the differences between the A-level and PNL frequency weightings and the allowance for duration, as well as the minor differences in approach to day-night considerations. Nevertheless, one may translate from one measure to another by the following approximate relationship:

(Eq. A-24)

$$L_{dn} \doteq CNEL \doteq NEF + 35 \doteq CNR - 35$$

For most circumstances involving aircraft flyover noise, these relationships are valid within about a ± 3 dB tolerance.

Comparison of Leq with HUD Guideline Interim Standards (1390.2 Chg. 1)

The interim HUD standards for outdoor noise are specified for all noise sources, other than aircraft, in terms of A-weighted sound level not to be exceeded more than a certain fraction of the day. Aircraft noise criteria are stated in terms of NEF or CNR.

The HUD exposure criteria for residences near airports are "normally acceptable" if NEF 30 or CNR 100 is not exceeded. A "discretionary acceptable" category permits exposures up to NEF 40 or CNR 115.

For all other noise sources, the HUD criteria specify a series of acceptable, discretionary, and unacceptable exposures. Since these specifications are similar to points on a cumulative statistical description of noise levels, it is of interest to compare the HUD criteria with L_{eq} for different situations. For discussion purposes, consider the boundary between the categories "discretionary-normally acceptable" and "unacceptable."

The first criterion defining this boundary allows A-weighted noise levels to exceed 65 dB up to 8 hours per 24 hours, while the second criterion states that noise levels exceeding 80 dB should not exceed 60 minutes per 24 hours. These two values may be used to specify two limit points on a cumulative distribution function, L33.3 = 65 dB and L4.2 = 80 dB. The relationship between Leq and the HUD criteria may then be examined for different types of distribution functions, restricting the shape of the distribution only so that it does not exceed these two limit points.

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First consider two cases of a normal distribution of noise levels, comparable to vehicle traffic noise. For the first case, assume a distribution with quite narrow variance so placed on the graph that the 65 dB point is not exceeded (see Figure A-8). For this curve, to the nearest decibel, L_{50} = 64 dB, and the corresponding standard deviation (arbitrarily chosen small) is 2.3 dB. The resulting L_{eq} is equal to 64.6 dB.

Now consider a normal distribution with the widest permissible variance (the curve marked Maximum Variance in Figure A-8); if the variance were any greater, the distribution would violate HUD's requirement that the level not exceed 80 dB for more than 60 minutes per 24 hours. This distribution, to the nearest decibel, has L_{50} = 60 dB, L_{10} = 74 dB and a standard deviation of approximately 11 dB. The resultant L_{eq} = 74 dB, is almost 10 dB higher than for the previous case. Both curves meet HUD's interim standards.

Next, consider a series of intermittent high level noises, superposed on a typical urban/ suburban background noise level, such that 80 dB is not exceeded more than 60 minutes per 24 hours, say 4%. Choosing a series of repeated triangular-shaped time signals of 90 dB maximum sound level will produce an L_{eq} value of 72.4 dB without exceeding an L_4 value of 80 dB.

However, one can allow the maximum level to increase indefinitely provided L_4 remains at 80 dB or less. The limiting case is that of a square-shaped time pattern, switched on and off. In this instance, if the total "on-time" is 4% or less, the value of L_{eq} is equal to L_{max} - 14 dB, and both L_{max} and L_{eq} can increase without limit and still remain acceptable within the HUD interim standards. Maximum A-levels for an aircraft can be as high as 110 dB, which would permit L_{eq} values of 96 to be obtained without exceeding the L_4 limit of 80 dB.

It is clear that no unique relationship can be specified between the HUD non-airport standards and L_{eq}. Values of L_{eq} ranging up to 95 dB can be found in compliance with the HUD outdoor noise standard depending on the time distribution of noise levels considered. Even if the nighttime penalty were applied to L_{eq} to yield L_{dn} there would still be no unique relation with the HUD standards.

Comparison of L^{eq} with Federal Highway Administration Noise Standards, PPM 90-2, February 8, 1973

The primary criteria of PPM 90-2 are that L_{10} for noise levels inside people-occupied spaces shall not exceed 55 dB, or for sensitive outdoor spaces "-in which serenity and quiet are of extraordinary significance-," 60 dB.

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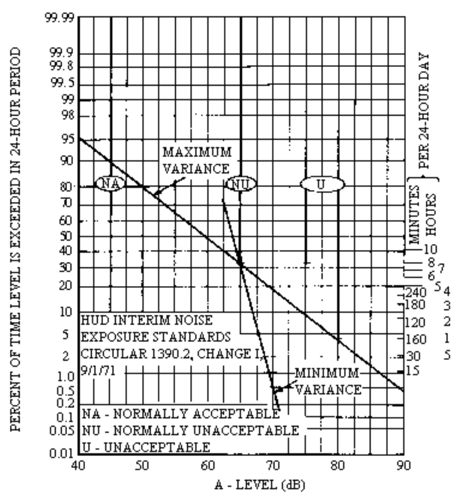

Figure A-8. Permissible Normal Distribution of L_{eq} Under HUD Standards[A-25]

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Highway noise often has a random distribution of noise level, the distribution function being approximately normal in many instances. In this case, the relationship between L_{eq} and L_{10} is given by the expression:

Where s is the standard deviation of the noise level distribution. The difference between L_{10} and L_{eq} for normal distribution of sound level is plotted in Figure A-6. It can be noted that Leq = L_{10} -2 dB within +2 dB, for s ranging from 0 to 11 dB. Highway noise rarely has a standard deviation of 11 dB; 2 to 5 dB is more typical.

Thus, setting L_{10} at 60 dB for highway noise impacting a sensitive outdoor space, we find that a L_{eq} value of 60 -2 = 58 +2 dB would meet the most sensitive FHWA criterion.

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APPENDIX B

LEVELS OF ENVIRONMENTAL NOISE IN THE U.S. AND TYPICAL EXPOSURE PATTERNS OF INDIVIDUALS

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APPENDIX B

LEVELS OF ENVIRONMENTAL NOISE IN THE U.S. AND TYPICAL EXPOSURE PATTERNS OF INDIVIDUALS

Levels of environmental noise for various defined areas are provided for both the outdoor and indoor situation. Examples are then used to illustrate how an individual's daily dose accumulates from the exposure to such noise levels.

LEVELS OF ENVIRONMENTAL NOISE

Outdoor Sound Levels

The range of day-night sound levels (L_{dn}) in the United States is very large, extending from the region of 20-30 dB estimated for a quiet* wilderness area to the region of 80-90 dB in the most noisy urban areas, and to still higher values within the property boundaries of some governmental, industrial and commercial areas which are not accessible to the general public. The measured range of values of day-night sound levels outside dwelling units extends from 44 dB on a farm to 88.8 dB outside an apartment located adjacent to a freeway. Some examples of these data are summarized in Figure B-1.

The dominant sources for outdoor noise in urban residential areas are motor vehicles, aircraft and voices. This conclusion has been found in several studies, including a recent survey [B-1] of 1200 people which is summarized in Table B-1.

The cumulative number of people estimated to reside in areas where the day-night sound level exceeds various values is given in Table B-2. In the areas where the L_{dn} exceeds 60 dB, the proportion between the number of people residing in areas where the outdoor noise environment is dominated by aircraft and those residing in areas where motor vehicles dominate is approximately one to four. This proportion is almost identical to the proportion found in the survey, previously summarized in Table B-1 where people were asked to judge the principle contributing sources of neighborhood noise. The estimates in Table B-2 of the

*Measurement approximately 25 feet from a mountain waterfall on a small canyon stream in Wyoming gave an L_{dn} of approximately 85 dB.[B-2]

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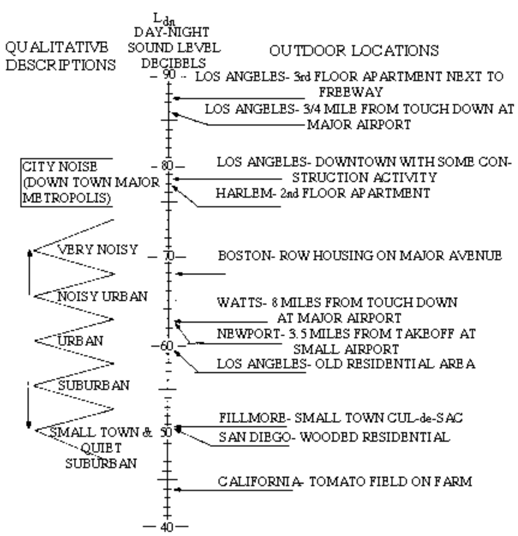

Figure B-1. Examples of Outdoor Day-Night Sound Level in dB (re 20 micropascals) Measured at Various Locations[B-4]

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Table B-1

PERCENT CONTRIBUTION OF EACH SOURCE IDENTIFIED BY RESPONDENTS CLASSIFYING THEIR NEIGHBORHOOD AS NOISY (72% OF 1200 RESPONDENTS)[B-3]

Source	Percentage
Motor Vehicles	55
Aircraft	15
Voices	12
Radio and TV Sets	2
Home Maintenance Equipment	2
Construction	1
Industrial	1
Other Noises	6
Not Ascertained	

Table B-2

ESTIMATED CUMULATIVE NUMBER OF PEOPLE IN MILLIONS INUNITED STATES RESIDING IN URBAN AREAS WHICH ARE EXPOSED TO VARIOUS LEVELS OF OUTDOOR DAY/NIGHT AVERAGE SOUND LEVEL,[B-4, B-5]

Outdoor L_{dn} Exceeds	Urban Traffic	Freeway Traffic	Aircraft Operations	Total
60	59.0	3.1	16.0	78.1
65	24.3	2.5	7.5	34.3
70	6.9	1.9	3.4	12.2
75	1.3	0.9	1.5	3.7
80	0.1	0.3	0.2	0.6

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number of people living in areas which are exposed to freeway and aircraft noise are taken from the EPA airport/aircraft noise report.[B-4] They were based on calculated noise contours and associated populations for a few selected situations which formed the basis for extrapolation to national values. The estimates for the number of people living in areas in which the noise environment is dominated by urban traffic were developed from a survey[B-5] conducted in Summer 1973 for EPA. The survey measured the outdoor 24-hour noise environment at 100 sites located in 14 cities, including at least one city in each of the ten EPA regions. These data, supplemented with that from previous measurements at 30 additional sites, were correlated with census tract population density to obtain a general relationship between L_{dn} and population density. This relationship was then utilized, together with census data giving population in urban areas as a function of population density, to derive the national estimate given in Table B-2.

These data on urban noise enable an estimate of the percentage urban population in terms of both noise levels and the qualitative descriptions of urban residential areas which were utilized in the Title IV EPA report to Congress in 1971.[B-6]

These estimates, summarized in Table B-3, show that the majority of the 134 million people residing in urban areas have outdoor L_{dn} values ranging from 43 dB to 72 dB with a median value of 59 dB. The majority of the remainder of the population residing in rural or other non-urban areas is estimated to have outdoor L_{dn} values ranging between 35 and 50 dB.

Indoor Sound Levels

The majority of the existing data regarding levels of environmental noise in residential areas has been obtained outdoors. Such data are useful in characterizing the neighborhood noise environment evaluating the noise of identifiable sources and relating the measured values with those calculated for planning purposes. For these purposes, the outdoor noise levels have proved more useful than indoor noise levels because the indoor noise levels contain the additional variability of individual building sound level reduction. This variability among dwelling units results from type of construction, interior furnishings, orientation of rooms relative to the noise, and the manner in which the dwelling unit is ventilated.

Data on the reduction of aircraft noise afforded by a range of residential structures are available.[B-7] These data indicate that houses can be approximately categorized into "warm climate" and "cold climate" types. Additionally, data are available for typical open-window and closed-window conditions. These data indicate that the sound level reduction provided by buildings within a given community has a wide range due to differences in the use of materials, building techniques, and individual building plans. Nevertheless, for

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Table B-3

ESTIMATED PERCENTAGE OF URBAN POPULATION (134 MILLION) RESIDING IN AREAS WITH VARIOUS DAY-NIGHT NOISE LEVELS TOGETHER WITH CUSTOMARY QUALITATIVE DESCRIPTION OF THE AREA [B-3,B-4]

Description	Typical Range L_{dn} in dB	Average L_{dn} in dB	Estimated Percentage of Urban Population	Average Census Tract Population Density, Number of People Per Square Mile
Quiet Suburban Residential	48-52	50	12	630
Normal Suburban Residential	53-57	55	21	2,000
Urban Residential	58-62	60	28	6,300
Noisy Urban Residential	63-67	65	19	20,000
Very Noisy Urban Residential	68-72	70	7	63,000

planning purposes, the typical reduction in sound level from outside to inside a house can be summarized as follows in Table B-4. The approximate national average "window open" condition corresponds to an opening of 2 square feet and a room absorption of 300 sabins (typical average of bedrooms and living rooms). This window open condition has been assumed throughout this report in estimating conservative values of the sound levels inside dwelling units which results from outdoor noise.

The sound levels inside dwelling units result from the noise from the outside environment plus the noise generated internally. The internally generated noise results from people activity, appliances and heating and ventilating equipment. Twenty-four hour continuous measurements were made in 12 living rooms (living, family or dining room) in 12 houses during the 100-site EPA survey[B-5] of urban noise, excluding areas where the noise resulted from freeways and aircraft. The results, summarized below in Table B-5, show that the inside day-night sound level in these homes was the result of internally generated noise. In fact, the internal L_{dn} and L_d values were slightly higher than those measured outdoors, despite the fact that the average house sound level reduction appeared to exceed 18 dB. The pattern for the indoor sound levels varies significantly among the homes, as portrayed by the data in Figure B-2. The hourly equivalent sound levels have an average minimum of approximately

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Table B-4

SOUND LEVEL REDUCTION DUE TO HOUSES * IN WARM AND COLD CLIMATES, WITH WINDOWS OPEN AND CLOSED[B-7]

	Windows *Open*	Windows *Closed*
Warm Climate	12 dB	24 dB
Cold Climate	17 dB	27 dB
Approximate national average	15 dB	25 dB

*(Attenuation of outdoor noise by exterior shell of the house)

Table B-5

COMPARISON OF INTERNAL AND OUTDOOR SOUND LEVELS IN LIVING AREAS AT 12 HOMES[B-7]

	Daytime Sound Level (L_d) in dB	Nighttime Sound Level (L_n) in dB	Day-Night Sound Level L_{dn} in dB
Outdoors:			
Average	57.7	49.8	58.8
Standard Deviation	3.1	4.6	3.6
Indoors:			
Average	59.4	46.9	60.4
Standard Deviation	5.6	8.7	5.9
Difference:			
Outdoors Minus Indoors	1.7	2.9	-1.6

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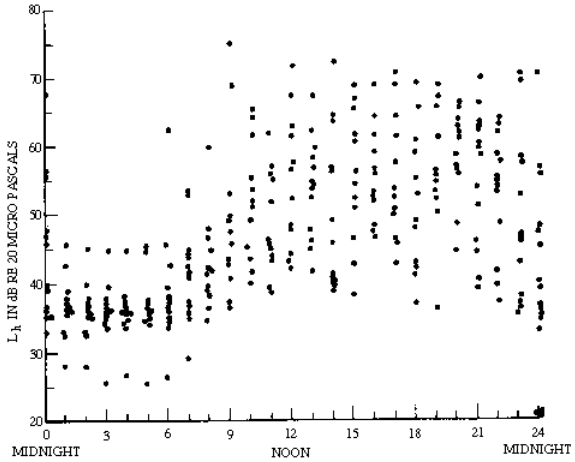

Figure B-2. Noise Inside Living Areas of 12 Homes - Values of Hourly Equivalent Sound Level as a Function of Hour of Day[B-5]

36 dB during the hours between 1 a.m. and 6 a.m. This minimum level is probably governed by outdoor noise in the majority of the situations. However, when people are active in the daytime, the hourly equivalent sound levels have a range of over 30 dB, depending on the type of activity. Thus, during the waking hours, the outdoor noise sets a lower bound of indoor noise. For the outdoor L_{dn} range of 52-65 dB this lower bound is significantly below the average level of the internally generated noise.

EXAMPLES OF INDIVIDUAL NOISE EXPOSURES

The noise exposures received by individuals are very much a function of the individual's life style. The variation in these exposures can be illustrated by examining several typical daily activity patterns. While these patterns are realistic, they should not be construed as applying to all individuals following the particular life style depicted.

The total daily exposure, $L_{eq(24)}$ is considered the sum of the sound energy from all daily exposure, including occupational exposures. Mathematically this can be interpreted as:

$$L_{eq}(24\ hr) = 10 \log \left[\sum_{i=1}^{n} t_i \times 10^{L(t_i)/10} \right] -49.4$$

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where $L(t_i)$ is the L_{eq} value for the appropriate time periods, (t_i) and the summation of all the t_i's must equal a total of 24 hours $\left(\text{i.e., } \sum_{i=1}^{n} t_i = 24 \text{ hours (86400 sec.)}\right)$

Five different exposure patterns for a 24-hour day are depicted in figures B-3 to B-7. The patterns are representative of the exposures that might be incurred by:

Factory worker	-	Figure B-3
Office worker	-	Figure B-4
Housewife	-	Figure B-5
School child	-	Figure B-6
Pre-school child	-	Figure B-7

Five different exposure patterns for a 24-hour day are depicted in Figures B-3 to B-7. The patterns are representative of the exposures that might be incurred by :

Certain assumptions were made in determining the levels shown in Figure B-3 to B-7. First, it was assumed that the suburban environment was equal to an L_{dn} of 50 (L_d = 50, L_n = 40). For the urban environment, the L_{dn} value was 75 (L_d = 72, L_n = 68). The levels for the various activities were determined from previous EPA reports on appliance noise, transportation noise, as well as information contained in the EPA Task Group No. 3 Report relating to aircraft noise.[B-4]

Values for the Equivalent Sound level ($L_{eq(24)}$) experienced by the individual are computed from the basic formulation of L_{eq}. For each of these life-styles, the $L_{eq(24)}$ value and the Ldn values are equivalent as the controlling noise dose normally does not occur at night. This emphasizes that for most practical situations, the average individual L_{dn} dose or $L_{eq(24)}$ individual dose are interchangeable.

Noise levels for other life-styles could also be generated. However, it is important to remember that $L_{eq(24)}$ values are, in most cases, controlled by the 2- to 3-hour exposures to relatively high level noise. For example, assume a motorcycle rider rode his vehicle for 2 hours a day at an exposure of 100 dB producing an $L_{eq(24)}$ of 89; if this were the case, then other noise producing activities during the day would have little effect on the L_{dn} if they were at a level of at least 15 dB below the level of the motorcycle.

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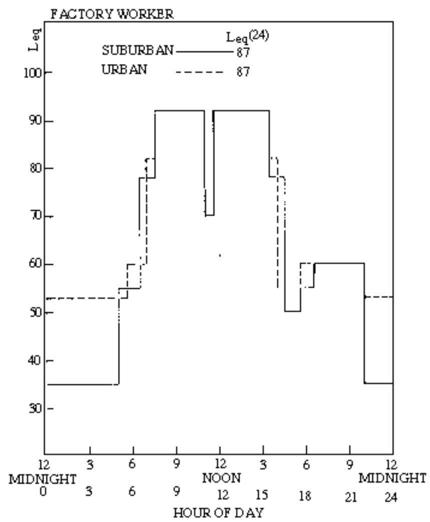

Figure B-3. Typical Noise Exposure Pattern of a Factory Worker[B-1, B-4, B-8, B-9]

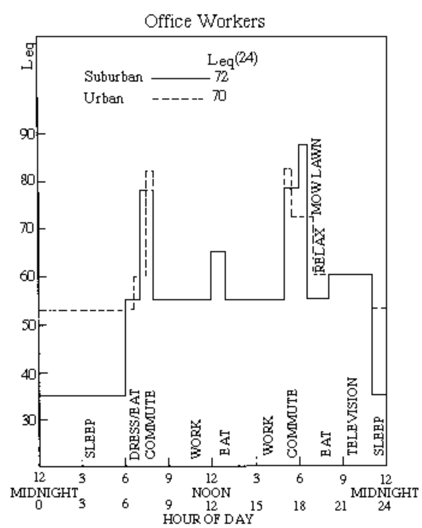

Figure B-4. Typical Noise Exposure Pattern of an Office Worker[B-1, B-4, B-8, B-9]

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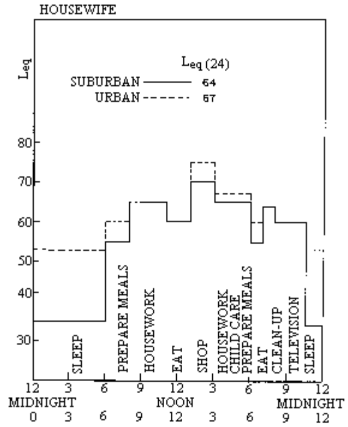
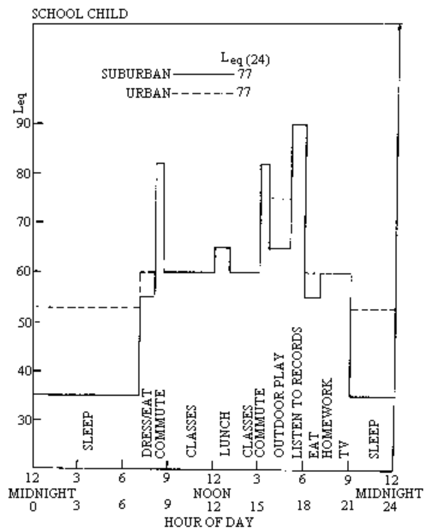


Figure B-5. Typical Noise Exposure Pattern of a Housewife[B-1, B-4, B-8, B-9]



FigureB-6. Typical Noise Exposure Pattern of a School Child[B-1, B-4, B-8, B-9]

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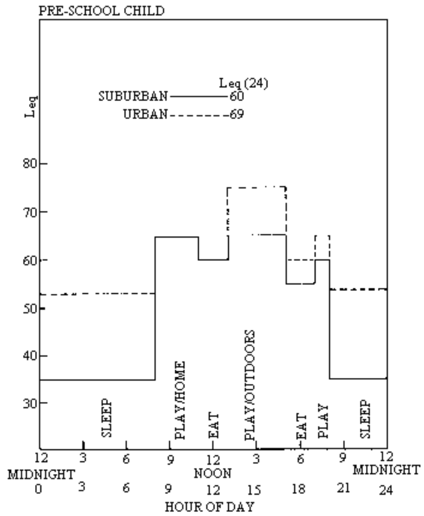

Figure B-7. Typical Noise Exposure Pattern of a Pre-School Child[B-1, B-4, B-8, B-9]

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APPENDIX C

NOISE-INDUCED HEARING LOSS

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APPPENDIX C

NOISE-INDUCED HEARING LOSS

INTRODUCTION

A considerable amount of hearing loss data have been collected and analyzed. These data include measurements of hearing loss in people with known histories of noise exposure. Much of the analysis consists of grouping these measurements into populations of the same age with the same history of noise exposure and determining the percentile distribution of hearing loss for populations with the same noise exposure. Thus, the evidence for noiseinduced permanent threshold shift can be clearly seen by comparing the distribution of a noise-exposed population with that of a relatively non-noise-exposed population.

Most of these data are drawn from cross-sectional research rather than longitudinal studies. That is, individuals or populations have been tested at only one point in time. Because complete noise-exposure histories do not exist, many conclusions are limited by the need to make certain hypotheses about the onset and progression of noise-induced hearing loss. Different hypotheses about the time history will lead to different conclusions even from the same data base, although the range of such conclusions is limited. Thus, in reaching conclusions about hearing loss, reliance is made on assumptions, hypotheses, and extrapolations which are not all universally accepted by the scientific community. However, attempts have been made to consider differing opinions and to insure that the methodology and conclusions in this section are in the mainstream of current scientific thought.

BASIC ASSUMPTIONS AND CONSIDERATIONS

In order to proceed further, it is necessary to make the following well-based assumptions:

1. Hearing shifts in the "non-noise-exposed" populations are attributable to aging and other causes rather than to noise exposure.

2. As individuals approach the high end of the distribution and their hearing becomes worse, they become less affected by noise exposure. In other words, there comes a point where one cannot be damaged by sounds that one cannot hear.

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In addition, there are some important considerations necessary for the identification of a level to protect against hearing loss.

Preservation of High Frequency Hearing

The levels identified in this document for hearing conservation purposes are those which have been shown to provide protection from any measurable degradation of hearing acuity. This protection is prodded even for those portions of the hearing mechanism which respond to the audiometric frequency at which noise-induced hearing impairment first occurs, namely 4000 Hz. The definition of hearing handicap originated by the American Academy of Opthalmology and Otolaryngology (AA00), and currently incorporated in many hearing damage-risk criteria, is somewhat different from the definition used in this document. Hearing handicap, (and later, hearing impairment) was defined by a formula which used the average hearing level at 500 Hz, 1000 Hz and 2000 Hz.

Although hearing loss for frequencies above 2000 Hz is not treated as significant by most of the existing occupational hearing damage-risk criteria, the ability to hear frequencies above 2000 Hz is important for understanding speech and other signals. Despite the traditional use of the term "speech frequencies" to apply to 500, 1000 and 2000 Hz, useful energy in speech sound ranges from about 200 to 6100 Hz.[C-l] It has been known for many years that the equal discriminability point in the speech spectrum is at about 1600 Hz. That is, frequencies above 1600 Hz are equal in importance to those below 1600 Hz for understanding speech. C-l However, there are other reasons for preserving the frequencies above 2000 Hz. Higher frequencies are important for the localization and identification of faint, high-pitched sounds in a variety of occupational and social situations. Detection of soft, relatively highfrequency sounds can be especially important in dgflance tasks, such as those which may occur in the military. In addition, good hearing for the higher frequencies is important to hear everyday occurrences such as sounds indicative of deterioration in mechanical equipment, crickets on a summer evening, bird song, and certain musical sounds. In fact, highfidelity sound reproducing equipment is often promoted on the basis of its fidelity up to 15,000 Hz, or even 30,000 Hz.

Any measurable hearing loss at any frequency is unacceptable if the goal is protection of health and welfare with an adequate margin of safety. For most environmental noise, protection at 4000 Hz will insure that all other frequencies are protected.[C-2] Thus, the 4000 Hz frequency has been selected as the most sensitive indicator of the auditory effects of environmental noise.

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Significant Changes in Hearing

In this section an attempt will be made to determine the relation between exposure level and noise-induced permanent threshold shift (NIPTS). Before this is accomplished, however, the significance of various amounts of NIPTS needs to be addressed.

For the purposes of identifying the levels in this document, it was necessary to adopt a criterion for an allowable amount of NIPTS. Whereas a NIPTS of 0 dB would be ideal, it is not appropriate for the following reasons:

1. Most audiometric equipment does not have the capability to measure hearing levels in less than 5 dB steps.

2. There is no known evidence that NIPTS of less than 5 dB are perceptible or have any practical significance for the individual.

3. Individual hearing thresholds are subject to minor fluctuations due to transitory psychological or physiological phenomena.

NIPTS of cunsiderably larger amounts have been permitted in various damage-risk criteria in the past. For instance, shifts of 10 dB to 20 dB have been considered reasonable.[C-3] However, the requirement for an adequate margin of safety necessitates a highly conservative approach. This approach dictates the prevention of any effect on hearing, which is defined here as an essentially insignificant and unmeasurable NIPTS, i.e., a NIPTS of less than 5 dB.The available evidence consists of statistical distributions of hearing levels for populations at various exposure levels. The evidence of NIPTS, then, is the shift in the statistical distribution of hearing levels for a noise-exposed population in comparison to that of a non-exposed population.

PREDICTION OF NOISE-INDUCED PERMANENT THRESHOLD SHIFT

Status of Hearing at 4000 Hz in the United States

Figure C-1 summarizes hearing levels of the general U.S. population at 4000 Hz. The data are from the Public Health Survey, (PHS) conducted in 1960-62 in the United States.C-4 Robinson's[C-5] non-noise-exposed and otologically screened population is shown for comparison. Several points should be noted.

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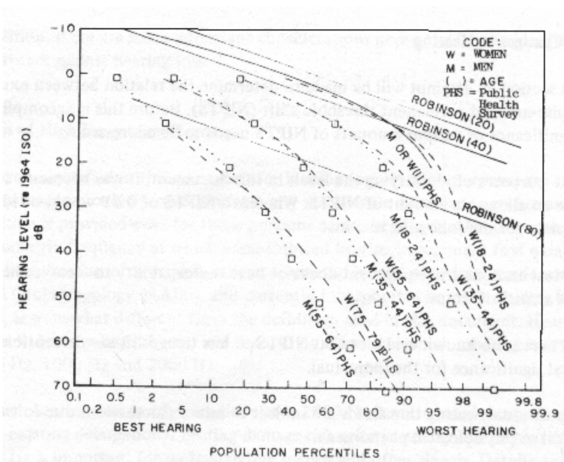

Figure C-1. Population Hearing Levels at 4000 Hz[C-4, C-5, C-6]

1. The hearing of a selected percentile of the population can be determined for various age groups. As displayed here, the higher the percentile point, the worse the hearing.
2. At age 11, there is no hearing difference due to sex,[C-6] but for the 18-24 age group, a definite difference is evident, with men's hearing considerably worse.
3. Considering that there is no evidence for any sex-inherent differences in susceptibility to hearing impairment, it is most likely that the differences displayed are due to noise exposure.

The Effect of Noise on Hearing

Table C-1 summarizes the hearing changes expected for daily exposures to various values of steady noise, for an eight-hour day, over 10- and 40-year periods.[C-7]

Four different measurement parameters are considered in Table C-1 :

1. Max NIPTS: The permanent change in hearing threshold attributable to noise. NIPTS increases with exposure duration. Max NIPTS is the maximum value during a 40-year

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Table C-1

SUMMARY OF THE PERMANENT HEARING DAMAGE EFFECTS EXPECTED FOR CONTINUOUS NOISE EXPOSURE AT VARIOUS VALUES OF THE A-WEIGHTED AVERAGE SOUND LEVEL [C-7]

	75 dB for 8 hrs		
	av.0.5,1,2 kHz	av.0.5,1,2,4 kHz	4 kHz
Max NIPTS 90th percentile	1 dB	2 dB	6 dB
NIPTS at 10 yrs. 90th percentile	0	1	5
Average NIPTS	0	0	5
Max NIPTS 10th percentile	0	0	0

	80 dB for 8 hrs		
	av.0.5,1,2 kHz	av.0.5,1,2,4 kHz	4 kHz
Max NIPTS 90th percentile	1 dB	4 dB	11 dB
NIPTS at 10 yrs. 90th percentile	1	3	9
Average NIPTS	0	1	4
Max NIPTS 10th percentile	0	0	2
	85 dB for 8 hrs		
	av.0.5,1,2 kHz	av.0.5,1,2,4 kHz	4 kHz
Max NIPTS 90th percentile	4 dB	7 dB	19 dB
NIPTS at 10 yrs. 90th percentile	2	6	16
Average NIPTS	1	3	9
Max NIPTS 10th percentile	1	2	5
	90 dB for 8 hrs		
	av.0.5,1,2 kHz	av.0.5,1,2,4 kHz	4 kHz
Max NIPTS 90th percentile	7 dB	12 dB	28 dB
NIPTS at 10 yrs. 90th percentile	4	9	24
Average NIPTS	3	6	15
Max NIPTS 10th percentile	2	4	11

Example: For an exposure of 85 dB during an 8-hour working day, the following effects are expected:

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Table C-1 (continued)

> For the 90th percentile point, the Max NIPTS occurring typically during a 40-year work lifetime, averaged over the four frequencies of 0.5, 1, 2 and 4 kHz, is 7 dB; averaged over the three frequencies of 0.5, 1, and 2 kHz is 4 dB and 19 dB at 4 kHz. For this same 90th percentile point of the population, the expected NIPTS after only 10 years of exposure would be 6 dB averaged over the four frequencies, 2 dB averaged over three frequencies, and 15 dB at 4 kHz.

exposure that starts at age 20. Data from the 90th percentile point of the population will be used to extrapolate to higher percentiles.

2. NIPTS at 10 years: The entries on this row also apply to the 90th percentile point of the population for 10 years of exposure.

3. Average NIPTS: The value of NIPTS is averaged over all the percentiles for all age groups. (This figure differs by only a couple of decibels from the median NIPTS after 20 years of exposure for the entire population.)

The values in Table C-1 are arithmetic averages of data found in the reports of PasschierVermeer,[C-8] Robinson,[C-5] and Baughn.[C-9]

DERIVATION OF EXPOSURE LEVELS

Selection of the Percentile and Related Exposure Level

The estimation of NIPTS for a given percentile has been accomplished by subtracting the hearing level of that percentile of the non-noise-exposed group from the hearing level of the respective percentile of the noise-exposed group. People above the 90th percentile are those whose hearing is worse than that of 90 percent of the population. Thus, for example, if the group at the 90th percentile shows a shift of 10 dB because of noise exposure, then it is considered that the group has a NIPTS of 10 dB. Extrapolations above the 90th percentile can be made from existing data, as done in Figure C-2. These extrapolations require cautious interpretation. First, the data for the 75 dB exposure levels in Table C-1 are themselves derived from extrapolations. The last firm data are at 78 dB. Second, for many of the studies that serve as the basis for the Passchier-Vermeer work, the 90th percentile is already extrapolated from the 75th percentile.

As stated earlier, the assumption has been made that if a person's hearing loss is severe enough, noise exposure will not make it worse. To be more precise, a person will not incur a hearing loss from a noise that he cannot hear (so long as it is within the audible frequency range). Granting this assumption, it follows that at some percentile, the amount of NIPTS

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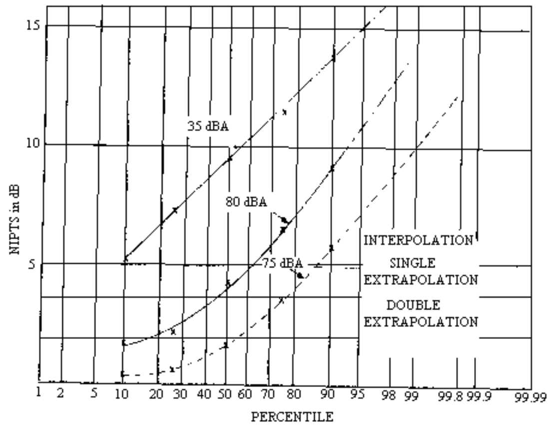

Figure C-2. NIPTS at 4000 Hz across Percentiles for Various 40-yr Exposure Levels [C-2]

for a given exposure level will approach an asymptote. In order for further hearing loss to be incurred above this critical percentile point, greater exposure levels must occur. In the extreme, a person who is totally deaf cannot suffer noise-induced hearing loss.

A study of the data provides a basis for a reasonable estimate of this critical percentile. Baughn's data gives an indication that the population with a hearing level greater than 60 dB after a 40-year exposure begins to become less affected by noise (Figures 9, 10, and 11 of ref. C-2). For example, if a person has a hearing loss greater than 75 dB, it is not reasonable to expect that an A-weighted noise of 75 dB (which normally means that only a level of 65 dB would be present at the octave band centered at 4000 Hz) will cause a further increase of the 75 dB loss. Next, it is necessary to determine the distribution of hearing levels of the non-noise-exposed population at age 60. The best data available are the hearing levels of 60 year-old women of the 1960-62 Public Health Survey,[C-4] While certainly some of the women in the sample may be noise exposed, the noise exposure of that population sample can be considered minor as compared to the apparent noise exposure of men. The data from the Public Health Survey predict the percentage of the population with hearing levels above 70, 75, and 80 dB.

Figure C-3 shows the exposure levels at which no more than 5 dB NIPTS at 4000 Hz will occur for various percentiles on the lowermost curve. The curve labeled PHS-4000 Hz

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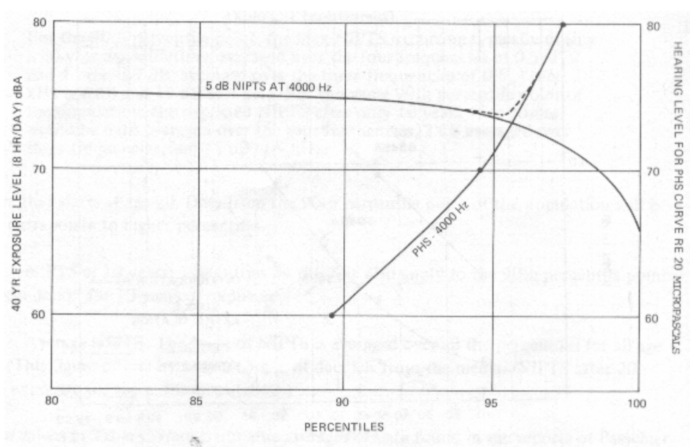

Figure C-3. Exposure Level and Hearing Level as a Function of Population Percentile, Showing the 5 dB NIPTS Curve

Merging with the PHS 4000 Hz Curve represents hearing levels by percentiles of the non-noise exposed population. If a noise level that cannot be heard by an individual is assumed not to change his hearing level, then the extrapolated 5 dB NIPTS curve of Figure C-3 cannot cross the curve labeled PHS. In fact, the 5 dB NIPTS curve must turn upward and merge with the PHS curve, shown in Figure C-3 by the dotted line. The point of merging is seen to be at approximately the 96th percentile and the exposure level required to protect this percentile from a shift of more than 5 dB is an $L^{eq(8)}$ of 72 to 74 dB, or approximately 73 dB. It may be concluded therefore, that a 40-year noise exposure below an $L_{eq(8)}$ of 73 is satisfactory to prevent the entire statistical distribution of hearing levels from shifting at any point by more than 5 dB. Generalizing from these conclusions, the entire population exposed to $L_{eq(8)}$ of 73 is protected against a NIPTS of more than 5 dB.

A similar analysis can be made for 5 dB and 10 dB NIPTS at the mid frequencies (Figure C-4). The upper PHS curve represents the better ear data for the average of 500, 1000 and 2000 Hz of both men and women from the Public Health Survey.[C-4] Both men and women are used since there is little difference due to sex and hearing levels for these frequencies. Considering that the curves will merge in the same manner as the 5 dB at 4000 Hz NIPTS and PHS curves, one can conclude that:

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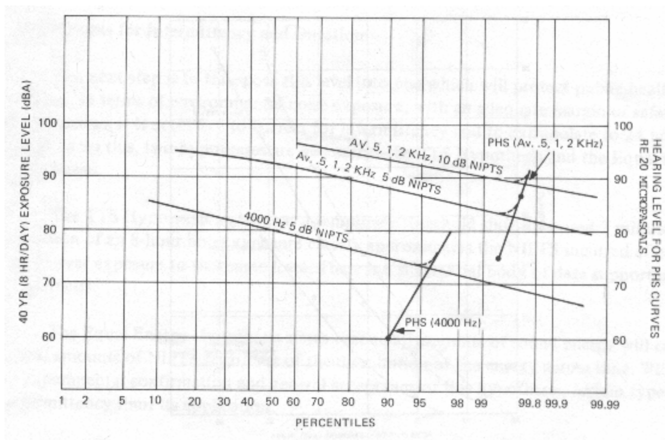

Figure C-4. Exposure Level and Hearing Level as a Function of Population Percent Showing Merging of Different NIPTS Curves with PHS Curves

1. $L_{eq\ (8)}$ of 84 dB will cause no more than a 5 dB shift at the critical percentile for the averaged frequencies 500, 1000 and 2000 Hz.

2. $L_{eq(8)}$ dB will cause no more than a 10 dB shift at the most critical percentile for the averaged)requencies 500, 1000 and 2000 Hz.

Although the data base used here is quite large, we cannot be absolutely certain that it is representative of the whole population. Any argument such as that presented above does not, in fact, provide 100% protection of the entire population. Obviously, there are a few individuals who might incur more than 5 dB NIPTS for an exposure level of 73 dB. There is the possibility that individuals might shift from lower to higher percentiles with a change in exposure level. In other words, there may be individuals who experience greater shifts in hearing level than those predicted here over periods of time much less than 40 years.

At this point, it may be useful to examine the same data in a slightly different way, without utilizing the concept of the critical percentile. Assuming that the NIPTS of the exposed population are distributed normally, the exposure levels which produce various amounts of NIPTS at the 50th and 90th percentiles may be extrapolated to levels which produce NIPTS at the 99th percentile. Using this extrapolation, Figure C-5 shows NIPTS as

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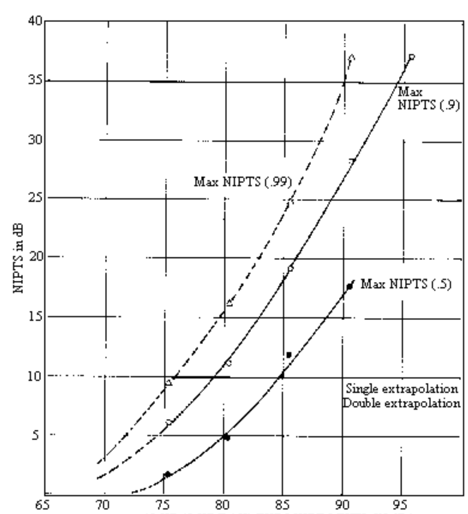

Figure C-5. NIPTS as a Function of Exposure Level for the 50th, 90th and 99th Percentiles

a function of exposure level for the 50th, 90th and 99th percentiles. The 99th percentile curve intersects the 5 dB NIPTS point at 71.5 dB (which is only 1.5 dB below the level previously identified). Thus, if one wishes to protect up to the 99th percentile without employing the concept of the critical percentile, the exposure level necessary to prevent more than 5 dB NIPTS is an $L_{eq(8)}$ of 71.5 dB.

The preceeding analysis utilizing the concept of the critical percentile, concludes that an 8-hour per day exposure to a 73 dB steady noise for 40 years will result in a noise-induced permanent threshold shift of no more than 5 dB at 4000 Hz. This conclusion was reached through the use of assumptions and considerations pointed out earlier in this appendix. Similar analysis of the same and similar data may be made using other assumptions and considerations. Some analyses lead to essentially the same conclusion while others do not. However, no such analysis has identified a level of much less than 65 dB or much greater than 80 dB for the same conditions (i.e., 5 dB NIPTS at 4000 Hz for 40 years of exposure). While the discussion of these levels and their derivations are a subject of great interest and activity in the scientific community, the Administrator of the Environmental Protection Agency is required to identify the level which, in his judgment, is requisite to protect public health and welfare. For that purpose, the level of 73 dB appears to be the most reasonable choice for the conservation of hearing based on the present state of scientific knowledge.

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Adjustments for Intermittency and Duration

The next step is to transpose this level into one which will protect public health and welfare, in terms of environmental noise exposure, with an adequate margin of safety. For this purpose, it is necessary to correct for intermittency and to extrapolate to 24 hours. In order to do this, two hypotheses are necessary-the TTS Hypothesis and the Equal Energy Hypothesis.

The TTS Hypothesis states that a temporary threshold shift measured 2 minutes after cessation of an 8-hour noise exposure closely approximates the NIPTS incurred after a 10- to 20-year exposure to that same level. There is a substantial body of data supporting this hypothesis.

The Equal Energy Hypothesis states that equal amounts of sound energy will cause equal amounts of NIPTS regardless of the distribution of the energy across time. While there is experimental confirmation and general acceptance of this hypothesis, certain types of intermittency limit its application.

Intermittency

The equal energy concept is considered by some to be a conservative approach for short exposure periods. An alternative approach may be necessary because there is little direct evidence to show the effect of short exposure periods or intermittency on the development of NIPTS. This approach implies the use of temporary threshold shift as a predictor of NIPTS.

Even for a continuous noise, TTS is not predictable for all possible durations using the equal energy rule. The equal energy rule predicts, with reasonable accuracy, the TTS at 4000 Hz for durations of 8 hours down to about 30 minutes. Effects from durations shorter than this, however, are better predicted by a slight deviation from the equal energy rule. While equal energy provides for a 3 dB increase in exposure level for each halving of exposure duration, TTS for durations of less than 30 minutes are better predicted by greater intensities for each halving of time. For instance, TTS for durations of less than 15 minutes are better predicted by a 6 dB rather than a 3 dB increase. For an exposure of two minutes duration, the level required to produce an expected TTS at 4000 Hz would be approximately 10 dB greater than the level predicted by the equal energy concept.

Investigations of environmental noise patterns reported in the EPA document "Community Noise" [C-10] indicate that in most environments, noise fluctuates or is intermittent. Moreover, intermittent noise for a given Leq having peak levels of 5 to 15 dB higher than the background level, may produce less hearing damage than a continuous noise

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with the same energy. C-11 Also, noise levels which are below 65 dB for 10 percent of the time tend to be less dangerous than continuous noise. [C-12] Therefore, intermittent noise as used in this document will be defined as noise which is below 65 dB for about 10 percent of each hour (i.e., L_{90} of less than 65 dB), with peak levels of 5 to 15 dB higher than the background. From the examples cited in "Community Noise", it is clear that most environmental noise meets these criteria. For this reason, the L_{eq} measured in many situations can be expected to produce less harmful effects on hearing than those depicted in Table C-1. Some correction factor is thus indicated for L_{eq} values describing noise expected in a typical environmental situation in which the exposure is relatively intense but intermittent in nature.

In order to determine an appropriate correction factor, Figure C-6 has been drawn. Using an exposure of 73 dB for 8 hours as a baseline, the sound pressure levels producing equal TTS_2 to be expected at 4000 Hz are plotted for durations of continuous noise as short as 1-1/2 minutes. [C-3] Plotted also (curve a), is the maximum intermittency correction suggested by "Second Intersociety Committee" [C-13] and discussed in the NIOSH criteria document. [C-11] This correction is for the mid frequencies. Recent work has indicated that for 4000 Hz the best intermittency correction to produce equal TTS_2 is represented by curve b. [C-14] The crosshatched area between the curves "a" and "c" signifies the area of uncertainty.

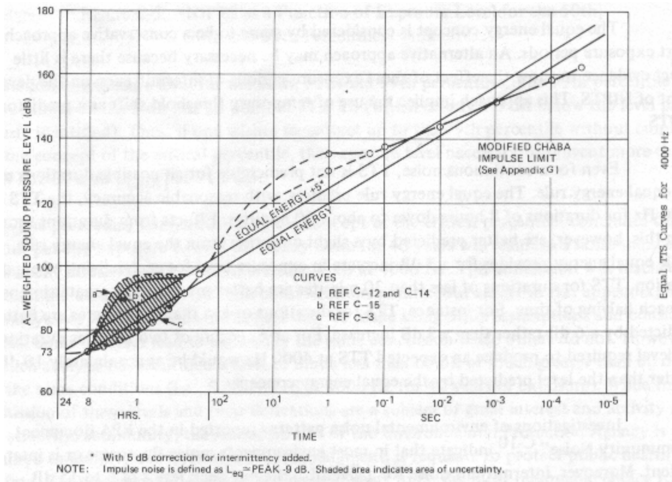

Figure C-6. Equal TTS Curves for 4000 Hz

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In addition, TTS curves for impulse noise are included in Figure C-6. Appendix G contains the details of the modified CHABA limit and the conversion necessary to derive from the peak sound pressure level of a decaying impulse the continuous A-weighted noise of the same duration. The impulse noise data show that the equal energy concept is still a reasonable approximation for very short durations. While certainly it may be overly protective for some noise pattems, in general it predicts the effects of noise on hearing reasonably well. Prediction is improved, however, with a 5 dB allowance for intermittency.

The average correction for intermittency suggested by Figure C-6 is 5 dB (i.e., placing the origin of the equal energy line at 78 dB for 8 hours). This correction should be used only if the noise level between events is less than 65 dBA for at least 10 percent of the time (L_{90} < 65 dBA). Since most environmental noise exposures will meet this requirement during any 8-hour period, it is further suggested that environmental noise should be considered intermittent unless shown otherwise. Using the 5 dB correction factor, the area of uncertainty (crosshatched) of Figure C-6 is approximately bisected. Further support for such a 5 dB correction factor is found in a recent Swedish study where exposure to continuous noise of L_{eq} 85 to 90 caused a hearing loss which corresponded to an intermittent noise of L_{eq} 90 to 95. The authors conclude that a 5 dB correction factor is appropriate. [C-15]

For certain noise situations, a larger intermittency correction might be justified. However, the use of large corrections when only part of the total noise exposure pattern is known entails a considerably higher chance of error. Therefore, the use of correction factors higher than 5 dB for intermittency are not considered consistent with the concept of an adequate margin of safety.

Conversion of 8-Hour to 24-Hour Exposure Levels

The TTS after 24 hours of exposure generally exceeds that after 8 hours of exposure by about 5 dB.[C-2] Thus the use of a 5 dB correction factor is suggested to extrapolate from the 8-hour exposure data to 24-hour exposure.[C-2] For example, the predicted effects of an exposure to 75 dB steady-state noise for a 24-hour duration are equivalent to the effects estimated from industrial studies for an 8-hour exposure to a continuous noise with a level of

80 dB. This 5 dB correction is consistent with the equal-energy trade-Jff between exposure duration and noise level. That is, the equal-energy rule in this case also dictates a correction of 5 dB for 24 hours.

It appears that exposures over a period longer than 24 hours need not be considered in this case. Various studies of TTS [C-16,C-17, C-18] have shown that, for an exposure to a specific noise level, TTS will not exceed a limiting valud regardless of exposure duration. This limit is reached at approximately 24 hours of exposure. However, this concept applies only to exposure levels less than 85 dB.

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Conversion of Occupational Dose to a Full Year (250 to 365 Days)

The applicability of occupational data to non-occupational exposure is questional in several ways. One concern is the use of the occupational exposure data to predict the general effects on populations composed of people who, for a variety of reasons, do not work. However, there are no data from which to derive approximate correction factors. Another concern is the fact that the occupational data are based on a 250-day working year. When predicting the effect of a known noise exposure over the 365-day year, certainly some correction is in order. The equal energy concept would predict at least a 1.6 dB lowering of the exposure level, and such a correction should be used when the concept of an annual exposure dose is used.

To summarize the adjustments, the following exposures over 40 years will result in the same effect:

- L_{eq} of 73 dB continuous noise during the 8-hour working day with relative quiet for the remaining 16 hours, 5 days per week. (See discussion of quiet requirements below).
- L_{eq} of 78 dB intermittent noise during the 8-hour working day with relative quiet for the remaining 16 hours, 5 days per week. 73 + 5 = 78
- L_{eq} of 76.4 dB intermittent noise for 8 hours a day, with relative quiet for the remaining 16 hours, for the 365-day year. 78 - 1.6 = 76.4
- L_{eq} of 71.4 dB intermittent noise for 24 hours a day, 365 days a year. 76.4 - 5 = 71.4

In view of possible uncertainties in the analysis of the data, it is considered reasonable to round down from 71.4 dB to 70 dB. These uncertainties will be discussed in the next section.

CONSIDERATIONS FOR PRACTICAL APPLICATION

The Data Base

In viewing the data in this appendix and elsewhere in the hearing impairment literature, a number of fundamental considerations must be noted :

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1. Few, if any, of the various "classic studies" (e.g., those of Robinson, Baughn, and Passchier-Vermeer) are on comparable populations. In addition, some of the data are derived from populations for which noise exposure histories are sketchy, if not absent (e.g., the 1960-62 U.S. Public Health Survey data).
2. There are major questions regarding the comparability of the audiometric techniques used in the various surveys.
3. There are a great number of unanswered questions and areas of uncertainty with regard to the relationship of hearing thresholds to individual physiological and metabolic state. The role of the adequacy of the blood supply to the ear (and the possible influence of changes in that blood supply resulting from cardio-vascular respiratory disease or the process of aging), as well as the fundamentals of cellular physiology involved in adverse effects within the organ of Corti, simply cannot be stated with any degree of reliability at this time. There is some evidence that these non-noise related influences may be of major significance. Moreover, part of the adverse effect of noise on hearing may be attributable indirectly to these influences.
4. There are no large-scale longitudinal studies on hearing loss in selected and carefully followed populations, whose physical state and noise exposure has also been carefully detailed.

Accuracy of Estimated Effects

There is imperfect agreement among various studies as to the exact relationship between sound exposure level and noise-induced hearing loss. The range of error involved is on the order of 5 dB [C-2] when examining the difference between the values in any single study and the values presented in Table C-1. Furthermore, the intermittency correction of 5 dB is only an approximation. It has been proposed that a correction as high as 15 dB could be used in some cases. Thus, the true intermittency correction for a particular noise exposure situation could be from 0-15 dB.

The selection of alternative population percentiles to be protected would cause relatively small changes. For instance, there is only a 7 dB difference in protecting the 50th percentile against incurring a 5 dB hearing loss instead of the 96th percentile.

Using the assumption that the noise is of broadband character can lead to errors of 5 to 10 dB by which the risk of the sound exposure is underestimated. This could lead to greater possible errors if a substantial portion of the exposure is to noise with intense pure tone components. These conditions, however, are rare in the environmental situation.

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There are apt to be errors in extrapolating beyond the 90th percentile in order to predict effects at higher percentiles. Likewise, there might be errors in extrapolating from known exposure data at 90 and 80 dB to estimated effects at 73 dB for an 8-hour exposure to continuous noise. One final potential source of error inherent in using the occupational data is the need to compare a population that has received an occupational noise exposure to a population that has not received an occupational noise exposure. However, this latter population may have been exposed to levels of environmental noise (other than occupational). As a consequence in comparing the two groups, occupational exposures may very well show negligible effects below a certain level because other environmental noises predominate. The direction of the possible error is not unequivocally clear, as certainly the adverse effect of many industrial exposures may very well have been due to an unfortunate combination with non-occupational exposures. At this time, it is impossible to properly analyze the possible bias that the nonoccupational noise exposure introduces into the data of Table C-1. At present it is assumed to be negligible. This assumption will require ultimate verification by experimentally relating the annual exposure dose of individuals to their hearing level. Only such studies will show how much of what we now tend to contribute to the physiological aging process of the hearing mechanism could be reduced by further reducing what we consider today as "normal" or "quiet" environmental noise levels associated with present-day living in our society.

Quiet Requirements

It has been shown that the quiet intervals between high intensity noise-bursts must be below 60 dB SPL for the octave band centered at 4000 Hz if recovery from temporary threshold shift at 4000 Hz is to be independent of the resting sound pressure level.[C-20] In this document, sound pressure level of 50 dB in the 4000 Hz octave band is suggested as a goal for "effective quiet". For typical spectra of community noise, 50 dB SPL in the 4000 Hz octave band translates to an A-weighted sound level of approximately 60 dB. Thus, for purposes of hearing conservation, the noise level where an individual sleeps should not be above an L_{eq} of 60 dB, based on the following considerations:

1. Total TTS recovery is required to prevent TTS from becoming NIPTS.
2. For some individuals, an 8-hour nighttime period is the only available recovery period.
3. In order to be consistent with the identified level of $L_{eq(24)}$ = 70, an 8-hour exposure of 75 dB would require an exposure of 60 dB or less for the remaining 16 hours.

C-16

It should be noted that this level would be too high to protect against other effects. (See Appendix D).

Contribution of Outdoor Noise to the Total Exposure in Residential Areas

A person's 24-hour exposure to outdoor noise will typically include both outdoor and indoor exposures. Since a building reduces the level of most intruding outdoor environmental noises by 15 dB or more (windows partially open), an outdoor L_{eq} will not adequately predict hearing effects, because the corresponding NIPTS estimates will be too high. Consider a situation where the average sound level is 70 dB outdoors and 55 dB indoors. The effective noise exposures for some of the possible exposure situations are:

24-hour L_{eq} in dB (assuming the noise is generated outdoors)

Indoor Time (55 dB)	Outdoor Time (70 dB)	Combined Indoor and Outdoor	Outdoor Only
24 hrs	0 hrs	55.0	
23	1	58.6	56.2
22	2	60.5	59.2
21	3	61.8	61.0
20	4	62.9	62.2
16	8	65.5	65.2
8	16	68.3	68.2
0	24	70	70

The 24-hour value of the combined Leq is essentially unchanged from the outdoor value (less than one dB) by the indoor noise exposure, so long as the outdoor exposure exceeds 3 hours. Thus, as long as the criterion is established with respect to outdoor noise exposure exceeding 3 hours per day, the contribution of the indoor level of intruding outdoor noise may be neglected in computing the 24 hour L_{eq}. This conclusion does not depend greatly on the actual noise attenuation provided by the house so long as the attenuation is greater than 10 dB.

C-17

Relation of L_{dn} to L_{eq} in Residential Areas

Although in residential areas, or in areas where individuals may be expected to be present for prolonged periods of time, it would appear desirable for practical considerations to use only one measure of noise, such as L_{dn}, it may be misleading to do so. The difficulty arises from the fact that to relate hearing loss to noise exposure, the basic element to consider is the actual energy (not weighted) entering the ear during a twenty-four hour period. L_{eq} measures the actual energy entering the ear whereas L_{dn} includes a 10 dB weighting for the nighttime period. Thus, L_{dn} values corresponding to actual L_{eq} values are dependent upon the distribution in noise levels occurring during the total twenty-four hour period and could be misleading. For example, the L_{dn} values corresponding to $L_{eq(8)}$ are between 0 to 6 dB greater than the L_{eq} values. The lower value corresponds to a situation where the average sound level during the night is 10 dB lower than that occurring during the day, whereas the higher value corresponds to the situation when the average sound level during the night equals that occurring during the day. In residential areas, the difference in L_{eq} values for the daytime and nighttime period often is approximately 4 dB based on community noise measurements.[C-20] In this particular case, this difference in L_{eq} values leads to an L_{dn} value which is three decibels above the L_{eq} value for the daytime period.

C-18

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Appendix D

NOISE INTERFERENCE WITH HUMAN ACTIVITIES AND RESULTING OVERALL ANNOYANCE/HEALTH EFFECTS

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Appendix D

NOISE INTERFERENCE WITH HUMAN ACTIVITIES AND RESULTING OVERALL ANNOYANCE/HEALTH EFFECTS

Environmental noise may interfere with a broad range of human activities in a way which degrades public health and welfare. Such activities include:

1. Speech Communication in Conversation and Teaching.
2. Telephone Communication.
3. Listening to TV and Radio Broadcasts.
4. Listening to Music.
5. Concentration During Mental Activities.
6. Relaxation.
7. Sleep.

Interference with listening situations (items 1-4) can be directly quantified in terms of the absolute level of the environmental noise and its characteristics. The amount of interference in non-listening situations (e.g.,) is often dependent upon factors other than the physical characteristics of the noise. These may include attitude towards the source of an identifiable noise, familiarity with the noise, characteristics of the exposed individual, and the intrusiveness of the noise.

The combination of the various interference effects results in an overall degradation of total well-being. Maximum noise levels that do not affect human well-being must be derived from the body of information on human behavioral response to various noise environments.

SPEECH INTERFERENCE

Speech communication has long been recognized as an important requirement of any human society. It is one of the chief distinctions between humans and other species. Interference with speech communication disturbs normal domestic or educational activities, creates an undesirable living environment, and can sometimes be a source of extreme annoyance. Continued long-term annoyance is considered to affect individual as well as public health and welfare in a variety of ways.

Noise can disturb speech communication in situations encountered at work, in vehicles, at home, and in other settings. Of chief concern for the purposes of this report, is the effect

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of noise on face-to-face conversation indoors and outdoors, telephone use, and radio or television enjoyment.

The extent to which environmental noise affects speech communication depends on the location (whether indoors or outdoors), the amount of noise attenuation provided by the exterior walls when indoors (including windows and doors), and the vocal effort of the talkers. Certainly, it is possible to maintain communication in the face of intruding noise if the voice level is raised, but in an ideal environment, one should not have to increase the voice level above that which is comfortable in order to communicate easily.

Research since the late 1920's has made great progress in quantitatively characterizing the effects of noise on speech perception. A review of that work is contained in references D-1 and D-2, and it is summarized here as the basis for the maximum environmental noise levels compatible with public health and welfare identified in Section 4 of this report.

The chief effect of intruding noise on speech is to mask the speech sounds and thus reduce intelligibility. The important contributants to intelligibility in speech sounds cover a range in frequency from about 200 to 6000 Hz, and at each frequency a dynamic level range of about 30 dB. The intelligibility of speech will be nearly perfect if *all* these and contributions are available to a listener for his understanding. To the extent that intruding noise masks out or covers some of these contributions, the intelligibility deteriorates more rapidly the higher the noise level, particularly if the noise frequencies coincide with the important speech frequencies.

It is no accident, from an evolutionary point of view, that the hearing of humans is most sensitive in the frequency range most important for the understanding of speech. Therefore, it is not mere coincidence that the A-weighting, designed to reflect the frequency sensitivity of the human ear, should also be useful as a measure of the speech interference potential of intruding noise. A-weighting gives greatest weight to those components of the noise that lie in the frequency range where most of the speech information resides, and, thus, yields higher readings (A-weighted levels) for noises in most of the 200 to 6000 Hz range than does the overall sound pressure level. A-weighted sound levels will be used throughout this appendix unless otherwise noted.

The principal results of relevant speech research can be utilized for practical application to provide the levels of noise that will produce varying degrees of masking as a function of average noise level and the distance between talkers and listeners. Other factors such as the talker's enunciation, the familiarity of the listener with the talker's language, the listener's motivation and, of course, the normality of the listener's hearing also influence intelligibility. This value is consistent with the upper end of the range of levels of steady state sound recommended by prior authors in Table D-10 (to be discussed later) as

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"acceptable" for design purposes for homes, hotels, motels, small offices, and similar spaces where speech communication is an expected and important human activity.

Indoor Speech Interference Due to Steady Noise

The effects of masking normally-voiced speech indoors are summarized in Figure D-1, which assumes the existence of a reverberant field in the room. This reverberant field is the result of reflections from the walls and other boundaries of the room. These reflections enhance speech sounds so that the decrease of speech level with distance found outdoors occurs only for spaces close to the talker indoors. At distances greater than 1.1 meters from the talker, the level of the speech is more or less constant throughout the room. The distance from the talker at which the level of the speech decreases to a constant level in the reverberant part of the room is a function of the acoustic absorption in the room. The greater the absorption, the greater the distance over which the speech will decrease and the lower the level in the reverberant field for a given vocal effort. The absorption in a home

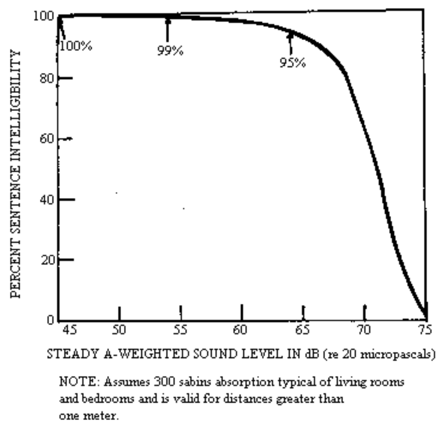

Figure D-1. Normal Voice Sentence Intelligibility as a Function of the Steady Background Sound Level in an Indoor SituationD-1, D-2 & D-4

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will vary with the type and amount of furnishings, carpets, drapes and other absorbent materials. It is generally least in bathrooms and kitchens and greatest in living rooms, with typical values ranging between 150 and 450 sabins. A typical value for living rooms and bedrooms is 300 sabins. For this value of absorption, the distance to the reverberant field from the talker is slightly greater than one meter, as stated above.

As shown in Figure D-1, the maximum sound level that will permit relaxed conversation with 100% sentence intelligibility throughout the room (talker-listener separation greater than approximately 1.1 meter) is 45 dB.

Outdoor Speech Interference Due to Steady Noise

The sound level of speech outdoors generally continues to decrease with increasing distance between talker and listener with the absence of reflecting walls which provide the reverberance found indoors. Figure D-2 presents the distances between talker and listener for satisfactory outdoor conversations, in different steady background noise levels (A-weighted), for three degrees of vocal effort. This presentation depends on the fact that the voice level at the listener's ear (outdoors) decreases at a predictable rate as the distance between talker and listener is increased. In a steady background noise there comes a point, as the talker and listener increase their separation, where the decreasing speech signal is masked by the noise.

The levels for normal and raised-voice "satisfactory conversation" plotted in the figure do not permit perfect sentence intelligibility at the indicated distances; instead, the sentence intelligibility at each distance is 95 percent, meaning that 95 percent of the key words in a group of sentences would be correctly understood. Ninety-five percent sentence intelligibility usually permits reliable communication because of the redundancy in normal conversation. That is, in normal conversation, some unheard words can be inferred if they occur in particular, familiar contexts. Moreover, the vocabulary is often restricted, which also helps understanding. Therefore, 95 percent intelligibility is satisfactory for most situations.

The levels given in Figure D-2 for relaxed conversation permit 100% speech intelligibility when communicating in a normal voice. This situation represents an ideal environment for speech communication and is considered necessary for acceptable conversation in the indoor environment. However, it does not define the situation outdoors where 95% intelligibility is adequate, and communication outdoors generally takes place between people who are walking or standing relatively close together, about 1 or 2 meters. Moreover, these levels appear to be consistent with the need for speech privacy.

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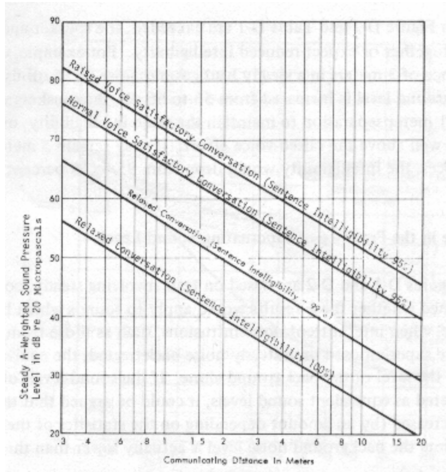

Figure D-2. Maximum Distances Outdoors Over Which Conversation is Considered to be Satisfactorily Intelligible in Steady Noise.[D-1, D-2]

The data for normal and raised voice of Figure D-2 are tabulated for convenience below:

Table D-1

STEADY A-WEIGHTED NOISE LEVELS THAT ALLOW COMMUNICATION WITH 95 PERCENT SENTENCE INTELLIGIBILITY OVER VARIOUS DISTANCES OUTDOORS FOR DIFFERENT VOICE LEVELS[D-2]

VOICE LEVEL	COMMUNICATION DISTANCE (meters)					
	0.5	1	2	3	4	5
Normal Voice (dB)	72	66	60	56	54	52
Raised Voice (dB)	78	72	66	62	60	58

If the noise levels in Figure D-2 and Table D-1 are exceeded, the speaker and listener must either move closer together or expect reduced intelligibility. For example, consider a conversation at a distance of 3 meters in a steady background noise of 56 dB using normal voice levels. If this background level is increased from 56 to 66 dB, the speakers will either need to move from 3 to 1 meter separation to maintain the same intelligibility, or alternatively, to raise their voices well above the raised-voice effort, if they remain 3 meters apart without raising their voices, the intelligibility would drop from 95 to 65 percent.

Speech Interference in the Presence of Fluctuating Sound Levels

The data in Figures D-1 and D-2 are based on tests involving steady, continuous sound.

It might be questioned whether these results would apply to sounds which have fluctuating levels. For example, when intermittent noise intrusions, such as those from aircraft flyovers or truck passbys, are superimposed on a steady noise background, the equivalent sound

level is greater than the level of the background alone, if the sound levels of Figure D-1 and D-2 are interpreted as equivalent sound levels, it could be argued that these values could be slightly increased (by an amount depending on the statistics of the noise), because most of the time the background noise level is actually lower than the equivalent sound level.

The amount of this difference has been calculated for the cases of urban noise and aircraft noise statistics shown in Figure D-3. The data in this figure[D-3] include a wide range of urban sites with different noise levels and an example of aircraft noise at a site near a major airport. in each case the speech intelligibility was calculated from the standard sentence intelligibility curve[D-4] for various values of L_{eq}, first with steady noise and then with the two specific fluctuating noises of Figure D-3. The calculation consisted of determining the incremental contribution to sentence intelligibility for each level (at approximately 2 dB increments) and its associated percentage of time occurrence. The incremental contributions were then summed to obtain the total value of intelligibility in each case.

The results, shown in Table D-2, demonstrate that, for 95 percent sentence intelligibility, normal vocal effort, and 2 meter separation between talker and listener outdoors, the maximum L_{eq} value associated with continuous noise is less than the maximum value for an environmental noise whose magnitude varies with time. It is therefore concluded that almost all time-varying environmental noises with the same L_{eq} would lead, averaged over long time periods, to better intelligibility than the intelligibility for the same L_{eq} values of continuous noise.

Alternatively, for a fixed L_{eq} value, the percentage of interference with speech (defined as 100 minus the percentage sentence intelligibility) is greater for steady noise than

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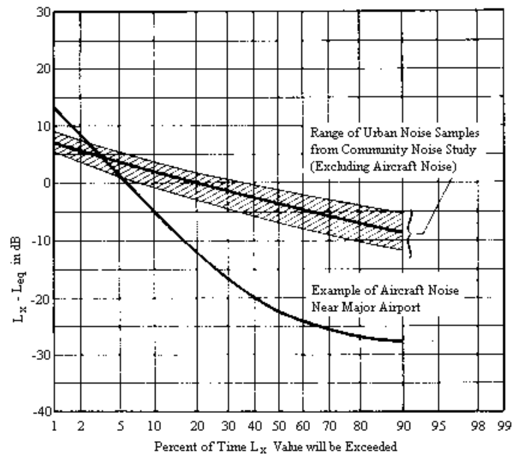

Figure D-3. Cumulative Distribution of Typical Community Noises During the Daytime Relative to the Equivalent Sound Level.[D-39]

Table D-2

MAXIMUM EQUIVALENT SOUND LEVELS THAT ALLOW 95 PERCENT SENTENCE INTELLIGIBILITY AT A DISTANCE OF 2 METERS USING NORMAL VOICE EFFORT OUTDOORS

(From Figures D-2 and D-3)

Noise Type	L_{eq} in decibels
Steady	60
Urban Community Noise	60+
Aircraft Noise	65

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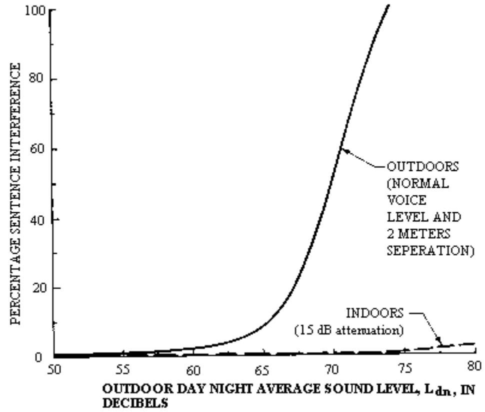
for almost all types of environmental noise whose magnitude varies with time. The relationship between L_{dn} and the *maximum* percentage sentence interference (i.e., for continous noise) is given in Figure D-4.



(re 20 micropascals)

NOTE: Percentage interference equals 100 minus percentage intelligibility, and L_{dn} is based on L_d + 3.[D-39]

Figure D-4. Maximum Percentage Interference with Sentences as a Function of the Day-Night Average Noise Level.

The extreme example of a fluctuating noise is a series of noise pulses of constant level that are of sufficient magnitude relative to the background to control the equivalent sound level. For example, there could be a case where the background noise during the off-cycle is assumed negligible, so that when the noise pulses are not present, the speech intelligibility is 100 percent. Table D-3 shows how the percentage interference with sentence intelligibility varies as a function of the level and on-time for a cycled steady noise whose level and duration are always adjusted to yield a fixed value for the equivalent sound level. Two situations are envisaged: indoors, relaxed conversation, L_{eq} = 45 dB, leading to 100 percent sentence intelligibility in the steady, continuous noise; and outdoors, normal voice effort at 2 meters separation, L_{eq} = 60 dB, leading to 95 percent sentence intelligibility in the steady, continuous noise.

Table D-3

PERCENTAGE INTERFERENCE WITH SENTENCE INTELLIGIBILITY IN THE PRESENCE OF A STEADY INTRUDING NOISE CYCLED ON AND OFF PERIODICALLY IN SUCH A WAY AS TO MAINTAIN CONSTANT EQUIVALENT SOUND LEVEL, AS A FUNCTION OF THE MAXIMUM NOISE LEVEL AND DURATION[D-39]
(Assumes 100% intelligibility during the off-cycle)

Situation	A-Weighted level of intruding noise during "on-cycle," decibels	Duration of intruding noise as percent of total time	Percent interference if intruding noise were continuous	Average percent interference in cycled noise
INDOORS Relaxed conversation, background L_{eq}=45dB, 100% intelligibility if background noise were continuous at 45 dB	45 50 55 60 65 70 75 80	100 32 10 3 1 0.3 0.1 0.03	0 0.5 1 2 6 40 100 100	0 0.16 0.1 0.06 0.06 0.12 0.1 0.03
OUTDOORS Normal voice at 2 meters, background L_{eq}=60dB, 95% intelligibility if background noise were continuous at 60 dB	60 65 70 75 80	100 32 10 3 1	5 7.7 53 100 100	5.0 2.5 5.3 3.0 1.0

The combination of level in the first column and duration in the second column are such as to maintain constant L_{eq} for each situation, 45 dB indoors and 60 dB outdoors. The third column gives the percent interference with sentence intelligibility that would apply if the noise were steady and continuous with the level indicated in column 1. The fourth column gives the percent interference for the cycled noise in each case.

The results for this extreme case indicate that no matter how extreme the noise fluctuation for the indoor case, on the average there is negligible speech interference for L_{eq} = 45 dB. On the other hand, with L_{eq} = 60 dB outdoors, the average speech interference tends to decrease as the fluctuations of the noise become more extreme. However, it should be recognized that if the duration of the intruding noise were to take place in one continuous period, and if its percentage interference (column 3) were equal to 100, then it would blot out all communication for the duration of its "on-cycle".

The following sections relating to activity interference, annoyance, and community reaction utilize equivalent sound level with a nighttime weighting (L_{dn}) which is discussed more fully in Appendix A. However, for the speech interference effects of noise, a similar measure without the nighttime weighting (L_{eq}) has been employed. To allow comparison between the various effects stated above, some relationships are necessary to allow at least approximate conversion from L_{eq} to L_{dn}. For indoor levels such as those described in Appendix A for various lifestyles, levels during the day are at least 10 dB higher than those during the night. Thus L_{eq} is virtually the same as L_{dn} for normal indoor situations.

For an outdoor L_{dn} of 55 dB or less, day time levels (L_d) are generally 8 dB higher than the nighttime levels (L_n). For this situation, L_{dn} is still quite close to L_{eq} during the day. The correction is less than one dB. For levels greater than L_{dn} 65 dB, the nighttime levels are generally only 4 dB less than during the day time. For these cases, L_{dn} is 3 dB higher than L_{eq} during the day.

For values of L_{dn} between 55 and 65, further interpolation is necessary using Figure A-7.

ACTIVITY INTERFERENCE

Activity interference due to noise is not new. The recent EPA document concerning public health and welfare criteria for noise[D-5] mentions an ordinance enacted 2500 years ago by the ancient Greek community of Sybaris, banning metal works and the keeping of

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roosters within the city to protect against noise that interfered with speech and might disturb sleep. History contains other examples indicating speech and sleep interference due to various types of noises, ranging from wagon noise to the noise of blacksmiths.

More recently, surveys have been conducted which further demonstrate that noise does interfere with various types of activity. For example, Figures D-5 and D-6, based on research done in England, give activity interference reported by the people who were disturbed by aircraft noise for various types of activities as a function of the approximate L_{dn} associated with noise from aircraft flyovers[D-14] (for explanation of the term L_{dn} see Appendix A). Thus, for an outside L_{dn} of approximately 55 dB, over 50% of the people who were disturbed reported some interference with TV sound, and 45% reported some interference with conversation. At the same level, about 45% reported that noise occasionally woke them up, while 30% claimed it sometimes disturbed their relaxation. The figures also indicate that at higher noise levels, greater percentages of people who were disturbed have reported activity interference.

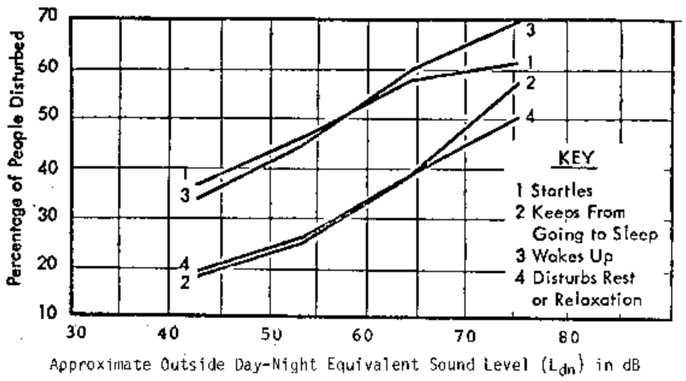

Figure D-5. Percentage of People Disturbed by Aircraft Noise for Various Types of Reasons Concerned With Rest And Sleep[D-6]

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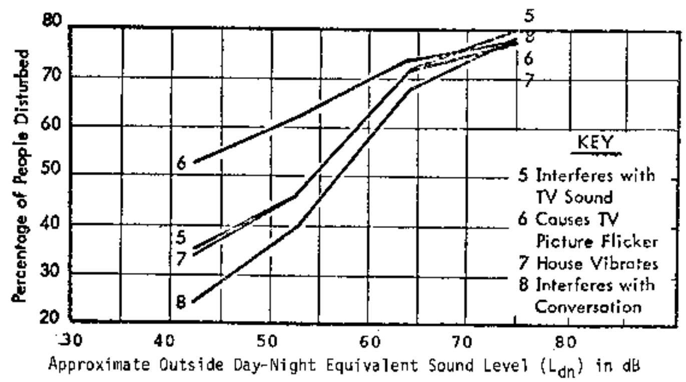

Figure D-6. Percentage of People Disturbed by Aircraft Noise for Various Types of Reasons Concerned with Domestic Factors [D-6]

Later research in the USA[D-7] provides the information on activity interference shown in Table D-4. This table gives the activity disturbance percentages of those who reported that they were *extremely dtsturbed* by the noise, which accounts in part for the low percentage values. It was reported that the daily activities of 98. 6% of those questioned (about 4000 people) were disrupted one or more times by aircraft noise. More activities are mentioned in Table D-4 than in the previous tables. For example, telephone use, reading, listening to tapes and records, and eating were reported to have been disturbed by noise.

A study performed in the Netherlands[D-8] gives further evidence that activity interference is associated with noise (see Table D-5). The data were taken in the urban/suburban areas in the vicinity of the Amsterdam Airport where the L_{dn} ranged from 45 to 85 dB. Activity interference is shown by percentage of people interviewed who have been frequently or sometimes disrupted in various activities. Also reported are the estimated tolerance limits for various portions of the exposed population. Thus, in an area where

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Table D-4

PERCENT OF THOSE PEOPLE WHO WERE EXTREMELY DISTURBED BY AIRCRAFT NOISE*, BY ACTIVITY DISTURBED[D-7]

Activity	Percent
TV/Radio reception	20.6
Conversation	14.5
Telephone	13.8
Relaxing outside	12.5
Relaxing inside	10.7
Listening to records/tapes	9.1
Sleep	7.7
Reading	6.3
Eating	3.5

*Percent scoring 4 or 5 on a 1-5 scale

noise produces "predominantly moderate nuisance," the "tolerance limit" is reached for one third of the population. Thirty-one percent report being sometimes disturbed by noise during conversation, and 21% report being sometimes disturbed by noise during sleep; occupational disturbance was reported by 12%. (The judgment of "admissibility" with respect to well-being in Table D-5 is the result of the referenced study and not a conclusion of this report.)

A recent study[D-9] in the USA found that 46% of the 1200 respondents were annoyed by surface vehicle noise at some time. Activities which were reported disturbed are indicated by percentages shown in Table D-6. Here we see that sleeping is the activity most disturbed by surface vehicle noise, followed in order by listening to TV, radio orrecordings; mental activity, such as reading, writing or thinking; driving; conversing; resting and walking.

From the studies reported here, it is clear that noise does indeed interfere with various activities in our everyday lives. Unfortunately, most of the studies do not provide activity interference as a function of noise exposure. However, the activity which is most sensitive to noise in most of the studies is speech communication (including listening to TV), which can be directly related to the level of the intruding noise.

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Table D-5

PERCENTAGE OF PERSONS INTERROGATED WHO FEEL THAT THEY HAVE FREQUENTLY, (F) OR SOMETIMES (S) BEEN DISTURBED IN CONVERSATION, RADIO LISTENING, TELEVISION, OCCUPATIONS, SLEEP; FEEL AFRAID, AND OF PERSONS IN WHOSE EXPERIENCE ON THESE OCCASIONS THE HOUSE VIBRATES. AT MEAN VALUE OF THE NUISANCE SCORES.[D-8]

	Disturbance of Conversation		Disturbance of Radio Listening		Disturbance of Occupations		Disturbance of Television		Afraid
Mean Nuisance Score	F*	S*	F	S	F	S	F	S	YES
0	0	0	0	0	0	0	0	0	0
1	7	12	2	4	6	10	1	3	25
2	16	24	5	8	12	18	3	7	48
3	27	31	10	15	20	23	7	12	66
4	39	35	18	22	31	25	11	19	78
5	56	37	27	30	42	23	19	28	91
6	67	31	38	36	57	23	34	39	94
7	83	17	56	44	72	28	55	45	100

*F denotes "frequently" S denotes "sometimes"

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Table D-5 (Continued)

House Vibrates	Disturbance of Sleep		Nuisance Felt Subjectively	Admissibility from point of view of physical, mental and social well being, in regard to which the stress is laid on disturbance of sleep, disturbance of conversation and feeling afraid
YES	F	S		
0	0	0	No nuisance	--------
21	3	7	Slight nuisance	Admissable
41	6	14	Slight to moderate nuisance	Admissable; the tolerance limit is reached for about one-third of the population.
56	12	21	Predominantly moderate nuisance	Limit of admissability; tolerance limit is reached in about one-third of the population.
72	20	28	predominantly serious nuisance	Inadmissable; the tolerance limit is exceeded for about half of the population.
83	31	33	Serious nuisance	Inadmissable; the tolerance limit is exceeded for about two-thirds of the population.
92	44	42	Intolerable	Absolutely inadmissable
100	72	28	Intolerable	Absolutely inadmissable

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Table D-6 ACTIVITIES OF RESPONDENTS DISTURBED BY SURFACE VEHICLE NOISE

(All Situations: Respondent's Usual Activity)[D-9]

Category	No. of Situations	Percentage of Total Situations
Driving	47	7
Walking	16	2
Talking with people present	42	6
Working at home	12	2
Reading, writing, thinking	80	12
Sleeping	155	22
Other	13	2
Not relevant	179	26
Listening to TV, radio, records	92	13
Resting (awake)	35	5
Not ascertained	22	3
Total	693	100

COMMUNITY REACTION TO ENVIRONMENTAL NOISE

There are two methods of indirectly assessing the cumulative effects of environmental noise on people. These are examining the reactions of individuals or groups of individuals to specific intruding noises, either (a) with respect to actions taken (complaints, suits, etc.), or (b) in terms of responses made to social survey questionnaires. The first category, involving overt action by individuals or groups, is summarized in this section, and key data regarding the second category, involving responses indicating annoyance, is summarized in the next section.

In the last 25 years, many new types of noise sources have been introduced into suburban and urban residential communities. These sources, such a jet aircraft, urban

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freeways, new industrial plants, and homeowner equipment, have created numerous community problems with environmental noise. These problems have provided significant data and insight relating to community reaction and annoyance and stimulated the development of several indices for measurement of the magnitude of intruding noises.

Various U.S. Governmental agencies began to investigate the relationships between aircraft noise and its effect on people in communities in the early 1950's. This early research resulted in the proposal of a model by Bolt, Rosenblith and Stevens[D-10] for relating aircraft noise intrusion and the probable community reaction. This model, first published by the Air Force, accounted for the following seven factors:

1. Magnitude of the noise with a frequency weighting relating to human response.
2. Duration of the intruding noise.
3. Time of year (windows open or closed).
4. Time of day noise occurs.
5. Outdoor noise level in community when the intruding noise is not present.
6. History of prior exposure to the noise source and attitude toward its owner.
7. Existence of pure-tone or impulsive character in the noise.

Correction for these factors were initially made in 5 dB intervals since the magnitudes of many of the corrections were based solely on the intuition of the authors, and it was considered difficult to assess the response to any greater degree of accuracy. [D-11-13] This model was incorporated in the first Air Force Land Use Planning Guide[D-14] in 1957 and was later simplified for ease of application by the Air Force and the Federal Aviation Administration.

Recently the day-night sound level has been derived for a series of 55 community noise problems [D-3] to relate the normalized measured L_{dn} with the observed community reaction. The normalization procedure followed the Bolt, Rosenblith and Stevens method with a few minor modifications. The correction factors which were added to the measured L_{dn} to obtain the normalized L_{dn} are given in Table D-7. The distribution of the cases among the various noise sources having impact on the community are listed in Table D-8. The results are summarized in Figure D-7.

The "no reaction" response in Figure D-7 corresponds to a normalized outdoor day-night sound level which ranges between 50 and 61 dB with a mean of 55 dB. This mean value is 5 dB below the value that was utilized for categorizing the day-night sound level for a "residential urban community," which is the baseline category for the data in the figure. Consequently, from these results, it appears that no community reaction to an intruding noise is expected, on the average, when the normalized day-night sound level of an identifiable intruding noise is approximately 5 dB less than the day-night sound level

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Table D-7

CORRECTIONS TO BE ADDED TO THE MEASURED DAY-NIGHT SOUND LEVEL (L_{dn}) OF INTRUDING NOISE TO OBTAIN NORMALIZED L_{dn} [D-3]

Type of Correction	Description	Amount of Correction to be Added to Measured L_{dn} in dB
Seasonal Correction	Summer (or year-round operation)	0
	Winter only (or windows always closed)	-5
Correction for Outdoor Noise Level Measured in Absence of Intruding Noise	Quiet suburban or rural community (remote from large cities and from industrial activity and trucking)	+10
	Normal suburban community (not located near industrial activity)	+5
	Urban residential community (not immediately adjacent to heavily traveled roads and industrial areas)	0
	Noisy urban residential community (near relatively busy roads or industrial areas)	-5
	Very noisy urban residential community	-10
Correction for Previous Exposure & Community Attitudes	No prior experience with the intruding noise	+5
	Community has had some previous exposure to intruding noise but little effort is being made to control the noise. This correction may also be applied in a situation where the community has not been exposed to the noise previously, but the people are aware that bona fide efforts are being made to control the noise.	0
	Community has had considerable previous exposure to the intruding noise and the noise maker's relations with the community are good	-5
	Community aware that operation causing noise is very necessary and it will not continue indefinitely. This correction can be applied for an operation of limited duration and under emergency	-10

	circumstances.	
Pure Tone or Impulse	No pure tine or impulsive character Pure tone or impulsive character present	0 +5

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Table D-8

NUMBER OF COMMUNITY NOISE REACTION CASES AS A FUNCTION OF NOISE SOURCE TYPE AND REACTION CATEGORY

Type of Source	Community Reaction Categories			Total Cases
	Vigorous Threats of Legal Action	Wide Spread Complaints	No Reaction or Sporadic Complaints	
Transportation vehicles, including:				
Aircraft operations	6	2	4	12
Local traffic			3	3
Freeway	1			1
Rail		1		1
Auto race track	2			2
Total Transportation	9	3	7	19
Other single-event or intermittent operations, including circuit breaker testing, target shooting, rocket testing and body shop	5			
Steady state neighborhood sources, including transformer substations, residential air conditioning	1	4	2	7
Steady state industrial operations, including blowers, general manufacturing, chemical, oil refineries, et cetera	7	7	10	24
Total Cases	22	14	19	55

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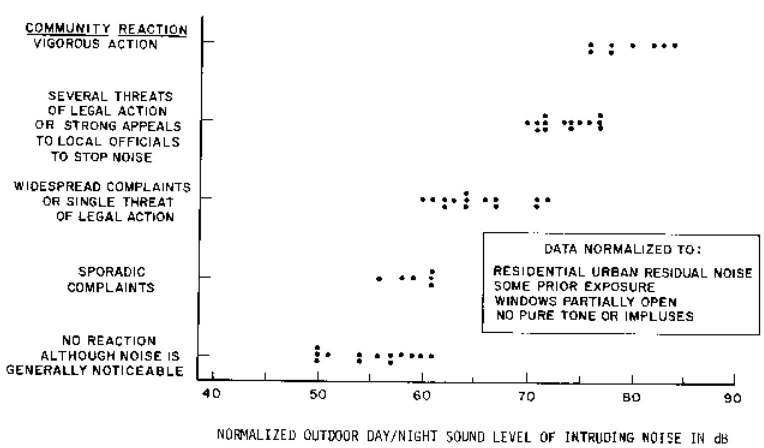

Figure D-7. Community Reaction to Intensive Noises of Many Types as a Function of the Normalized Outdoor Day Night Sound Level of the Intruding Noise[D-3] that exists in the absence of the identifiable intruding noise. This conclusion is not surprising; it simply suggests that people tend to judge the magnitude of an intrusion with reference to the noise environment that exists without the presence of the intruding noise source.

The data in Figure D-7 indicate that widespread complaints may be expected when the normalized value of the outdoor day-night sound level of the intruding noise exceeds that existing without the intruding noise by approximately 5 dB, and vigorous community reaction may be expected when the excess approaches 20 dB. The standard deviation of these data is 3.3 dB about their means and an envelope of +5 dB encloses approximately 90 percent of the cases. Hence, this relationship between the normalized outdoor day-night sound level and community reaction appears to be a reasonably accurate and useful tool in assessing the probable reaction of a community to an intruding noise and in obtaining one type of measure of the impact of an intruding noise on a community.

The methodology applied to arrive at the correlation between normalized L_{dn} and community complaint behavior illustrated in Figure D-7 is probably the best available at

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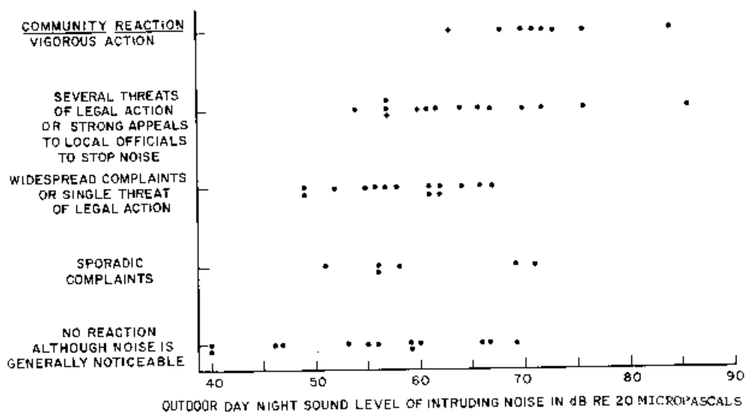
present to predict the most likely community reaction in the U.S. Unfortunately, readiness to complain and to take action is not necessarily an early indicator of interference with activities and annoyance that the noise creates. The fact that correction for the normal background noise level without intruding noise results in better correlation of the data points might be interpreted to mean that urban communities have adapted to somewhat higher residual noise levels that are not perceived as interfering or annoying. On the other hand, it is more likely that the higher threshold for complaining is caused by the feeling that higher residual noise is unavoidable in an urban community and that complaining about "normal" noise would be useless. For the present analysis, it might therefore be more useful to look at the same data without any corrections for background noise, attitude, and other subjective attributes of the intruding noise. Figure D-8 gives these data for the same 55 cases,

The increase in spread of the data is apparent in comparing Figures D-7 and D-8, and the standard deviation of the data about the mean value for each reaction is increased from 3.3 dB for the normalized data to 7.9 dB. The mean value of the outdoor day-night sound level associated with "no reaction" is 55 dB; with vigorous reaction, 72 dB; and, for the three intermediate degrees of reaction, 62 dB.



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There is no evidence in these 55 cases of even sporadic complaints if the L_{dn} is less than 50 dB.

ANNOYANCE

Annoyance discussed in this report is limited to the long-term integrated adverse responses of people to environmental noise. Studies of annoyance in this context are largely based on the results of sociological surveys. Such surveys have been conducted among residents of a number of countries including the United States.[D-6, D-7, D-15, D-16]

The short-term annoyance reaction to individual noise events, which can be studied in the field as well as in the laboratory, is not explicitly considered, since only the accumulating effects of repeated annoyance by environmental stimuli can lead to environmental effects on public health and welfare. Although it is known that the long-term annoyance reaction to a certain environment can be influenced to some extent by the experience of recent individual annoying events, the sociological surveys are designed to reflect, as much as possible, the integrated response to living in a certain environment and not the response to isolated events.

The results of sociological surveys are generally stated in terms of the percentage of respondents expressing differing degrees of disturbance or dissatisfaction due to the noisiness of their environments. Some of the surveys go into a complex procedure to construct a scale of annoyance. Others report responses to the direct question of "how annoying is the noise?" Each social survey is related to some kind of measurement of the noise levels (mostly from aircraft operations) to which the survey respondents are exposed, enabling correlation between annoyance and outdoor noise levels in residential areas.

The results of social surveys show that individual responses vary widely for the same noise level. Borsky[D-17] has shown that these variances are reduced substantially when groups of individuals having similar attitudes about "fear" of aircraft crashes and "misfeasance" of authorities are considered. Moreover, by averaging responses over entire surveys, almost identical functional relationships between human response and noise levels are obtained for the whole surveyed population as are obtained for the groups of individuals having neutral attitudinal responses. Therefore, in deriving a generalized relationship between reported annoyance and day-night sound level, it seems reasonable to use the average overall group responses, recognizing that individuals may vary considerably from the average, both positively and negatively depending upon their particular attitudinal biases. In most cases, the average group response can also be interpreted as the average individual's response during his life period. That is to say, each individual changes his attitudinal biases according to various factors and personal experiences not necessarily connected to the noise or

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even to the environment in general, which lead to fluctuations of each individual's attitude. The average group response does, to some extent, express the individual's response averaged over longer periods of his life. Therefore, this response reflects the effects most likely to affect his health over a longer time period. A comparison of the results of three of the most prominent social surveys around airports are presented in the following paragraphs. These are the first and second surveys around London's Heathrow Airport, [D-6, D-15] and the Tracor study [D-7] around eight major airports in the United States. The noise level data reported for each survey were converted to outdoor day-night sound levels for the purpose of this analysis. In addition, data are presented from a survey of response to motor vehicles in U.S. urban areas.[D-18]

First London-Heathrow Survey

The first survey of about 2,000 residents in the vicinity of Heathrow airport was conducted in 1961 and reported in 1963.[D-6] The survey was conducted to obtain responses of residents exposed to a wide range of aircraft flyover noise. A number of questions were used in the interviews to derive measures of degrees of reported annoyance. Two results of this survey are considered here.

A general summary of the data, aggregating all responses on a category scale of annoyance ranging from "not at all" to "very much annoying," is plotted as a function of approximate L_{dn} in Figure D-9. This figure presents a relationship between word descriptors and day-night sound level.

Among the respondents in every noise level category, a certain percentage were classified in the "highly annoyed" category. This percentage of each group is plotted as a function of approximate L_{dn} on Figure D-10.

Comparison of the data on the two figures reveals that, while the average over the population would fit a word classification of "little annoyed" at an L_{dn} value of approximately 60 dB, more than 20% of the population would still be highly annoyed at this L^{dn} value.

In addition to the derivation of overall annoyance scales, this study examined the attitude of the people towards their area and their desire to move as a function of both noise level and several other factors. The results are summarized in Figs. D-11 and D-12. They indicate that when the approximate L_{dn} exceeded 66-68 dB, aircraft noise became the reason most often cited by those who either "liked their area less now than in the past" or "wanted to move". Further, the data indicate that aircraft noise was of little importance,

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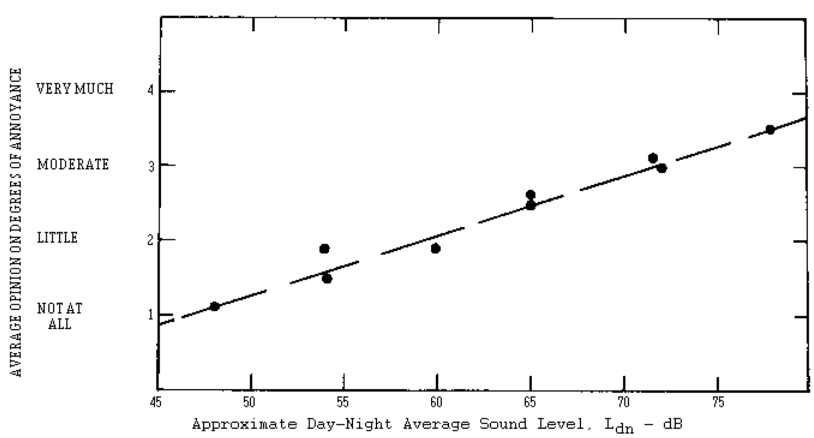
Figure D-9. Average Degree of Annoyance as a Function of the Approximate Day-Night Noise



Level - Results of First London Heathrow Survey[D-39 from D-6]

compared to other environmental factors, when the approximate L_{dn} was below 53 dB and was of average importance as a factor when the approximate L_{dn} was 60 dB.

Results of Second London Survey and Tracor Surveys

In 1967, a second survey[D-15] was taken around Heathrow Airport in the same general area as the first survey. While refinements were attempted over the first survey, the results were generally the same. In 1971, the results of an intensive three year program under NASA sponsorship which studies eight air carrier airports in the United States were reported by Tracor. [D-7] Since each of these efforts is discussed in detail in the references, only an analysis of their combined results is considered here. Borsky[D-17] used the data from these studies to correlate annoyance with noise exposure level for people having different attitudinal characteristics and different degrees of annoyance.

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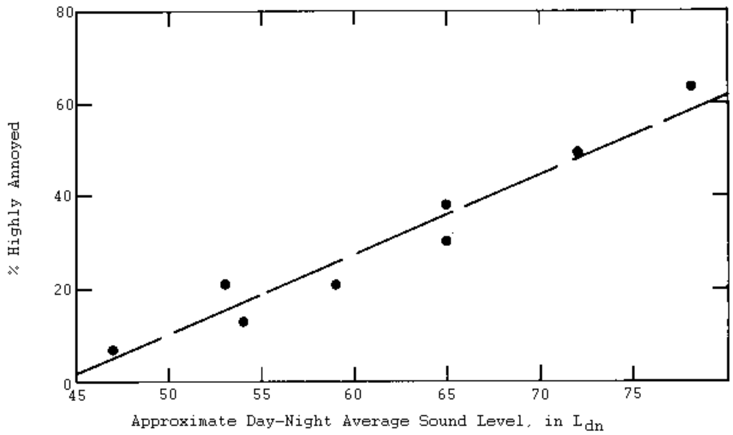

Figure D-10. Percentage Highly Annoyed as Function of Approximate Day-Night Noise Level - Results of First London Heathrow Survey[D-39 from D-6]

Utilizing Borsky's data for "moderate" responses to the attitudes of "fear" and "misfeasance", the relationship between percent highly annoyed and noise exposure level is plotted on Figure D-13. Again, noise levels have been converted to approximate L_{dn} values. It is worth noting that more than 7500 respondents are included in the data sets from which the computations were derived.

The comparison between the results shown on Figures D-10 and D-13 is striking in the near identity of the two regression lines-indistinguishable at any reasonable level of statistical confidence. The importance of these two sets of data lies in the stability of the results even though the data were acquired 6 to 9 years apart, at nine different airports in two different countries. This complete agreement led to the proposal of an average curve for the nominal relationship between sound level and percentage of people annoyed, which has been coordinated among and used by various U.S. Government agencies, [D-19] applied in the studies of ICAO'S coordinating committee on aircraft noise; and verified by a recent analysis of British, French and Dutch survey results conducted by the Organization for Economic Cooperation and Development (OECD). [D-20] According to the OECD work,

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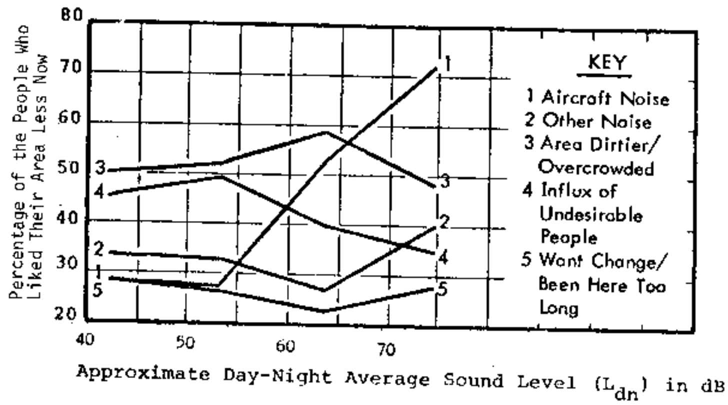

Figure D-11. Percentage of People Liking Their Area Less Now than in the Past for Various Reasons[D-6]

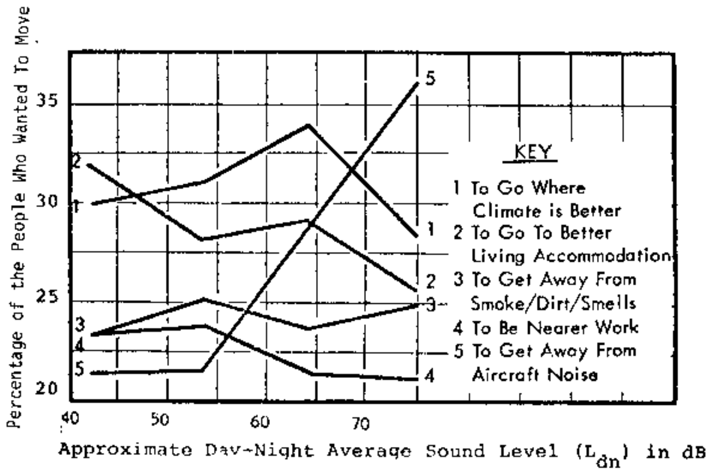

Figure D-12. Percentage of People Giving Particular Reasons for Wanting to Move[D-6]

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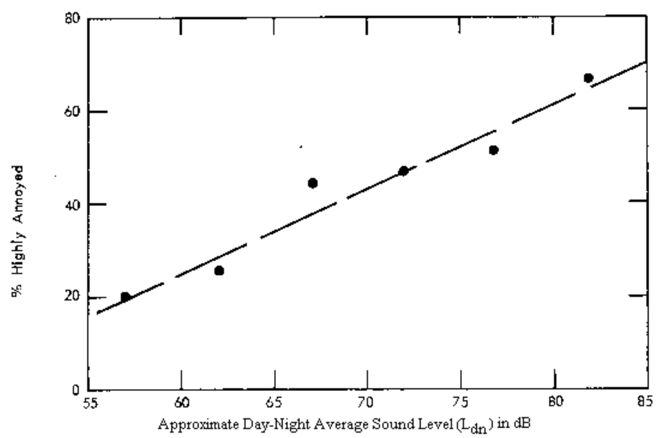

Figure D-13. Combined Results-British and U.S. Surveys [D-17]

the percentage of annoyed people can be predicted as follows: Percentage of annoyed people = 2 (L_{dn} - 50).

The results of the Tracor Study [D-7] also give a relationship between the number of people who indicate in a social survey that they are highly annoyed and the number of people who indicate that they have ever complained about the noise to any one in authority. The results, presented in Figure D-14, indicate that when 1% of the people complain, 17% report being highly annoyed; and when 10% of the people complain, 43 are highly annoyed.

Judgement of Noisiness at Urban Residential Sites

In 1972, a study of urban noise was conducted primarily to evaluate motor vehicle noise for the Automobile Manufacturers Association. [D-9] As part of this survey, 20 different urban-suburban residential locations *not in the vicinity of airports* were studied in Boston, Detroit, and Los Angeles. Noise measurements were acquired and a social survey of 1200

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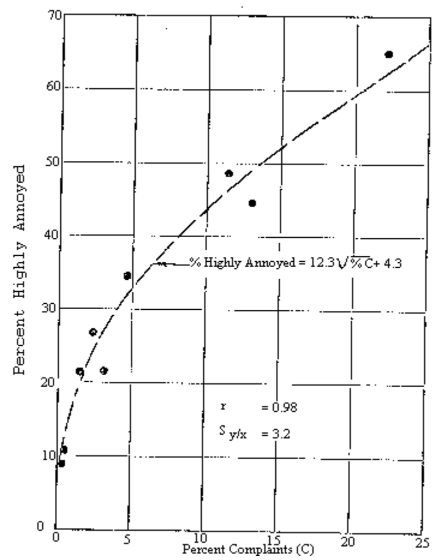

Figure D-14. Percentage of Highly Annoyed As A Function of Percent of ComplaintsD-7

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respondents was conducted. Part of the survey was directed towards obtaining the respondents' judgement, on a category scale, of the exterior noisiness at their places of residence.

The averaged judged noisiness values per site are plotted on Figure D-15 as a function of measured L_{dn} values. The significance of these "non-aircraft" data is the comparison they permit with other survey data acquired exclusively around airports. Intercomparison of these data with previous data indicate that for an L_{dn} value of 60 dB, the site would be judged "quite" noisy. The average annoyance for a group would be classified as "little," but about 25% of the people would still claim to be highly annoyed.

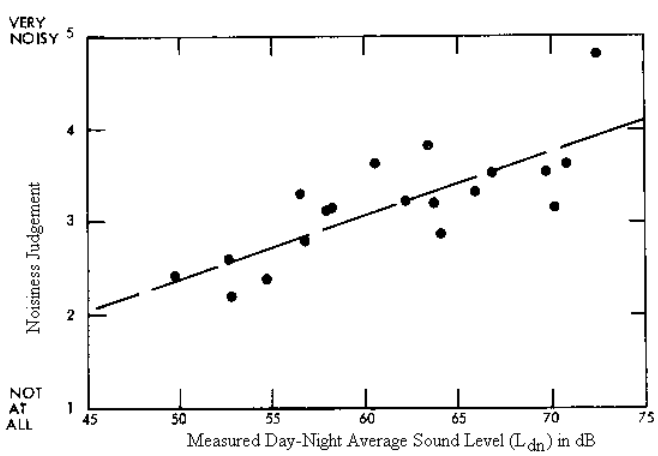

Figure D-15. Judged Noisiness at Automobile Manufacturers Association Survey SitesD-9

When all respondents, irrespective of exposure site, were asked whether they were annoyed by motor vehicle noise, 53% were not annoyed, while 46% were, with an average intensity of annoyance of 4.2 on a scale where 3 stood for "quite annoying," 4 for "definitely annoying" and 5 "strongly annoying." Of the 46% of respondents who stated they were annoyed by motor vehicle noise, 77% experienced annoying noises while in their homes, 12% while in transit, and only 5% at work.

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This indication, that the principle annoyance with environmental noise occurs in the residential situation is further confirmed in the results of the London City Noise Survey [D-18] summarized in Table D-9.

Summary of Annoyance Survey Results

The relationships among percent complainants and percent highly annoyed (Figure D-14) together with the combined results of the two Heathrow surveys and the Tracor survey (Figures D-10 and D-13) have been combined in Figure D-16 to produce a general summary relationship between day-night sound level, percent complainants and percent highly annoyed. Also included in the figure is a scale of the relative importance of aircraft noise as a factor in disliking an area or wanting to move (Figures D-11 and D-12) and the average values of the three main community noise reaction categories (Figure D-7).

The results indicate that below an outdoor day-night sound level of 55 dB, less than 1% of the households would be expected to complain, although 17% of the people may respond as highly annoyed when questioned in a social survey. "No reaction" would be expected in the average community, and noise would be the least important factor in attitude towards neighborhood. When the outdoor L_{dn} is 60 dB, approximately 2% of the households might be expected to complain, although 23% of the people may respond as highly annoyed when questioned, and some reaction would be expected from an average community. If the levels increase over 65 dB, more than 5% may be expected to complain, and over 33% would respond as highly annoyed. Increasingly, vigorous community reaction could be expected, and noise becomes the dominant factor in disliking an area.

Table D-9

PERCENTAGE OF PEOPLE WHO WERE EVER DISTURBED BY NOISE AT HOME, OUTDOORS AND AT WORK IN LONDON CITY SURVEY[D-18]

	At Home	Outside	At Work
Disturbed from time to time	56	27	20
Notice but not disturbed	41	64	70
Do not notice	3	9	10

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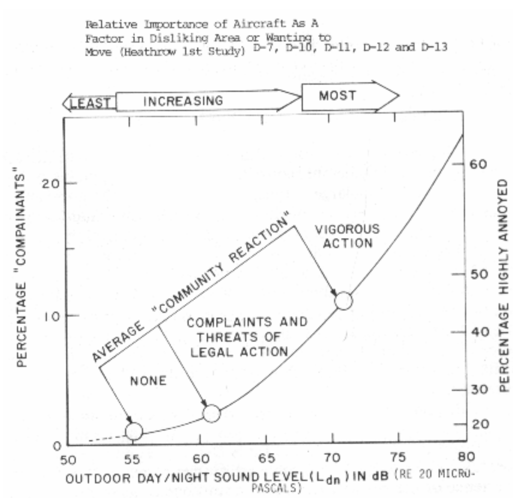

Figure D-16. Summary of Annoyance Survey and Community Reaction Results

It is important to keep in mind that the annoyance/tolerance limits obtained from the social survey results have been found to be based on relatively well defined health and welfare criteria: the disturbance of essential daily activities. [D-19]

VARIOUS PRIOR RECOMMENDATIONS FOR ACCEPTABLE SOUND LEVELS

Recommended values for acceptable sound levels in various types of spaces have been suggested by a number of authors over the past two decades. These recommendations generally have taken into consideration such factors as speech intelligibility and subjective judgements by space occupants. However, the final values recommended were largely the result of judgements on the part of the authors, which in the case of acoustical consultants, have been motivated by the need for design values which will be on the "safe" side. One of the earliest publications providing recommended values in modern terminology was that

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of Knudsen and Harris [D-21] in 1950. It is of interest to quote from the text to understand the reasoning used to develop the recommended levels:

> **Acceptable Noise Levels in Buildings**
>
> The highest level of noise within a building that neither disturbs its occupants nor impairs its acoustics is called the acceptable noise level. It depends, to a large extent, on the nature of the noise and on the type and customary use of the building. The time fluctuation of the noise is one of the most important factors in determining its tolerability. For example, a bedroom with an average noise level of 35 dB, with no instantaneous peak levels substantially higher, would be much more conducive to sleep than would be a room with an average noise level of only 25 dB but in which the stillness is pierced by an occasional shriek. Furthermore, levels that are annoying to one person are unnoticed by another. It is therefore impossible to specify precise values within which the noise levels should fall in order to be acceptable. It is useful, however, to know the range of average noise levels that are acceptable under average conditions. A compilation of such levels for various types of rooms in which noise conditions are likely to be a significant problem is given in [Table D-10.*] The recommended acceptable noise levels in this table are empirical values based on the experience of the authors and others they have consulted. Local conditions or cost considerations may make it impractical to meet the high standards inherent in these relatively low noise levels. In more than 80 percent of the rooms of some of the types listed, the prevalent average noise levels exceed the recommended acceptable levels. However, it should be understood that the acceptance of higher noise levels incurs a risk of impaired acoustics or of the comfort of the individuals in the room.

Since 1950 recommendations by a number of authors, as well as national standards, have been presented. Eighteen of these recommendations are tabulated in Table D-10. [D-21 through D-38] It is encouraging to note the consistency displayed, although many of the later recommendations may be based on the recommendations of the earlier authors.

SUMMARY OF NOISE INTERFERENCE WITH HUMAN ACTIVITIES AND RESULTING HEALTH/WELFARE EFFECTS

The primary effect of noise on human health and welfare due to interference with activity comes from its effect on speech communication.

*These values are given in the first column of Table D-10.

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Table D-10

PRIOR RECOMMENDATIONS OF SOUND LEVELS IN VARIOUS SPACES[D-21 through D-38]

B&M

August 10, 1973

RECOMMENDED ACCEPTABLE NOISE LEVELS

	Knudsen-Harris 1950 1 dB(A)	Beranek 1953 2 db(A)c	Beranek 1957 3 dB(A)	Lawrence 1962 4 dB(A)	Kosten-Van Os 1962 5 dB(A)c	Ashrae 1967 6 dB(A) *	Denisov 1970 7 dB(A)	Kryter 1970 8 dB(A)	Tokyo 1971 9 dB(A)	USSR 1971 10 db(A)	Beranek 1971 11 dB(A)	Doelle 1972 12 dB(A) c	Wood 1972 13 dB (A)c	Rettinger 1973 14 dB(A)	Sweden (p-9) 15 dB(A)	Switzerland 1970 (p-4) 16 dB(A)	Czechoslovakia 1967 (p-10-11) 17 dB(A)
RESIDENT																	
Home																	
Bedroom	35-45	35	35-45	25	30	25-35	-	40	-	35	34-47	35-45	35	34-42	25	35-45	40
Living Room	35-45	35	-	40	35	30-40	-	40	-	35	38-47	-	40	-	25	35-45	40
Apartment	35-45	-	35-40	30	-	35-45	-	18	-	-	34-47	-	-	38-42	-	35-50	40
Hotel	35-45	-	35-40	35-40	-	35-45	-	38	-	35	34-47	35-54	30-40	42	-	35-50	40
COMMERCIAL																	
Restaurant	50-55	55	55	40-60	50	40-55	-	55	-	55	42-52	45-60	45-50	50	-	40-50	55
Private Office	40-45	50	30-45	35-45	30-45	25-45	40-45	35	-	-	38-47	30-45	40-45	46	40	-	-
General Office	45-55	-	40-55	40-60	60	35-65	50-60	35-40	-	50	42-52	45-55	45-55	50	-	-	-
Transport.	-	-	-	-	-	35-55	-	-	-	60	-	-	-	-	-	-	-
INDUSTRIAL																	
Workshop																	
Light	-	50	-	40-60	-	-	-	-	-	-	52-61	-	55-65	-	-	45-55	-
Heavy	-	75	-	60-90	70	-	85	-	-	-	66-80	-	60-75	70	-	50-60	-
EDUCATION																	
Classroom	35-40	35	35	30-40	30	35-45	-	35	-	40	38-47	35	35-45	38	35	35-45	-
Laboratory	-	-	-	40-50	-	40-50	40-50	-	-	-	47-46	-	45-50	42	-	-	-
Library	40-45	40	42-45	35-45	35	35-45	-	40	-	-	38-47	40-45	40-45	42	-	-	40
HEALTH																	

Hospital	35-40	40	42	20-35	35	30-45	-	40	-	25	34-47	40	40-45	38	25-35	25-35	35-40
RECREATION																	
Swimpool	-	-	-	-	-	45-60	-	-	-	-	-	-	50-60	50	-	-	-
Sports (ampl.)	-	60	30	-	-	35-45	-	-	-	60	-	60	-	46	-	-	60
Gymnasium	-	-	-	-	55	40-50	-	-	-	-	-	55-60	45-55	46	-	-	-
AUDITORIUM																	
Assembly Hall	35-40	35	35-40	40-45	-	30-40	-	38	-	-	30-42	35-45	35-45	-	-	-	-
Church	35-40	40	40	35-40	35	25-35	-	40	-	35	30-42	35-40	35-40	38-42	-	-	-
Concert Hall	30-35	30-35	25-35	25-35	30	25-35	-	28-35	-	-	21-30	25-35	30-35	34	-	-	35
Court Room	40-45	40	40-45	40-45	35	-	-	40	-	-	42	35-40	35-40	-	-	-	-
Record Studio	25-30	30	25-30	20-30	20	25-35	-	28	-	-	21-34	25-30	30	30	-	-	-
TV Studio	25-30	30	30	25-35	30	25-35	-	28	-	-	21-34	30-35	35	34-38	-	-	-
Mot. Pict. Studio	25-30	30	25-30	-	25-35	-	-	28	-	-	21-34	35	25	-	-	-	-
Mot. Pict. Theater	35-40	40	40	-	35	35-45	-	40	-	40	-	40	35-40	38	-	-	-
Lec. Theater	30-35	35	30-35	-	25	30-40	-	33	-	-	30-34	30-35	-	34	-	-	35
OUTSIDE																	
Rural	-	-	-	-	-	-	-	-	35-45	35	-	-	-	-	-	-	-
Suburb	-	-	-	-	-	-	-	-	40-50	45	-	-	-	-	-	-	-
Urban	-	-	-	-	-	-	-	-	50-60	-	-	-	-	-	-	-	-
Industrial	-	-	-	-	-	-	-	-	50-60	-	-	-	-	-	-	-	-
Res Areas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	55	-	-
Near Schools	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hospitals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Note: db(A)^c = MC = 10
*6 dB greater than ASHRAE'S cited MC

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The levels that interfere with human activities which do not involve active listening cannot be quantified relative to the level of a desired sound. Rather, the level of an intruding sound that will cause an interference depends upon its relation to the level of the other background sounds in the environment and the state of the human auditor, e.g., the degree of concentration when endeavoring to accomplish a mental task, or the depth of sleep, etc.

The levels of environmental noise that are associated with annoyance depend upon local conditions and attitudes. They cannot be clearly identified in terms of the national public health and welfare. The only levels which can be so identified are the levels which are required to assure that speech communication in the home and outdoors is adequate in terms of public health and welfare. Lower levels may be desirable and appropriate for specific local situations.

The level identified for the protection of speech communication is 45 dB within the home. Allowing for the 15 dB reduction in sound level between outdoors and indoors, this level becomes an outdoor day-night sound level of 60 dB (re 20 micropascals) for residential areas. For outdoor voice communication, the outdoor day-night level of 60 dB allows normal conversation at distances up to 2 meters with 95 sentence intelligibility.

Although speech interference has been identified as the primary interference of noise with human activities, and as one of the primary reasons for adverse community reactions to noise and long-term annoyance, a margin of safety of 5 dB is applied to the maximum outdoor level to give adequate weight to all of these other adverse effects.

Therefore, the outdoor day-night sound level identified for residential areas is a daynight sound level of 55 dB.

The associated interior day-night sound level within a typical home which results from outdoors is 15 dB less, or 40 dB. The expected indoor daytime level for a typical neighborhood which has an outdoor day-night sound level of 55 dB is approximately 40 dB, whereas the nighttime level is approximately 32 dB (see Figure A-7). This latter value is consistent with the limited available sleep criteria. [D-5] Additionally, these resulting indoor levels are consistent with the background levels inside the home and which have been recommended by acoustical consultants as "acceptable" for many years (Table D-10).

The effects associated with an outdoor day-night sound level of 55 dB are summarized in Table D-11. The summary shows:

1. Satisfactory outdoor average sentence intelligibility may be expected for normal voice conversations over distances of up to 3.5 meters;

Table D-11

SUMMARY OF HUMAN EFFECTS IN TERMS OF SPEECH COMMUNICATION, COMMUNITY REACTION, COMPLAINTS, ANNOYANCE AND ATTITUDE TOWARDS AREA ASSOCIATED WITH AN OUTDOOR DAY/NIGHT SOUND LEVEL OF 55 dB re 20 MICROPASCALS

Type of Effect	Magnitude of Effect
Speech - Indoors	100% sentence intelligibility (average) with a 5 dB margin of safety
- Outdoors	100% sentence intelligibility (average) at 0.35 meters
	99% sentence intelligibility (average) at 1.0 meters
	95% sentence intelligibility (average) at 3.5 meters
Average Community Reaction	None, 7 dB below level of significant "complaints and threats of legal action" and at least 16 dB below "vigorous action" (attitudes and other non-level related factors may affect this result)
Complaints	1% dependent on attitude and other non-level related factors
Annoyance	17% dependent on attitude and other non-acoustical factors
Attitudes Toward Area	Noise essentially least important of various factors

2. Depending on attitude and other non-acoustical factors, the average expected community reaction is "none" although 1% may complain and 17% indicate "highly annoyed" when responding to social survey questions; and

3. Noise is the least important factor governing attitude towards the area.

Identification of a level which is 5 dB higher than the 55 dB identified above would significantly increase the severity of the average community reaction, as well as the expected percentage of complaints and annoyance. Conversely, identification of a level 5 dB lower than the 55 dB identified above would reduce the indoor levels resulting from outdoor noise well below the normal background indoors. It would decrease speech privacy outdoors to marginal distance. Little change in annoyance would be made since at levels below the identified level, individual attitude and life style, as well as local conditions, are more important factors in controlling the resulting magnitude of the level of the intruding noise.

In conclusion, a L_{dn} level of 55 dB is identified as outdoor level in residential areas compatible with the protection of public health and welfare. The level of 55 dB is identified as maximum level compatible with adequate speech communication indoors and outdoors. With respect to complaints and long term annoyance this level is clearly a maximum satisfying the large majority of the population (see Table D-11). However, specific local situations, attitudes, and conditions may make lower levels desirable for some locations. A noise environment not annoying some percentage of the population cannot be identified at the present time by specifying noise level alone.

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D-39 "Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure." EPA Document NTID 73.4, July 27, 1973.

Appendix E

GENERAL EFFECTS OF NOISE NOT DIRECTLY USED IN IDENTIFYING LEVELS OF NOISE REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE

Appendix E

GENERAL EFFECTS OF NOISE NOT DIRECTLY USED IN IDENTIFYING LEVELS OF NOISE REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE

There are a multitude of adverse effects that can be caused by noise which may, both directly or indirectly, affect public health and welfare. However, there are only three categories of adverse relationships in which the cause/effect relationships are adequately known and can be justifiably used to identify levels of environmental noise for protection of public health and welfare. These are: (1) the effect of noise on hearing, (2) the effect of noise on the general mental state as evidenced by annoyance, and (3) the interference of noise with specific activities. These three categories of effects, discussed in detail in Appendices C and D, will serve as the main basis for identifying the levels in Section 3 of this document.

Since a causal link between community noise and extra-auditory disease has not been established, this document proceeds on the assumption that protection against noise-induced hearing loss is sufficient for protection against extra-auditory effects. However, the generation of most stress-related disorders is somewhat longer than that required for noise-induced hearing loss, and this time interval may have clouded a causal association. Noise of lesser amplitude than that traditionally identified for the protection of hearing causes regular and dependable physiological responses in humans. Similar noise-induced physiological changes in sensitive animals regularly leads to the development of stress-related disease. The implications of generalizing from these animal studies to humans is not clear. With the availability of new information concerning the role of noise as a stressor in the pathogenesis of stress-related disease, the levels identified in this document may require further review.

In the meantime, the question that is invariably asked is, "What is the significance of omitting all other physiological effects?"

In answer to this question, most experts agree that, at present, there is insufficient knowledge of the effect of noise on health except for noise-induced hearing loss, (defining health in the more restricted sense, as the absence of disease). In a recent review of this subject E-1 it was concluded that: "if noise control sufficient to protect persons from ear damage and hearing loss were instituted, then it is highly *unlikely* that the noises of lower level and duration resulting from this effort could directly induce non-auditory disease." Therefore, in this document, hearing loss will be considered the controlling effect.

This is not to say that there are no indications to arouse concern in the area of nonauditory effects, but substantial further research on these effects of noise on health would be required to alter the above statements. Such research should be fostered, and the results should be carefully monitored for any evidence indicating that the maximum sound levels identified herein are excessive.

Although noise can affect people indirectly by disturbing the general environment in which they live, the noise levels required to produce significant non-auditory physiological effects are normally much higher than the levels required to protect the public health and welfare from adverse effects on hearing or interference with activities.

However, for special conditions, certain effects which have not been directly utilized in identifying the levels in this document, should be examined. For this purpose, certain of the summary paragraphs of the EPA criteria document "Public Health and Welfare Criteria for Noise"[E-2] are included in this appendix. Caution must be exercised when using such information since, in many cases, there is no way to relate the exact exposure level to the effect in question.

EFFECTS OF NOISE ON HUMANS

Performance and Work Efficiency

Continuous noise levels above 90 dBA appear to have potentially detrimental effects on human performance, especially on what have been described as noise-sensitive tasks such as vigilance tasks, information-gathering and analytical processes. Effects of noise on routine-type tasks appear to be much less important, although cumulative degrading effects have been demonstrated by researchers. Noise levels of less than 90 dBA can be disruptive, especially if they have predominantly high frequency components, are intermittent, unexpected, or uncontrollable. The amount of disruption is highly dependent on:

- The type of task.
- The state of the human organism.
- The state of morale and motivation.

Noise does not usually influence the overall rate of work, but high levels of noise may increase the variability of the work rate. There may be "noise pauses" or gaps in response, sometimes followed by compensating increases in work rate. Noise is more likely to reduce the accuracy of work than to reduce the total quantity of work. Complex or demanding tasks are more likely to be adversely affected than are simple tasks. Since laboratory studies represent idealized situations, there is a pressing need for field studies in real-life conditions.

Although these possibly adverse effects were not used in identifying the noise levels in this document, employers or educational authorities should consider their influence since it might provide additional motivation to achieve the values seen in Table D-10 of Appendix D.

Effects of Noise on the Autonomic Nervous System and Other Non-Auditory Physiological Effects

Noise can elicit many different physiological responses. However, no clear evidence exists to indicate that the continued activation of these responses leads to irreversible changes and permanent health problems. Sound of sufficient intensity can cause pain to the auditory system, however, such intense exposures are rarely encountered in the nonoccupational environment. Noise can also affect one's equilibrium, but the scarce data available indicates that the intensities required to do so must be quite high, similar to the intensities that produce pain.

Noise-induced orienting reflexes serve to locate the source of a sudden sound and, in combination with the startle reflex, prepare the individual to take appropriate action in the event of danger. Apart from possibly increasing the chance of an accident in some situations, there are no clear indications that the effects are harmful since these effects are of short duration and do not cause long-term physiological changes.

Noise can definitely interfere with sleep, however, relating noise-exposure level to the quality of sleep is difficult. Even noise of moderate levels can change the pattern of sleep, but the significance of these changes is still an open question.

Noise exposure may cause fatigue, irritability, or insomnia in some individuals, but the quantitative evidence in this regard is also unclear. No firm relationships between noise and these factors can be established at this time.

Interaction of Noise and Other Conditions or Influences

Determination of how various agents or conditions interact with noise in producing a given effect requires three separate determinations: the effect produced by the noise alone, the effect produced by the other agent alone, and the effect produced by the combined action of the agent and the noise. These results indicate whether the combined effect is indifferent, additive, synergistic, or ameliorative.

Chemical agents may have a harmful effect when combined with noise. Ototoxic drugs that are known to be damaging to the hearing mechanism can be assumed to produce at least an additive effect on hearing when combined with noise exposure. There are instances in which individuals using medication temporarily suffer a hearing loss when exposed to noise, but there is no definitive data on the interaction of ototoxic drugs and noise on humans. Evidence linking hearing loss with the combination of noise and industrial chemicals is also inconclusive.

The possibility of a synergistic effect exists when noise and vibration occur together. Vibration is usually more potent than noise in affecting physiological parameters. There appears to be consensus that vibration increases the effect of noise on hearing, but such increases are probably quite small.

Health disorders may interact with noise to produce a hearing loss. Mineral and vitamin deficiencies are one example but little research has been done on the effect of such deficiencies on susceptibility to noise. A reasonable hypothesis is that illness increases an individual's susceptibility to the adverse effects of noise. However, as with the other hypotheses, conclusive evidence is lacking.

Noise exposure can be presumed to cause general stress by itself or in conjunction with other stressors. Neither the relationship between noise exposure and stress nor the noise level or duration at which stress may appear have been resolved. .

Exposure to moderate intensities of noise that are likely to be found in the environment may affect the cardiovascular system in various ways, but no definite permanent effects on the circulatory system have been demonstrated. Noise of moderate intensity has been found to cause vasoconstriction of the peripheral blood vessels and pupillary dilation. There is no evidence that these reactions to noisy environments can lead to harmful consequences over prolonged periods of noise exposure. However, speculation that noise might be a contributing factor to circulatory difficulties and heat disease is not yet supported by scientific data.

EFFECTS OF NOISE ON WILDLIFE AND OTHER ANIMALS

Noise produces the same general types of effects on animals as it does on humans, namely: hearing loss, masking of communications, behavioral, and non-auditory physiological effects.

The most observable effects of noise on farm and wild animals seem to be behavioral. Clearly, noise of sufficient intensity or noise of aversive character can disrupt normal

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patterns of animal existence. Exploratory behavior can be curtailed, avoidance behavior can limit access to food and shelter, and breeding habits can be disrupted. Hearing loss and the masking of auditory signals can further complicate an animal's efforts to recognize its young, detect and locate prey, and evade predators. Competition for food and space in an "ecological niche" results in complex interrelationships and, hence, a complex balance.

Many laboratory studies have indicated temporary and permanent noise-induced threshold shifts. However, damage-risk criteria for various species have not yet been developed. Masking of auditory signals has been demonstrated by commercial jamming signals, which are amplitude and frequency modulated.

Physiological effects of noise exposure, such as changes in blood pressure and chemistry, hormonal balance and reproductivity have been demonstrated in laboratory animals and, to some extent, in farm animals. But these effects are understandably difficult to assess in wildlife. Also, the amount of physiological and behavioral adaptation that occurs in response to noise stimuli is as yet unknown.

Considerable research needs to be accomplished before more definitive criteria can be developed. The basic needs are:

- More thorough investigations to determine the point at which various species incur hearing loss.
- Studies to determine the effects on animals on low-level, chronic noise exposures.
- Comprehensive studies on the effects on animals in their natural habitats. Such variables as the extent of aversive reactions, physiological changes, and predator-prey relationships should be examined.

Until more information exists, judgments of environmental impact must be based on the existing information, however incomplete. The most simple approach is to assume that animals will be at least partially protected by application of maximum levels identified for human exposure.

EFFECT OF NOISE ON STRUCTURES

Airborne sound normally encountered in real life does not usually carry sufficient energy to cause damage to most structures. The major exceptions to this are sonic booms produced by supersonic aircraft, low frequency sound produced by rocket engines and some construction equipment, and sonic fatigue.

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From an environmental point of view, the most significant effects are those caused by sonic booms on the secondary components of structures. These effects include the breaking of windows and cracking of plaster. Effects such as these have led to the speculation that historical monuments and archeological structures may age more rapidly when exposed to repeated sonic booms. However, the levels identified in Appendix G to protect against adverse effects on public health and welfare are low enough to protect against damage to structures.

E-6

REFERENCES FOR APPENDIX E

E-1 "Effect of Noise on People," Environmental Protection Agency, NTID 300.7, December 1971.
E-2 "Public Health and Welfare Criteria for Noise," Environmental Protection Agency, 550/9-73-002, July 27, 1973.

E-7

Appendix F

EPA's RESPONSIBILITY TO IDENTIFY SAFE LEVELS FOR OCCUPATIONAL NOISE EXPOSURE

Appendix F

EPA's RESPONSIBILITY TO IDENTIFY SAFE LEVELS FOR OCCUPATIONAL NOISE EXPOSURE

Although the workplace is a vital component of the human environment, the Environmental Protection Agency does not have jurisdiction over most occupational health and safety matters. These matters have traditionally been the responsibility of the Departments of Labor and Health, Education and Welfare. Section 6(b)(5) of the Occupational Safety and Health Act of 1972 specifies that the Secretary of Labor, ". . . in promulgating standards dealing with toxic materials or harmful physical agents . . . shall set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life . . . In addition to the attainment of the highest degree of health and safety protection for the employee, other considerations shall be the latest available scientific data in the field, the feasibility of the standards, and experience gained under this and other health and safety laws."

In contrast, section 5(a)(2) of the Noise Control Act of 1972 directs EPA's Adminisrator to "publish information on the levels of environmental noise, the attainment and maintenance of which in defined areas under various conditions are requisite to protecting the public health and welfare with an adequate margin of safety."

The words "public health and welfare" appear in a number of places in the Noise Control Act, and have a broader reference than those defining jurisdiction in the Occupational Safety and Health Act, namely, the entire American public at all times rather than the American worker during his workday. In addition, the requirement of an "adequate margin of safety" does not appear in the Occupational Safety and Health Act, which instead uses the phrase, "no employee will suffer material impairment of health or functional capacity." These distinctions indicate that EPA's duty to identify levels for exposure to noise is broader in scope and more stringent that OSHA'S duty to protect in the occupational area. Furthermore, the intent of this document is to identify safe levels for a variety of settings, whereas the responsibility of HEW is to develop occupational exposure criteria and that of the Department of Labor is to promulgate and enforce standards. In the writing of such standards, the Labor Department must take feasibility into account, a consideration omitted in the writing of this document.

EPA's responsibility to identify levels of exposure to noise "in defined areas under various conditions" necessarily includes an identification of exposure levels in the workplace

F-1

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in order to satisfy the intent of the law to consider total human exposure to noise. Working hours are an inseparable part of the individual's 24-hour day, and they must be considered in order to evaluate the contributions of nonoccupational exposure to his daily and lifetime dose. For this reason, it is of utmost importance that the levels specified for occupational and non-occupational noise be compatible.

F-2

Appendix G

IMPULSE NOISE AND SOME OTHER SPECIAL NOISES

Appendix G

IMPULSE NOISE AND SOME OTHER SPECIAL NOISES

IMPULSE NOISE

Impulse noise is defined in various ways [G-1, G-2, G-11] but generally means a discrete noise (or a series of such noises) of short duration (less than a second), in which the sound pressure level rises very rapidly (less than 500 ms, sometimes less than 1 ms) to a high peak level before decaying below the level of background noise. The decay is frequently oscillatory, because of sound reflections and reverberation (ringing) in which case the spectrum of the oscillation may also be important in determining the hazard to hearing. Some authors distinguish reverberant impulse noise as "impact" noise (typically produced by metal to metal impact as in industrial forging), to distinguish it from simple oligophasic impulses (typified by a gunshot in the open air). [G-3]

The peak sound pressure level (SPL) is an important but not the sole parameter determining hazard. Some typical values for disturbing or hazardous impulse noises are given in Table G-1.

NOTE: Peak SPL for impulses cannot be properly measured with a standard sound level meter, which is a time-averaging device. Oscillographic techniques must be used.

Table G-1

SOME TYPICAL VALUES OF PEAK SPL FOR IMPULSE NOISE

(in dB re 20 micropascals)

SPL	EXAMPLE
190+	Within blast zone of exploding bomb
160-180	Within crew area of heavy artillery piece or naval gun when shooting
140-170	At shooter's ear when firing hand gun
125-160	At child's ear when detonating toy cap or firecracker
120-140	Metal to metal impacts in many industrial processes (e.g., drop-forging; metal-beating)
110-130	On construction site during pile-driving

Effects of Impulse Noise on People

Cochlear Damage and Hearing Loss

Impulse noise can produce temporary (TTS) and permanent threshold shift (PTS). The pattern essentially resembles that produced by a continuous noise but may involve somewhat higher frequency losses (maximal at 4 to 6 kHz) and recovery from impulse-NIPTS can be more variable.[G-9] A blow to the head can have a similar effect. TSS (and, by inference, PTS) in man depends on many factors, the more important of which are reviewed in more detail later. Impulse noise (like continuous noise) can also be shown to produce pathological changes in the inner ear (cochlea) of mammals, notably destruction and degeneration of the haircells of the hearing organ, and atrophic changes in related structures. A quantitative relationship between the amount of visible damage to the cochlea and the amount of NIPTS has not yet been clearly established. [G-2, G-4, G-5]

Other Pathological Effects

Exposure to blast or to sustained or repeated impulsive airborne over-pressures in the range of 140 to 150 dB (239 to 718 pascals) or higher can cause generalized disturbance or damage to the body apart from the ear. This is normally a problem for military personnel at war (e.g., artillerymen firing field guns), and need not be considered further here. Transient over-pressures of considerable magnitude can be experienced due to sonic boom but are unlikely to be hazardous to the ear.

Startle and Awakening

Impulsive noises which are novel, unheralded, or unexpectedly loud can startle people and animals. Even very mild impulsive noises can awaken sleepers. In some circumstances (e.g., when a person is handling delicate or dangerous objects or materials), startle can be hazardous. Because startle and alerting responses depend very largely upon individual circumstances and psychological factors unrelated to the intensity of the sound, it is difficult to make any generalization about acceptable values of SPL in this connection. A high degree of behavioral habituation, even to intense impulse noises such as gunfire, is normally seen in animals and humans when the exposure is repeated, provided that the character of the stimulus is not changed.

Parameters of Impulse Noise Exposure

Impulse noise is characterized completely by the waveform and spectrum. Various summary parameters are also useful in characterizing an impulsive noise, these include:

1. Peak SPL (in dB re 20 micropascals)

2. Effective duration (in milliseconds or microseconds)

3. Rise time

In addition, the following are important for predicting the effects of the impulse on people:

4. Number of repeated impulses in a daily or other cumulative exposure

5. Intervals or average interval between repeated impulses (or rate of impulse occurrence)

6. Individual susceptibility to inner ear damage

7. Orientation of the ear with respect to the noise

8. Preceding or simultaneous exposure to continuous noise at TTS-producing levels

9. Action of acoustic reflex, if elicited

10. Audiometric frequency

Impulse Noise Exposure Criteria and Limits

Hearing Damage and Criteria for Impulse Noise

It is obvious from the above lists that limiting impulse noise exposure for hearing conservation is not an easy matter. Existing guidance in this matter in some spheres is seriously inadequate or misleading.[G-3] For instance, the Occupational Safety and Health Act prescribes a limiting level of 140 dB SPL for industrial impulse noise, with no allowance for any other parameter.

In 1968, Working Group 57 of CHABA prepared a damage risk criterion for gunfire noise, based essentially on the work of Coles *et. al.*, [G-6] which included procedures to allow for repetition of impulses and some of the other parameters listed above.[G-1] Some modification has recently been proposed by Coles and Rice. [G-7] The CHABA proposal was intended to protect 95% of the exposed population.

Guidelines for Evaluating Hazard from Impulse Noise Exposure

Peak Level

The growth of TTS at 4 kHz with increase in peak level above 130 dB SPL of impulses (clicks) presented at a steady rate has been demonstrated by Ward *et. al.* [G-8] Based on TTS data from rifle shooters, Kryter and Garinther[G-18] estimated permanent hearing levels expected to result from daily exposure to a nominal 100 rounds of rifle shooting noise in selected percentiles. Their data are reproduced in Table G-2 below, showing the increasing hazard with increasing peak level and with increasing audiometric frequency up to 6000 Hz.

CHABA'S 1968 Damage-Risk Criteria (DRC) [G-1] recommended limits to peak level as a function of impulse duration for a nominal exposure of l00 impulses per day at normal incidence (discussed below and shown in Figure G-1). These limits were intended to protect 95% of the people according to an implied criterion of NIPTS not exceeding 20 dB at 3 kHz or above, after 20 yrs. If 90% of the people were to be protected to a criterion of NIPTS not exceeding 5 dB at 4 kHz, it would be necessary to lower the CHABA limits by 12 dB (15 dB reduction to meet the more stringent criterion, assuming an approximately decible to decibel relationship in the range of interest [see Table G-2], less 3 dB elevation to apply the limit to the 90th percentile). This modified CHABA limit is shown in Figure G-1 by hatched lines.

Duration of Impulse

Hazard increases with the effective duration of impulses. [G-10] Impulse duration is defined according to the type of impulse (A, simple peak, or B, oscillatory decay) ; [G-1, G-6] and CHABA has recommended separate limits for A- and B-durations (Figure G-1). For effective durations much above 1 ms, a more stringent limit should be applied to reverberant oscillations (e.g., metallic impacts in industry or gunshots in a reverberant indoor range) than to simple A-type impulses (e,g., gunshots in the open). When the type of impulse cannot be determined, it is conservative to assume the B-duration.

Table G-2

ESTIMATED EXPECTED PERMANENT HEARING LEVEL (IN DB RE ASA:1951) IN SELECTED PERCENTILES OF THE MOST SENSITIVE EARS FOLLOWING NOMINAL DAILY EXPOSURE TO RIFLE NOISE (DURING TYPICAL MILITARY SERVICE), NAMELY, 100 ROUNDS AT ABOUT 5 SECOND INTERVALS[G-18]

Peak SPL* (dB)	Percentile Exceeding HL	Audiometric Test Frequency (Hz)				
		1000	2000	3000	4000	6000
170	10	25	35	70	85	90
	25	15	25	55	65	70
	50	0	10	35	45	50
165	10	16	20	62	60	67
	25	9	10	32	45	52
	50	0	0	12	25	47
160	10	15	16	25	45	60
	25	7	8	18	35	45
	50	0	0	0	15	25
150	10	10	15	15	35	50
	25	3	4	8	25	40
	50	0	0	0	10	20
140	10	0	5	10	30	45
	25	0	2	2	18	30
	50	0	0	0	5	10

*At the ear, grazing incidence.

Figure G-1. The 1968 CHABA [G-1] Damage-Risk Criterion for Impulse Noise Exposure (solid lines) and a Proposed Modification (hatched lines). Peak Sound Pressure Level is Expressed as a Function of A- or B-Duration in the Range 25 Microseconds to 1 Second. [G-1]

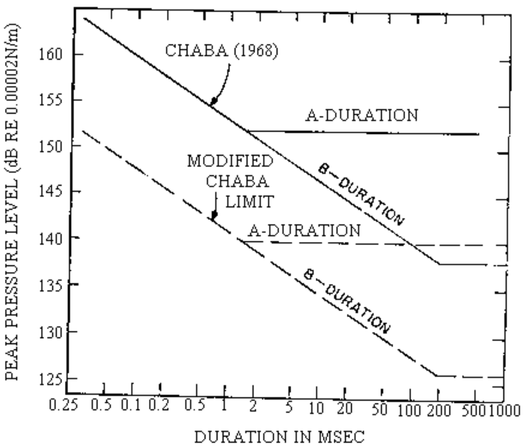

Figure G-1. The 1968 CHABA[G-1] Damage-Risk Criterion for Impulse Noise Exposure (solid lines) and a Proposed Modification (hatched lines). Peak Sound Pressure Level is Expressed as a Function of A- or B-Duration in the Range 25 Microseconds to 1 second.[G-1]

Rise Time

This parameter is usually correlated closely with peak pressure. Present evidence as to its effect on hearing risk is insufficient for allowance to be made for it in damage risk criteria.

Spectrum (Or Waveform)

Impulses with largely high frequency spectral components (e.g., reverberant gunshots) are generally more hazardous to the hearing mechanism than predominantly low-frequency impulses (e.g., distance-degraded blast waves; sonic booms) of the same peak SPL. However, comparative data are as yet too scanty to serve as the basis of differential damage risk criteria.

Number of Repeated Impulses

TTS (and, by inference, NIPTS) grows linearly with the number of impulses in a series, or linearly with time when the rate of impulses is constant. [G-8] CHABA [G-1] recommended an allowance of -5 dB for every tenfold increase in number of impulses in a daily exposure (Figure G-2). Recently, Coles and Rice [G-7] have contended that this rule is underprotective for large numbers (N) of impulses and have recommended a modification (see Figure G-2). In 1973, McRobert and Ward [G-3] questioned this modification, maintaining that it is probably grossly overprotective for N>1000, and commented also on the CHABA rule in the light of recent experiments. Figure G-2 reproduces a comparison by McRobert and Ward of the CHABA rule with Coles and Rice [G-7] and an "equal-energy" rule (10 dB weighting for each tenfold increase in N) originating at N = 100.

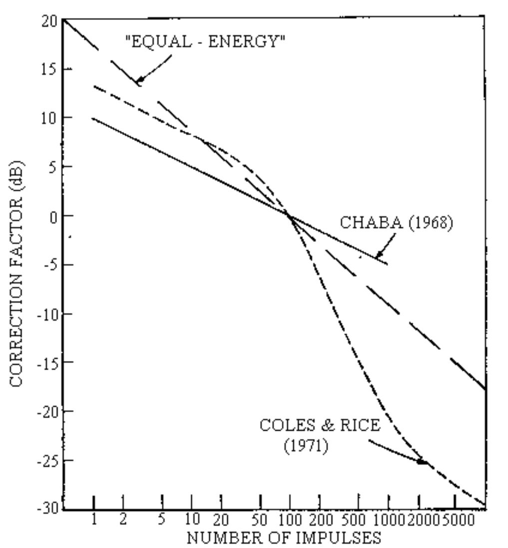

Figure G-2. Comparison of CHABA Weighting (Re: Zero at N=100 Impulses per Day) for Number (N) of Impulses in Daily Exposure[G-1] with the Proposed Modification by Coles and Rice[G-7] and an "Equal-Energy" Rule. After McRoberts and Ward.[G-3]

All in all, an "equal-energy" rule appears to fit the existing data tolerably well and is easy to apply in practice, but it may underestimate the hazard for values of N substantially less than 100 (isolated impulses).

Interval Between or Rate of Occurrence of Impulses

Ward, *et. al* G-8 showed that, when equal impulses occur at more than 1/s, TTS development is slower than when the average interval is in the range 1 to 9 s, presumably because the acoustic reflex is maintained. When the interval is long (range 9 - 30 seconds), TTS again develops more slowly, probably because the interval allows some recovery. A conservative rule would be to apply a 5 dB penalty when the average impulse interval lies between 1 and 10 seconds; such an interval may be typical of such activities as range shooting in groups, heavy hammering in industry, or pile-driving.

Individual Susceptibility to Inner Ear Damage

The distribution of individual susceptibility to NITTS and NIPTS in the population is believed to have the same pattern for impulse as for continuous noise. Similar rules may therefore be applied when predicting risk of impulse-NIPTS. The CHABA [G-1] DRC was intended to protect 95% of the population; a relaxation of 3 dB may be applied to obtain limits for the 90th percentile.

Orientation of the Ear

Based on Hodge & McCommons[G-12] and other data, CHABA[G-1] has recommended, in the case of gun noise, a penalty of 5 dB to apply when the noise strikes the eardrum at normal rather than grazing incidence. If uncertain, it is conservative to assume normal incidence.

Combinations of Impulse and Continuous Noise

Certain combinations of impulsive and continuous noise, such as occur in industry may be antagonistic-that is, one may provide some protection from the other-probably because of acoustic reflex activation. Other studies, however, show that the effects of combined impulse and steady noise are additive.[G-2, G-16] ISO, in its Recommendation R/1999,[G-17] proposed a flat weighting of 10 dB for "impulsiveness" in distributed noise, but the validity of this rule is questionable. On present evidence, it is probably safest to

evaluate simultaneous impulsive and continuous noise separately, each according to its own criterion.

Action of the Acoustic Reflex

This protective mechanism is valueless in the case of brief single or isolated impulses because it has a latency of at least 10 ms and takes up to 200 ms before being fully effective. Rapidly repeated impulses, [G-7] however, or simultaneous continuous noise,[G-15] may activate it sufficiently to provide up to 10 dB of protection : but this is too variable and uncertain to be allowed for in damage risk criteria.

Audiometric Frequency

Generally speaking, impulse noise affects the hearing in much the same way as does continuous noise, with TTS and PTS beginning and growing most rapidly at 4 to 6 kHz. It is possible, however, that impulse noise may have relatively more effect on high-frequency hearing or affect hearing at higher frequencies.[G-13,G-14]

Use of Equivalent Continuous Sound Level (L_{eq}) In Evaluation of Impulse Noise

Support for the extension of the equal-energy (equivalent A-weighted sound energy) concept of hearing hazard from continuous noise exposure to include impulse noise exposure has recently been gaining ground. [G-19] At the 1970 Teddington Conference on "Occupational Hearing Loss", it was suggested that a unifying rule based on this concept might be drawn up to link continuous and impulse noise exposure limits in a single continuum relating A-weighted sound level to effective daily exposure duration. [G-20] An empirical formula enabling the A-weighted L_{eq} to be calculated from the peak sound pressure (p_h) repetition rate in impulses per second (N) and the decay constant of the impulse envelope (k) in inverse seconds, was introduced as follows: [G-21]

where p_h is absolute pressure in pascals; not sound pressure level in dB. For one impulse of the B-type, this formulation simplifies such that the L_{eq} of an A-weighted continuous pulse of duration T is equal to the peak sound pressure level (in dB) of an impulse which decays by 20 dB in time T minus 9 dB. The use of this formula assumes the impulse is composed of broad-band noise that exponentially decays. This relationship, at the present time, should not be used to evaluate impulse data until it is further justified by more experimental research. However, it does provide further support of the equal energy concept outlined in Appendix C.

Summary and Conclusions

Hearing Conservation

The following rules may be recommended if it is desired to protect 90% of the people from significant impulse-NIPTS, that is, from impulse-NIPTS exceeding 5 dB at 4 kHz after 10 years of repeated exposures:

1. Measure or predict the peak level (SPL) and A- or B-type duration of the impulse, using proper oscillographic technique (NOTE: if the noise is sufficiently rapidly repetitive to fit Coles and Rice's [G-7] category "C", it may be treated and measured as continuous noise and evaluated accordingly in dBA. This usually means a repetition rate exceeding 10/s).

2. Use the "modified CHABA limit" in Figure G-1 to determine the maximum permissible peak SPL. If in doubt as to impulse type, assume B-duration.

3. If the number of similar impulses (N) experienced per day exceeds 100, reduce the permissible level by 10 dB for every tenfold increase in N (e.g., 10 dB when N = 1000, 20 dB when N = 10,000).

4. If N is less than 100, a higher peak level may be allowed in accordance with the same rule (e.g., 10 dB more when N = 10), provided that an absolute maximum value of

167 dB for durations less than 25 microseconds, grazing incidence (or 162 dB normal incidence) is not exceeded.

5. If the average repetition rate of impulses falls in the range 0.1 to 1 per second (i.e., the average interval between impulses is 1 to 10 seconds), reduce the permissible peak level by 5 dB.

6. If the impulses are known to reach human ears in the vicinity at grazing incidence, the permissible peak level may be raised by 5 dB. NOTE: This allowance should be used with caution and must not be applied if the surroundings are reverberant. If in doubt, assume normal incidence.

Effects Other Than on Hearing

See Section 3 in main document.

SPECIAL NOISES

Infrasound [G-26]

Frequencies below 16 Hz are referred to as infrasonic frequencies. Sources of infrasonic frequencies include earthquakes, winds, thunder, and jet aircraft. Man-made infrasound occurs at higher intensity levels than those found in nature. Complaints associated with high levels of infrasound resemble mild stress reactions and bizarre auditory sensations, such as pulsating and fluttering. It does not appear, however, that exposure to infrasound, at intensities below 130 dB SPL, present a serious health hazard. For the octave band centered at 16 Hz, the A-weighted equivalent to 130 dB SPL is 76 dB(A).

Ultrasound[G-26]

Ultrasonic frequencies are those above 20,000 Hz. They are produced by a variety of industrial equipment and jet engines. The effects of exposure to high intensity ultrasound (above 105 dB SPL) are also the effects observed during stress. However, there are experimental difficulties in assessing the effects of ultrasound since:

1. Ultrasonic waves are highly absorbed by air

2. Ultrasonic waves are often accompanied by broad-band noise and by sub-harmonics.

At levels below 105 dB SPL, however, there have been no observed adverse effects.

SONIC BOOMS

Present day knowledge regarding the acceptability of sonic booms by man is based on observations from both experimental field and laboratory studies and observations of community response to actual sonic boom exposures. Individual human response to sonic boom is very complex and involves not only the physical stimulus, but various characteristics of the environment as well as the experiences, attitudes and opinions of the population exposed. [G-22] One of the most comprehensive studies to date on sonic boom exposure of a large community over a relatively long period of time was the Oklahoma City study conducted in 1964. [G-23, G-24] Eight sonic booms per day at a median outdoor peak overpressure level of 57.46 pascals (or 1.2 psf)* were experienced by this community over a

* 1 psf = 47.88 pascals

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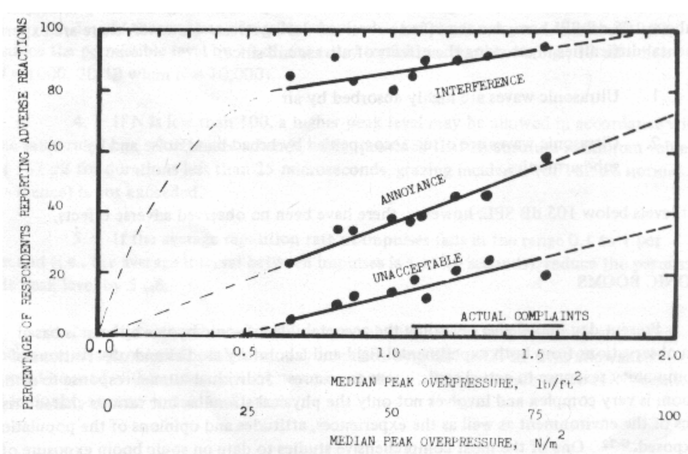
6 month period. Some results of this study are summarized in Figure G-3. For eight sonic booms/day, there is clear evidence that the median peak overpressure must be well below 47.88 pascals (or 1 psf) if no annoyance is reported. When interviewed, part of the population considered eight sonic booms/day to be unacceptable. By extrapolation, the level at which eight sonic booms per day should be acceptable for the population is slightly less than 23.94 pascals (or 0.5 psf). But even at 23.94 pascals, approximately 20% of the population consider themselves annoyed by an exposure of eight sonic booms/day. Linear extrapolation of the annoyance data of Figure G-3 indicates that annoyance will disappear in the total population only when the 8 sonic booms per day are less than 4.79 pascals. A linear extrapolation is probably not entirely justified, however, as certainly for sonic booms much less than 4.79 to 9.58 pascals, a large percentage of the population is not even expected to sense the boom. The fact that the extrapolation must curve is best illustrated by the interference curve of Figure G-3. Unless the extrapolation is curved as shown, interference would be predicted for about 70% of the population even when the peak overpressure is zero, i .e., no boom at all.



NOTE: Data compiled from Oklahoma City Study. Dashed lines are extrapolations. All data for 8 sonic boom/day.[G-22]

Figure G-3. Percentage of Respondents Reporting Adverse Reactions to Sonic Booms

G-12

So far the discussion has been about eight sonic boom exposures per day on a daily recurring basis. The more difficult question is how to interpret the effect on public health and welfare of sonic booms that are more infrequent than eight times per day. Kryter [G-25] provides a relationship which indicates that a sonic boom of 90.97 pascals once a day would be equal to 110 PNdB or a CNR of 98 dB. It further suggests that the level (which is proportional to P^2) should be reduced by one half (3 dB) for each doubling of number of occurrences. From Appendix A, L_{dn} is approximately related to CNR by L_{dn} = CNR -35 dB. Thus, a CNR of 98 equals an L_{dn} of 63 dB. If the sonic boom is made equivalent to an L_{dn} = 55 dB, so as to be consistent with the levels identified in the interference/ annoyance section of this document, the level of one daytime sonic boom per day must be less than 35.91 pascals. For more than eight sonic booms/day, the level should be less than 12.45 pascals or pascals. This result is slightly lower than the data from Figure G-3. However, extrapolating the annoyance line in the figure suggests that the 12.45 pascals level of 8 booms would annoy only 8% of the people and more would find it unacceptable. Therefore, the relationship proposed is: daytime peak over-pressure per day = pascals where N = number of sonic booms/day. Thus, the peak over-pressure of a sonic boom that occurs during the day should be no more than 35.91 pascals if the population is not to be annoyed or the general health and welfare adversely affected.

The standard sound level meter, which is a time-averaging device, will not properly measure the peak sound pressure level of sonic booms.

G-13

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Exhibit P

NBW Sound Study

RSG
the science of insight

EDF RENEWABLES

NORTHERN BOBWHITE SOLAR SOUND STUDY

Report | December 18, 2020

PREPARED FOR:
EDF RENEWABLES

SUBMITTED BY:
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INTRODUCTION

Northern Bobwhite Solar is a 96 Megawatt (MW) solar power project, proposed for Marion County, Kentucky. As part of the permitting for the project, RSG has performed sound propagation modeling of proposed project equipment to assess the acoustical impact of the project on the surrounding area. This report includes:

- A description of the project;
- A review of applicable sound level limits;
- Sound propagation modeling procedures;
- Sound propagation modeling results; and
- Conclusions.

A primer on acoustical terminology is included as Appendix A.

1.0 PROJECT DESCRIPTION

The Northern Bobwhite Solar project ("Project") is proposed for the northern part of Marion County, Kentucky. A map of the Project area is shown in Figure 1 and a map showing the Project layout is shown in Figure 2.

The Project is bounded on the west by Springfield Highway, on the east by Mays Chapel Road and Willis Trail Road, and on the north by the Marion/Washington County line and Simmstown Road. Danville Highway (U.S. Route 68) runs to the south at a distance of at least 2.1 kilometers (1.3 miles). The closest population center is the City of Lebanon, located approximately 1.8 kilometers (1.1 miles) to the southwest.

The Project is currently proposed to have a total output of 96 MW. Sound producing equipment will include inverters, tracking motors, medium voltage transformers, and a large step-up transformer. A total of 42 3,200 kW centralized inverters are proposed. The larger substation transformer is proposed to be rated at 75/100/125 MVA and 550 kV BIL.

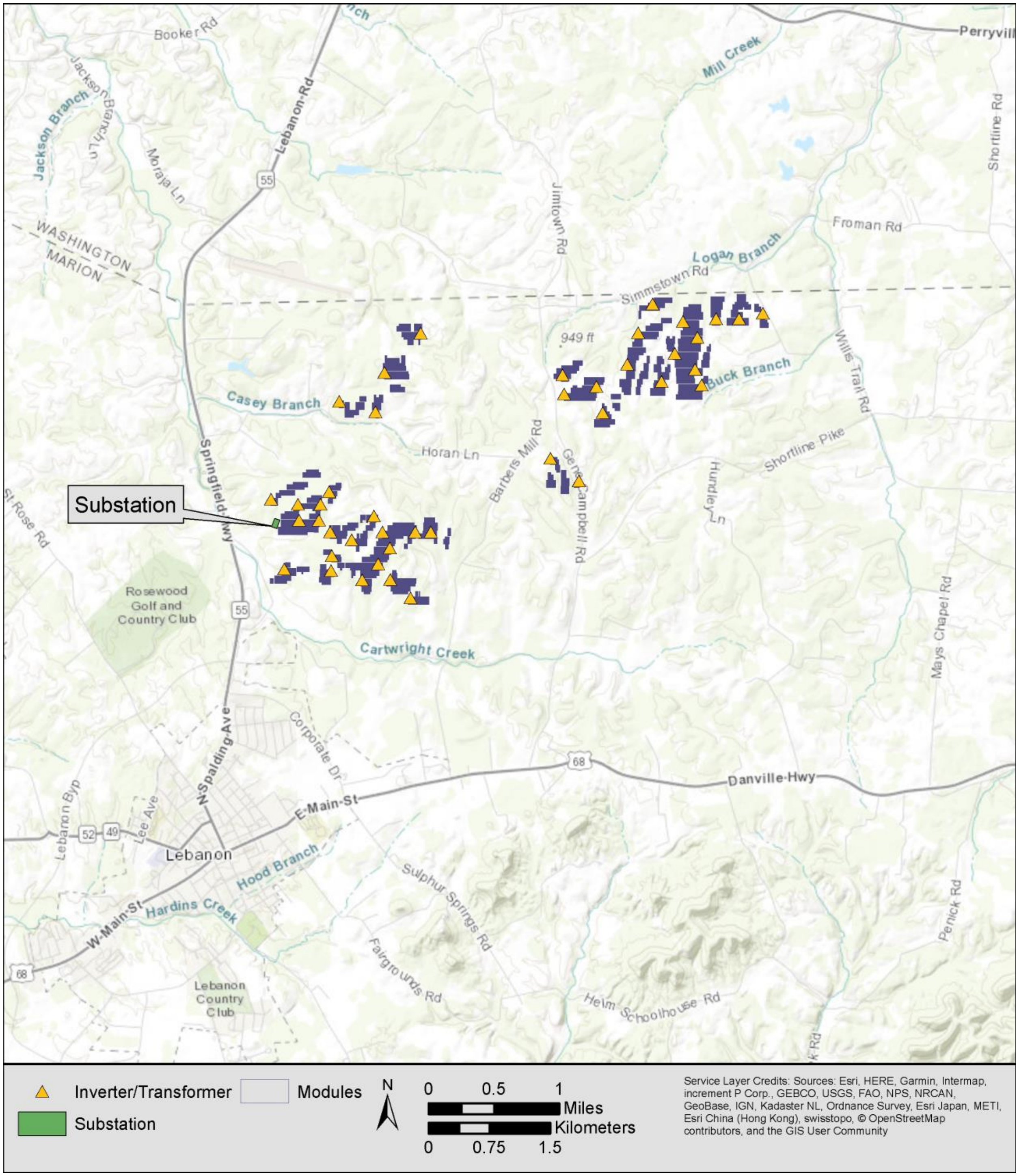

FIGURE 1: NORTHERN BOBWHITE SOLAR AREA MAP

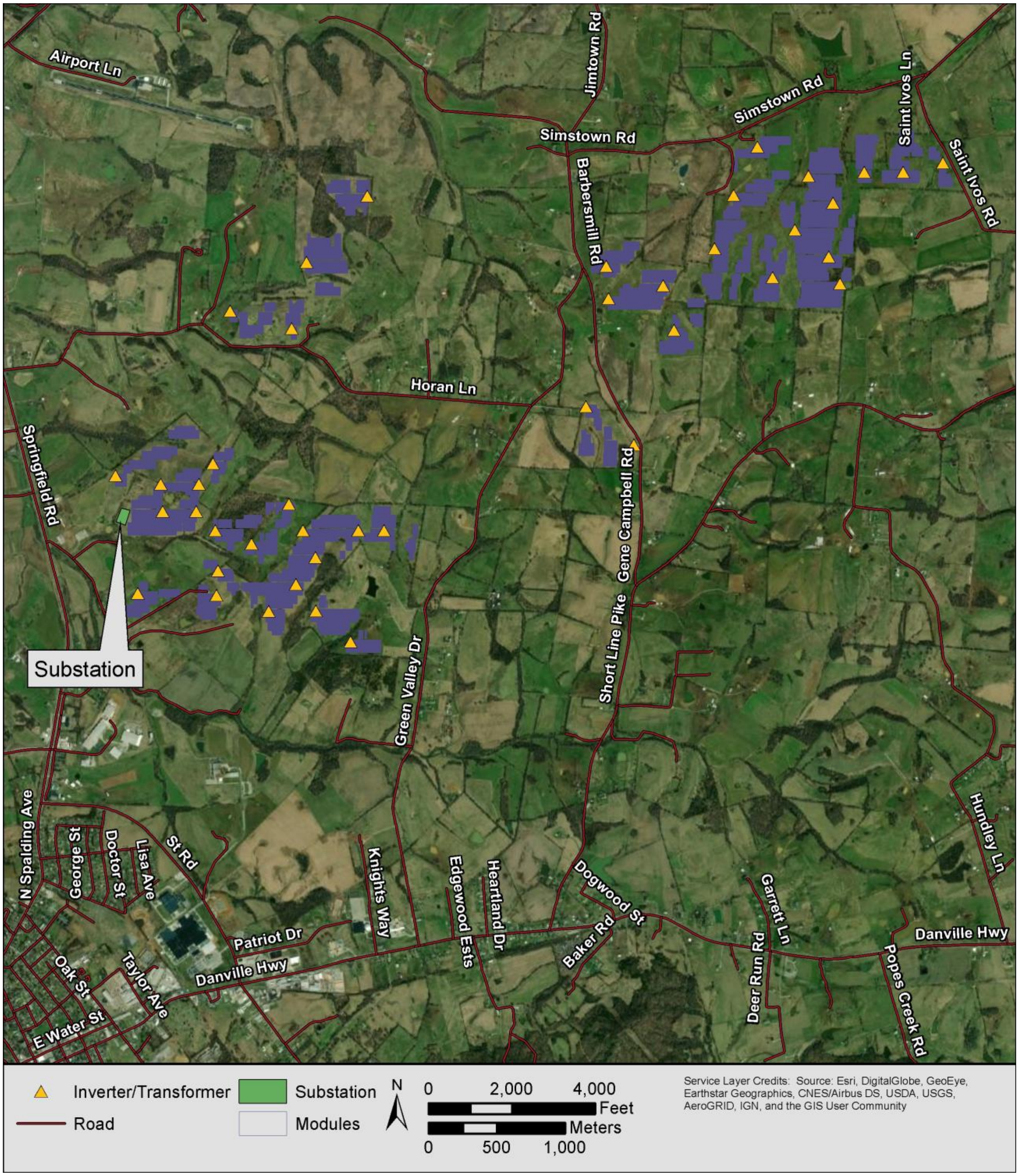

FIGURE 2: NORTHERN BOBWHITE SOLAR SITE MAP

2.0 APPLICABLE SOUND LEVEL LIMITS

Neither Marion County, nor the State of Kentucky have quantitative sound level limits applicable to this project. As a result, the project will develop design goals for comparison with Project sound emissions. The World Health Organization (WHO) has published sound level guidelines for community noise, which are discussed below. These guidelines are among the most comprehensive available and were developed as the culmination of an extensive literature review on the effects of sound on humans.

2.1 WORLD HEALTH ORGANIZATION GUIDELINES

The United Nation's World Health Organization (WHO) has published "Guidelines for Community Noise" (1999) which uses research on the health impacts of noise to develop guideline sound levels for communities. The foreword of the report states, "The scope of WHO's effort to derive guidelines for community noise is to consolidate actual scientific knowledge on the health impacts of community noise and to provide guidance to environmental health authorities and professionals trying to protect people from the harmful effects of noise in non-industrial environments."

Table 4.1 of the WHO's "Guidelines for Community Noise" (1999) provides guideline values for community noise in specific environments. The WHO guidelines suggest daytime and nighttime protective noise levels. During the day, the levels are 55 dBA L_{16h}, that is, an average over a 16-hour day, to protect against serious annoyance and 50 dBA L_{16h} to protect against moderate annoyance.

During the night, the WHO recommends limits of 45 dBA L_{8h}[1] and an instantaneous maximum of 60 dBA L_{Fmax} (fast response maximum). These are to be measured outside the bedroom window. These guidelines are based on the assumption that sound levels indoors would be reduced by 15 dBA with windows partially open. That is, the sound level inside the bedroom that is protective of sleep is 30 dBA L_{8h}. So long as the sound levels outside of the house remains at or below 45 dBA, sound levels in the bedroom will generally remain below 30 dBA. By closing windows, an additional ~10 dB of sound attenuation will result. In addition to protection against annoyance, these guidelines are intended to protect against speech disturbance, sleep disturbance, and hearing impairment. Of these factors, protection against annoyance and sleep disturbance require the lowest limits.

The WHO long-term guideline to protect against hearing impairment is 70 dBA L_{24h} over a lifetime exposure, and higher for occupational or recreational exposure.

Since the WHO guidelines were developed to protect human health, all suggested limits apply to sound levels at residences or areas where humans typically frequent. For example, the guidelines reflective of sleep disturbance are specified to be measured outside the bedroom window.

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[1] This is the equivalent average sound level, averaged over eight nighttime hours, measured outside the bedroom window.

In October 2009, WHO Europe conducted an updated literature review and built upon WHO's guidelines for nighttime noise. They added an *annual average* nighttime guideline level to protect against adverse effects on sleep disturbance. This guideline is 40 dBA $L_{night, outside}$, measured outside the bedroom window.

Neither the 1999 nor 2009 guidelines were developed specifically for noise from solar power generation.

Based on the discussion above, we recommend a nighttime sound level design goal of 45 dBA L_{8h} at night and 50 dBA L_{16h} during the day, as assessed at residences.

3.0 SOUND PROPAGATION MODELING

3.1 PROCEDURES

Sound Propagation modeling for the project is being conducted in accordance with the international standard ISO 9613-2, "Acoustics – Attenuation of sound during propagation outdoors, Part 2: General Method of Calculation." The ISO standard states,

> This part of ISO 9613 specifies an engineering method for calculating the attenuation of sound during propagation outdoors in order to predict the levels of environmental noise at a distance from a variety of sources. The method predicts the equivalent continuous A-weighted sound pressure level … under meteorological conditions favorable to propagation from sources of known sound emissions. These conditions are for downwind propagation … or, equivalently, propagation under a well-developed moderate ground-based temperature inversion, such as commonly occurs at night.

The algorithm takes into account source sound power levels, ground surface reflection and absorption, atmospheric absorption, geometric divergence, meteorological conditions, walls, barriers, berms, and terrain.

ISO 9613-2 also assumes downwind sound propagation between every source and every receiver, consequently, all wind directions, including the prevailing wind directions, are taken into account.

The acoustical modeling software used to implement 9613-2 was CadnaA, from Datakustik GmbH. CadnaA is a widely accepted acoustical propagation modeling tool, used by many noise control professionals in the United States and internationally.

For this analysis, we used porous ground (G = 1) except within the substation, which was assumed to be mostly porous (G = 0.6). Inverter pads were assumed to be concrete and are modeled as acoustically hard (G = 0). Other sound propagation model parameters are shown in Table 3. Modeling was done at every point in a 20-meter by 20-meter (131-foot by 131-foot) grid, with receivers placed at a height of 4 meters (13 feet). Sound sources were modeled as point sources with the transformers modeled at a height of 3 meters (9.8 feet), the inverters and medium inverters at a height of 2 meters (6.6 feet), and the trackers at a height of 1.5 meters (4.9 feet). The model does not consider sound dampening effects of solar panels or trees within the property boundary. Since most of the sound-producing equipment is surrounded by solar panels, this should be considered a conservative assumption.

One large transformer was modeled in the project substation. This transformer will step electricity up to the voltage of the power lines. Sound emissions were calculated from a combination of manufacturer specified sound pressure levels, expected transformer dimensions, and spectra from RSG measurements of similar-size transformers.

Forty-two 3,200 kW inverters were modeled at locations throughout the project area. The currently-proposed inverter is the Sunny Central UP inverter, though this may change later in development of the project. Inverter sound powers were derived from manufacturer-specified sound pressure levels, unit dimensions, and the sound spectrum of a similar size. A medium voltage transformer was co-located at each of the inverter locations. This sound power was derived from NEMA TR-1 specified sound emissions, the dimensions of similar equipment, and a sound spectrum measured by RSG for a similar size transformer.

A total of 210 trackers were modeled. The modeled tracker type is manufactured by Array Technologies, Inc. (ATI). The modeled tracker sound power was obtained by EDF from the manufacturer.

Two different scenarios were modeled. The first, the “daytime” configuration models the trackers, inverters, medium voltage transformers, and the large transformer in the ONAF (with fans) cooling mode. The “nighttime” configuration includes the inverters, medium voltage transformers and large transformer in the ONAN (no fans) cooling mode. Note night inverter operation has not yet been decided for this project, so the inverters were modeled at night as a conservative assumption.

Table 1 shows the number of each type of equipment modeled, the modeled sound power, and the configurations it was modeled for. Note the equipment manufacturers shown below, along with the locations of the inverters, trackers, and medium transformers may change in the constructed layout. Any installed layout will be designed to meet Project sound level goals. All sound sources that are expected to be tonal were modeled with a 5 dB penalty added to the overall sound power.

TABLE 1: MODELING CONFIGURATIONS

Equipment Type	Manufacturer	Mode	Modeled Sound Power (dBA)	Number Modeled	Modeling Configuration	
					Day	Night
Large Transformer	Iljin	ONAN	102	1	-	X
Large Transformer	Iljin	ONAF	103	1	X	-
Medium Voltage Transformer	NA	ONAN	85	42	X	X
Inverter	SMA	Maximum Output	97	42	X	X
Tracker	Array Technologies, Inc.	Continuous Operation	66	210	X	-

3.2 RESULTS

Sound propagation modeling results are shown in Figure 3 for the Daytime scenario and Figure 4 for the Nighttime scenario. Modeled sound levels at each residence are shown in Table 5 of Appendix C. The highest sound levels at a residence are 42 dBA for both the daytime and nighttime scenarios. These levels are 3 dB and 8 dB below the project design goals. The worst case residence from a single inverter is located approximately 115 meters (377 feet) away, though that still includes contribution from other sound sources. Table 1 shows sound levels at different distances from a single inverter location (also including trackers and medium voltage transformers) including a tonal penalty.

TABLE 2: SOUND LEVELS AT DIFFERENT DISTANCES FROM SINGLE INVERTER LOCATIONS

Distance (meters)	Distance (feet)	Sound Pressure Level (dBA)
25	82	58
50	164	51
90	295	45
100	328	44
150	492	40
200	656	37

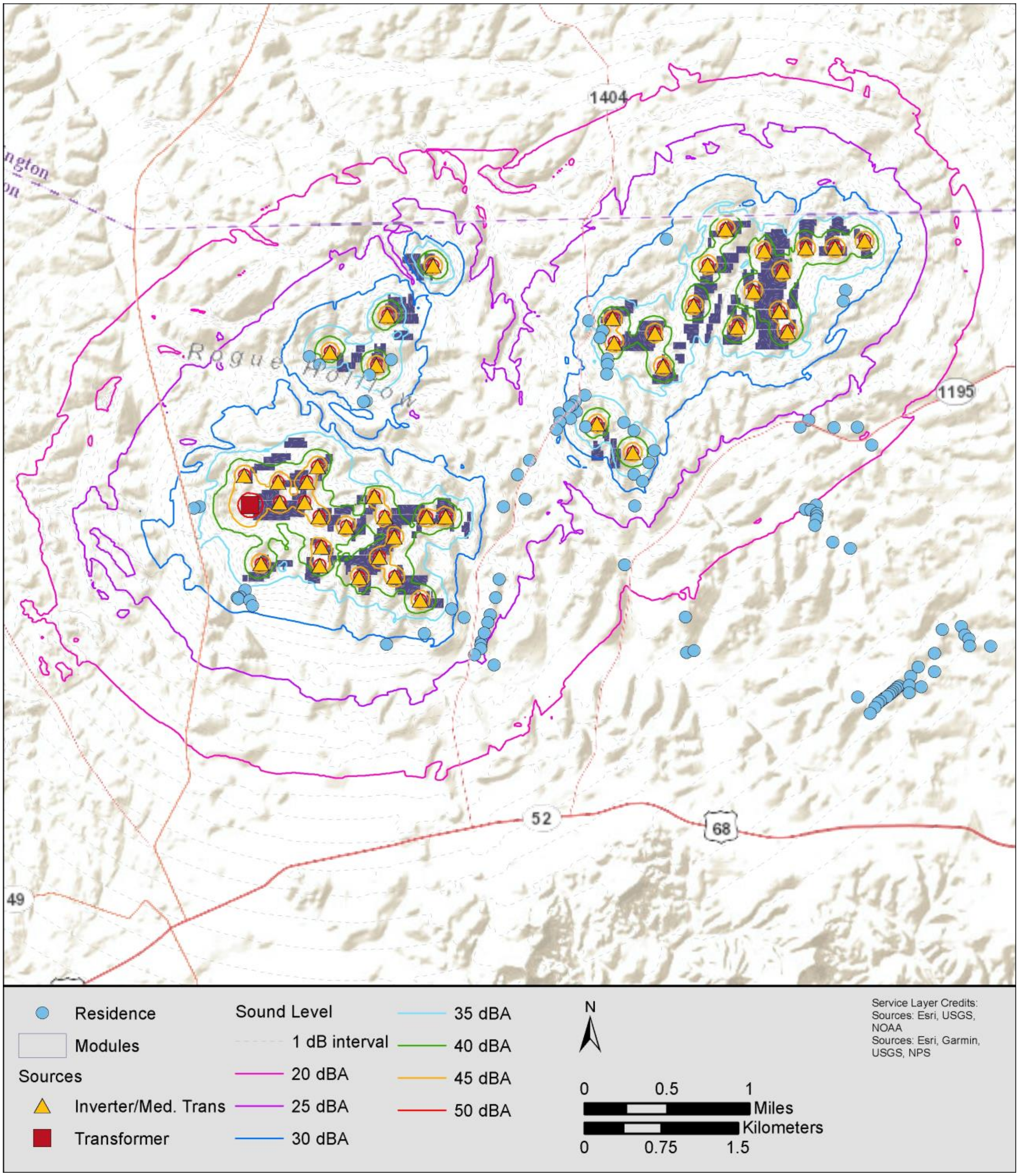

FIGURE 3: SOUND PROPAGATION MODELING RESULTS – DAYTIME SCENARIO

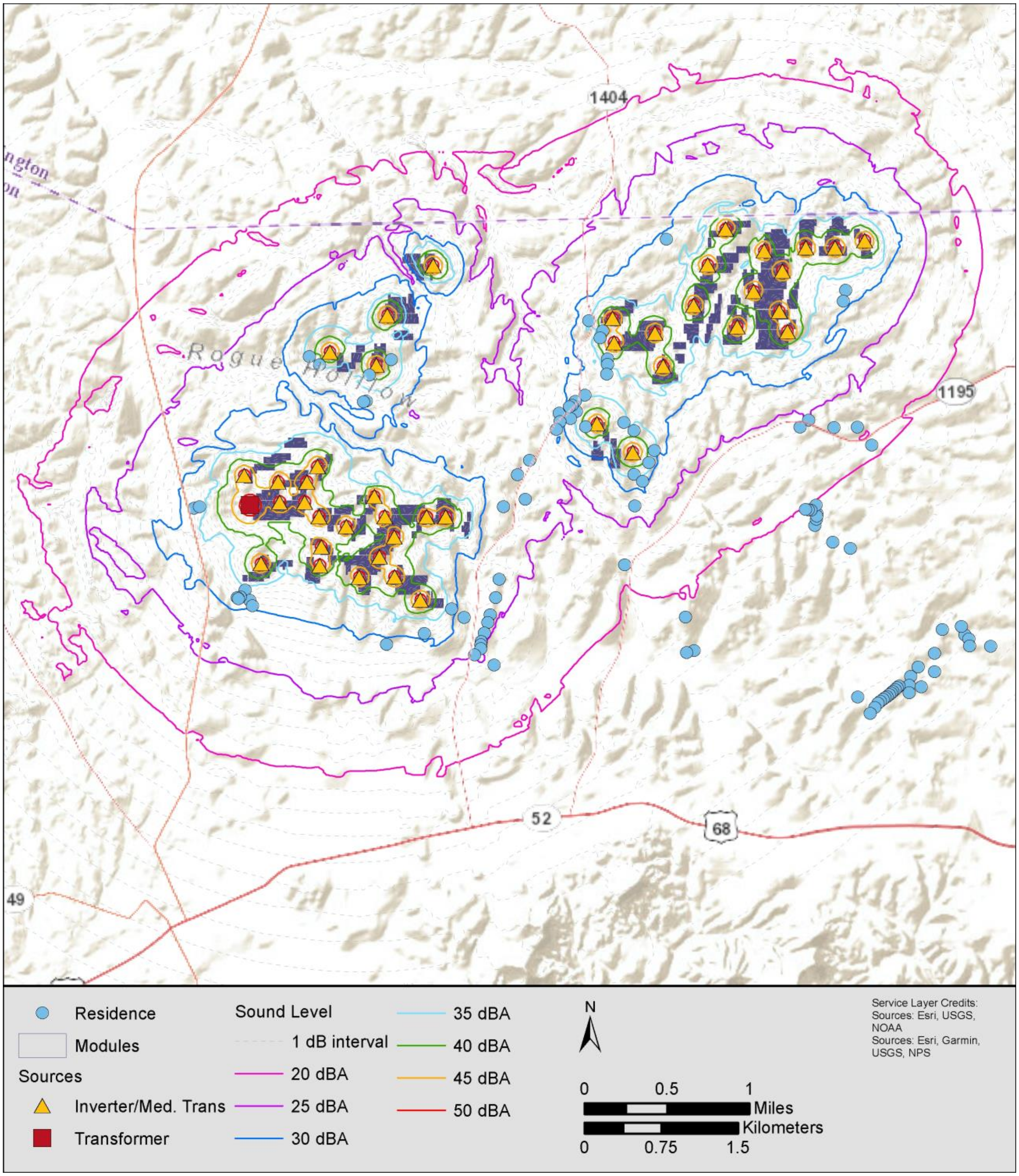

FIGURE 4: SOUND PROPAGATION MODELING RESULTS – NIGHTTIME SCENARIO

4.0 CONCLUSIONS

The Northern Bobwhite Solar power project (“Project”) is a 96 Megawatt (MW) solar power project, proposed for Marion County, Kentucky. As part of the permitting for the Project, RSG has performed a noise analysis for proposed components, including, trackers, inverters, and transformers. Sound propagation modeling was performed according the ISO 9613-2 sound propagation modeling algorithm. Both Daytime and Nighttime scenarios were modeled, that included equipment expected to operate during daytime and nighttime hours, respectively.

There are currently no quantitative sound level limits that are applicable to the Project. As a result, we have developed Project design goals based on World Health Organization (WHO) guidelines. These design goals are 50 dBA L_{16h} during the daytime and 45 dBA L_{8h} at night. In addition, we added a 5 dB penalty to sources that are expected to generate tonal sound.

Our conclusions are as follows:

- Modeled sound levels at the worst-case residence are 42 dBA for both the daytime and nighttime scenarios.
- Modeled sound levels were 3 to 8 dB below design goal sound level thresholds at all homes surrounding the Project.

APPENDIX A. ACOUSTICS PRIMER

EXPRESSING SOUND IN DECIBEL LEVELS

The varying air pressure that constitutes sound can be characterized in many different ways. The human ear is the basis for the metrics that are used in acoustics. Normal human hearing is sensitive to sound fluctuations over an enormous range of pressures, from about 20 micropascals (the “threshold of audibility”) to about 20 Pascals (the “threshold of pain”).[2] This factor of one million in sound pressure difference is challenging to convey in engineering units. Instead, sound pressure is converted to sound “levels” in units of “decibels” (dB, named after Alexander Graham Bell). Once a measured sound is converted to dB, it is denoted as a level with the letter “L”.

The conversion from sound pressure in pascals to sound level in dB is a four-step process. First, the sound wave’s measured amplitude is squared, and the mean is taken. Second, a ratio is taken between the mean square sound pressure and the square of the threshold of audibility (20 micropascals). Third, using the logarithm function, the ratio is converted to factors of 10. The final result is multiplied by 10 to give the decibel level. By this decibel scale, sound levels range from 0 dB at the threshold of audibility to 120 dB at the threshold of pain.

Typical sound sources, and their sound pressure levels, are listed on the scale in Figure 5.

HUMAN RESPONSE TO SOUND LEVELS: APPARENT LOUDNESS

For every 20 dB increase in sound level, the sound pressure increases by a *factor* of 10; the sound *level* range from 0 dB to 120 dB covers 6 factors of 10, or one million, in sound *pressure*. However, for an increase of 10 dB in sound *level* as measured by a meter, humans perceive an approximate doubling of apparent loudness: to the human ear, a sound level of 70 dB sounds about “twice as loud” as a sound level of 60 dB. Smaller changes in sound level, less than 3 dB up or down, are generally not perceptible.

[2] The pascal is a measure of pressure in the metric system. In Imperial units, they are themselves very small: one pascal is only 145 millionths of a pound per square inch (psi). The sound pressure at the threshold of audibility is only 3 one-billionths of one psi: at the threshold of pain, it is about 3 one-thousandths of one psi.

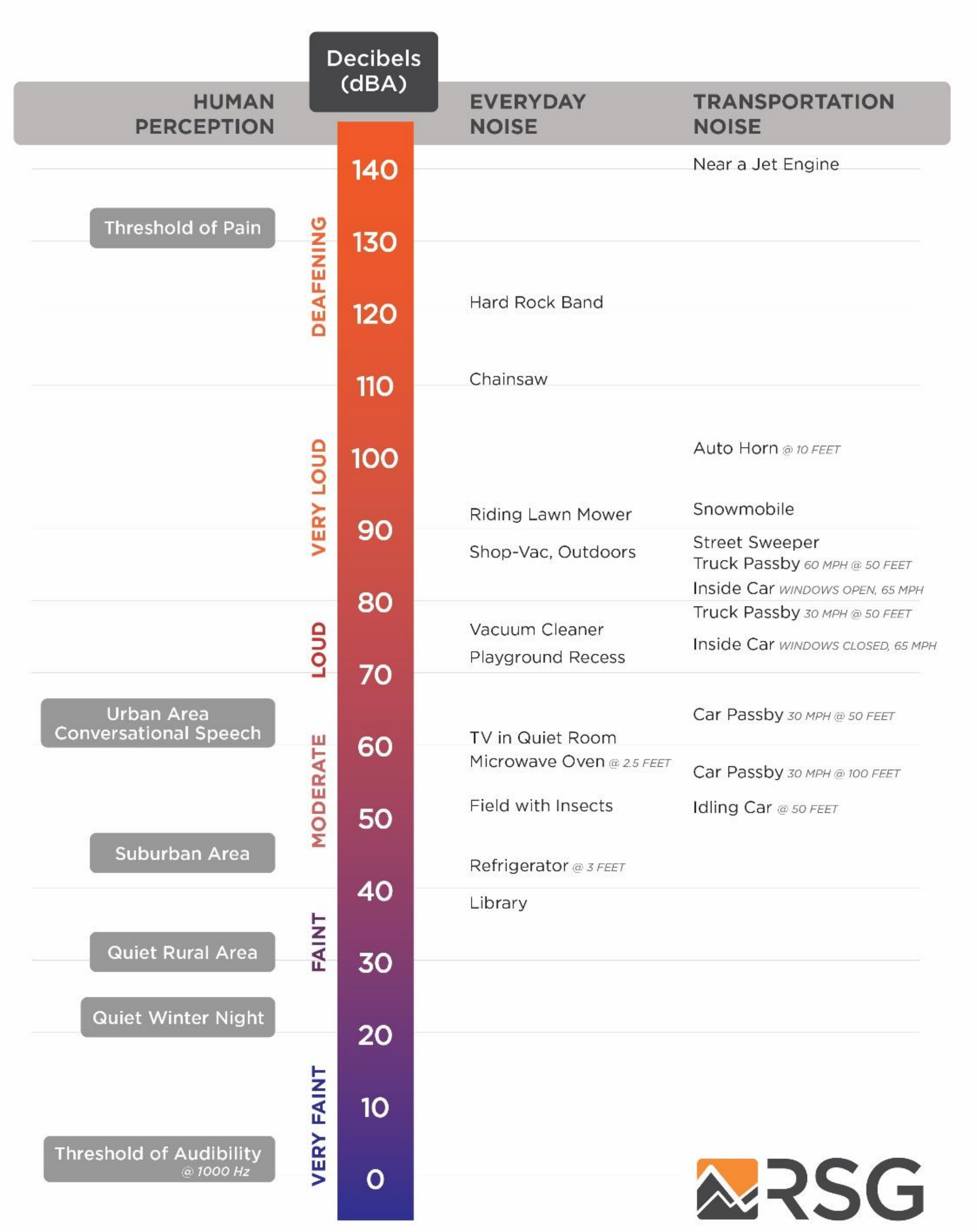

FIGURE 5: A SCALE OF SOUND PRESSURE LEVELS FOR TYPICAL SOUND SOURCES

FREQUENCY SPECTRUM OF SOUND

The “frequency” of a sound is the rate at which it fluctuates in time, expressed in Hertz (Hz), or cycles per second. Very few sounds occur at only one frequency: most sound contains energy at many different frequencies, and it can be broken down into different frequency divisions, or bands. These bands are similar to musical pitches, from low tones to high tones. The most common division is the standard octave band. An octave is the range of frequencies whose upper frequency limit is twice its lower frequency limit, exactly like an octave in music. An octave band is identified by its center frequency: each successive band's center frequency is twice as high (one octave) as the previous band. For example, the 500 Hz octave band includes all sound whose frequencies range between 354 Hz (Hertz, or cycles per second) and 707 Hz. The next band is centered at 1,000 Hz with a range between 707 Hz and 1,414 Hz. The range of human hearing is divided into 10 standard octave bands: 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz, 4,000 Hz, 8,000 Hz, and 16,000 Hz. For analyses that require finer frequency detail, each octave-band can be subdivided. A commonly used subdivision creates three smaller bands within each octave band, or so-called 1/3-octave bands.

HUMAN RESPONSE TO FREQUENCY: WEIGHTING OF SOUND LEVELS

The human ear is not equally sensitive to sounds of all frequencies. Sounds at some frequencies seem louder than others, despite having the same decibel level as measured by a sound level meter. In particular, human hearing is much more sensitive to medium pitches (from about 500 Hz to about 4,000 Hz) than to very low or very high pitches. For example, a tone measuring 80 dB at 500 Hz (a medium pitch) sounds quite a bit louder than a tone measuring 80 dB at 60 Hz (a very low pitch). The frequency response of normal human hearing ranges from 20 Hz to 20,000 Hz. Below 20 Hz, sound pressure fluctuations are not "heard", but sometimes can be "felt". This is known as "infrasound". Likewise, above 20,000 Hz, sound can no longer be heard by humans; this is known as "ultrasound". As humans age, they tend to lose the ability to hear higher frequencies first; many adults do not hear very well above about 16,000 Hz. Most natural and man-made sound occurs in the range from about 40 Hz to about 4,000 Hz. Some insects and birdsongs reach to about 8,000 Hz.

To adjust measured sound pressure levels so that they mimic human hearing response, sound level meters apply filters, known as "frequency weightings", to the signals. There are several defined weighting scales, including "A", "B", "C", "D", "G", and "Z". The most common weighting scale used in environmental noise analysis and regulation is A-weighting. This weighting represents the sensitivity of the human ear to sounds of low to moderate level. It attenuates sounds with frequencies below 1000 Hz and above 4000 Hz; it amplifies very slightly sounds between 1000 Hz and 4000 Hz, where the human ear is particularly sensitive. The C-weighting scale is sometimes used to describe louder sounds. The B- and D- scales are seldom used. All of these frequency weighting scales are normalized to the average human hearing response at 1000 Hz: at this frequency, the filters neither attenuate nor amplify. When a reported sound level has been filtered using a frequency weighting, the letter is appended to "dB". For example, sound with A-weighting is usually denoted "dBA". When no filtering is applied, the level is denoted "dB" or "dBZ". The letter is also appended as a subscript to the level indicator "L", for example "L_A" for A-weighted levels.

TIME RESPONSE OF SOUND LEVEL METERS

Because sound levels can vary greatly from one moment to the next, the time over which sound is measured can influence the value of the levels reported. Often, sound is measured in real time, as it fluctuates. In this case, acousticians apply a so-called “time response” to the sound level meter, and this time response is often part of regulations for measuring sound. If the sound level is varying slowly, over a few seconds, “Slow” time response is applied, with a time constant of one second. If the sound level is varying quickly (for example, if brief events are mixed into the overall sound), “Fast” time response can be applied, with a time constant of one-eighth of a second.[3] The time response setting for a sound level measurement is indicated with the subscript “S” for Slow and “F” for Fast: L_S or L_F. A sound level meter set to Fast time response will indicate higher sound levels than one set to Slow time response when brief events are mixed into the overall sound, because it can respond more quickly.

In some cases, the maximum sound level that can be generated by a source is of concern. Likewise, the minimum sound level occurring during a monitoring period may be required. To measure these, the sound level meter can be set to capture and hold the highest and lowest levels measured during a given monitoring period. This is represented by the subscript “max”, denoted as “L_{max}”. One can define a “max” level with Fast response L_{Fmax} (1/8-second time constant), Slow time response L_{Smax} (1-second time constant), or Continuous Equivalent level over a specified time period $L_{eq,max}$.

ACCOUNTING FOR CHANGES IN SOUND OVER TIME

A sound level meter’s time response settings are useful for continuous monitoring. However, they are less useful in summarizing sound levels over longer periods. To do so, acousticians apply simple statistics to the measured sound levels, resulting in a set of defined types of sound level related to averages over time. An example is shown in Figure 6. The sound level at each instant of time is the grey trace going from left to right. Over the total time it was measured (1 hour in the figure), the sound energy spends certain fractions of time near various levels, ranging from the minimum (about 27 dB in the figure) to the maximum (about 65 dB in the figure). The simplest descriptor is the average sound level, known as the Equivalent Continuous Sound Level. Statistical levels are used to determine for what percentage of time the sound is louder than any given level. These levels are described in the following sections.

EQUIVALENT CONTINUOUS SOUND LEVEL - LEQ

One straightforward, common way of describing sound levels is in terms of the Continuous Equivalent Sound Level, or L_{eq}. The L_{eq} is the average sound pressure level over a defined period of time, such as one hour or one day. L_{eq} is the most commonly used descriptor in noise standards and regulations. L_{eq} is representative of the overall sound to which a person is exposed. Because of the logarithmic calculation of decibels, L_{eq} tends to favor higher sound levels: loud and infrequent sources have a larger impact on the resulting average sound level than quieter but more frequent sounds. For example, in Figure 6, even though the sound levels

[3] There is a third-time response defined by standards, the “Impulse” response. This response was defined to enable use of older, analog meters when measuring very brief sounds; it is no longer in common use.

spends most of the time near about 34 dBA, the L_{eq} is 41 dBA, having been "inflated" by the maximum level of 65 dBA and other occasional spikes over the course of the hour.

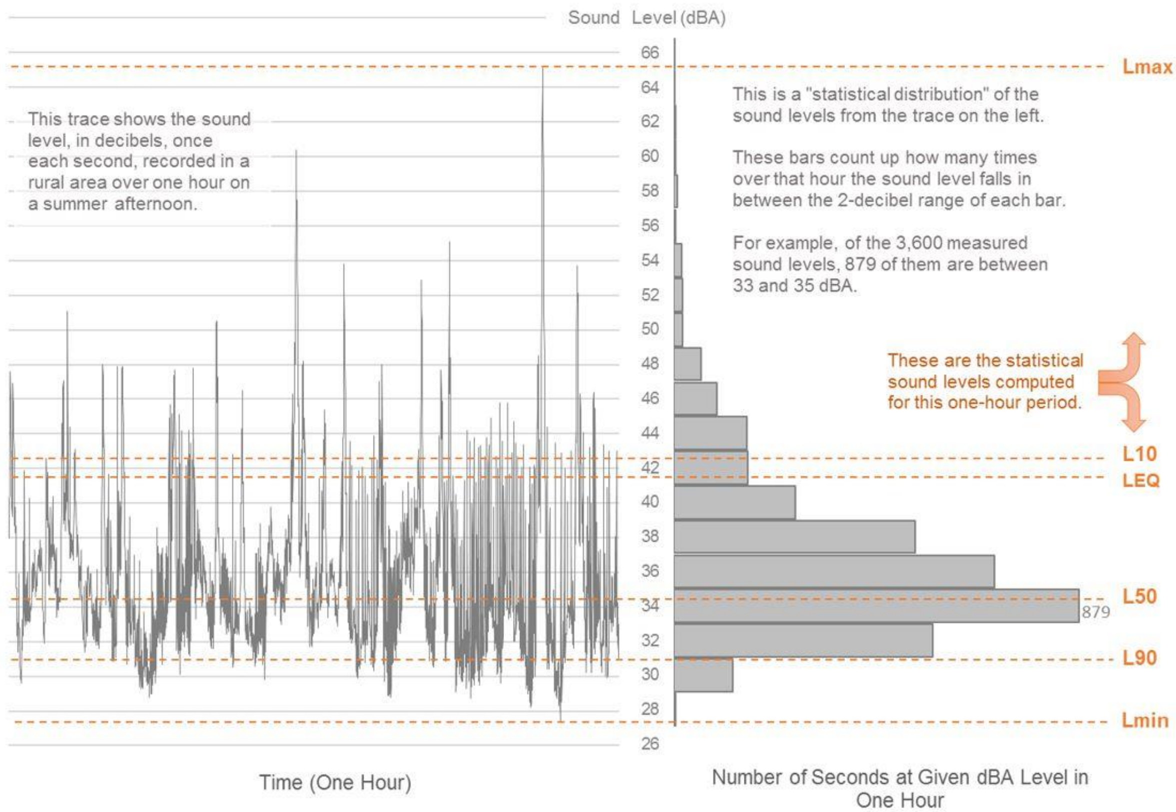

FIGURE 6: EXAMPLE OF DESCRIPTIVE TERMS OF SOUND MEASUREMENT OVER TIME

PERCENTILE SOUND LEVELS – LN

Percentile sound levels describe the statistical distribution of sound levels over time. "L_n" is the level above which the sound spends "n" percent of the time. For example, L_{90} (sometimes called the "residual base level") is the sound level exceeded 90% of the time: the sound is louder than L_{90} most of the time. L_{10} is the sound level that is exceeded only 10% of the time. L_{50} (the "median level") is exceeded 50% of the time: half of the time the sound is louder than L_{50}, and half the time it is quieter than L_{50}. Note that L_{50} (median) and L_{eq} (mean) are not always the same, for reasons described in the previous section.

L_{90} is often a good representation of the "ambient sound" in an area. This is the sound that persists for longer periods, and below which the overall sound level seldom falls. It tends to filter out other short-term environmental sounds that aren't part of the source being investigated. L_{10} represents the higher, but less frequent, sound levels. These could include such events as barking dogs, vehicles driving by and aircraft flying overhead, gusts of wind, and work operations. L_{90} represents the background sound that is present when these event sounds are excluded.

Note that if one sound source is very constant and dominates the soundscape in an area, all of the descriptive sound levels mentioned here tend toward the same value. It is when the sound is varying widely from one moment to the next that the statistical descriptors are useful.

APPENDIX B. MODELING INFORMATION

TABLE 3: SOUND PROPAGATION MODELING PARAMETERS

Parameter	Setting
Ground Absorption	Spectral for all sources, porous ground (G=1), mostly porous ground (G=0.6) for substations, hard ground (G=0) for inverter pads
Atmospheric Absorption	Based on 10 Degrees Celsius, 70% Relative Humidity
Reflections	None
Receiver Height	4 meters (13.2 feet) for residences and grid
Search Distance	8 kilometers (5 miles)

TABLE 4: MODELED SOUND SOURCE LOCATIONS[4]

Source ID	Source Type	Relative Height (m)	Coordinates (UTM NAD83 Z16N)		
			X (m)	Y (m)	Z (m)
Inv01	Inverter	2	660943	4166178	269
Inv02	Inverter	2	659695	4165338	282
Inv03	Inverter	2	659407	4165941	277
Inv04	Inverter	2	660652	4166110	272
Inv05	Inverter	2	660367	4166110	275
Inv06	Inverter	2	659958	4166079	272
Inv07	Inverter	2	660137	4165882	277
Inv08	Inverter	2	659583	4166294	273
Inv09	Inverter	2	659857	4165686	276
Inv10	Inverter	2	660106	4165489	276
Inv11	Inverter	2	660188	4165292	285
Inv12	Inverter	2	659270	4165548	282
Inv13	Inverter	2	658970	4164952	289
Inv14	Inverter	2	658892	4165278	279
Inv15	Inverter	2	658490	4165182	289
Inv16	Inverter	2	658474	4165420	285
Inv17	Inverter	2	658676	4164112	268
Inv18	Inverter	2	658326	4164392	289
Inv19	Inverter	2	656722	4165935	271
Inv20	Inverter	2	656276	4165449	268
Inv21	Inverter	2	656167	4164963	264
Inv22	Inverter	2	655716	4165091	259
Inv23	Inverter	2	655591	4163975	270
Inv24	Inverter	2	654878	4163887	259

[4] Due to the number of Trackers modeled, they are not shown in this table. Five trackers were modeled co-located with each inverter.

Source ID	Source Type	Relative Height (m)	Coordinates (UTM NAD83 Z16N)		
			X (m)	Y (m)	Z (m)
Inv25	Inverter	2	655488	4163821	266
Inv26	Inverter	2	655208	4163821	262
Inv27	Inverter	2	655223	4163624	252
Inv28	Inverter	2	655468	4163624	259
Inv29	Inverter	2	655873	4163386	261
Inv30	Inverter	2	655608	4163482	257
Inv31	Inverter	2	656148	4163678	283
Inv32	Inverter	2	656846	4163482	263
Inv33	Inverter	2	656657	4163482	277
Inv34	Inverter	2	656250	4163482	279
Inv35	Inverter	2	656342	4163285	274
Inv36	Inverter	2	655628	4163190	265
Inv37	Inverter	2	655039	4163023	250
Inv38	Inverter	2	655616	4163007	269
Inv39	Inverter	2	656199	4163088	266
Inv40	Inverter	2	656000	4162892	265
Inv41	Inverter	2	656346	4162894	266
Inv42	Inverter	2	656600	4162669	271
MTrans01	Med. Transformer	2	660943	4166178	269
MTrans02	Med. Transformer	2	659695	4165338	282
MTrans03	Med. Transformer	2	659407	4165941	277
MTrans04	Med. Transformer	2	660652	4166110	272
MTrans05	Med. Transformer	2	660367	4166110	275
MTrans06	Med. Transformer	2	659958	4166079	272
MTrans07	Med. Transformer	2	660137	4165882	277
MTrans08	Med. Transformer	2	659583	4166294	273
MTrans09	Med. Transformer	2	659857	4165686	276
MTrans10	Med. Transformer	2	660106	4165489	276
MTrans11	Med. Transformer	2	660188	4165292	285
MTrans12	Med. Transformer	2	659270	4165548	282
MTrans13	Med. Transformer	2	658970	4164952	289
MTrans14	Med. Transformer	2	658892	4165278	279
MTrans15	Med. Transformer	2	658490	4165182	289
MTrans16	Med. Transformer	2	658474	4165420	285
MTrans17	Med. Transformer	2	658676	4164112	268
MTrans18	Med. Transformer	2	658326	4164392	289
MTrans19	Med. Transformer	2	656722	4165935	271
MTrans20	Med. Transformer	2	656276	4165449	268
MTrans21	Med. Transformer	2	656167	4164963	264
MTrans22	Med. Transformer	2	655716	4165091	259

Source ID	Source Type	Relative Height (m)	Coordinates (UTM NAD83 Z16N)		
			X (m)	Y (m)	Z (m)
MTrans23	Med. Transformer	2	655591	4163975	270
MTrans24	Med. Transformer	2	654878	4163887	259
MTrans25	Med. Transformer	2	655488	4163821	266
MTrans26	Med. Transformer	2	655208	4163821	262
MTrans27	Med. Transformer	2	655223	4163624	252
MTrans28	Med. Transformer	2	655468	4163624	259
MTrans29	Med. Transformer	2	655873	4163386	261
MTrans30	Med. Transformer	2	655608	4163482	257
MTrans31	Med. Transformer	2	656148	4163678	283
MTrans32	Med. Transformer	2	656846	4163482	263
MTrans33	Med. Transformer	2	656657	4163482	277
MTrans34	Med. Transformer	2	656250	4163482	279
MTrans35	Med. Transformer	2	656342	4163285	274
MTrans36	Med. Transformer	2	655628	4163190	265
MTrans37	Med. Transformer	2	655039	4163023	250
MTrans38	Med. Transformer	2	655616	4163007	269
MTrans39	Med. Transformer	2	656199	4163088	266
MTrans40	Med. Transformer	2	656000	4162892	265
MTrans41	Med. Transformer	2	656346	4162894	266
MTrans42	Med. Transformer	2	656600	4162669	271
LTrans	Large Transformer	3	654933	4163590	250

APPENDIX C. RECEIVER INFORMATION

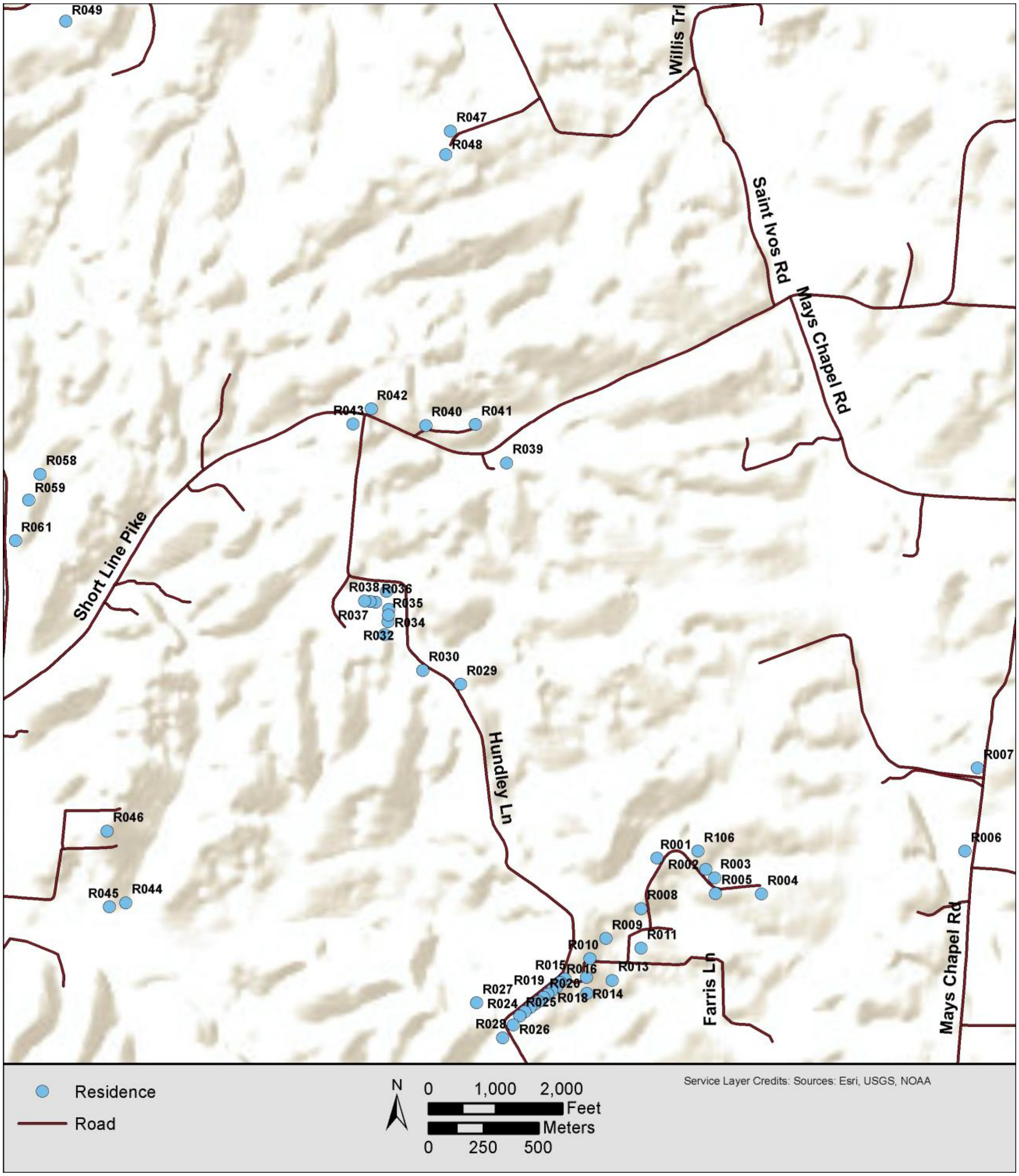

FIGURE 7 : RECEIVER LOCATIONS – EASTERN VIEW

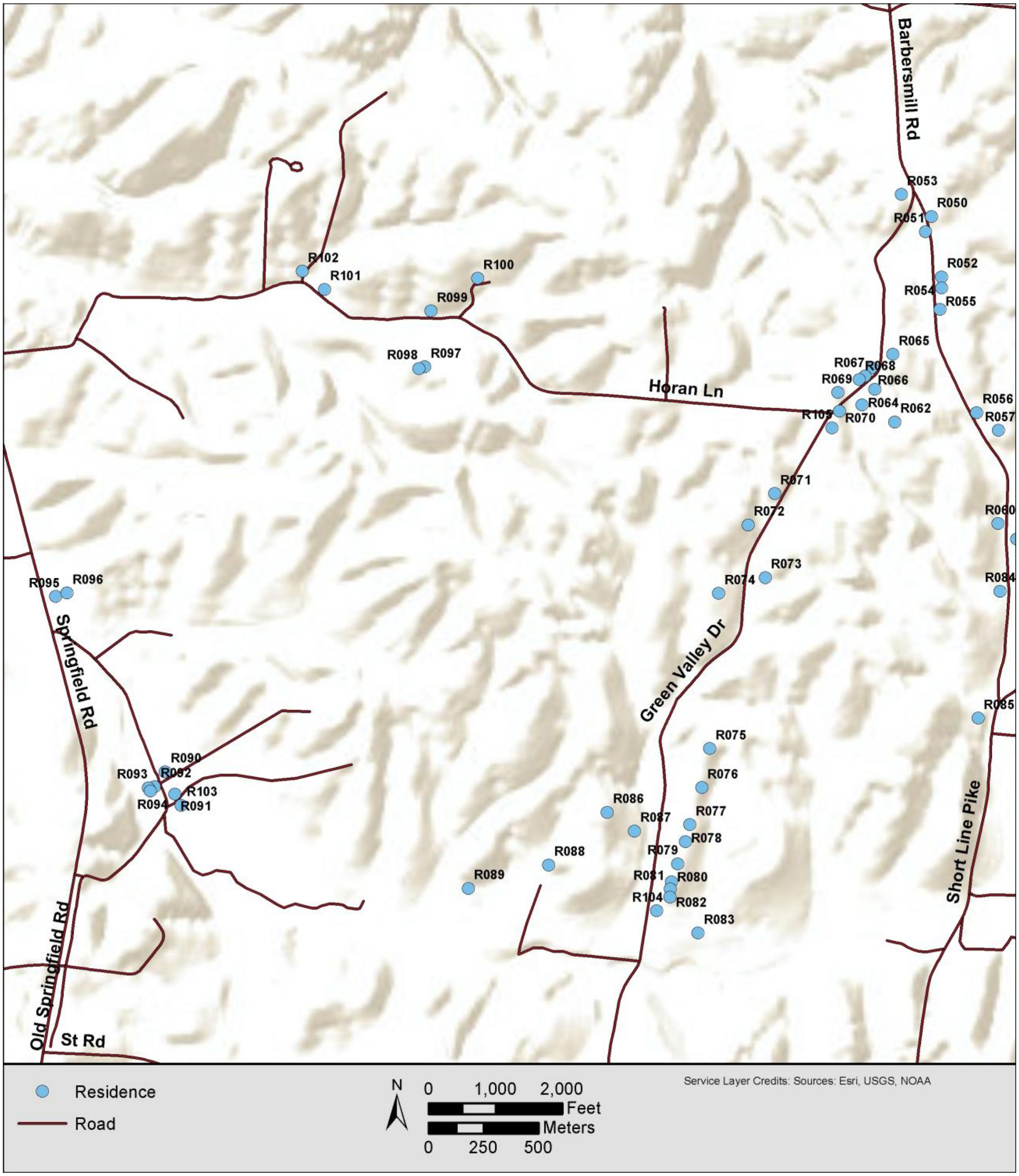

FIGURE 8: RECEIVER LOCATIONS - WESTERN VIEW

TABLE 5: DISCRETE SOUND PROPAGATION MODELING RESULTS

Receiver ID	Sound Pressure Level (dBA)		Relative Height (m)	Coordinates (UTM NAD83 Z16N)		
	Day	Night		X (m)	Y (m)	Z (m)
R001	13	13	4	661698	4162376	296
R002	12	12	4	661919	4162324	290
R003	12	12	4	661959	4162286	289
R004	12	12	4	662174	4162212	286
R005	12	12	4	661964	4162215	291
R006	10	10	4	663102	4162408	272
R007	10	10	4	663159	4162786	277
R008	13	13	4	661625	4162146	300
R009	12	12	4	661464	4162010	290
R010	13	12	4	661391	4161918	299
R011	12	12	4	661624	4161965	292
R012	12	12	4	661376	4161832	295
R013	12	12	4	661493	4161818	286
R014	12	12	4	661376	4161758	290
R015	13	13	4	661277	4161825	297
R016	13	13	4	661257	4161808	297
R017	13	13	4	661240	4161790	297
R018	13	13	4	661216	4161771	298
R019	13	13	4	661200	4161756	298
R020	13	13	4	661180	4161742	298
R021	13	13	4	661157	4161722	299
R022	13	13	4	661138	4161710	299
R023	13	13	4	661118	4161695	299
R024	13	13	4	661094	4161675	298
R025	13	13	4	661071	4161656	297
R026	13	12	4	661041	4161614	296
R027	13	13	4	660874	4161716	298
R028	12	12	4	660993	4161557	293
R029	17	17	4	660801	4163169	298
R030	18	18	4	660628	4163232	297
R031	19	19	4	660454	4163394	297
R032	19	19	4	660470	4163453	297
R033	20	19	4	660474	4163511	298
R034	19	19	4	660473	4163485	297
R035	20	20	4	660463	4163593	297
R036	20	20	4	660414	4163542	299
R037	20	20	4	660389	4163545	298
R038	20	20	4	660363	4163548	297
R039	21	21	4	661011	4164178	291

Receiver ID	Sound Pressure Level (dBA)		Relative Height (m)	Coordinates (UTM NAD83 Z16N)		
	Day	Night		X (m)	Y (m)	Z (m)
R040	23	23	4	660642	4164349	291
R041	22	22	4	660869	4164353	285
R042	25	25	4	660393	4164424	296
R043	24	24	4	660310	4164355	297
R044	17	17	4	659274	4162172	260
R045	18	18	4	659198	4162153	265
R046	19	19	4	659189	4162500	289
R047	33	33	4	660755	4165691	277
R048	31	31	4	660733	4165584	277
R049	32	32	4	659000	4166192	278
R050	42	42	4	658380	4165295	293
R051	41	41	4	658353	4165226	289
R052	39	39	4	658427	4165019	291
R053	34	34	4	658243	4165396	291
R054	37	37	4	658427	4164969	291
R055	33	33	4	658419	4164871	288
R056	36	36	4	658587	4164401	278
R057	37	37	4	658686	4164319	279
R058	37	37	4	658882	4164126	280
R059	38	38	4	658831	4164008	280
R060	35	35	4	658684	4163894	268
R061	33	33	4	658770	4163823	267
R062	42	42	4	658213	4164357	292
R063	36	36	4	658122	4164506	292
R064	32	32	4	658064	4164436	289
R065	34	34	4	658205	4164666	293
R066	34	34	4	658109	4164605	292
R067	34	34	4	658079	4164566	291
R068	32	32	4	658051	4164552	290
R069	30	30	4	657953	4164492	291
R070	30	29	4	657961	4164407	290
R071	26	26	4	657666	4164031	283
R072	26	26	4	657545	4163889	282
R073	26	26	4	657623	4163648	278
R074	28	28	4	657410	4163576	279
R075	28	28	4	657369	4162869	279
R076	27	27	4	657333	4162691	273
R077	27	26	4	657278	4162522	268
R078	26	26	4	657258	4162445	268
R079	26	26	4	657223	4162344	267

Receiver ID	Sound Pressure Level (dBA)		Relative Height (m)	Coordinates (UTM NAD83 Z16N)		
	Day	Night		X (m)	Y (m)	Z (m)
R080	27	27	4	657194	4162260	267
R081	26	26	4	657189	4162229	267
R082	26	26	4	657188	4162191	266
R083	23	23	4	657316	4162028	253
R084	26	26	4	658694	4163586	263
R085	21	21	4	658593	4163008	262
R086	33	33	4	656901	4162578	273
R087	27	27	4	657026	4162493	258
R088	32	32	4	656634	4162338	261
R089	29	29	4	656268	4162231	253
R090	34	33	4	654884	4162763	242
R091	32	31	4	654929	4162662	242
R092	33	32	4	654838	4162696	241
R093	32	32	4	654809	4162690	240
R094	32	32	4	654818	4162676	240
R095	33	32	4	654385	4163562	243
R096	34	33	4	654436	4163578	245
R097	33	33	4	656070	4164609	280
R098	33	33	4	656042	4164601	280
R099	42	42	4	656098	4164864	256
R100	39	39	4	656311	4165013	263
R101	36	36	4	655611	4164963	250
R102	37	37	4	655510	4165045	248
R103	31	31	4	654957	4162610	242
R104	26	26	4	657126	4162129	258
R105	29	29	4	657928	4164330	292
R106	13	13	4	661885	4162408	294

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Exhibit Q

Master Plant List

Trees	Botanical	Common	Size	Growth Rate	Mature Size	Approx. Years to 8 ft Height	Approx. Years to Mature Height
	Acer rubrum	Red Maple	2" Cal. (~12 to 14' Ht.)	Fast	40`-60` H x 35`-45` W	0 Years (8+ ft high at install)	20-25 years
	Acer saccharum	Sugar Maple	2" Cal. (~8 to 10' Ht.)	Medium	60`-75` H x 40`-50` W	0 Years (8+ ft high at install)	30-40 years
	Aesculus glabra	Ohio Buckeye	2" Cal. (~8 to 10' Ht.)	Medium	20`-40` H x 20`-40` W	0 Years (8+ ft high at install)	20-25 years
	Amelanchier arborea	Downy Serviceberry	1.5" Cal. (~6 to 8' Ht.)	Medium	15`-25` H x 15`-25` W	1-3 years	15-20 years
	Carpinus caroliniana	American Hornbeam	1.5" Cal. (~6 to 8' Ht.)	Slow	20`-40` H x 20`-30` W	2-4 years	20-25 years
	Cercis canadensis	Eastern Redbud	5` Ht.	Medium	20`-30` H x 25`-35` W	2-4 years	15-20 years
	Cladrastis kentukea	American Yellowwood	1.5" Cal. (~6 to 8' Ht.)	Medium	30`-50` H x 40`-55` W	1-3 years	20-25 years
	Juniperus virginiana	Eastern Red Cedar	5` Ht.	Medium	40`-50` H x 8`-20` W	2-4 years	30-40 years
	Liquidambar styraciflua	American Sweet Gum	2" Cal. (~8 to 10' Ht.)	Medium	60`-75` H x 40`-75` W	0 Years (8+ ft high at install)	35-45 years
	Nyssa sylvatica	Sour Gum	2" Cal. (~8 to 10' Ht.)	Medium	30`-50` H x 20`-30` W	0 Years (8+ ft high at install)	20-25 years
	Ostrya virginiana	American Hophornbeam	1.5" Cal. (~6 to 8' Ht.)	Slow	25`-40` H x 20`-30` W	2-4 years	25-30 years
	Oxydendrum arboreum	Sourwood Tree	1.5" Cal. (~6 to 8' Ht.)	Medium	25`-30` H x 20`-25` W	1-3 years	20-25 years
	Pinus strobus	White Pine	8` Ht.	Fast	50`-80` H x 20`-40` W	0 Years (8+ ft high at install)	20-25 years
	Pinus virginiana	Virginia Pine	8` Ht.	Slow	15`-40` H x 10`-30` W	0 Years (8+ ft high at install)	20-25 years
	Quercus alba	White Oak	2" Cal. (~8 to 10' Ht.)	Medium	50`-80` H x 50`-80` W	0 Years (8+ ft high at install)	30-40 years
	Quercus coccinea	Scarlet Oak	2" Cal. (~8 to 10' Ht.)	Medium	40`-75` H x 40`-75` W	0 Years (8+ ft high at install)	30-40 years
	Quercus rubra	Red Oak	2" Cal. (~8 to 10' Ht.)	Medium	60`-75` H x 60`-75` W	0 Years (8+ ft high at install)	30-40 years
	Quercus velutina	Black Oak	2" Cal. (~8 to 10' Ht.)	Slow	50`-60` H x 50`-60` W	0 Years (8+ ft high at install)	40-45 years
	Sassafras albidum	Sassafras	5` Ht.	Medium	20`-30` H x 25`-40` W	2-4 years	15-20 years
	Tilia americana	American Linden	2" Cal. (~8 to 10' Ht.)	Medium	60`-80` H x 30`-60` W	0 Years (8+ ft high at install)	30-40 years

Shrubs	Botanical	Common	Size	Growth Rate	Mature Size	Approx. Years to 8 ft Height	Approx. Years to Mature Height
	Aronia melanocarpa	Black Chokeberry	4` Ht.	Medium	3`-6` H x 3`-6` W	N/A	1-3 years
	Calycanthus floridus	Sweetshrub	3` Ht.	Medium	6`-10` H x 6`-10` W	4-6 years	3-6 years
	Cornus racemosa	Gray Dogwood	3` Ht.	Medium	10`-15` H x 10`-15` W	4-6 years	6-8 years
	Cornus sericea	Red Twig Dogwood	3` Ht.	Fast	7`-10` H x 7`-10` W	2-4 years	2-4 years
	Corylus americana	American Hazelnut	3` Ht.	Medium	6`-10` H x 6`-10` W	4-6 years	3-6 years
	Hamamelis virginiana	Common Witch Hazel	5` Ht.	Medium	15`-20` H x 15`-20` W	2-4 years	8-10 years
	Rhus typhina	Staghorn Sumac	5` Ht.	Fast	15`-25` H x 20`-30` W	1-3 years	3-6 years
	Rosa carolina	Carolina Rose	2` Ht.	Fast	3`-6` H x 3`-6` W	N/A	1-3 years

Exhibit R

Landscaping Maps

Northern Bobwhite Solar

Marion County, Kentucky

Conceptual Mitigation Planting Plan

Figure 1. Example Module Locations

Conceptual Planting Modules

- Module 1 - Roadside Enhancement
- Module 2 - Open Field/ Supplemental Hedgerow
- Module 3 - Adjacent Resource/Residence
- Public Road 300-foot Offset
- Residence 500-foot Offset
- Fence Line
- Access Road
- Panel Array
- Inverter
- Residence
- Parcel Boundary

Notes: 1. Basemap: USDA NAIP "2019 New York 60cm" orthoimagery map service. **2.** This map was generated in ArcMap on February 11, 2021. **3.** This is a color graphic. Reproduction in grayscale may misrepresent the data.

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Exhibit S

Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach

Federal Aviation Administration

DOT/FAA/AM-15/12
Office of Aerospace Medicine
Washington, DC 20591

Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach

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Final Report

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16. Abstract

Solar power is a growing source of energy for airports and for their communities. While solar power panels provide a useful means to generate revenue and to provide energy locally, it does pose a potential hazard in the form of glare. In the current study, pilots were exposed to glare during a series of flights in a flight simulator, and their perceived impairment was recorded.

During the approach phase of each flight, we simulated glare from one of four possible angles (0, 25, 50, and 90 deg left of straight ahead) and for glare durations of either 0 (no glare control), 1, and 5 s. The glare was simulated using halogen lamps that, under the lighting conditions of our lab, approximated the visual effect of solar glare. Subjective measures of impairment were recorded for each condition. There was a significant main effect of glare duration and a significant main effect of glare angle.

Impairment was perceived as being worse for glare sources that are straight ahead of the pilot and of longer duration, with a gradual decline in impairment as the glare source moves toward the side of the pilot. However, there was no significant interaction between glare duration and of glare angle.

17. Key Words
Human Factors, Aircraft Simulation, Solar Panel Glare, Airport, Pilot Hazard

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Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach

INTRODUCTION

Solar power is a growing source of energy for airports and for their communities. For example, in 2012 Manchester-Boston International Airport completed installation of 42,000 photovoltaic panels (Manchester-Boston Regional Airport, 2012). In 2011, private development of a 75-acre solar farm on land owned by the Indianapolis International Airport began with an expected capacity to generate 15 gigawatts of electricity. The airport was collecting approximately $315,000 a year in rent for the land on which the solar farm was built (Indianaplois Airport Authority, 2011; Swiatek, 2013). The Denver International Airport currently has three separate solar arrays, and in June 2014, announced that a fourth solar installation will be built and altogether spread over 55 acres (Montgomery, 2012). In the same month, General Mitchell International Airport in Milwaukee, WI, completed acceptance of requests for proposals (RFP) to "evaluate the feasibility of siting a large-scale solar photovoltaic system at General Mitchell International Airport" (U.S. Department of Transportation, 2014). It is worth noting that there is no clear indication in the RFP as to how large this solar installation will be, but if some of the installations at other airports are an indication, it is likely to cover many acres in solar panels.

While solar power panels provide a useful means to generate revenue and to provide energy locally, they do pose a potential hazard to pilots, in the form of glare. For example at the Manchester-Boston Regional Airport, air traffic controllers (ATCs) reported significant problems seeing due to glare reflecting from the solar panels toward the tower. Aside from the Manchester-Boston Regional ATCs suffering from solar glare, reports from pilots flying near the Ivanpah Solar Electric Generating System have included complaints about the glare from the facility (Motley, 2014). Pilots have described the glare as "blinding," and at least one individual reported in the Aviation Safety Reporting System (ASRS) database that the glare was "like looking into the sun" and that they thought the glare was a hazard because they could not see if there was air traffic nearby (ASRS Database, 2013).

The effect of transient glare from a solar panel can produce a sudden increase, or flash of light. Sudden changes in the appearance or the presentation of new stimuli at a point within the visual field are known to capture attention (Yantis, 1993a; Yantis & Hillstrom, 1994), including interrupting attention allocated to another task (Yantis, 1993b). A particularly salient cue for the capture of visual attention is a sudden change in brightness within a point of the visual field (Theeuwes, 1991; Wright & Richard, 2003). The pulling of attention away from a primary task (such as flying) produces some level of distraction and introduces a secondary task (noting a source of glare) (Lavie, 2005; Wickens, Sandry, & Vidulich, 1983). Visual distractors, both internal and external to a vehicle, have been known to influence control (Engstrom, Johansson, & Östlund, 2005; Ranney, Garrott, & Goodman, 2000). Flooding the cockpit of an aircraft with glare will likely decrease visibility for the pilot thereby making it more difficult to control the aircraft. The increased difficulty will likely be reflected by increased cognitive load as the pilot will now have to work a bit harder to maintain visual contact with the runway, instruments, and the management of their aircraft.

In the current study, pilots were exposed to glare during a series of flights in a flight simulator, and their perceived impairment was recorded. During the approach phase of each flight, we simulated glare from one of four possible angles (0, 25, 50, and 90 degrees left of straight ahead), and for glare durations of either 0 (no glare control), 1, and 5 s. The glare was simulated using halogen lamps that, under the lighting conditions of our lab, approximated the visual effect of solar glare. During the flight, the pilots wore an EEG cap to record any changes in neural activity that would indicate increased cognitive and visual load as a function of glare exposure. An eye tracker was used to monitor eye movements to ascertain if they looked toward the glare and what compensatory eye movements were made in response to glare exposure. The results of the EEG and eye tracking will be reported in separate reports. Finally, we asked pilots to provide subjective ratings of their own perceptions of how the glare affected their ability to fly and to read their instruments. Additionally, we asked them to rate the similarity of the simulated glare to glare they have experienced in the real world.

METHODS

This study was completed using the AGARS Simulator (described in detail later) at the Federal Aviation Administration's Aerospace Human Factors Research Lab (AHFRL) at the Civil Aerospace Medical Institute (CAMI), which is located at the FAA Mike Monroney Aeronautical Center (MMAC) in Oklahoma City, OK.

Participants

All participants in this experiment were federal employees recruited via distribution of emails internal to the MMAC facility. The experiment was completed as part of the each employee's work activities, which required that the participants negotiate the time with their individual managers. Because this study was completed as part of the employee's normal work activities, no additional compensation was given. The minimum requirements for this study included having been a certified private pilot (though not necessarily current) and normal or corrected-to-normal visual acuity. A total of 20 participants coordinated their time for participation. One was excluded from analysis due to early termination of his experiment session, leaving 19 participants, all male. All participants were required to provide their informed consent via two consent forms, one for CAMI and one for Sandia National Laboratories, approved by each institutions' Institutional Review Board.

Design

We combined four angles of glare exposure (0, 25, 50, and 90 deg) and two levels of exposure duration (1 and 5 s) to create eight possible experimental conditions. The durations were selected as they represent a range of transit times across solar installations at a variety of speeds. Additionally we had the pilots fly a single trial in which no glare was present as a control condition, thereby producing a total of nine conditions. Each pilot flew one trial of each of the nine conditions. The order of trials was randomized for each participant, so the pilot did not know if a glare event would occur during any given trial, or from what angle.

Stimuli and Apparatus

Glare Experience Questionnaire

The glare experience questionnaire asked questions about the pilot's experience with solar glare while flying, as well as some general demographic questions.

Pilot Demographics

The pilots were asked to indicate their current age, gender, how long they have been flying, if they wear corrective lenses (and if so what kind), and if they have had vision corrective surgery (and if so to indicate how long ago).

Questions Related to Solar Glare

Pilots were asked to provide ratings of their experience related to direct sunlight, glare from solar panels, and glare from other objects. For each, they were asked to indicate what stage of flight they had their encounter (departure, take-off, cruising, approach, touch-down), impairment of ability to fly the plane and the impairment to the ability to read their instruments (each on a 5-point scale: no impairment, slight impairment, moderate impairment, significant impairment, severe impairment), typical duration of exposure (less than 1 s, 1-5 s, 5-10 s, greater than 10 s), and to indicate what compensatory strategies they have used (use sun shade, use sunglasses, avert eyes, other). With regard to glare from other objects, we asked them to indicate the source of the glare.

AGARS Flight Simulator

The flight simulator used in this study was the Advanced General Aviation Research Simulator (AGARS). The AGARS is a simulation of a Piper PA-46 Malibu single-engine aircraft. Unique features of this simulator include the replacement of the hardware-based instrumentation with a touchscreen representation of flight instruments. This was done to mediate configurability of the cockpit for use across multiple research projects. For this study, we maintained use of the traditional round dial configuration.

AGARS Flight Simulator Host System

The AGARS simulation host computer is a custom-built system that uses a AMD Opteron 2218 processor with 1Gb of RAM. The operating system is Fedora Linux 12 and the simulation software was written by ZedaSoft, Inc.

AGARS Out-the-Window Display System

The AGARS out-the-window (OTW) display system used five Sharp Aqous 60-inch LC-60LE835U flat panel televisions mounted on stands in front and to the sides of the cockpit, thereby creating a segmented display system spanning 180 degrees and creating a reasonably realistic OTW scene.

Each of the OTW displays is driven by a custom-built computer. These computers have Intel, Inc. i7 CPUs, 12Gb DDR3 RAM, and two Sli-connected NVidia GTX 470 video cards with 128 Mb of memory. The computers are running the 64-bit edition of Microsoft Windows 7 Professional. The image generator (IG) software, which is responsible for the OTW scene, is VRSG 5.7.2 from MetaVR, Inc.

Navigation Map Display

A JeppView FlightDeck 3.5.6 GPS navigation map display was positioned above the glare shield and centered in the cockpit near the forward windscreen. The JeppView software was running on a Dell Optiplex 780 computer with an Intel Core 2 Duo 2.93 Ghz processor with 4 Gb RAM. The operating system of this computer was the 32-bit edition Windows 7 Professional. The display was a Faytech 9.5 inch touchscreen (model: FT10TMB).

Glare Simulation Devices

To simulate glare being reflected from solar panels, we used a series of four SoLux halogen bulbs (12 V, 50 W, MR16, black back) with a 10-d beam spread and a color temperature of 4700 K to reproduce the full solar spectrum. Each of the lamps was mounted atop a Leica Tri 100 tripod. Each light was controlled by its own control box, built by Sandia National Laboratories. Each control box featured a trigger switch, which, when thrown, activated a PTC-1A digital timer manufactured by Omega Engineering, Inc., which determined how long the attached lamp would stay on (1 or 5 s). The lamps, tripods, and control boxes are collectively referred to as the glare simulation devices (GSDs).

The four GSDs were placed straight ahead of the pilot (0 degrees), and at 25, 50, and 90 deg away from straight ahead on the left side of the simulator cockpit, between the cockpit and the simulator OTW view. The distance between the lamp and the pilot's eyes was approximately 0.8 m. Depending on the location of the lamp, the measured luminance at the eye was between ~1,000 – 2,000 Lux (measured using a digital Lux meter LX1330B), which corresponds to a corneal irradiance of ~10 – 20 W/cm^2 (1 W yields approximately 100 lumens of visible light in the solar spectrum). The subtended angle of the glare based on the bulb aperture of ~0.05 m and a distance of ~0.8 m was approximately 0.06 rad. The retinal irradiance was calculated from the measured corneal irradiance, subtended glare angle, and measured pupil diameter (~5 mm) to be ~0.024 – 0.048 W/cm^2. Together with the subtended glare angle of 0.06 rad (60 mrad), the retinal irradiance was sufficient to cause a temporary after-image, similar to solar glare reflected from flat solar panels (Ho, Ghanbari, & Diver, 2011; Ho, 2013).

Figure 1. *Placement of two of the Glare Simulation Devices are at 5 deg and 50 deg.*

Figure 2. *Interior view of the AGARS cockpit, with the 0-deg GLD triggered.*

Post-Trial Questionnaire

Following trials with simulated glare, we asked pilots to rate their experience. The three questions and possible responses (on a 5-point rating scale) were as follows:

1. Rate the degree of impairment from the simulated glare on your ability to fly the plane.
   - ☐ 1 = No impairment: Can easily perform functions necessary to fly the plane with no noticeable impact of glare
   - ☐ 2 = Slight to no impairment: Can still perform functions necessary to fly the plane, but glare is noticeable
   - ☐ 3 = Moderate impairment: Can perform functions necessary to fly the plane, but glare required some action (e.g., physically blocking glare, averting eyes)
   - ☐ 4 = Significant impairment: Difficulty performing functions necessary to fly the plane, even after performing actions in response to glare
   - ☐ 5 = Severe impairment: Unable to perform functions necessary to fly the plane
2. Rate the degree of impairment from the simulated glare on your ability to read your instruments.
   - ☐ 1 = No impairment: Can easily read instruments and values (e.g., altitude, speed) with no noticeable impact of glare
   - ☐ 2 = Slight to no impairment: Can still read instruments and values, but glare is noticeable
   - ☐ 3 = Moderate impairment: Can read instruments and values, but glare required shifting of eyes, blinking, or refocusing in order to read values
   - ☐ 4 = Significant impairment: Difficulty reading instruments and values, even after shifting of eyes, blinking, or refocusing
   - ☐ 5 = Severe impairment: Unable to read instruments and values
   - ☐ N/A (did not view instruments during or after glare event)
3. How similar was the simulated glare to actual glare you have observed while flying, if applicable?
   - ☐ 1 = No similarity
   - ☐ 2 = Slight similarity
   - ☐ 3 = Moderate similarity
   - ☐ 4 = Very similar
   - ☐ 5 = Extremely similar
   - ☐ Not applicable

For all trials, we asked the subjects the open-ended question "[are there] any additional comments or questions regarding this test or your experience that you would like to provide?"

Procedure

Pilot Preparation

Pilots were required to provide their informed consent prior to participation. Upon consent, we measured the pilot's head size in order to select the appropriate EEG cap. We then asked the pilot to enter the cockpit so that initial eye tracking camera calibration and seat position adjustments could be made. The pilots completed the glare experience questionnaire. The EEG cap was placed upon the pilot's head and the position and chin strap adjusted to ensure proper fit and comfort. Once all EEG electrodes indicated good signal, the pilot was reminded not to make any sudden head movements and then was escorted to and seated in the AGARS cockpit. We asked the pilot to verify the correct alignment of the GSDs, and made any minor adjustments that were required to optimize the glare simulation. Final eye tracking calibration was then performed.

Familiarization Flight

Each pilot was informed about the performance characteristics of the Piper Malibu simulated by the AGARS and was given a few minutes to become familar with the location and characteristics of the instrumentation. Once the pilot felt ready, we began one to three familiarization flights, depending on how quickly they became comfortable flying the AGARS. While familiarization took place, one of the researchers familiar with flying the AGARS remained available to the pilot to answer any questions and to guide them along the experimental route .

Flight Route

For all flights, the pilots flew from Max Westheimer Airport (KOUN) in Norman, OK, to the GALLY navigation fix, located in Newcastle, OK, at an altitude of 2,500 feet MSL (see Figure 3). From there, they headed north to Will Rogers International Airport (KOKC) to land on runway 35R. The pilots were able to use the GPS navigation display to maintain spatial awareness of their current location in relation to the GALLY navigation fix and KOKC 35R. Each flight lasted about 5 min.

Figure 3. *Map of flight route depicting the route flown by pilots in our study. Take off was from KOUN. Pilots then flew to the GALLY waypoint (Stacks on sectional charts) and then turned north to KOKC.*

The radios for AGARS were set to the frequencies for KOKC 35R automatically. This enabled localizer, glideslope, and distance measuring equipment (DME) instrumentation to work appropriately without intervention from the pilot. This was done to minimize their workload, particularly because the AGARS touchscreens can make manipulation of the radio dials extremely difficult, which would dramatically increase pilot workload.

We controlled glare with the GSDs. When a trial called for using glare, the appropriate GSD was selected and the exposure duration was programmed into the digital timer for that GSD. One of the researchers observed a display that replicated the DME display from the AGARS cockpit. The trigger for the GSD was activated when the DME was 2.6, which places the aircraft at 1 mile from the runway threshold, on final approach to landing at Will Rogers.

RESULTS

Glare Experience Questionnaire

Pilot Demographics

Pilots' mean age was 47.6 years (*SEM = 1.88*). The mean flight years was 21.7 (*SEM = 2.32*). Two pilots had stopped flying several years prior to participating in this experiment (one had ceased five years ago, while the other had not flown in 20 years). Both of these pilots demonstrated that their flying skills were sufficient for participation. Eleven pilots (58%) wore corrective lenses while flying. Of those who wore corrective lenses, nine (81%) wore glasses, one wore contacts, and one declined to respond. Three pilots had received vision corrective surgery, with a mean of 3.25 years since their surgery (SEM = 1.01).

As can be seen in Figure 4, the majority of participants had some real world experience with direct sunlight or with solar glare reflecting from other objects. From the Figure, it is also clear that the majority of encounters with sunlight and glare from other objects took place while the pilot was in cruise or on approach. Less than a third of pilots had encountered direct sunlight during departure or take-off. These results suggest that this study design is well-positioned to generalize outside the lab, since the experimental design exposed pilots to glare during approach, rather than another stage of flight such as take off. Of key interest was the low number of respondents (two) who had encountered glare from solar installations. This was likely due the lack of solar installations in the Oklahoma City area, where our subjects were recruited and may have spent the majority of their time flying.

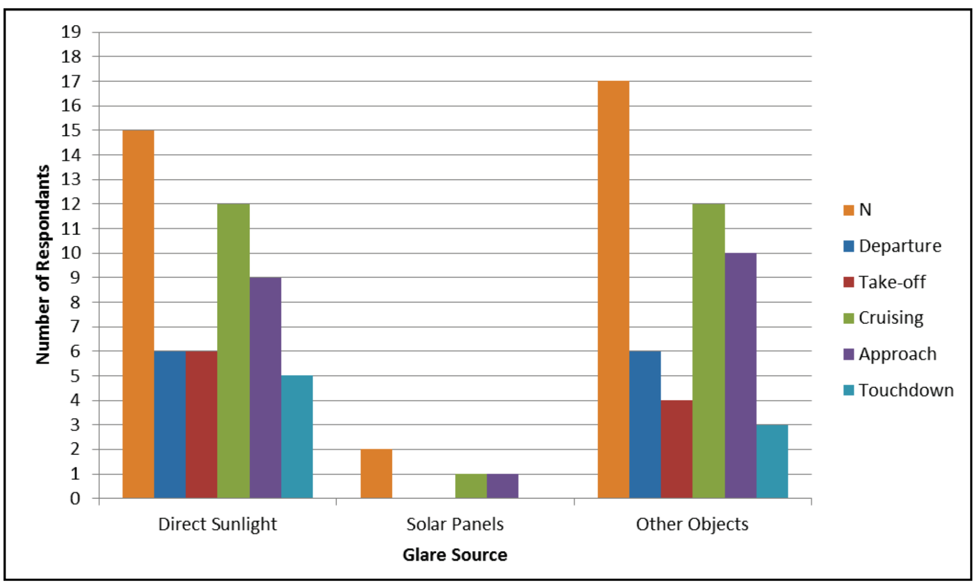

Figure 4. *Real-world sources of solar glare that pilots have encountered.*

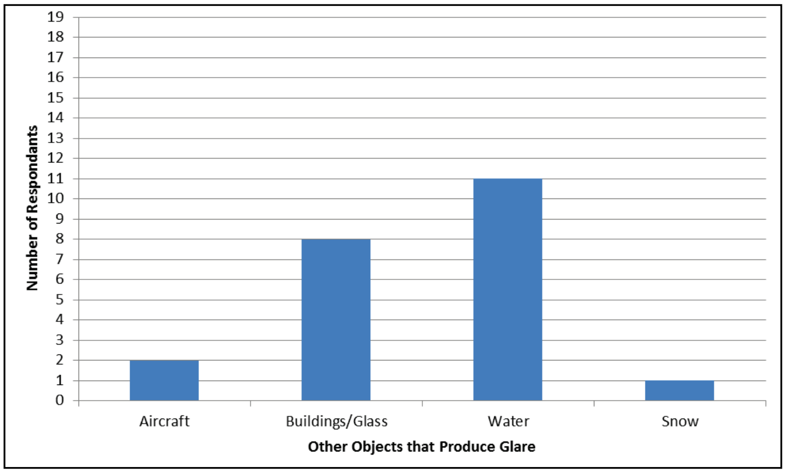

Figure 5. *Duration of glare from real-world objects encountered by pilots.*

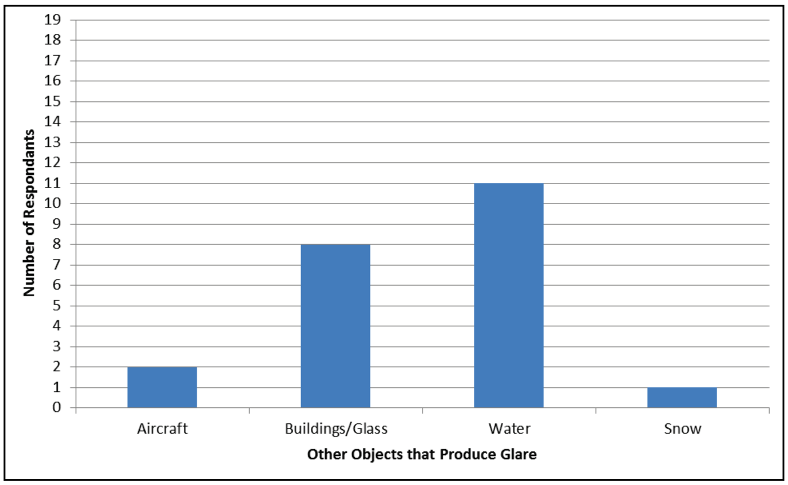

Figure 6. *Frequency of glare from sources other than direct sunlight or solar panels.*

Figure 5 shows that the majority of our pilots had encountered glare with durations between 1 and 10 s with longer durations being encountered for objects other than direct sunlight or solar panels. Figure 6 shows that, for most, glare emanated primarily from bodies of water.

AGARS Flight Simulator Data

The lateral deviation from the runway centerline of the initial touch down point was submitted to an analysis of variance (ANOVA) for within-subjects designs (a.k.a. repeated measures). In this instance, there were two factors (Independent Variables, or IVs): 1) duration with two levels (1 s and 5 s) and 2) angle of the simulated glare exposure (0, 25, 50, and 90 deg to the left of straight ahead). The outcome measure, or Dependent Variable (DV), was the lateral deviation of the initial touch-down point from centerline.

Neither duration, $F(1,18) = .406$, $MSe = 5.282$, $p < .532$, $\acute{\eta}^2 = .022$, nor the angle of simulated glare exposure was significant, $F(3,54) = 1.407$, $MSe = 3.228$, $p < .251$, $\acute{\eta}^2 = .073$. Likewise, no significant interaction was found between these two variables, $F(3,54) = .451$, $MSe = 4.046$, $p < .717$, $\acute{\eta}^2 = .024$.

It should be noted, however, that there were two runway impacts (crashes) during the course of the experiment. The first took place during a control condition during which no glare was present. This pilot, we suspect, may have been testing the limits of the simulator, because the pilot appeared to be showing signs of boredom, such as making delayed approaches requiring a steeper approach angle. Following this impact, the pilot appeared to fly much more conservatively. Since this pilot had no difficulty with any other landing, it seems more than coincidental that the one time he had a problem was also the one time he did not have a glare event during the main trials.

The second runway impact took place when the glare was presented straight ahead of the pilot for a duration of 5 s. This pilot bounced the aircraft twice while landing. The third contact was ultimately registered as an impact (crash). While the previously mentioned lack of significant groupwise interaction between glare angle and glare duration does not directly support *causation* of this particular impact, that notion is suggestive for this one case.

Post-Trial Questionnaire

Pilot ratings of perceived impairment of glare on the ability to fly the airplane and to read their instruments, for both the 1-s and the 5-s durations, are presented in Figures 5 and 6.

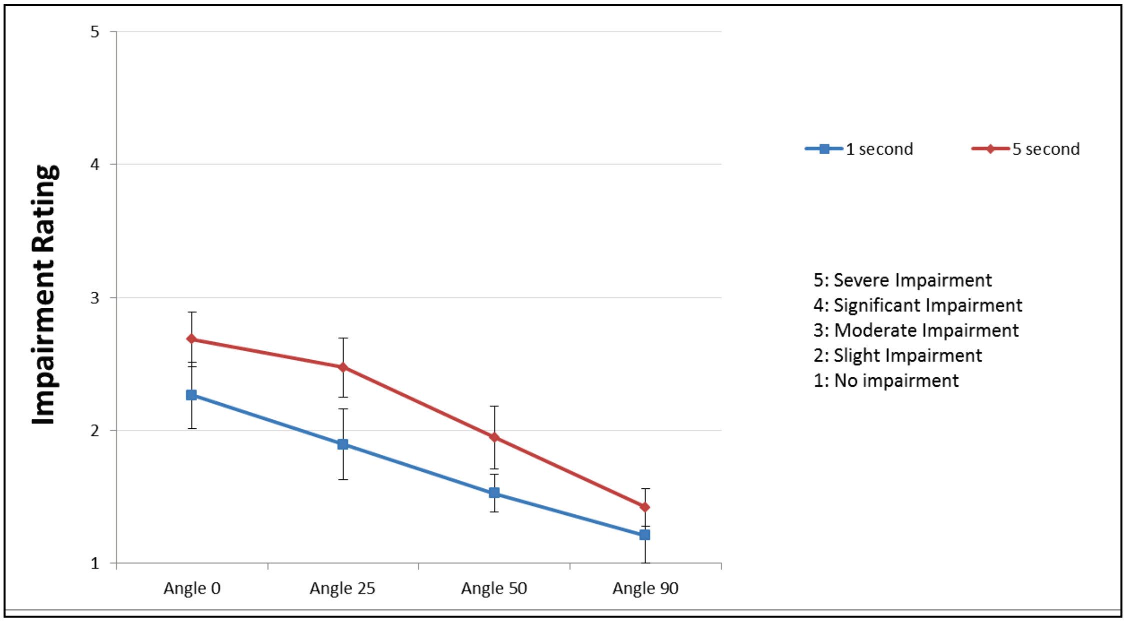

Figure 7. *Mean ratings of impairment to ability to fly based upon the angle and duration of simulated glare exposure. Error bars represent the standard error of the mean.*

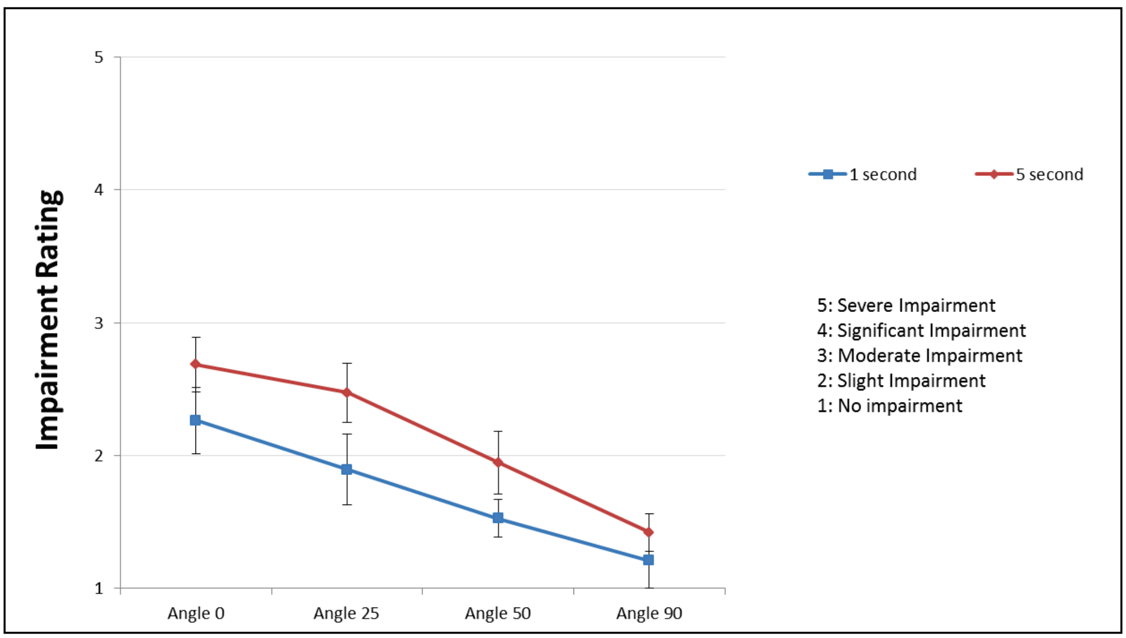

Figure 8. *Mean ratings of impairment to read instrumentation based upon the angle and duration of simulated glare exposure. Error bars represent the standard error of the mean.*

The average results for the 1- and 5-s durations are presented in Figure 7. It is obvious by looking at the Figures 7 and 8 that impairment is worse for glare sources that are straight ahead of the pilot, with a gradual decline in impairment as the glare source moves toward the side of the pilot. If we look at the ratings of impairment on the ability to fly, we can see that the mean rating, for both 1 s (M = 3.16, SEM = 0.23) and 5 s (M = 3.53, SEM = 0.16) glare durations at 0 deg is above 3, a rating of moderate impairment. At an angle of 25 deg, the mean impairment rating for an exposure duration of 5 s (M = 2.89, SEM = 0.20) is just below the rating of 3, and the error bar rises above the rating of 3. This indicates that this particular condition results in moderate impairment of the ability to fly. Also, at the angle of 25 deg, the mean impairment rating for a glare duration of 1 s is M = 2.47, SEM = 0.25, indicating slight to moderate impairment.

For the control (no glare) condition, all pilots rated the impairment for both the ability to fly and impairment for reading their instruments as a 1 (no impairment). This indicated that they were able to fly the aircraft and see their instruments with no difficulty when glare was not present in a flight. However, since the absence of glare uniformly produced a rating of 1 (a clear floor effect) we excluded those data from further analysis because leaving them in would have automatically led to higher statistical significance when glare was present. We instead opted to leave those data out and focus solely on conditions in which glare was present to determine how those conditions differed from each other.

To isolate the sources of variation in our study, a doubly multivariate analysis was conducted. The doubly multivariate analysis is an extension of ANOVA for within-subjects designs that allows for the measurement of changes in multiple DVs as a function of different IVs. This analysis measured three DVs: the pilot rating of a) impairment of flying ability, b) impairment to read their instruments, and c) how similar the simulated glare was to what had been experienced in the real world. Two IVs were used in this analysis. The first was the duration of the glare exposure with two levels (1 s and 5 s). The second was the angle of glare exposure, with four levels (0, 25, 50, and 90 deg to the left from straight ahead). Wilks' λ was used in the multivariate testing. Wilks' λ, also called the maximum likelihood criterion, is a multivariate statistic that measures the proportion of variance in the DVs that is unaccounted for by the IV(s). Because it is measuring the variance that is unaccounted for, a small Wilks' λ is associated with a statistically significant result and therefore rejection of the null hypothesis.

There was a significant main effect of glare duration, Wilks' ή = .508, $F(9,10) = 9.325$, $p < .011$, $ή^2 = .492$. This indicates that there is a difference among the DVs based upon the duration of glare exposure. There was also a significant main effect of the angle of glare exposure, Wilks' ή= .106, $F(9,10) = 9.325$, $p < .001$, $ή^2 = .894$. This indicates that there was a difference among the DVs based upon the angle of glare exposure. However, there was not a significant interaction between duration of glare exposure and the angle of glare exposure, Wilks' ή= .711, $F(9,10) = .452$, $p < .877$, $ή^2 = .289$.

Given the significant multivariate tests, univariate tests were carried out to further parse the relation supported by the multivariate main effects. These univariate tests are two-factor ANOVAs for within-subjects designs. Each of these univariate tests measured the effect that the two IVs had on a single DV (the pilot's rating of impairment on flying ability, the pilot's rating of impairment to read the instruments, and the pilot's rating of how similar the simulated glare was to what they had experienced in the real world).

The first univariate test assessed how glare angle and duration affected pilots' rated impairment of glare on flying ability. This test showed a significant main effect of simulated glare duration on impairment of flying ratings, $F(1,18) = 11.272$, MSe = .675, $p < .004$, $ή^2 = .385$, with the 5-s duration having a higher overall mean (M = 2.645, SEM = .136) than the 1 s duration (M = 2.197, SEM = .128). There was also a significant main effect of the simulated glare exposure angle on the pilot ratings of how it affected their ability to fly, $F(1,18) = 32.898$, MSe = .675, $p < .000$, $ή^2 = .646$, with an orderly rating of straight ahead as the most impairing (M = 3.342, SEM = .171), 25 deg left of straight ahead as second most impairing (M = 2.684, SEM = .172), 50 deg left of straight ahead as less impairing (M = 2.026, SEM = .130), and 90 degr to left of straight ahead as the least impairing (M = 1.632, SEM = .166).

To determine if there were significant differences between the ratings of how piloting ability was affected for each of the various angles, pairwise comparisons were performed. A Bonferroni correction was used to control for familywise error rate inflation. The pairwise comparisons of angle of exposure revealed that straight ahead was rated as significantly higher than 25 deg to the left of straight ahead ($p < .038$). Likewise, straight ahead was found to be significantly higher than 50 deg to the left of center ($p < .000$), and 90 deg left of center ($p < .000$). Further, 25 deg left of center was found to result in a higher rating than 50 deg left of center ($p < .001$), and 90 deg left of center ($p < .000$). Finally, with regard to the rating impact to piloting ability, there was no significant difference found between 50 deg and 90 deg left of the center ($p < .236$).

The second univariate test we conducted assessed how glare angle and duration affected pilot ratings of their ability to read instruments. We found a significant main effect of glare duration on rated ability to read instrumentation, $F(1,18) = 11.046$, MSe = .572, $p < .004$, $ή^2 = .385$, with the 5-s duration having a higher overall mean (M = 2.132, SEM = .151) than the 1-s duration (M = 1.724, SEM = .154).

Mauchly's test for Sphericity determines whether the variances across the different conditions are equal. When the variances across levels are equal, the sphericity assumption of an ANOVA has been met and Mauchy's test for Sphericity will not be significant. When Mauchly's test for Sphericity is significant, it means that the sphericity assumption has been violated, which results in a greater risk of a Type II error (failure to reject the null hypothesis). To compensate for this, the degrees of freedom for the ANOVA have to be adjusted; typically by using a Greenhouse-Geisser correction. When analyzed for the effect of glare angle on pilot ratings of their ability to read their instruments, we found that Mauchly's test for Sphericity was significant, $ή^2(5) = 12.362$, $p < 0.030$. The corrected ANOVA showed a significant main effect of simulated glare exposure angle on ratings of how it affected their ability to read the instruments, $F(2.281,46.319) = 13.611$, MSe = .948, $p < .000$, $ή^2 = .646$, with an orderly rating of straight ahead as the most impairing (M = 2.474, SEM = .189), 25 deg left of straight ahead as second most impairing (M = 2.184, SEM = .214), 50 deg left of straight ahead as less impairing (M = 1.737, SEM = .168), and 90 deg to left of straight ahead as the least impairing (M = 1.316, SEM = .159).

To determine if there were significant differences between the ratings of how the ability to read instrumentation was impacted for each the various angles of simulated glare, pairwise comparisons were performed using a Bonferroni correction. The pairwise comparisons of angle of exposure revealed that straight ahead is not rated as significantly higher than 25 deg to the left of straight ahead ($p < 1.000$). However, straight ahead was found to be significantly higher than 50 deg to the left of center ($p < .014$) and 90 deg left of center ($p < .000$). Further, 25 deg left of center was significantly higher than 50 deg left of center ($p < .014$) and 90 deg left of center ($p < .006$). Finally, with regard to the rating impact to the ability to read instrumentation, it was found that there was not a significant difference between 50 deg and 90 deg left of the center ($p < .098$).

The last univariate test assessed how glare angle and duration affected pilot ratings of the simulated glare verse glare they had experienced while flying in the real world. We found no main effect of duration on ratings of the similarity of represented glare to real-world glare ($F(1,18) = .471$, $MSe = .893$, $p < .501$, $ή^2 = .026$). We analyzed the effect of the angle of glare exposure on pilot's ratings of the similarity of the simulated glare to real-world glare, Mauchly's test was again significant($ή^2(5) = 11.218$, $p < 0.048$). Subsequent Greenhouse-Geisser-corrected ANOVA was not significant ($F(2.117,38.102) = .626$, $MSe = 1.370$, $p < .549$, $ή^2 = .034$). This means that regardless of the duration or the angle of the glare, the ratings of how realistic they perceived the simulated glare to be remained about the same.

DISCUSSION

AGARS Flight Simulator Data

Results of the landing data showed no significant, systematic lateral deviation from runway centerline, regardless of the duration or angle of simulated glare presented to the participant.

The one case that we considered to be of any potential concern was when a pilot crashed during landing with the glare presented straight ahead for a duration of 5 s. However, we would suggest tempering any concern by pointing out that if there was a problem with that particular angle and duration, we would have likely seen more individuals who had crashed.

Post-Trial Questionnaire

Data from the post-trial questionnaire demonstrate that, for the most part, higher glare durations result in greater self-perceived impairment in the pilots' ability to safely fly an aircraft and to read aircraft instrumentation relative to shorter durations. Further, as expected, the more forward-facing the glare was, the more impairment the pilots reported experiencing. More precisely, we found that when glare was present, the ability to read aircraft instrumentation was not statistically different between glare that was presented straight ahead and when it was 25 deg to the left of straight ahead. Likewise, no statistical difference was found between 50 deg and 90 deg of straight ahead. Taken together, this suggests that as far as reading instrumentation is concerned, two groupings of angles resulted in similar impairment among the member angles: The first grouping included the member angles of 0 and 25, and the second grouping included the member angles of 50 and 90. While there was a significant increase in these ratings, it is still considered to be less than a moderate impairment on the ability to read instrumentation. Though the rating was, ultimately, below our threshold of "moderate impairment," one could speculate that longer durations may result in higher impairment ratings for reading instrumentation, particularly for angles of 0 and 25 deg of straight ahead.

In terms of how glare impacted the ability to fly, we found a similar effect of glare duration as described above: A longer duration resulted in greater self-reported impairment to the ability to land on a runway center. We found that glare from the angles of 50 and 90 deg was not statistically different from each other with regard to the relative impairment to the ability to fly. Interestingly, there is a statistically significant increase in the ratings of impairment when glare comes from an angle of 25 deg, and a still larger increase in the ratings of impairment for glare that is straight ahead. Again, the closer the glare was to straight ahead, the more likely it became problematic for the pilot, and glare toward the side is unlikely to be a problem.

Figure 9 shows that ratings of the impairment to the ability to fly for glare from straight ahead were above a rating of 3. Additionally glare from 25 deg for a 5 s duration yielded a rating that was, statistically, indistinguishable from a rating of 3. Therefore, it is reasonable to say that glare from straight ahead or from 25 deg (if it is long enough) will result in moderate impairment.

To summarize, the safe course of action would appear to be to locate sources of glare such that they do not produce glare from angles less than 50 deg from the pilots' view straight ahead on approach to landing.

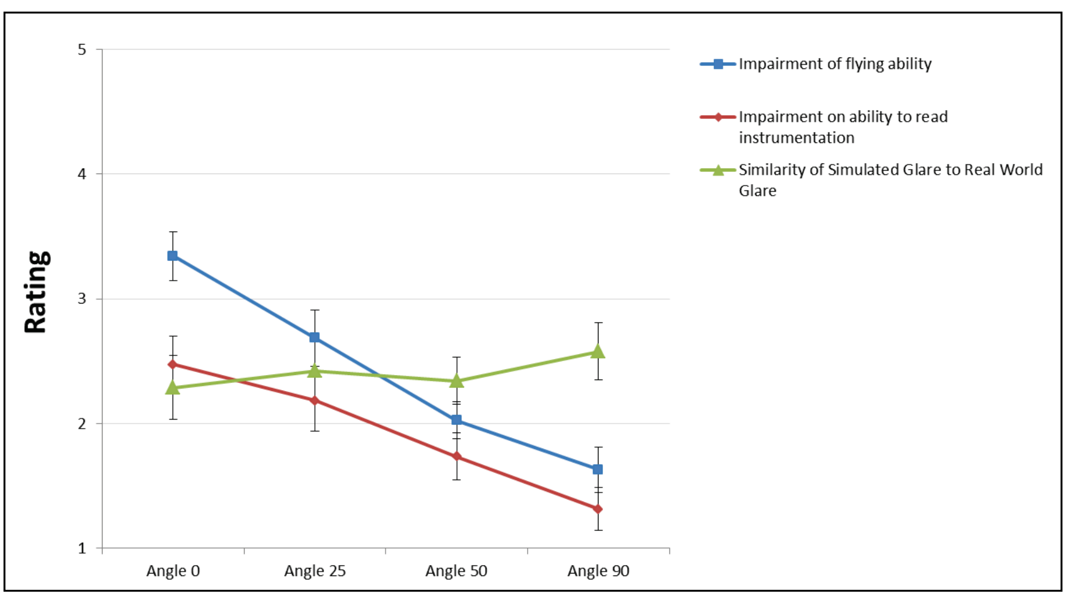

***Figure 9.** Mean ratings of impaired flying ability, impaired ability to read instrumentation, and the similarity of simulated glare to real glare, as a function of glare exposure angle. Error bars represent one standard error of the mean.*

CONCLUSIONS

The presence of glare was associated with the most impairment in the pilot's ability to see their instruments and to fly their airplane when the glare was straight ahead, as well as slightly to the side. The more forward the glare is and the longer the glare duration, the greater the impairment to the pilots' ability to see their instruments and to fly the aircraft. These results taken together suggest that any sources of glare at an airport may be potentially mitigated if the angle of the glare is greater than 25 deg from the direction that the pilot is looking in. We therefore recommend that the design of any solar installation at an airport consider the approach of pilots and ensure that any solar installation that is developed is placed such that they will not have to face glare that is straight ahead of them or within 25 deg of straight ahead during final approach.

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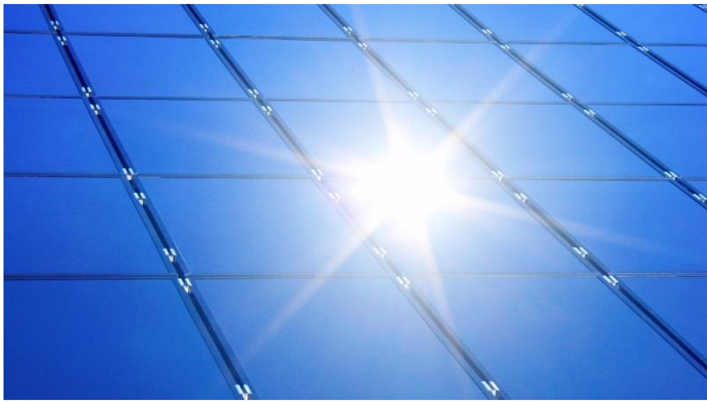
Exhibit T

Solar and Glare Fact Sheet

MEISTER CONSULTANTS GROUP

June 2014

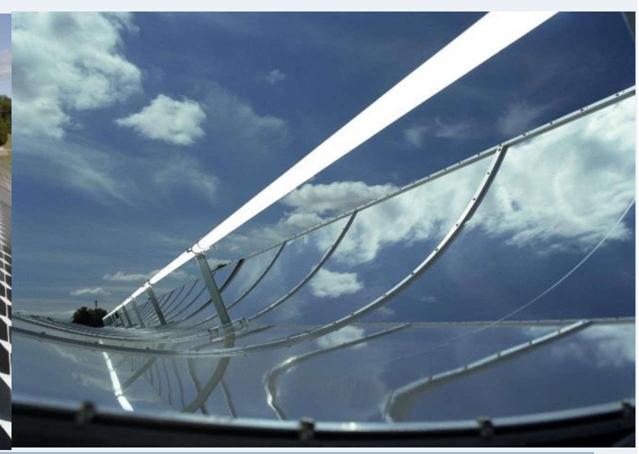
Solar and Glare



I. Introduction

A common misconception about solar photovoltaic (PV) panels is that they inherently cause or create "too much" glare, posing a nuisance to neighbors and a safety risk for pilots. While in certain situations the glass surfaces of solar PV systems can produce glint (a momentary flash of bright light) and glare (a reflection of bright light for a longer duration), light absorption, rather than reflection, is central to the function of a solar PV panel - to absorb solar radiation and convert it to electricity. Solar PV panels are constructed of dark-colored (usually blue or black) materials and are covered with anti-reflective coatings. Modern PV panels reflect as little as two percent of incoming sunlight, about the same as water and less than soil or even wood shingles (SEIA/Sandia 2013). Some of the concern and misconception is likely due to the confusion between solar PV systems and concentrated solar power (CSP) systems. CSP systems typically use an array of mirrors to reflect sunlight to heat water or other fluids to create steam that turns an electric generator. These typically involve large ground-mounted reflectors, usually in remote desert locations, and are not installed in residential or commercial areas or near airports.

Solar PV system on the left compared to a parabolic trough CSP system on the right. Photo Copyright DOE/NREL/ORNL



II. PV on or near airports

Solar and Glare

As of June 2013, there were over 30 solar projects in operation at airports in 15 different states (Barrett 2013). Solar installations have been successfully located at or near US international airports in Boston, New York, San Francisco, and Denver, among others. Yet concerns over glint (a quick reflection) and glare (a longer reflection) often arise when a PV system is proposed on or near an airport. Pilots are familiar with both glint and glare as reflection is a common phenomenon, especially off of bodies of water or in the form of glare from the sun itself. However, issues can arise if the solar PV system were to cast glare into an air traffic control tower.[1]

The Federal Aviation Administration (FAA) has been actively reviewing the impact of glare from solar panels to streamline an evaluation process that ensures safety while creating more opportunity for solar installations on or near airports. The FAA filed notice of its Interim Policy for review of solar energy systems on federally obligated airports (i.e. airports which receive federal funding) in October of 2013.[2] This policy requires that a sponsor of a federally obligated airport must request FAA review and approval to install solar on its "airport layout plan." Federally-obligated airports must also notify the FAA of its intent to construct any solar installation by filing FAA form 7460-1. The interim FAA policy also requires the use of the Solar Glare Hazard Analysis Tool for on-airport solar development.

III. FAA and the Solar Glare Hazard Analysis Tool

In order to understand and model glare in accordance with FAA standards, Sandia National Laboratories developed the Solar Glare Hazard Analysis Tool (SGHAT). Standardized safety metrics define what glare intensity will cause unwanted visual impacts to Air Traffic Control towers and airplane pilots. SGHAT can be used to evaluate the potential of a particular PV array to produce glare intensity, predicting when and where glare will occur from a prescribed PV array at user-defined observation points (i.e. from the Air Traffic Control Tower or from a series of points along an aircraft landing route) and be combined with Google maps for an easy user interface. In instances where glare may be a concern, the tool can prescribe minor adjustments to the tilt, direction, and location of the panels to alleviate any issues. SGHAT will predict annual energy production for the various adjusted positions (SEIA/Sandia PPT).

IV. Role for Local Governments

Local governments may wish to include airport guidance within their local zoning ordinances that address solar PV. The North Carolina Solar Center *Template Solar Energy Development Ordinance for North Carolina*[3] includes a section on airports and recommends aviation notification steps for both on-airport solar projects and installations within 5 nautical miles of an airport. In addition to amendments to local zoning codes, local governments have the opportunity to conduct outreach to airports,

[1] http://www.unionleader.com/article/20120830/NEWS02/708309966/0/newhampshire
[2] http://www.gpo.gov/fdsys/pkg/FR-2013-10-23/pdf/2013-24729.pdf
[3] http://ncsc.ncsu.edu/wp-content/uploads/Template-Solar-Ordinance_V1.0_12-18-13.pdf

Solar and Glare

organizations and local stakeholders about methods for predicting and managing glare impacts from solar panels near airports or other locations. Such outreach furthers the safety goals of the FAA and the solar energy development goals of municipalities and communities. Spreading awareness of the safety of PV systems along with FAA guidance and glare measurement tools will help foster informed communities and enable the deployment of safe and productive solar PV projects in locations where glint and glare may be of concern.

V. Useful Links

Sandia Solar Glare Mapping Tools: https://share.sandia.gov/phlux

V. Citations

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SEIA/Sandia Webinar on Solar PV and Glare:
http://www.seia.org/sites/default/files/resources/Final%20FAA%20Webinar%20Slides%20August%202013.pdf

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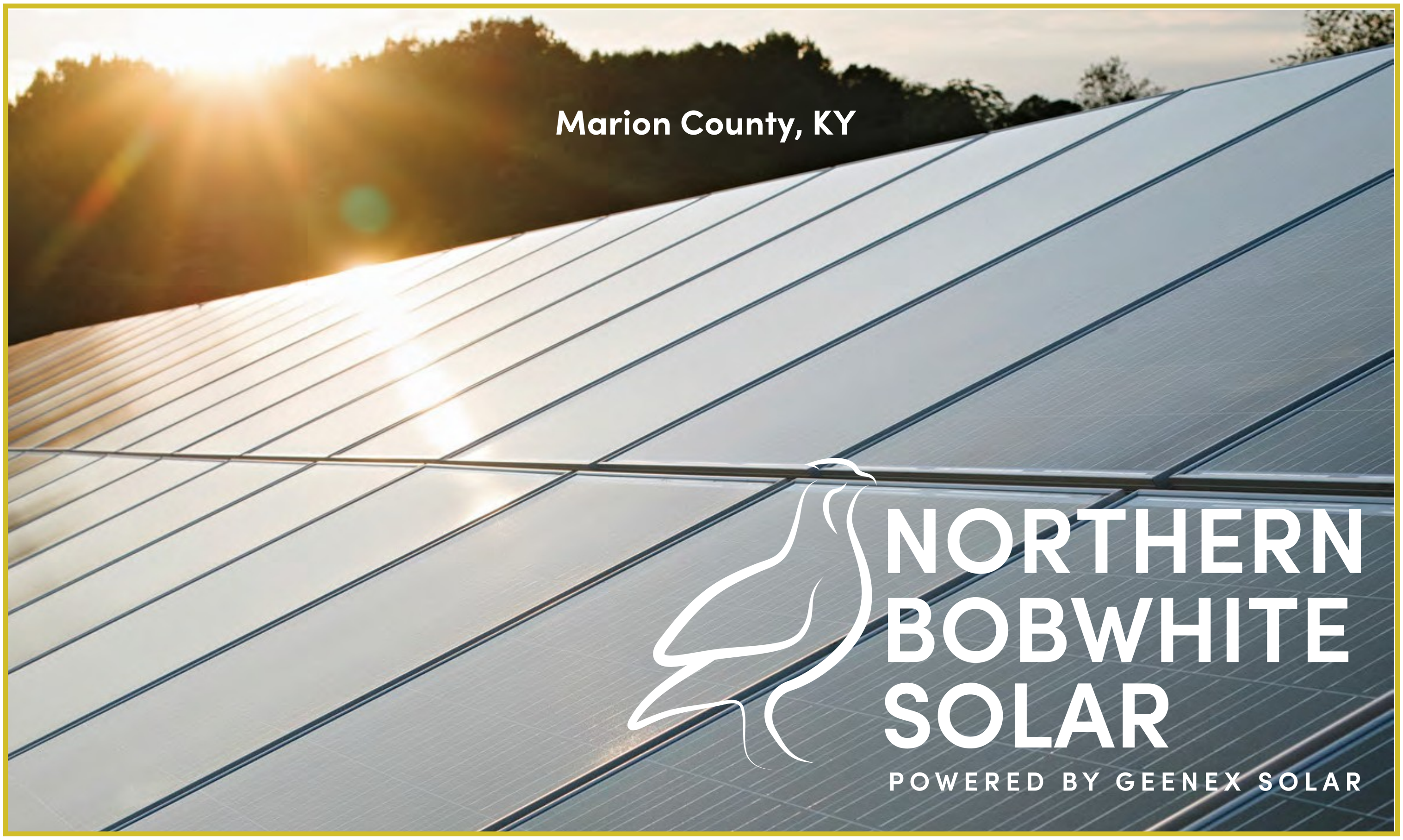
Exhibit U

Information Sheet



PROJECT OVERVIEW

Northern Bobwhite Solar is a proposed solar photovoltaic electric generation facility under development in Marion County, KY. The project plans to deliver 96 MW of clean renewable energy to the utility grid by the end of 2022.

Solar photovoltaic systems produce no emissions or contaminants, generate no noise outside of the fence line, and the panels are designed to absorb light so there is no glare. The land can be returned to agricultural use after its life as a solar farm making solar a great placeholder for the future. The developer will provide setbacks and vegetative screening to mitigate viewshed impacts to neighbors of the project.

Please visit
www.geenexsolar.com/northernbobwhite
for more details.

- SOLAR IS CLEAN, QUIET, SAFE WITH NO HEALTH OR PERMANENT LAND USE IMPACTS.
- SOLAR INCREASES THE COUNTY'S TAX BASE AND PROVIDES ECONOMIC DEVELOPMENT OPPORTUNITIES.
- THE DEVELOPERS OF NORTHERN BOBWHITE SOLAR DIRECTLY SUPPORT THE EDUCATION AND WORKFORCE DEVELOPMENT PROGRAMS OF THE CENTER FOR ENERGY EDUCATION.
- THE PROJECT WILL RECRUIT & HIRE FROM WITHIN THE LOCAL & REGIONAL COMMUNITY. THE SOLAR INDUSTRY NOW EMPLOYS MORE WORKERS THAN THE OIL, COAL AND GAS INDUSTRIES COMBINED.



NORTHERN BOBWHITE SOLAR

96 MW GROUND-MOUNTED SINGLE-AXIS TRACKING PHOTOVOLTAIC SYSTEM

ENOUGH POWER FOR 24,000 AVERAGE U.S. HOMES ANNUALLY

POSSIBLE CONSTRUCTION START IN 2021

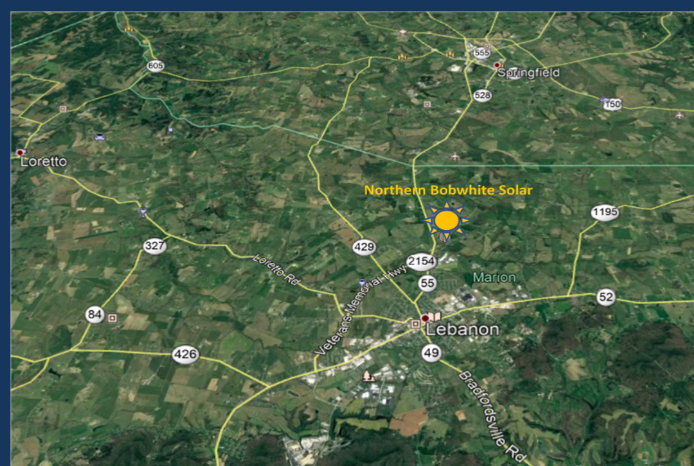
USE OF SETBACKS & VEGETATIVE SCREENING WILL MITIGATE IMPACTS TO NEIGHBORS AND COMMUNITY

Why Solar? Why Now? Why Marion County, KY?

- High demand for low-carbon renewable energy by customers, corporations and institutions.
- Cost of solar continues to decrease making it highly competitive with traditional fossil fuel sources.
- Location, location, location - great solar resource combined with good topography near areas with high energy demands.
- Available land with existing and accessible utility infrastructure.
- Landowners wanting to diversify their income and protect their real estate assets.

NORTHERN BOBWHITE SOLAR BENEFITS

Northern Bobwhite Solar will provide a number of benefits to the county and surrounding community. The Project will bring a significant number of jobs to the area during construction. In addition, long-term jobs are created by the on-going maintenance of the site and the facility as well as the future growth of the solar industry in Kentucky.



The spending on development, construction and operation of such a project also provides a number of financial opportunities for local businesses (fencing, landscaping, machine rentals, etc.). The increased economic activity in the area also increases revenue for local hotels, restaurants and other vendors.

Northern Bobwhite Solar has and will continue to engage in local community outreach to address questions from neighboring landowners. The Project also looks forward to supporting local charities and will provide funds to the County for future projects that support education, workforce development and local first responders.

And finally, the Northern Bobwhite Solar Facility will be producing clean renewable energy that will have a number of positive impacts for the community and our environment for years to come.

geenex

Geenex Solar is a developer of utility-scale solar projects. For more information, see http://www.geenexsolar.com/

Please feel free to reach out to us at northernbobwhite@geenexsolar.com or call Kara Price at 859-309-4415 or Doug Schulte at 859-309-7662.

Exhibit V

Full Transcript of Public Information Meeting

Terry:

Good evening. My name is Terry and I will be moderating tonight's call. As a result of COVID-19, today's public information meeting is being broadcast live via telephone and internet in order to give all members of the community the opportunity to participate. This evening, we'll be discussing a newly proposed solar energy facility in Marion County, Kentucky, Northern Bobwhite Solar. Know that this meeting is interactive and we would love to hear from you. We'll be taking as many questions and comments from participants as we possibly can live on this event. If you have a question, you can press star three on your telephone key pad at any time, and you will be placed in queue to speak publicly.

An operator will take down your name and a brief overview of your question, and then the next time you hear your name, you will be live on the call and you'll be able to ask your question or make your comment directly. If you're listening through the website, please type your name and question or comment below the streaming player. Your question or remark will be read out loud and a member of the Northern Bobwhite team will address it. We will do our best to take as many questions as we possibly can this evening. Again, if you have any questions throughout the event, please press star three on your telephone keypad or type your name and question below the streaming player. At this time, I will turn it over to tonight's host for their opening remarks.

Kara Price:

Thank you very much. Welcome to everyone on the line and on the web, and thank you for taking the time to join us this evening to learn about our project, Northern Bobwhite Solar. I am Kara Price, Senior VP of Permitting and Development for Geenex Solar. On the line with me are a variety of our team members for Kentucky. I'll quickly go through some of the names because you may hear from them later today on this call. We have Doug Schulte, our Director of Operations in Kentucky who will be sharing detailed information with you about the project and its site plan. Donna Robichaud, our Senior VP of Development Strategy. She is our expert in interconnection and timelines and state permitting for this project. We have two members of our land development team here in Kentucky, Nathan Coleman and Aron Caudill who are on the line.

We also are joined by our managing director, Juergen Fehr, out of our Charlotte office who's very important to our team. And then Patrick Russ, who is one of our engineering leads here with Geenex as well. We also have Mozine Lowe with the Center for Energy Education, which you're going to learn a little bit more about and hopefully here from Mozine later in this presentation. We also have some other experts available based on the questions we may get and that you have, we will possibly toss some things to them. We have Karen Thompson with Smith Management Group out of Kentucky, Rich Kirkland with Kirkland Appraisers who can speak to property value impacts of solar, and then we have a number of Terracon's environmental permitting team who include Lou Smith, Scott West and Ben Taylor. Appreciate them all being here with me and you may hear more from them later. Before we get into the details of the project and we'll start going through the slideshow here, I think it's important to learn a little bit about who we are, Geenex Solar, and the developers of this project.

Geenex Solar has been developing utility scale solar projects since 2012. The picture you actually see on this slide show right here is the first project that we did in Halifax County, North Carolina. This was actually an abandoned airfield that the county was trying to repurpose. A consultant came forward and said that this would make a great solar project. Geenex Solar was one of the companies that responded to a request for proposal to the county. What won Geenex the ability to develop this project was not only our expertise in solar development, but the fact that we had a vision, that these projects not only deliver clean, renewable energy to the grid, but they provide valuable education and workforce development opportunities for the communities in which we develop. From there we have certainly grown our portfolio of utility scale projects. We develop in North Carolina, Virginia, Ohio, Indiana, and now Kentucky.

A little bit more detail about Geenex and that vision we had about leaving behind education and workforce development opportunities is we were the founders of an organization called the Center for Energy Education. The Center for Energy Education is a nonprofit who has a headquarters based out of Halifax County, North Carolina, but all of its programs are designed to go into the communities in which we develop. In fact, the van you see in this picture here was actually in Marion County today for our open house that we had earlier. The programs that are held at the Center in Halifax County are all designed to be able to go out in the communities.

We host summer camp for kids where they learn about renewable energy and other STEM programs. We have training programs for teachers where we give them kits so they can learn about renewable energy and then take those kits back to the classroom. There's a variety of other workshops, construction classes, and workforce development programs that come out of the Center as well. So that's something Geenex is very proud of, that we helped found that organization and that now its programs are growing and moving into other states with us, such as Kentucky and here in Marion County.

Just a little background on utility scale solar. We know it's new in your community. It's new in Kentucky and it's a little important to understand why we are developing here. I don't come to solar from the engineering side of things. So it's important to see that solar is a very basic technology when you look at it. There's a solar panel. You'll have to excuse me. I'm having a little trouble seeing my own slideshow here. You've got the solar panel that converts the sunlight into DC power. Panels are connected them to the inverters that take the power from those panels and then convert that DC power to AC power, which is what we all use in our homes and our offices every day. You'll have a transformer in a substation on the site that gathers all the electricity throughout the solar farm and then converts that voltage to the same caliber of voltage that's on the distribution or transmission lines. And then that power goes into your local transmission grid.

On the next slide, it gives you a little more detail on why solar, why now and why Marion County, Kentucky. There's a high demand for solar energy right now by renewable energy customers. You hear in the press every day, the Amazon's, the Facebook's, the Google's of the world, and now institutions such as universities as well as cities and municipalities want to source their energy from renewable sources. Cost of solar has continued to decrease as well, making it very competitive against other traditional fossil fuel sources, so that really helps the energy mix. What Kentucky also has that other states have who are welcoming solar in is location.

You've got a great solar resource combined with good [tectography 00:08:05] near areas with high energy demands. Kentucky also has available land. When we're looking for a solar facility, it's important to understand that not just any ag land or farmland will work for solar facilities. There has to be existing infrastructure, and that infrastructure has to have the ability to take in more energy and have the capacity to deliver it. It gets very costly if you have to build infrastructure for these projects. You also have landowners that want to diversify their income and protect their real estate assets.

Our projects are secured primarily through long term leases with our landowners, and that's an important thing to understand. This next slide just has a quote from one of our landowners in North Carolina, talking about why he chose to move into solar. I think that's important to understand, that all of our landowners who are involved with our projects have their own reasons. Some people are only taking a part of their land and putting it into solar, and this income allows them to continue ag operations on other parts of their land. It also allows them to keep the land within their own family during this period of time. Once this project is no longer a solar farm and we can decommission it and return it back to ag production, their family will still own that land. Another key point that's a big question we get is property values.

"How is this going to impact my property value if I'm a neighboring landowner?" North Carolina, by virtue of its history with solar, has a lot of data in regards to that. What has been found is it just really doesn't have an impact either negative or positive. Solar just doesn't have the land use impacts that other more intrusive development has. There's no noise. There's no sound outside the fence line. Once it's constructed, it operates very quietly and very passively. Actually, it's one of the few developments where we can remove all the equipment at the end of its life and the land can go back to ag use.

Solar is also a very proven and environmentally safe technology. Solar has been used since, goodness, I think NASA was one of the first companies who started using solar in their satellite systems. There's no emissions or contaminants of any kind in a solar panel. There's no noise outside the fence line. There's very little reflectivity or glare. That's a common misconception that people think they're going to be blinded by these solar projects, but the panels are designed to absorb as much light as possible. If you ride by one, they almost look purple and black, most of the times, as you ride by.

The materials that are in a solar panel and the other aspects of the solar facility, more than 90% of those can be recycled at the end of their life, which actually is another testimony to the fact that they don't have any hazardous materials in them. I also mentioned that the land can actually be returned to its original ag use. Solar is a great placeholder for the future. 35, 40 years down the road, we won't need as much land. The technology is getting more and more efficient every year. In addition, there could be other ag crops, 35, 40 years down the road that allow a landowner to make a lot more money off ag operations as well.

Decommissioning is another very frequent question we get from a community. Our landowner agreements have a decommissioning clause in them, which means this project guarantees to the landowner that once this project is no longer operating as a solar facility and generating power, it can be decommissioned, which means all the equipment is removed from the site and the land can go back to ag operation. So these agreements will make that promise. There's actually even a decommissioning plan and estimate that are included as part of that and a surety put in place to ensure there are funds that will allow that decommissioning to happen at the end of the project's life.

There is extensive permitting oversight with these projects, and that's another important thing to understand. It's one of the reasons the timeframe for these projects are very extensive. From the time we secure land and we move through interconnection studies, it sometimes can take years. A lot of times people are like, "Oh, well, we just heard about this project, and we've heard you had this land for two or three years." Well, that's because we're still going through a lot of the permit processes and environmental testing on the land. At the federal level, you'll have the Army Corps of Engineers who'll be looking at the site for wetlands impact. If there's any airport or other facilities nearby, the FAA will get involved and we'll have to do a glare study. There's the US Fish and Wildlife Service who looks at threatened and endangered species for our projects. At the state level, we have the Kentucky Sate Siting Board that we'll look at this project over a, goodness, I think it's close to a 10 month period, if not more.

Karen Thompson with SMG is going to talk more about that, from all different levels and different state agencies who will review it. The Kentucky Department of Transportation will deal with the state driveway permits involved with this project. You also have the preconstruction permit, the stormwater and erosion sediment control. The local jurisdiction, we get involved with any local use permits or building and electrical permit that will be needed for this project. While all of these processes are in place, you also have the interconnection studies that are being handled through the overarching utility system. PJM, this acronym that you see there, it relates to an energy marketplace. It's a regional transmission operator that extends from Northeastern North Carolina up through the Midwest and the

Northeast. It's one of the largest energy marketplaces in the world. This project is interconnected through there. Even though it uses the local transmission infrastructure of your Kentucky utilities, it's actually interconnected through this larger group.

Now I'm going to introduce Karen Thompson with Smith Management Group. Her company is a great resource for all sorts of development in Kentucky in regards to electrical infrastructure, and she's helped guiding us through some of these processes. So Karen, if you want to introduce yourself and talk a little bit about the State Siting Board process, that would be great.

Karen Thompson:

Thanks. I'm Karen Thompson with Smith Management Group, and I'm going to be taking you through the State Siting Board permit that we're going to be doing for Geenex. Just to give you a little bit of background, the Siting Board started in about 2002 and it was set up for projects just like this. At the time we were looking at other, what they call merchant plants, which are plants and facilities that aren't part of the KU LG&E East Kentucky power cooperative, those utilities that are regulated by the Public Service Commission. So the state wanted to make sure everybody was playing by the same rules so the board was established. So it has three members that are part of the Public Service Commission that sits on the board. And then to make sure things are looking on the upside, we also have the cabinet for Economic Development.

So the secretary or one of his designees will be there. Environmental Protection cabinet will be there or one of their designees. This is just to make sure that everybody that needs to be involved is involved in the first part of the permitting process. You, as Marion County citizens, will have two ad hoc members. Usually it's going to be your County Judge executive, and then one other citizen resident of the community. Those would be put on the board for this particular hearing by the governor. So that's the basis of what goes on there. If we go look at the application process, there's been a Notice of Intent filed or will be filed. But the Public Service Commission is aware of this particular project. If you go online, you'll see that it's there.

You'll see that there's several other folks that are putting in for permits at the same time. There's a filing application. When that happens, Geenex is going to throw in everything that Kara just talked about and provide all that information back to the board. They're going to review it. They're going to ask questions. And then we're going to set up a hearing on that. They're going to bring forth all of the pieces and parts of the application and have a formal proceeding that's going to decide whether or not this facility can be built. This is part of the process, tonight's town hall. Local support is part of this process. The public hearing and public comments, once everything is in, will be there too. The deciding board will also look at those comments from the public and answer those questions.

Kara Price:

Thank you, Karen. Doug Schulte, our Director of Operations for Kentucky will now take us through some more detailed look into the actual project and the site plan and what is being proposed in Marion County. Doug.

Doug Schulte:

Good evening. This is Doug Schulte. I've been working with Geenex for about four years doing development work, and what we're going to talk about now is the specific project that we're working on. Northern Bobwhite is a project that's based on about 1500 to 1900 acres of property just to the north of Lebanon, Kentucky. It will connect to the transmission grid via the substations with EKPC that are located on Radio Station Road. So you can see that most of the project, then, is to the north and northeast of that location, and kind of surrounding that location.

As we build this facility, it's important to understand that because we leave space between the solar panels to prevent shading and things like that of adjacent sets of solar panels, we don't completely cover the ground with solar panels. There's space left between them, and we actually only cover about 30% of the ground. That gives us space to be able to get in to mow grass and, as I said before, to keep one row of panels from shading the row behind it. So the ground will get plenty of sunlight and grass will continue to grow and we will maintain that. Typically we will leave the entire site in grass. We don't come in and cover it in gravel and things like that. We want to maintain the natural grass that's there and keep that in place for control of runoff and protection of the ground.

We will pursue an issuance of an industrial revenue bond with Marion, Kentucky. An industrial revenue bond is a program that's been authorized by the state in the past, and has recently been revised to include solar farms as one of the areas that it can be applied to. It's a state tax incentive program for that allows counties to promote economic development and attract programs to their county. It's being used in many counties across the state right now. Once operational, this project will generate 96 megawatts of electricity, which is about enough to offset the consumption of 24,000 average American homes. Next slide, please.

Terry:

While we're transitioning those slides, I'll just make a quick reminder that if you'd like to ask a question of our group tonight, please press star three on your phone keypad at any time. You'll be placed in queue to speak with an operator who will take down your name and question and then the next time you hear your name, you will be live on the call. Also, if you're listening on the website, please type your name and question or comment below the streaming player. Again, a reminder, if you are listening live on the phone and you'd like to ask a question or make a comment, please press star three and you'll be put in queue. If you're listening on live streaming on the web, please go below the streaming player and enter your name and question, and I will read that out loud when we get to the Q&A session. Thank you, Doug.

Doug Schulte:

Okay. These drawings we're going to go through in the next couple of slides are larger views of some of the project or some of the sections of the project. As we've said, large portions of the site are areas that will not be visible from roadways or neighbors. Oops, I think I skipped a slide here. I'm sorry. Large portions of the site are areas that will not be visible from roadways. We provide setbacks and things of that nature to make sure that you don't have an unsightly area. In many cases, we'll put up vegetative screening along roadways and in front of houses that are within a certain proximity to the fences so that they've got an attractive view and not some sort of an eyesore.

There are 12 Marion County land owners whose land comprise the project. The current panel placement that's shown here is preliminary. It will get revised as we go through the engineering process and see things that we have to avoid and have to shift panels around a little bit. But the general footprint is expected to be pretty much solid. You can see the areas where the fence line is surrounding the area. We put up a six to eight foot chain link fence that's consistent with the requirements for the National Electric Code to protect people from electrical equipment and also for security purposes for the solar farm itself. Next, please.

The minimum setbacks from roadways around the project. We have equipment setback 100 feet from the roadways. The fence itself is not included with that. So the solar equipment itself will be set back 100 feet from the roadways and the fence and the vegetative screening would be within that 100 foot setback. Setbacks from property lines that are between properties that are not participating in the project are at least 50 feet. We try to keep setbacks from all electrical equipment setback from local neighboring residences at least 200 feet. We have a couple of residences currently that are at or slightly below that 200 foot limit, and we'll be making some adjustments to the layout to accommodate that. But currently the average setback or average distance between any electrical equipment, solar panels from any of the residences in the area is averaging 1000 feet. Again, we use vegetative screening and buffering to minimize the visual impact to the surrounding land owners and people driving in the vicinity.

The design of the site allows for different fenced areas. You notice that this project is broken up into a number of sections and that allows for wildlife and so forth to continue to move and not be impeded by having a large contiguous area completely fenced in. The site itself is primarily open land requiring only minimal tree removal and further protects wildlife and wetlands. We have found that a lot of wildlife, particularly things that are struggling at this point in time like quail, find the solar farms to be a very attractive place to be. We've seen recoveries in some areas because of that protection from predators.

Community benefits. The project will have a significant workforce development in the area. Solar construction companies will actively seek to use local people as much as possible, and you'll see activities on a site like this will take 12 to 18 months for construction and probably engage 100 to 150 people from the local area in that construction effort. Local contractors will also be utilized for things like equipment rental, material supplies such as fencing or steel for the supports, clearing of the site and grading and things like that. Some of the electrical work may be done by people from the local companies. So there'll be a wave of impacts and benefits to some of the other companies and businesses in the area, hotels and restaurants and things like that, as well as economic impact. Permanent positions supported will include landscaping and groundskeeping.

They may not be direct hires of the solar company, but there will be people engaged through contracts to provide those services and will provide employment in the area. We'll also look for site operations and maintenance personnel or maintenance contracts with local companies to help support the project. There will be local workforce development programs through the Center for Energy Education, engagement with local colleges and so forth. That training will be set up to help provide training the people that are interested in working on the solar farms or performing maintenance activities, and will get them, depending on the...

PART 1 OF 4 ENDS [00:29:04]

Doug Schulte:

... activities and we'll get them depending on the program involved will result in certification that gets them to the point that they can participate in the projects and work not only on this particular project, but on other projects in the region. Next slide please. As I already mentioned, you'll see increased economic business for local restaurants, supply stores, the various infrastructure that's within the area of facility as they serve as not only the solar farm itself, but the people that come to work at it. Solar facilities can be an economic development boom to the county. It provides a marketing possibility for the county to demonstrate their receptiveness to environmentally friendly things and the companies that are interested in that sort of activity. And most companies now are coming out with goals for their shareholders and their customers to demonstrate their commitment to being carbon neutral in the environment and decreasing their footprint and impact on the planet.

This can also attract companies because they see the solar farm as being an indication of that same sort of mentality in this area. We've already talked a little bit about industrial revenue bonds which are used to help finance the solar facilities and as a tax incentive program from the state offered the counties to encourage activity in their county. There's also a pilot program or payment in lieu of taxes that's made to help make sure that the county has held hold through that process and doesn't see any financial negative side and in fact, what they will see is a significant economic input to the county, a tax revenue benefit from this project being in place.

Geenex solar facilities are also a resource for educational opportunities for local residents and teachers. Not only this, the center for energy education help work with local teachers and training institutions to develop programs and provide education, it's a facility that those local educators and community groups and things like that can point to and make arrangements to visit and help see and understand firsthand how these facilities work. With that, I think we're going to turn it back to the narrator and process any questions that have come through.

Terry:

All right. Thank you Doug. Thank you for the presentation. At this point, we've got some questions coming in from the internet. Just a reminder, before we jump to those, if you're listening on the phone and you'd like to ask a question or make a comment, please press star three on your telephone key pad and if you're watching this on the web, please type your name and question or comment below the streaming player. So at this time we have an interested party who's chosen not to leave their name. The first question from interested party is, you say there's assurance of decommissioning. How is that assured financially? If the company goes bankrupt, what happens?

Doug Schulte:

This is Doug Schulte. I can go ahead and handle that question, is as part of the process and as written into our contracts, we will provide a bond or some other financial instrument. We will have an independent engineer, not somebody that works for us, but an engineer registered in the state of Kentucky to put together a cost estimate and decommissioning plan for what it will take once the facility is designed and we know what we're putting in.

They will put together a plan and an estimate for what it will take to remove it and cut it off to be recycled and disposed of appropriately. When that's in place and we know what that estimate is through a calculation process, we will determine the amount of money that needs to be put in place to make sure that that decommissioning can be accomplished and we will put an economic instrument, generally a bond in place to cover that and it will be controlled by either the county or an executor from like a legal officer or a land manager that will manage that fund and make sure that if something does happen to the company, that money can be drawn upon to accomplish the removal and decommissioning.

Terry:

Thank you Doug. Our next question is for Donna. If solar generated energy exceed local demands, are other controllable electric generating sources reduced to take advantage of the solar generated power? If not, can it be stored in any way or is it just lost?

Donna Robichaud:

This is Donna Robichaud from Geenex I'm the senior VP of strategy. So yes, the seller does and could often exceed local demand. But it is connected to large transmission wires that run through 13 different states as part of PJM. So the power then goes... It will keep going to different areas until it's used. There is a little bit of clipped energy that is not used and there is a possibility it could be stored but that's not our current plan.

Terry:

Thank you Donna. Our next question, Kara is going to take this one, is how long does the increase in labor demand last?

Kara Price:

Sure. For this particular project as Doug mentioned, you've got a construction timeline of 12 to 18 months, which is when people will actually be on that site performing construction related duties. So for this project, there is a limit to that time of the labor demand. However, I'm based in North Carolina as an example, which is now the number two country in the nation for install capacity and we have an entire industry and the same thing is going to happen in Kentucky. This is one project in Marion County. There will be other projects in the general vicinity of Marion County and the surrounding county. So people that then work on this project have learned the tools, the skill, have the tools and the skills needed to go to the next project and the county over.

So we see that there's going to be an industry where there's opportunity for long time employment. In addition, we find that a lot of solar facilities are funding support from those people who are underemployed in the community. They may be electricians, they may be plumbers, they may have other jobs where they may not work a full 40-hour week and they can supplement their income by taking on these positions at a particular solar project. Thank you.

Terry:

Okay. Thanks Kara. Our last question is how many people were on the webinar tonight and how many showed up at the open house today?

Kara Price:

I can take that question Carrie. We don't know how many yet are on the webinar tonight. I think the stats are generated after the event happens and Doug and the other gentlemen from Geenex who were at the open house today, I think we had close to 20. Is that correct?

Doug Schulte:

Yes, that's correct Kara.

Kara Price:

Okay.

Terry:

Okay. That's it for our questions so far. I'll turn it over the Geenex team to continue the conversation.

Kara Price:

Sure. If there's no other questions from participants, we certainly have some that we get a lot of times in our communities that we can speak to. I think one of the key ones and one we have an expert on the line about is how the solar farms affect surrounding property values. Obviously Geenex has committed developing projects that take into account the rural character of the surrounding community. It's why we do vegetative screening and have extensive setbacks to mitigate, you said impacts, but I'm going to let Rich Kirkland with Kirkland Appraisals, speak a little bit more about his findings about properties that are surrounding solar projects. Rich.

Rich Kirkland:

Yes. Hi. Again, I've been looking at the question about solar farms and adjoining property values for about nine years. I started looking at that in North Carolina. Since then I've looked in about 17 states, including Kentucky. The way you look to see if there's any impact on property value, is you do a paired sales analysis or a match pair analysis, which is simply you look at a property that's sold next to a solar farm and compare that to similar properties that are not near the solar farm near it to see if there was any impact that happened. It's a very straightforward process. It's supported by the appraisal institute. It's supported by all the... Essentially it's used by appraisers in every appraisal they do when they look at your house and they compare two houses trying to appraise it for the bank and they say, "Well, this house is like yours, but it doesn't have a garage."

They do a match pair to see how much value is there in a garage. In this case, we're just measuring to see what kind of differences there between a home next to a solar farm and essentially identical home not next to a solar farm. I've looked at about 700 solar farms so far. I have identified sales next to them that I'm able to extract and look to see if there's any impact on property value on about 84 different sales and I'm finding consistently no impact on property value that there's a cluster that you see all around plus and minus 5% and real estate is a very imperfect market and plus or minus 5% is the variability you'd expect in real estate in any normal circumstance. If you looked at two homes in the same subdivision, it might be identical floor plan, everything the same, they still don't sell for the exactly the same price.

So there's always a little bit of variation. So, everything I'm finding is really consistently showing no impact on property values and that the sort of the characteristics that go with that is that I'm looking at the landscaping buffers that are between homes and solar farms, as well as the topography, as well as distance between the home and the panels. I'm finding no impact on property values with brand new homes being built within 100 feet of an existing solar panel. So not 100 feet to the property land, but when I measured from the closest panel to the closest part on a home, I found them as close as 105 feet showing no impact on property value, brand new homes in the $400,000 price range. There are lots of other sales data out there showing similar, no impacts businesses between 100 and 200 feet and I know in this project, they're really working to make sure that everything is well beyond those distances.

You're looking at 200 feet or greater with an average distance of 1000. So there's really no concern about impacts on property value in this area. And I guess I should follow up with... I've also looked at specifically a number of solar farms in Kentucky and there's a project in Crittenden that is a really good example of solar panels joining residential uses nearby. And again, those home prices are showing no impact on property value and due to the topography in that area, those panels are visible. There are distant views of the panels from those homes, but they're still showing no impact. So this project here has got much greater buffers. It's got very good landscape buffers and it's got much greater setbacks, so there's really no anticipation of any impacts to property value.

Kara Price:

Thank you.

Terry:

Thank you Rich. We have a question from the internet. If someone is interested in discussing a contract, how would they go about doing that?

Kara Price:

Well, I'm not exactly sure what specific contract, but yes, we are not the company that will actually build and be the construction firm. However, we will have a direct line of communication with that company. So if you're interested in possibly being considered for landscape maintenance or mowing on the project or anything like that, certainly provide us with your contact information and we would love to share that with our partners who'll be taking this all the way through construction. When we can utilize local resources, we certainly would like to. So providing us that contact information and what you're interested in at this point would be very helpful.

Terry:

Okay. Our next question is when is the anticipated starting date for this project?

Kara Price:

Doug, I'll let you take that one. I believe construction is sometime starting next year, but if you've got more detail-

Doug Schulte:

Yeah. I can take that one. I mean, these meetings that we're having currently are the start of the state permitting process and we anticipate right now being able to get our state permit in late May or early June of next year. Assuming we accomplish that, then the planning and construction mobilization and things like that would allow us to start construction sometime around this time next year or sometime in the fall, perhaps after people have harvested crops and things like that.

Terry:

Okay. And Doug, maybe you can address this. What about the land availability for the project?

Doug Schulte:

We have already secured enough land to pretty much do what we need to do. There are some areas that we may acquire or fill in spots, particularly if we run into some technical issues as we do some of the engineering studies and geological work and things like that. But generally, we've acquired the land already and that's the site that we will be presenting to the state as part of the permitting process.

Terry:

Okay. But-

Kara Price:

I might want to make a comment to the audience as well. There's a couple other places where you can go for information. We do have a website for the project, which is geenexsolar.com/northernbobwhite altogether. We actually have a rendering of what the vegetative screening may look like and we will be adding that to the website in the next day. In addition, the Kentucky office of energy policy has a great website now that's called the Kentucky Solar Toolkit. We're going to put a link to that as well on our website for more information.

Terry:

Okay, great. Just another reminder that if you're calling in on your telephone and you'd like to make a comment or leave a question or ask a question rather, please press star three on your telephone key pad. And if you're listening online, please type your name and question below the streaming player. At this point, we have another internet question. If someone has a crop lease agreement, how do you work with that in terms of letting crops be harvested or buying out the lease agreement?

Doug Schulte:

I can go ahead and handle that one. This is Doug Schulte. We've put terms in our lease agreement and what we do is if the farmer has a crop lease agreement with somebody else in the process, we ask them to make sure that those people are aware of the existence of this agreement with the land owner for the solar farm and then in the event that we start construction or we need to take control of the land sometime during the process of the cropping season, we have two options.

We can either defer any activity on site or in that particular area of the site until after they've been able to harvest their crops for the year. If that's not possible, and for some scheduling or economic reason, we need to start construction on that site immediately, then we will pay whoever, the landowner or whoever he's leased the land to for cropping the fair market value for that crop and that will enable us then to go ahead and proceed with activities on site.

Terry:

Thank you Doug. Kara, I'll turn it back to you for some more discussion from the team.

Kara Price:

Sure. Thank you very much Carrie. Let me just follow up here some of our other questions. One thing that we often hear is just concerns about health and safety related to a solar facility. And I think it's important for people to understand again that solar technology has been in use for more than 50 years. They do not emit any gases or at least anything into the environment and most of the components can be recycled when the system is removed. Universities and electrical engineers have studied this technology for years and there's an abundance of research backing up the safety of solar farms in North Carolina and North Carolina State University has done a research paper on the health and safety impacts of solar photovoltaics.

Environmental engineers have also done a lot of work into this and research. So we can provide this full data and access to universities and other research avenues if anybody has concerns about that. I'm going to, if you don't mind, but the experts that we have with Terracon, it might be helpful for you guys to speak to what your role is with a solar project and what type of studies you're involved with on the land that we utilize for solar. Hello?

Benjamin Taylor:

[crosstalk 00:49:16] Sorry. Wasn't sure who going to go first. This Benjamin Taylor. I'm with Terracon here in Louisville. I'm a geotechnical engineer and the engineering geologist for the project. And so part of what we're going to be looking at is the design for foundations to support the solar panels for the farm. And then any geological impacts of this project site that may affect the design and construction to assist with the design of the facility. Scott you were in queue next maybe.

Scott West:

Yeah. Sorry about that. I was muted. Yeah. My name's Scott West. I have been the Natural Resource Project Manager on this site as well as many other than I've done with Geenex and our role has been to assess all the sites, especially this one to determine any potential ecological risk factors, as well as any potential wetlands and streams that we locate on site and we work with the team to hopefully avoid any impacts that we can to these natural features. We also do a threatened endangered species survey of the site and help them out to work with the regulatory agencies to ensure that all state and federal guidance's are followed and make sure that just everything's staying on the up and up. So I think that's about it, but if you have any questions, I'll be happy to answer them.

Lou Smith:

[crosstalk 00:51:00] Can you guys hear? This is Lou Smith with Terracon. Just adding to that. We've also looked at the solar farm and assess for any potential environmental concerns as it relates to due diligence for the land.

Kara Price:

Thank you all very much. Appreciate that. Just wanted to make sure everyone understood our experts are. Mozine, if you are still on the line, I think it might be helpful for you to speak to the center for energy education and some of the things that you're working on. I think he just had some summer camps that wrapped up that you could possibly share with the community.

Mozine Lowe:

Yes. Hi. Thanks. Thanks Kara. This is Mozine Lowe and I am the Executive Director for the Center for Energy Education. I've been the executive director for four years now. We are based in North Carolina. However, our reach is into Kentucky, Ohio, Indiana, and Virginia. We have been doing providing educational opportunities in Marion County now for I guess the past year. We started with a workshop for teachers, solar education workshop for teachers that took place last year. We've offered a solar education workshop for county officials.

I think it was last fall and we are completing our summer camp program for K through 12 students, had a wonderful showing of students from Marion county and going forward, we look forward to offering some community education programs on solar farms and how they work, the technology behind them, providing what information on workforce development opportunities and just finding different ways to engage with the community. So if there are events that are going on, if there are programs that are going on, if there are ways that you would like for us to engage with the community, please feel free to call the office. We'll be more than happy to work with you. Okay back to you Kara.

Kara Price:

Doug, I think you had a couple of things you wanted to share as well.

Doug Schulte:

Yeah, I can point out a couple of things that people usually ask about these facilities. We talk a little bit about the decommissioning process and things like that and how we can actually restore ground to a farmable condition or the condition that it was out at the time the lease was signed. These facilities are built generally with nothing more than a CLIBean, like a post that a guard rail is mounted on, on the side of the road, driven into the ground, say six feet or so into the soil to provide support for the structure then that holds the solar panels. So there's really, in most cases, no concrete installation into the ground. We've got the post driven into the ground. There's a little bit of buried wiring that connect to other things or to connect the solar panels to the inverters and other components of the facility.

Those inverters might have a concrete pad underneath them, but at the end of the day, we can pick that up and take it away with us. There'll be a more substantial concrete foundation under a transformer, but as we remove all that equipment, there's in the grand scheme of things, really very little concrete that would need to be broken up and removed. For the vast majority of the site, 90% of the site, all we need to do is dismantle the equipment and remove it and then pull the post up out of the ground and pull up the buried wiring and take down the fencing and the site is pretty much back the way it was when we arrived.

The facility itself is very rugged. Part of the reason for driving posts six or eight feet or whatever into the ground and some of the work that we do with Terracon is to make sure that the installed facility can handle 120 mile an hour wind without failing. The panels themselves are subject to impact tests and can handle, I forget the exact specifications, but I've heard people talk about a one inch seal ball hitting the panel at 50 to 60 miles an hour or something like that without damaging the panel. So hailstorms and things like that are rarely of any consequence to the security of the panel.

Even if there is a panel damage, the panel is filled with the same kind of resin and structure you would see in your automobile windshield. So even if it cracks, you're not going to have glass and chemicals and things like that seeping out of the panel and getting anywhere. It's all pretty much sealed in the resin between the plates of glass. These facilities really are very innocuous and have very little impact even if they're damaged on the surrounding environment. So those are a few things that people asked about issues like what happens with these things and what do they need to be worried about and frankly I struggle to find things of any consequence to worry about with them.

Terry:

Thank you Doug. Again, a reminder that if you're listening on the phone, please press star three to get in queue to ask your question or leave your comments and if you're listening through their website, please type your name and question below the streaming player. We have another internet question come in. If someone has land that wants to participate in this project, who would they talk to?

Kara Price:

That would be-

Doug Schulte:

In the absence, another answer. I'm going to have to throw myself under the bus I guess. The person they would need to talk to is me, Doug Schulte and I think the phone numbers and contact information have been posted on the website. So you're free to use those numbers and alternatively, they could send an email to our central office in Charlotte, North Carolina-

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Doug Schulte:

They could send an email to our central office in Charlotte, North Carolina, and somebody would pass it on to me and proceed from there. My email address, if somebody wants to send a note to me, is Douglas. Schulte, S-C-H-U-L-T-E, @geenexsolar.com.

Terry:

Thank you, Doug.

Kara Price:

Thanks, Doug. And in light of not having any other questions from the participants, the next thing we would do is basically recycle through the presentation again, instead of just asking ourselves questions. So if anybody on the line wants to hear about the [inaudible 00:58:52] and the project again, you're welcome to stay or please feel free to ask us any questions.

Terry:

And again, if you are listening on the telephone and you want to ask a question, please press star three on your telephone keypad. Or if you're listening on the web, please type in your name and question below the streaming player. I'll turn it back over to the team.

Kara Price:

Well, once again, this is Kara Price. I'm Senior VP of permitting and development for Geenex Solar based out of Charlotte, North Carolina. We do also have another office now in Ohio for our work in that area. But looking forward to being on the ground more in Kentucky as well with our first project in Kentucky called Northern Bobwhite Solar, which is located in the Marion County Community. Some of you may have heard already, we have a great group of experts from Geenex Solar, as well as outside resources that we utilize to develop these projects on the line with you tonight, and look forward to answering any questions that you have. From the Geenex team, you have myself, Doug Schulte, who's our director of operations in Kentucky, two of our key land developers in Kentucky, which are Nathan Coleman and Aron Caudill. Juergen Fehr, Our managing director of Geenex is on the line with us as well. And Patrick Rust, who is our engineering lead, coordinating all the efforts with Terracon for us.

Our experts that have joined us tonight are Mozine Lowe, Executive Director with The Center for Energy Education, Karen Thompson with Smith Management Group, Rich Kirkland with Kirkland Appraisers, and Terracon's team of Lou Smith, Scott West and Ben Taylor. I do see before we get further along, there is a question. Terry, I didn't know if you want to key that up and I don't know, Doug, if you want to address that question yourself before I [inaudible 01:01:03] back into the [inaudible 01:01:04] .

Terry:

Thanks Kara [inaudible 00:03:04]. Happy to do that. So the question is what is the average dollars per acre that's being offered [inaudible 01:01:18] the lease rate?

Doug Schulte:

Yeah, that's what I take it to be. That changes from project to project. And then depending on what area of the country and the state that you're in. In general, we try to honor the confidentiality of the land owners that are doing business with us and trust that they are honoring those kinds of things as well. So we typically don't talk about that information with everybody and don't make that public. If somebody knows somebody and one of the landowners that's participating in the project, and wants to ask them and they want to tell you, that's up to them, but we don't really make that information widely available. I can say that in general, we see a range of prices, like I said, depending on where you are, but we've leased property for anywhere from $400 an acre.

I've seen land in some projects in some areas of the country as high as $1,000 an acre. Recognize that in some of those areas, when you... I'll say in our current process, we're in the lower half of that number. While you can see equipment or land being leased at higher rates, that electricity has to be sold competitively against other sources of electricity. So we're competing with gas-fired and coal-fired, oil-fired generation and other renewable sources, such as wind and hydro. So, the people, you see a lot of people offering really high prices for land rates. And a lot of those projects don't end up being built because they can't offer an economic electrical rate to some of the buyers of the electricity at what they've promised to pay for the land rates. So a lot of those projects tend to fall through after a while. And a lot of them don't even get built.

Kara Price:

Thanks, Doug. I'll continue back to our slideshow, giving a little more background on Geenex Solar as I mentioned. We are strictly a utility scale solar developer. We only do projects that feed into the local transmission corridor, unlike a residential solar developer, or a commercial solar developer. We have been developing utility scale solar projects since 2012. And Geenex is known not only for its well-cited and well-designed solar projects, but also for our local community engagement. And that's key for us on this call. It's important for you to understand that we're available for questions, we're available to discuss information with you along the way, want to be as transparent as possible as we develop this project. The fact that we have these great projects as well as great community engagement has made our projects attractive to a lot of investors along the way, which means they're more likely to be built in your community.

As I mentioned, Geenex founders had a vision where these projects would not only be delivering clean, renewable energy to electricity grid, but they would have other benefits along with that. And those benefits are education and workforce opportunities for the local communities. That's the reason that we founded The Center for Energy Education, which Mozine Lowe is executive director of and has already been on the ground. In fact, I believe they just wrapped up summer camp here in Kentucky and had hundreds of students involved in a virtual summer camp this year. Unfortunately, it couldn't be in person, but the students had a great time. We got some screenshots of their participation and that was quite hilarious. But anyway, that's a little bit about Geenex. Mozine has talked a little bit about The Center for Education.

Our van is right there in your community tonight as well. It was available at the open house today. This shows the mobile nature of our programs and the fact that we're looking forward to bringing them into the local community at the local school systems, the local technical schools, and everywhere else that we can put our programs in place to advance education and workforce development opportunities. As I mentioned about utility scale solar, it's a very simplistic technology. Even someone with a non-engineering background, such as myself, can understand. You have the solar panel, which absorbs the sunlight and is specifically designed to be able to absorb as much light as possible, but there's no glare. Then you have the inverters on the site that are converting that power from the solar panel, stepping it up into the transformer, then takes that power and matches the voltage of the local electricity grid so the power can be delivered into that and then go on its way where it's most in need along the way.

Talked a little bit about how we select land as a solar developer to support and to understand that not all ag land will work for solar. We certainly get a lot of people who are interested in the possibility of utilizing their land for solar, but it has to be the right land. It has to be near electrical infrastructure. It has to be near infrastructure that has the capacity to take the power that has to be fairly flat and make sure there's no wetlands and other issues that could be on the land. So if there's a lot of elements that come into play about the selection of the land that we use, which is important to understand, and why is Kentucky seeing this demand right now? This is being driven from a lot of different areas. You've got corporations who are wanting to say they're sourcing their power from renewable sources. Universities are doing the same thing. You even have local municipalities who are now converting to renewable energy as their sources. And all of that drives the demand of these projects.

And this is a demand that can't be serviced by just rooftop solar or anything else. It would take a utility scale solar project to meet the demands of these groups. You've also got a situation Kentucky where you have the right topography for us, and you've got a great solar resource. It's all about that location again, as I mentioned, and that is coming into play and you have willing landowners, which is another important part of this, who want to do something different with their land. Maybe they don't have family who want to continue farming, or maybe they're only doing this with part of their land so that they continue their ag operations. We spoke earlier about property impact analysis, those neighboring landowners. When they see that solar is coming in their community, they may be concerned about how that impacts their property values.

Rich Kirkland with Kirkland Appraisers spoke a little bit about that earlier and can certainly speak again. The solar just doesn't have the high impact land use that makes it have the impact. Once it's constructed, it is one of the quietest neighbors you can have. There's no noise outside the fence line. There's no smells, there's no lights and there's no traffic in the area. Solar does not have a lot of demands on the local infrastructure. We don't need additional water, a lot of additional roads or anything else that comes along a lot of times with more intrusive development. In addition, our landowners are usually entering into these agreements with us so they can keep the land in the family. It's usually secured through long-term leases that may be an initial 20-year period that could be extended up to another 20-year period. But the end of the life of this solar farm, that land still remains in the control of the landowner or the landowner's family.

Solar is also a proven and environmentally safe technology. Solar has been utilized for over 50 years. NASA was one of the first companies to utilize solar consistently. There's no emissions or contamination in the air, the soil or the water. There's no noise outside the fence line. Some of the equipment might hum just like your air conditioning unit hums next to your house. But by the time you get to the exterior areas of the site, you don't hear any of that noise. There's very little reflectivity or glare coming from the solar panels. We often get this question and the panels are designed to absorb as much sunlight as possible and almost look black or purple most of the times when you drive by them. It's also important understand that the site will be building in Marion County as a tracking system, which means it sits on an access and tracks the sun during the day to maximize as much energy generation as possible.

So during midday, it might be the panels might be almost completely flat, straight up to the sky. And the end of the day, they'll be facing one way and the next day they start over again and then talking about the glare, you'll also see a lot of airports and military institutions that have solar on their facilities. So that's another reflection of the fact that there's no glare issue. A lot of the materials used in these projects, I think Doug has mentioned all of that. They're recyclable. They can be utilized again. You've got steel, copper wiring, silicone, glass. These are the same types of things you would see in any commercial construction, much of the materials you might see in your everyday car as well.

So there's nothing really out of the ordinary with these panels. The land can also be returned to its original use. I don't think you can say that about many other types of development. As Doug mentioned previously, this racking system is just [inaudible 01:11:50] into the ground and then can just be removed. I always equate it like tinker toy set, where they can just be taken apart and disassembled. And then the small amounts of concrete that might be near an inverter or transformer pad can easily be removed. And the site returned to ag production.

Decommissioning, I think this is one of the biggest topics and questions that we have from community officials and neighbors of a project. Our land lease agreements actually include a decommissioning clause where the project guarantees that the site will be decommissioned and returned to its original ability to be ag gland after the life of the project. So there's actually a decommissioning plan that's filed. And once the facility stops generating electricity, that goes into place. And there's a certain amount of time that we have to actually remove the equipment. It was also mentioned about the surety that is in place to ensure that no matter who owns the project at that time, or if the original company is still around, there's a financial way to ensure that the project has the means to be decommissioned.

We've talked a little bit about the extensive permitting oversight [inaudible 01:13:11] are with these projects, which is why they have the long development timeline that they do from the federal level to the state level to the local level, through the utility infrastructure. There's a wide variety of steps and different processes that these projects have to go through before they can start on construction toward delivering power to the grid. Karen Thompson, who's on the line is with Smith Management Group. She is helping us prepare our project and our application to submit to the Kentucky State Siting Board. So I will let Karen give a little more detail into that process.

Karen Thompson:

Thanks for that introduction. This is Karen Thompson and the Kentucky State Siting Board was established in about 2002. It is specifically for merchant electric, electric generation facilities, what a solar farm is going to be, but it also handles other types of electric generation. So it would be the same process for wind or another plant that would come in and address electricity through natural gas or even coal that wasn't part of our established system through LG&E, KU or one of the other cooperatives around the state. There's five members of the siting board and two ad hoc members. The two ad hoc members are going to be coming from the local community. Most likely it's going to be your county judge executive, and one additional person that lives in the area, at least within the county. So you all will be represented as Marion County by two members that'll be put on the commission, the planning commission through the governor.

The other members of are made up of three members from the Kentucky Public Service Commission, and that is the parent commission of the siting board, let's say. They're the folks that regulate your rates and other issues within the realm of both electricity and water and several other utilities within the state. The other two members will be coming from the Public Protection Cabinet, Environmental and Public Protection Cabinets on here, but it's the Environmental Cabinet now, and then the other one will be from the Cabinet for Economic Development. Both of those sit on the committee just to make sure that the environmental issues are fully vetted and with economic development, it is to make sure that any proposed economic benefit for the state is truly there. Next slide, please.

The application process. Well, Geenex is in the middle of that process now. We are pulling together that application, but they've already submitted paperwork to the siting board to let them know that an application will be coming through. There are other notices that are out there, so Geenex is not the only one, but you can look that up on their website. You can visit the PSCKY.gov to find out more information there. We will be following that application and going back a couple of slides to what Kara was talking about, we'll be putting in a lot of information to this committee that will include the PJM and utility studies, that interconnection. We'll be looking at wildlife, we'll be looking at vegetation, water quality. We'll be looking at cultural resources, we'll be looking at noise, we'll be looking at transportation. And all of that has been put into the package and sent to the siting board who then will go over a hearing with Geenex and decide if the permit is actually viable or not.

During that process, there's also a need for public participation. That means your comments and your ability to add to the discussion both tonight and through any of the community efforts that will be happening over the next few months and that have already happened. And then there is also a point at which there's a public hearing and they will take comments at that point, too. That will be part of your participation through the board. Other considerations are going to take into account will be the effect on the local economy again, and the local environment. Thank you, Kara.

Terry:

Okay. We have another question coming in from the internet. The question is how likely is this project actually going to take place?

Doug Schulte:

I guess I can take that if [inaudible 01:19:11], or Kara, do you want to take it?

Kara Price:

We could probably both address that. I mean, this project is now moving to the state siting permit, that requires a lot of investment on our part to do the studies and do the analysis on the land. So this project is at a point in its interconnection studies and in its environmental studies where we feel it is completely viable and are willing to take the continued investment in this project to move it forward. So from our perspective, it is very likely unless there's something unforeseen as we go through the permitting process. Doug, if there's anything you want to add to that.

Doug Schulte:

No, that's pretty much what I was going to say. I mean, we have essentially secured the land that we're looking for to be able to build the capacity that we've asked to be able to build. We are moving forward with the permitting processes and engaging other services and things like that to do engineering and layout and the various investigations that need to be done as well as some other geo-technical work to allow design of the foundation facilities and things like that. So, we wouldn't be spending that kind of money out of our pocket to develop a project that we didn't think was going to move forward. So at this point, I'd say that the tough bits are probably already behind us and we feel a pretty good degree of confidence that this project is going to go through to completion.

Kara Price:

Thank you, Doug. And I guess I'll let you lead into the next part of the slide show then given once again, a good review of this site itself.

Doug Schulte:

Okay. The project is shown here in the general arrangement to the site. The Bobwhite Project is going to generate, or is expected to generate 96 megawatts of electricity at peak output. Project will consist of 1500 to 1900 acres of property. It's generally located in the area around the North and Northeast of the place that we will connect [inaudible 01:21:34] transmission grid, which is at East Kentucky Power Corporation Substation on Radio Station Road, just to the North of Lebanon. It's important to understand as well that as far as the ground and so forth is concerned, the project will be arranged with spaces between the solar panels and that provides for or prevents one row of panels from shading another row, also provides space for us to be able to get between the rows of panels and mow grass and things like that, or do maintenance work if it's necessary.

So the end result is that only about 30% of the surface area of the ground will be covered with panels. And it'll even be significantly less than that if you can imagine that the panels are on a tracking system that is pointing to the East to catch the rising sun and gradually tracks through the course of the day until it's flat at noon and facing West in the evening and picking up as much sunlight as possible. That means that the only time that the ground is really significantly shaded is when all the panels are flat in the noontime or the middle of the day. The rest of the time, there's plenty of exposure and reflection and things like that to provide sunlight down into the ground and keep the ground healthy, keep the vegetation growing and things of that nature.

So, there's a lot of stuff that's done to protect and maintain the viability of the ground so that when we remove the facility at the end of the project, the ground can go back into production almost immediately. [inaudible 01:23:32] Bobwhite will pursue the issuance of an industrial revenue bond, which is a process that the state has instituted to give counties a mechanism to incentivize the location of projects in their counties. And we're working with Marion County now to pursue such a process and look forward to that being accomplished successfully. Once completed, this project will generate enough capacity, enough electricity to offset the consumption of approximately 24,000 average households. So that's a significant contribution to the energy mix in the area and decreases the strain in some cases that may be placed on other sources of energy, other generating facilities.

Next slide, please. This again, repeats the comment that you can see the general area of the site. The amount of electricity generated will offset the consumption of about 24,000 average households. It's two sections divided up into various sections if you would notice. There's a section down in the lower left that's the largest piece of the plant, a couple of smaller sections in the middle and another large section of the project up in the upper right hand. Next slide, please.

That separation of the various sections of the project leaves a lot of open area in between and minimizes the impact on wildlife movement and things of that nature throughout the location of the project. We don't have, as in many cases we would, but we won't have, in this case, a large contiguous site surrounded by a fence that would interfere with the movement of wildlife, deer and whatnot. You'll also note that in those areas where the site would be visible from roadways, or other households, we put in vegetative screening along the fence that we surround the project with and try and make the view or the impact on the view from those locations as attractive as possible.

There'll be very large part of the site, frankly, where people won't be able to see anything of the solar panels and things like that, because they will be so remote from the perspective or the point that they'd be viewing things from. And a lot of cases, even the [inaudible 01:26:33] closer, you wouldn't be able to see it over the fence.

Next slide, please. The diagram here shows that there's approximately 12 landowners in Marion County that make up the bulk of the project. Note that generally the footprint or the outside boundary of the project is better known at this point.

PART 3 OF 4 ENDS [01:27:04]

Doug Schulte:

The outside boundary of the project is better known at this point in time. We've got some preliminary locations of the panels within that footprint that are shown here. That's generally the dark gray areas. Those panels may get shifted around as we go through the design process, or as we move things around a little bit to further minimize the visual impact of the project on some of our neighbors or from the local roadways. Next. There'll be minimum setbacks from roadways of 100 feet. So the solar panels and related equipment would be at least 100 feet from the roadways and at least 50 feet from a neighboring non-participating landowner's property line. So we do our best to keep things in an area that it won't be offensive to anybody, and particularly the immediate neighbors. We also keep all of the equipment.

We strive to keep it all at least 200 feet from any neighboring residents or any residents for that matter. Currently in this arrangement, we have some adjustments to make, but we've got two landowners. One is right at 200 feet away, and another is just a little bit under 200 feet away. Overall however, the average distance between the equipment and any neighboring landowner is right now 1000 feet. So once we make a couple of adjustments, we'll increase the separation between the two that are at that point, but we should be in very good shape as we move forward.

The design of the site allows different fenced areas for the panels. We've already talked about the wildlife movement and things like that in the area. The openness of the site is also... There's not a lot of tree cover, so we won't be disturbing a lot of wildlife and cutting down a lot of trees and things of that nature and minimize the impact of our site in that process. If we could continue on, that presents the site. Some of the benefits and activities that will occur due to our presence in the area. We expect to have positive impacts on the local labor force. Solar companies will actively seek to hire local people. It makes sense if you understand that they'd rather hire local people, if they can find qualified people to do work and things like that, either directly for them or as contracted services, rather than have to pay people from out of state to come in and do the work here.

So the construction process will take 12 to 18 months. The slide says 12 to 16 months, but all of those are a little flexible. We would expect to see something on the order of 100 to 150 local hires, maybe even be a little bit more than that. We will also use local suppliers and contractors for equipment rental, fencing, supply of materials such as steel for the supports, other site work that needs to get done. Electrician work, for example, and things of that nature. Permanent positions. We hire very few people to work directly on the project site, but we will have contracts with local contractors for landscaping and groundskeeping, site operations and maintenance activities, things of that nature that will create jobs in the area to support the project.

Local workforce programs will be developed through the Center for Energy Education. They will work with the local technical colleges and community colleges and provide mechanisms for people that want to be employed in this solar farm and in other solar farms in the region, the technical skills to be able to do that and to understand what's involved in the process and give them a certification at the end of the day, so that they're qualified and accepted to go do that kind of work wherever they decide to use those skills. Next slide. There'll be a number of economic and educational improvements or opportunities for the county.

You could expect to see various restaurants, hotels, property rentals, supply stores, gas stations, et cetera, seeing an increased revenue from people coming in to work on the project. So for at least the year to year and a half of the erection of the project and construction efforts, the people that are coming in to work on the project will need all the support services and infrastructure that's developed around the county and the county people should see increased business opportunities because of that. The solar facility being here can also provide a good marketing opportunity for the county.

Companies that want to come and locate facilities can look at a solar farm being in the area as indication of the county's willingness to work with them and their interest in doing things that protect the environment and meet the philosophies and commitments that a lot of companies have made to minimize their carbon footprint on the planet. So companies will look to those kinds of areas and communities to locate their businesses in, and the county can utilize that presence to attract additional activity into their County.

We've talked a little bit already about the industrial revenue bonds, which is something that the state puts together as an opportunity for the counties to attract projects to their location. The state has recently revised their regulations regarding industrial revenue bonds to make it clear that they do apply to solar farms. They're trying to encourage and recognizing that a lot of solar farms are being planned or promoted and developed within the state. These facilities also provide opportunities for educational benefits. Not only for the things that the Center for Energy Education will do with the local schools and to help develop people and train them for job opportunities and things of that nature, but it provides a location for people in the school system or other parts of the educational industry to bring people to come and see firsthand what a solar farm looks like, how it works, what benefits it has to the environment and so forth. At that point, I think if there are any questions I'll turn it back over to the moderator and we can go from there.

Terry:

Thank you, Doug. We have a couple of questions coming in from the internet. The first one is, "Have you already acquired all the land that you'll need, or do you need additional land?"

Doug Schulte:

I'll go ahead and take that one. At this point, I'm going to say that we think we have all the land that we need. We have to, as part of the permitting process, we have to show or present to the state regulator what the site will look like and how we will arrange everything to get the output that we're asking to be able to generate. To do that we have to demonstrate to them that we've got all the land and that we're moving forward on that footprint. We may have to make some adjustments to that as we move forward, based on things that we come up with that we don't understand at this point in time. There might be some sort of geologic problem or something like that, that we would have to come back and make adjustments for. So while we're not actively looking for a lot of land, we may entertain additional opportunities to secure land or maybe have land that we could bring into bear on the project if necessary.

Terry:

Okay. We have another question from the internet. "Do you have maps that show the power plant relative to the land that has been acquired?"

Doug Schulte:

I believe-

Kara Price:

Doug, I'll take this one.

Doug Schulte:

Go ahead.

Kara Price:

Yeah. I was about to say we do. It may be hard to see on the PowerPoint that's been shared, but we do have a site plan which shows the preliminary panel placement and the parcels being utilized. There is an actual copy of this presentation on our website, which again is Geenex, G-E-E-N-E-X, solar, S-O-L-A-R.com/NorthernBobwhite altogether. Not only is there the site plan that we shared in this presentation, there's also an overall map of the parcels that are involved. As I said, the parcels will show more land than are actually going to be under panels, but it'll give you an idea of the location and then you can look at the site plan. If anybody has problems accessing the web and seeing them that way, please reach out to us and we could provide the site plans in another format for you if necessary.

Doug Schulte:

Okay. Kara, I'll turn it back to you for more discussion.

Kara Price:

Yes. If we don't have any other questions... I didn't know if there was any just additional comments any of our other Geenex team members or experts would like to make at this time. I'm happy to have you share any insights that you would like to?

Okay. Well, I will continue asking myself questions, then. A lot of times people ask, what are the financial benefits of a solar facility for a community? We have certainly outlined some of those in the presentation from a workforce development perspective where there's job creation and there's work creation for local contractors from fencing and restaurants and a variety. But what's more important a lot of times to the county officials and others, is the tax revenue from these projects. The revenue from this project will greatly support the local school system and other community and needs, while in return requiring little of the county. We don't need a lot of water service. We don't need any of those services such as water and other infrastructure that some big developments would need. In addition, solar development's providing a steady source of income for the local landowners, which is key to helping the local economy.

You got the improved tax base and the delivery of clean, renewable energy to the utility grid. Once again, the county can utilize the fact that there's renewable energy within its bounds to attract other utilities and corporations and economic development. We've seen this a lot in North Carolina and Virginia, where, because there's renewable energy in a local community, people will source data centers there. Facebook has certainly developed a large footprint in Virginia because it can source renewable energy from the local infrastructure. That's some of the economic benefits. And then I'm going to turn it back over to Mozine, Executive Director of the Center for Energy Education, who can speak a little bit more about their programs, which we're very excited about.

Mozine Lowe:

Yes. Hi. I just wanted to let everyone know about upcoming community events that we're hoping to have in the county. We call them our Solar 101 community events. It's a great opportunity to come and ask questions about this new technology that you may have in your community. There are many questions about the makeup of solar panels, how solar farms actually operate. We talked a little bit about job opportunities, but it's a chance to come and learn about some of the jobs and the skills that are required for the job. We hope to have our mobile classroom available at these events and in the mobile classroom, we actually have solar modules and solar panels, different kinds, and they are the actual size that you see on some of the solar farm facilities. So you have a chance to just look at it and understand the makeup of it, to understand more about the electrical connections and how all of it comes together.

In our mobile classrooms we have actual workshops that we bring to schools. We really want our students to learn more about this new technology and to learn some of the very interesting STEM careers that are available for students to pursue. There is a great need for scientists and engineers, as Kara mentioned earlier, to make the panels smaller and more efficient. So we have workshops that are in the vans that can be taken to schools and to offer hands-on activities. There was some questions about workforce development. We have hardhats in the van and we have safety glasses and a safety vest. Along with that, we have an actual racket system so you can see the kinds of materials that are used to mount the panels into the ground. So I just want to encourage everyone, if you see the van coming through your neighborhood or in the community, please take a moment to take a look at the contents inside and please ask questions about our educational programs.

We're more than happy to come to your schools, to your community organizations, just places in the community to help the community learn more about the projects that are coming and to answer any questions that they may have. So please feel free to call us. My email address is Mozine.lowe, that's M-O-Z-I-N-E dot low, L-O-W-E at center4ee.org. Look forward to working with you. Back to you, Kara.

Kara Price:

Thanks, Mozine. Looks like, Terry, we have another question.

Terry:

Okay. We've got another question from the internet. Thanks for participating. The question is, "Has there been any major objection to this project from the community?"

Kara Price:

Doug and I can probably both speak to this. We have certainly had questions from the community since solar is so new in Kentucky, and obviously new in Marion County. So that's certainly one of the reasons we're having this type of event and we had the open house today, to be able to address those questions. But really as regards to calling a major objection, I would have to say no. Like I said, it's more curiosity. It's more trying to answer questions that have been posed and providing information. Doug, anything to add there?

Doug Schulte:

Only a little bit. I mean, I'd say the only real reaction we've had that I would say is potentially considered negative has been people that have decided they didn't want to participate and lease property to us or work with the projects. However, are still supportive the project and glad to see that they feel solar is something that ought to be developed. They're glad to see opportunities coming into the county, but they liked their farm the way it is and don't want to give up their farming operations and so forth. So I wouldn't even call that an a real serious objection. It's just a matter of personal preference.

Kara Price:

Thank you, Doug. I would encourage anyone who is still listening or with us on the web, if you have additional questions, please reach out to us. As we said, we are moving toward the Kentucky State siting permit application process, but it will be a few more months before that application is submitted. We want to continue to have open conversations with the community and the neighbors of this project and provide as much detail as we can. So we do hope you'll take that time to not only join us tonight on this call, but to reach out to us in other ways if we can answer your questions.

Terry:

And one more time, I'll remind our listeners that if you have a question, you're listening on the phone, please press star three on your keypad. Or if you're listening on the web, please type your name and question below the streaming player. Kara, back to you.

Kara Price:

All right. Let me look in my bag of trick questions. I mean, tricks here and see if I can find another question that is often asked to us in our community meetings for our projects. Hold on. Sorry. Pardon my... I'll bet you love technology when everything has disappeared on your screen. Another question we often get, is solar compatible with agriculture? Sometimes the pushback in communities is, does this make sense to be in an agricultural area? It certainly does. Once again, solar is a very low impact land use that can safely operate next to other ag operations or even residential areas. There's natural ground cover under and between the rows of panels, which allow the soil to rest and rebuild nutrients. We have seen projects where sheep are even used for ground maintenance on the site. There's starting to be an entire field of study around agrivoltaics, which is what type of crops can we grow and work in conjunction with solar, which is an exciting thing that we're looking forward to delving into later.

Again, at the end of the solar farm's life, all this equipment can be removed and it can immediately go back to ag production, which I think is why it can safely operate in ag. I think we all know that there are some ag operations themselves that can be very intrusive to neighbors from smells, sights and sounds, and solar just doesn't have those types of elements, which makes it a very quiet neighbor for any other type of ag operation.

Additionally, another question... We've talked about financial benefits, education, workforce development, but it's important to understand there is very, very real environmental benefits from a project of this scope. When you look at a solar plant, for each megawatt of solar installed, and to give you an idea, we look at one megawatt of energy generation can power, depending on the area of the country, around 250 average US home, to give you an idea. But each megawatt is the equivalent of 129,000 gallons of gasoline eliminated. It's the equivalent of 150 passenger vehicles being removed from the streets and the equivalent of 18,000 light bulbs being eliminated per year. That's just per megawatt, and this project is a 96 megawatt project. So when you look at that, it can help you understand the scope of how it will impact greatly our environment and provide that clean energy that is so needed.

Another thing we didn't mention is these projects in regard to agricultural operation, we talked about sheep, but there's also a lot of pollinator ground cover we can utilize in certain areas of the site, which is something we can consider. That creates new habitats for the bees, obviously. I think Doug has mentioned earlier that a lot of this ground cover, because a lot of larger predators cannot get into the site, quail and other small ground mammals really thrive within a solar project, which is interesting to see how they grow that environment within it. Doug, before we move on, is there anything else you would like to add about the project or you think it's important to share with our audience?

Doug Schulte:

The only thing I can think of, that we had one question asking about whether the panels would come from the US or not. We really can't answer that at this point in time. The company that comes in and does the acquisition of equipment and materials and the erection of the facility will likely go out for bids from any number of suppliers. There are a couple of American-based suppliers that would be considered and might be utilized. There's also suppliers from Europe and Canada and China that are all viable sources of equipment, and it will end up being an evaluation of the cost against the quality and durability of the equipment that will allow people to make a decision on what's the best economic choice for the project.

I'm sure if there are economic American suppliers available, they would probably be selected because it's always preferable to do that than have to deal with international trade issues and things of that nature. That imposes a risk that we can avoid it if possible, but ultimately it's going to be a cost and quality suitability of technology and things like that, that will make that decision. I don't think I can add anything else at this point, Kara.

Kara Price:

Okay. Thank you very much, Doug. I think we accidentally lost our moderator. So Jen, if you want to jump in here.

Jen:

Absolutely. Absolutely. We do have just a comment from our interested party, which has been great and offered a lot of great questions and comments this evening. They just wanted to acknowledge that they are impressed that all the questions asked tonight were addressed. Thank you for that comment, interested party. Kara, I don't know if you want to piggyback that at all.

Kara Price:

No. I do appreciate that comment very much. That's important to us as Geenex to ensure we are answering as many questions as we can, and we want to continue that over the coming month as well. So interested party and whoever else is participating and listening and others in the community, please know we are available and reach out when you can with questions and comments. We'd be happy to engage with you.

Aron:

Hi, Kara. This is Aron Caudill with the Land Development team in Kentucky. I just thought I'd make a fun comment here regarding the Center for Energy Education. Recently, I was able to work with some landowners in Kentucky that were so interested in the project that they wanted to go see the Center for Energy Education and see what we're doing and how the thing works. They were able to go take a trip to the Center and get to spend the day with Mozine and learn about solar and just had a very positive experience while they were there and were able to come back and talk to the community about what they saw and what they learned and just thought that was a really cool thing that was able to be provided.

Kara Price:

Thank you, Aron, very much for adding that information. That's great to hear that they took that effort. If there's no other questions, I'll turn this back over to our support team. And once again, from the Geenex side and on behalf of Northern Bobwhite Solar, thank you for all who joined us tonight and participated and asked great questions. That's what we were here for and we hope it was helpful to you. Thank you.

Terry:

All right. Thank you. We're coming to the end of this public information meeting this evening. Thank you for taking the time to join us for this important event with the team from Northern Bobwhite Solar. We appreciate the opportunity to speak directly with you and answer your questions. If at a later time you have a question or comment, visit geenexsolar.com/northernbobwhite and scroll to the bottom of the page, or send an email at northernbobwhite@geenexsolar.com. Thank you again. Be safe and have a good evening.

PART 4 OF 4 ENDS [01:55:28]

Exhibit W

Annual Salary Level

REDACTED IN ITS ENTIRETY

Exhibit X

Annual Expenditures

REDACTED IN ITS ENTIRETY

Exhibit Y

Form of Pilot Agreement

EXHIBIT C
TO INDUCEMENT RESOLUTION

Form of Payment In Lieu of Taxes Agreement

PAYMENT IN LIEU OF TAXES AGREEMENT

This **PAYMENT IN LIEU OF TAXES AGREEMENT** (this "*Agreement*") is made as of [____], by and between the **COUNTY OF MARION, KENTUCKY**, a county and political subdivision of the Commonwealth of Kentucky (the "*County*") and **[NORTHERN BOBWHITE SOLAR LLC**, a Kentucky limited liability company] (the "*Company*").

RECITALS

A. The Company or an affiliate thereof is currently acquiring, constructing, installing, and equipping an industrial project consisting of the facilities and properties, including any franchise (the "*Franchise*") as that term is used in Sections 136.116 to 136.180 of the Kentucky Revised Statutes (the "*KRS*), described in **ATTACHMENT A** attached hereto (the "*Project*"), the Project being located within the County; and

B. The Project represents new investment and is expected to generate economic development within the County; and

C. On [____], the County adopted a Bond-authorizing Ordinance (the "*Ordinance*") providing for, among other things, the issuance of taxable industrial building revenue bonds in an aggregate principal amount of up to $[____________] (the "*Bonds*") for the benefit of the Company, pursuant to KRS 103.200 through 103.285, inclusive, (the "*Act*"), to finance the acquisition, construction, installation, and equipping of the Project, to acquire title to the Project, and to lease said portion back to the Company, all pursuant to the Act; and

D. The County and the Company have agreed that title to the Project will be conveyed to the County and leased back to the Company, pursuant to the Act, so long as the Bonds are outstanding; and

E. A condition of the County's agreement to enter into the documents necessary to vest title to the Project in the County and to effect the lease of the Project to the Company, the Company has agreed to make certain payments to the County in lieu of County and other local ad valorem property taxes and to enter into this Agreement with respect thereto;

NOW, THEREFORE, in consideration of the foregoing, the mutual agreement of the parties contained herein and other good and valuable consideration, receipt of which is hereby acknowledged, the parties hereto agree as follows:

Section 1. Recitals Incorporated. It is hereby found, determined, and declared that the recitals set forth in the preambles to this Agreement, including the definitions contained therein, are true and correct and are hereby incorporated in this Section 1 by reference.

Section 2. Project Exempt From Taxation. It is understood, acknowledged, and agreed by the parties that pursuant to KRS 103.285, the Project is exempt from ad valorem taxation by the State, County, and other political subdivisions in Kentucky to the same extent as other public property used for public purposes, so long as same is owned by the County and any balance remains outstanding on the Bonds. The parties further agree that (a) the Company's leasehold interest is exempt from local ad valorem property taxation pursuant to KRS 132.200(7) and (b) any proportion of the value of the leasehold interest created through any private financing is taxable at applicable state and local tax rates. The parties agree that the recording of the Lease Agreement with the County Clerk of Marion County, Kentucky shall constitute the listing of the taxable leasehold interest in real property created thereby pursuant to KRS 132.220. The Company agrees annually to list any taxable leasehold interest in real property, tangible personal property and any Franchise created by each Lease Agreement by listing such interest on and filing a Form 61A200 (Public Service Company Personal Property Tax Return) or other applicable property tax return.

Section 3. Agreement To Make PILOT Payments. In consideration of the County's agreement to issue the Bonds and take all other actions authorized by the Ordinance, the Company hereby agrees that in each calendar year during the term of this Agreement with respect to all series of the Bonds, beginning on and after the first January 1st assessment date following issuance of the first series of said Bonds (each an "*Assessment Date*") that the County owns the Project or any portion thereof, the Company shall make an annual payment to the County of Ten Thousand Dollars and No/100s ($10,000.00) as provided below for each of the up to forty Assessment Dates during the term of said Bonds, while any portion of the Bonds remains outstanding (each, a "*PILOT Payment*" and together, the "*PILOT Payments*").

Section 4. Timing Of PILOT Payments. Any PILOT Payment payable in any calendar year hereunder shall be paid at the same time and in the same manner as County ad valorem property taxes for such calendar year, except that the Company shall deliver the PILOT Payment directly to the County at the address provided in Section 6 below, instead of the regular tax collector.

Section 5. Termination. Notwithstanding any other provision herein and with the exception of Sections 1 and 2 hereof, this Agreement shall terminate on the day immediately following the first date that no Bonds issued by the County pursuant to the Ordinance remain issued and outstanding. If for any reason the Project or any part of the property included within the Project and financed by the Bonds is legally placed on the ad valorem tax rolls, the obligation of the Company to make the PILOT Payments shall terminate, and the owner of the property shall thereafter pay ad valorem taxes on that property as required of a tax-paying entity.

Section 6. **Notices.** All notices, certificates, or other communications hereunder shall be sufficiently given and shall be deemed given when delivered or mailed by registered or certified mail, postage prepaid, addressed as follows:

To the County:	County of Marion, Kentucky c/o County Judge/Executive 223 North Spalding Avenue Suite 201 Lebanon, Kentucky 40033
With a copy to:	Marion County Attorney 104 West Main Street P.O. Box 678 Lebanon, Kentucky 40033
To the Company:	Northern Bobwhite Solar LLC 7804-C Fairview Road #257 Charlotte, North Carolina 28226
With a copy to:	Timothy J. Eifler Stoll Keenon Ogden PLLC 500 West Jefferson Street Suite 2000 Louisville, Kentucky 40202-2828

The County and the Company may by notice given hereunder designate any further or different addresses to which subsequent notices, certificates, or other communications shall be sent.

Section 7. **Entire Agreement.** This Agreement contains all of the agreements and conditions made between the parties hereto regarding the subject matter of this Agreement and there are no other agreements or understandings, written or oral, between the parties relating to the subject matter of this Agreement. This Agreement supersedes all prior agreements and understandings, written and oral, between the parties with respect to such subject matter. This Agreement may not be modified orally or in any other manner than by an agreement in writing signed by both parties hereto or their respect successors in interest. The invalidity, illegality, or unenforceability of any provision of this Agreement will not affect the validity, legality, or enforceability of the remaining provisions.

Section 8. **Binding Effect.** This Agreement shall inure to the benefit of and shall be binding upon the County, the Company, and their respective successors and assigns.

Section 9. **Execution In Counterparts.** This Agreement may be signed by each party upon a separate copy or separate signature page, and any combination of separate copies signed by all parties or including signature pages so signed will constitute a single counterpart of this Agreement. This Agreement may be signed in any number of counterparts, each of which will be deemed to be an original, but all of which together will constitute one and the same agreement. It will not be necessary, in proving this Agreement in any proceeding, to produce or account for more than one counterpart of this Agreement. This Agreement will become effective when one or more counterparts have been signed by each party, and delivered to the other parties, respectively. Any party may deliver an executed copy of this Agreement (and an executed copy of any documents contemplated by this Agreement) by facsimile transmission to another party or e-mailed .pdf files of scanned copies bearing their respective signatures, and such delivery will have the same force and effect as any other delivery of a manually signed copy of this Agreement (or such other document).

Section 10. Applicable Law. This Agreement shall be governed by and construed in accordance with the laws of the Commonwealth of Kentucky.

Section 11. Captions. The captions or headings in this Agreement are for convenience only and in no way define, limit, or describe the scope or intent of any provisions or sections of this Agreement.

[*Signature Page To Follow*]

[SIGNATURE PAGE TO PAYMENT IN LIEU OF TAXES AGREEMENT]

MARION COUNTY, KENTUCKY

By: ______________________________

David R. Daugherty
County Judge/Executive

Attest:

By: ______________________________

Chad Mattingly
County Clerk

[NORTHERN BOBWHITE SOLAR LLC]

By: ______________________________

Name: ______________________________

Its: ______________________________

ATTACHMENT A
TO PILOT AGREEMENT

Project Description

The Project includes all industrial building facilities to be financed by the Bonds and to be acquired, constructed, installed, and equipped by the Company in Marion County, Kentucky for the purpose of manufacturing approximately 96 megawatts (MW) of electricity, including any land, Franchise and all related distribution facilities and operating equipment and machinery deemed necessary in connection therewith, but excluding any underlying land which is to be leased for the Project.